Groundwater Reserve Determination Study for Mokolo (A42) Catchment

RAPID GRDM ASSESSMENT

Chief Directorate Resource Directed Measures
Department of Water Affairs and Forestry

WATER GEOSCIENCES CONSULTING

Report Number: Mokolo 03/08

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1 Introduction

1.1 Background

The study area falls within the Limpopo WMA forming part of the Limpopo Province in the northern part of the Republic of South Africa. The water resources (i.e. surface water resources) in the Limpopo WMA are described as being 'on the verge of stress' with a significant provision made for the ecological component of the Reserve. Groundwater may be further developed to supply basic human needs in rural areas.

The objective of conducting the Reserve assessment is to undertake a desktop GRDM determination for identified groundwater resource units and/or groundwater dependent ecosystems. The study, conducted over a period of one month, will comprise of a literature review of available geohydrological reports and an analysis of the groundwater data. Each quaternary catchment will be subjected to a GRDM study. Significant aquifer systems will be delineated for the study area and aspects for further detailed studies identified.

The key components of the study are:

- Description of study area.
    - Background information.
    - Physiography and climate.
    - Geohydrology.
- Determining level of confidence for a Groundwater Resource Directed Measures (GRDM) study.
- Delineate Resource Units.
- Classification of Resource Units.
- Set groundwater reserve.

1.2 Scope of Services Required

The scope of the services required during the GRDM for the Mokolo Catchment, as outlined by Xu et al, (2003) include the following:

- Delineate the area.
- Delineate the groundwater regions.
- Delineate the groundwater response units.
- Delineate areas of common as well as multiple groundwater use.
- Indicate the level of importance of various 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.
- Delineate management units.
- Describe scenarios of management goals and actions for each management unit.

A desktop study was completed for the Mokolo Catchment. Due to a reliance on existing data a few of the above requirements were not addressed.

1.3 Technical Approach

1.3.1 The Reserve Determination Process

The Reserve as defined in the National Water Act (Act 36 of 1998) constitutes the quantity and quality of the groundwater required to:

- Satisfy the basic human needs set at 25 ℓ/day for each person. This requirement must be, in the context of this project, secured for persons who are or will be dependent on the groundwater resource.
- Protect aquatic ecosystems to ensure the ecologically sustainable development and use of the relevant water source.

The project approach is linked to the National Water Act (Act 36 of 1998) which emphasizes the importance of the protection of water resources for utilization covering the basic human need as well as the ecological reserves. Ecological reserve estimation includes the determination of all interactive water systems in the hydrogeological cycle, including groundwater and surface water.

The Basic Human Needs (BHN's) Reserve has been established by the Department of Water Affairs and Forestry (DWAF). As for the Ecological Reserve it must be established by experience and expert judgment by a competent person to define, maintain and improve the ecosystem. Appropriate levels of protection can be set for each resource depending on the importance of the resource and according to an envisaged National Water Resource Classification System.

Components in the Groundwater Resource Directed Measures (GRDM) broadly include the categorizarion/classification of the resources, setting resource quality objectives (RQO's) and define monitoring objectives for the resource. This will contribute to the successful management of the resource and to ensure the long-term sustainability of the resource.

Understanding the basic human needs and ecological Reserve together with the groundwater components (e.g. surface-groundwater interaction) the resource units can be classified, delineated, RQO's defined and monitored for management purposes. The resources can be effectively managed for long-term sustainability by combining acceptable levels of impact with appropriate protection measures.

1.3.2 Specific Technical Approach

The approach will take into account each quaternary catchment within the Mokolo Catchment formulating different confidence levels according to the level of determination required. With the confidence levels determined for each quaternary catchment, key indicators will be identified and summarized. Hydraulic properties (e.g. groundwater levels), hydrochemistry (e.g. TDS) and aquifer properties (e.g. transitivity) can be used as key indicators.

An initial rapid level assessment is required where-after areas of concern (e.g. over-abstraction) determined during a higher level GRDM study will be investigated at a more intermediate level.

1.4 Report layout

The Groundwater Resource Directed Measure (GRDM) of the Mokolo Catchment is presented in ten (10) sections that make up the main body of the report with a number of appendices containing important summarized data for the different quaternary catchments.

Section 1	Introduction
Section 2	Description of study area
Section 3	Description of data collected
Section 4	Hydrogeology
Section 5	Delineation of the Resource Units
Section 6	Resource Classification
Section 7	Quantification of the Reserve
Section 8	GRDM assessment
Section 9	Management Objectives
Section 10	Conclusion and Recommendation

2 Description of study area

2.1 Technical Information

The following list of attributes has been collected in order to establish the groundwater characteristics of the Mokolo Catchment:

- Geology
- Quaternary catchments' information
- Surface water systems (rivers and dams)
- Existing Nature Reserves
- Mean Annual Rainfall
- Borehole information (NGA/DB)
- Hydrochemistry (NGA/DB)
- Regional classification of aquifer systems
- Recharge estimates
- Groundwater exploitation potential

2.2 Locality

The study area falls within the Limpopo WMA forming part of the Limpopo Province in the northern part of the Republic of South Africa. The primary focus areas consist of quaternary catchments A42A, A42B, A42C, A42D, A42E, A42F, A42G, A42H and A42J covering an area of approximately 8400 km^2. Geographically the study area extends from the South African and Botswana border in a south-east direction towards Modimolle (Nylstroom). The Mokolo River is the major river system flowing through the study area eventually joining the Limpopo River to form the international boundary between the Republic of South Africa and Botswana. **Figure 1 1** shows the general layout and location of the Mokolo Catchment.

2.3 Physiography

The topography varies depending on the type geological formations present (Figure 2). The northern part of the study area, is typically characterized as relatively flat lying with elevations ranging between 600 to 700 mamsl (meters above mean sea level). Localized hills and granite inselbergs are found to the north associated with the resistant Bushveld Igneous Complex and igneous intrusions of the Basement. The central and southern part of the area is distinguished by the presence of the Waterberg Formation forming the scenic Waterberg Mountain range. Elevation within the Waterberg Mountain range varies between 600 and 800 mamsl.

2.4 Climate

The mean annual precipitation varies between 600 mm to 700 mm in the south-eastern part to 300 mm to 400 mm in the north-western part of the study area (Figure 3). The greatest part of the study area receives a mean annual precipitation of between 300 mm and 500 mm. The rainfall generally occurs as thunder showers that deliver almost all of the annual rainfall during the warm to hot summer months between October and March. The winter months are typically dry and cold with localized frost occurrences.

The mean annual potential evaporation is more than twice the amount of rainfall over most of the area, as shown in (Figure 4). It varies across the Mokolo Catchment from about 1600 mm/a in the south to about 2000 mm/a in the north.

2.5 Vegetation and Conservation

The vegetation of the Mokolo Catchment is characterized by mostly Bushveld Biomes (Figure 5); *Arid Sweet Bushveld* biome in the north, *Mixed Bushveld* biome in the north-centre fingering down to the south, *Sour Bushveld* biome to the south-east and south-west and *North Eastern Mountain Sourveld* biome in localized areas in the south.

The two most important conservation areas include the Marakele National Park and Welgevonden National Park (Figure 5) situated south-west of the Mokolo catchment. Smaller parks such as the Hans Strjidom and Mokolo Dams (wetlands) are also classified as protected areas.

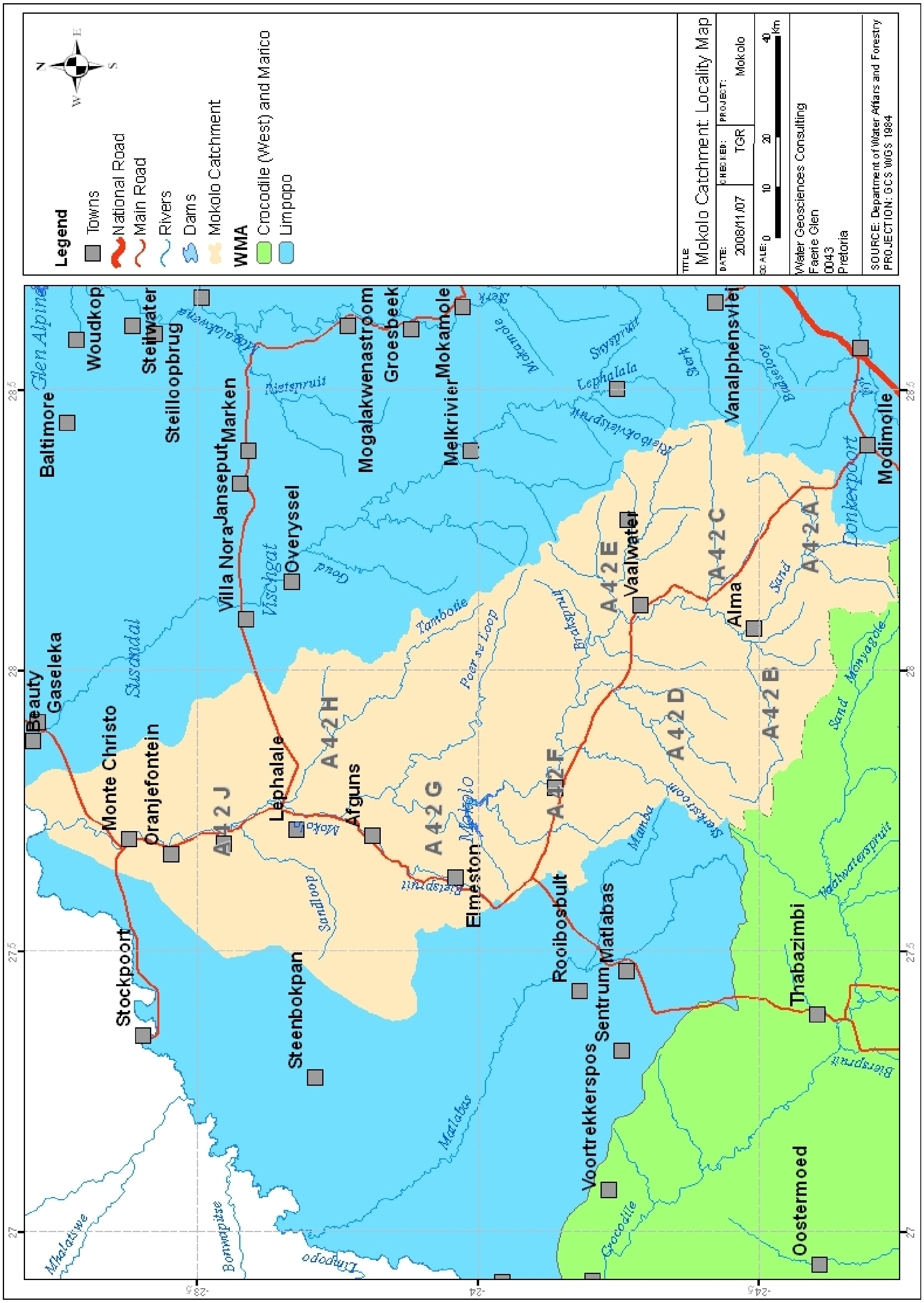

Figure 1: Location of the Mokolo (A42) Catchment

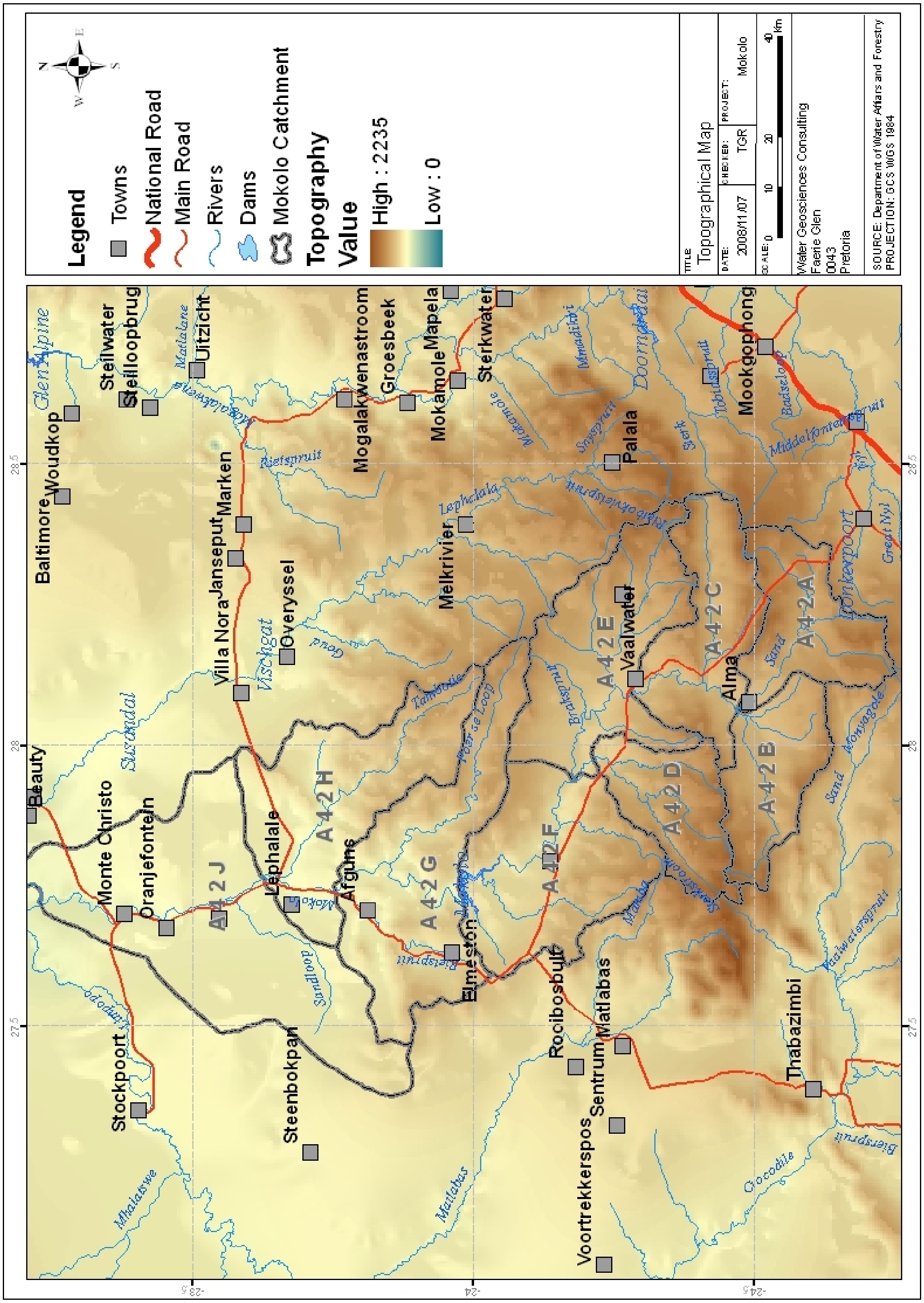

Figure 2: Topography (mamsl) of the Mokolo Catchment

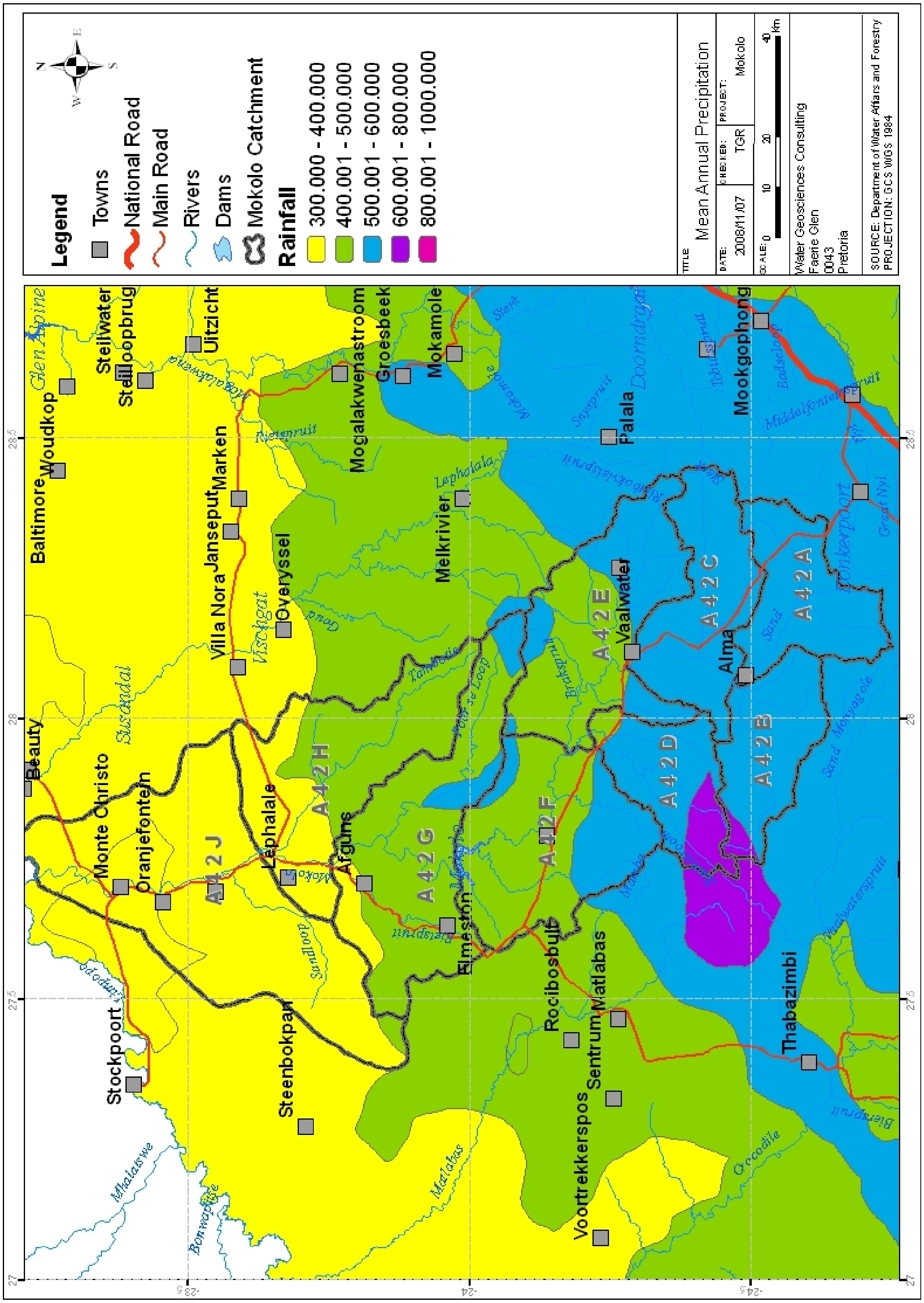

Figure 3: Mean Annual Precipitation (mm/a) of the Mokolo Catchment

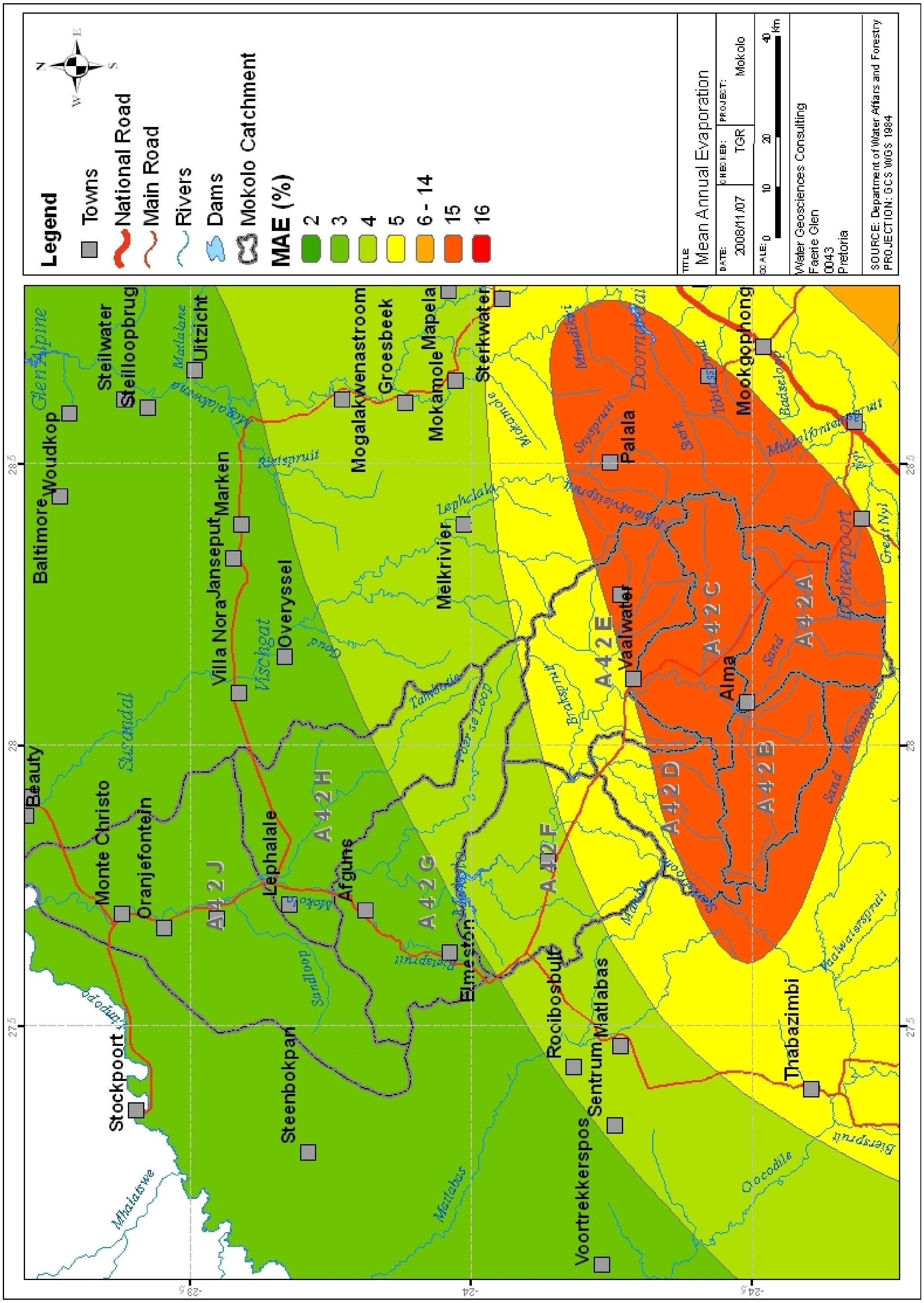

Figure 4: Mean Annual Potential Evaporation (mm/a) of the Mokolo Catchment

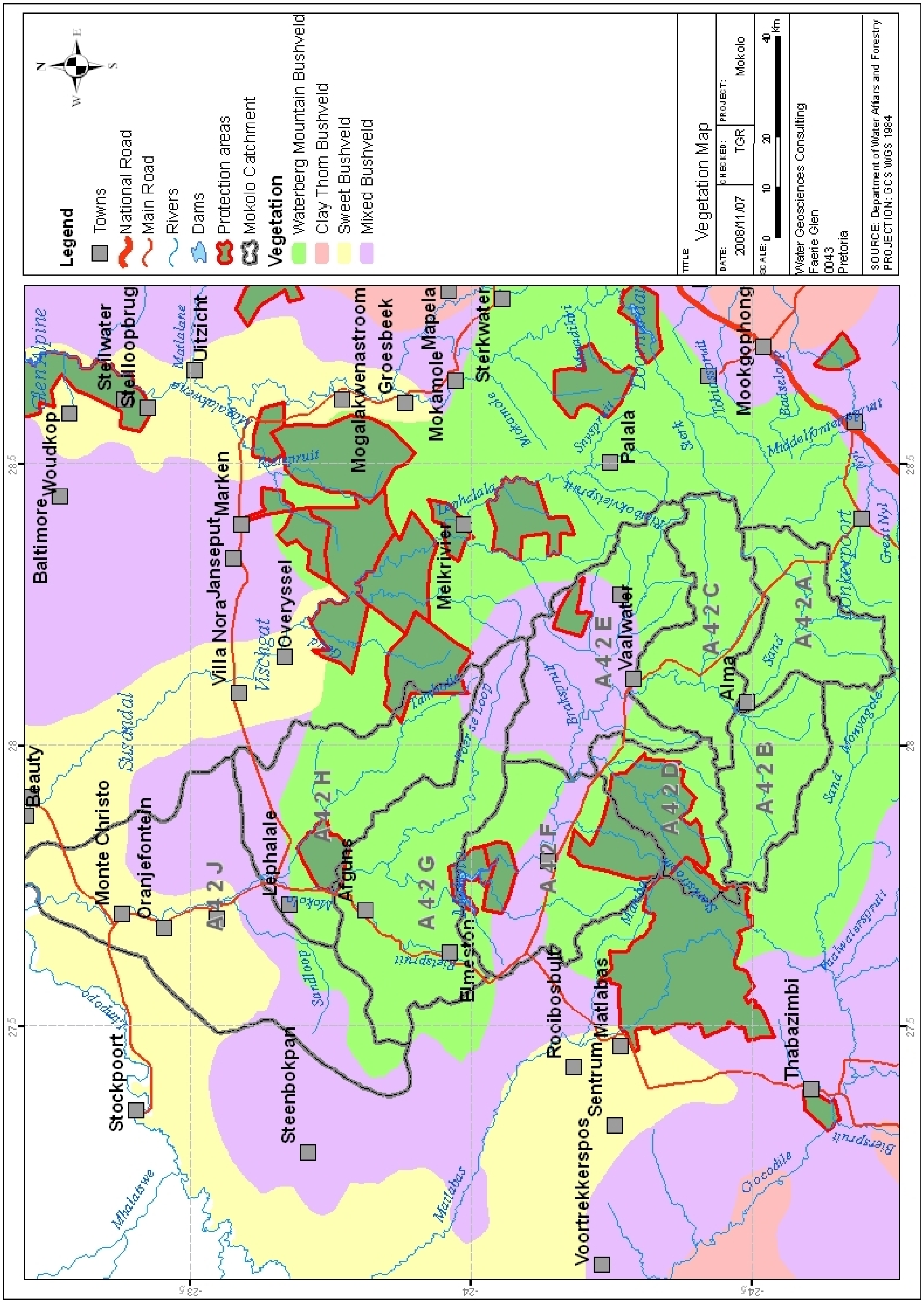

Figure 5: Biomes and Protection areas of the Mokolo Catchment

2.6 Population

The population in the Mokolo Catchment is only concentrated in and around the urban to peri-urban areas while the rural areas are sparsely populated. The three major towns in the study area are Vaalwater and Alma situated in the southern part of the Mokolo Catchment and Lephalale situated in the north. A population of 28 000 people is recorded for the entire Mokolo Catchment with an areal extend of approximately 8400 km^2 and a population density of approximately 3 persons per km^2.

2.7 Land use

Although the southern eastern parts of the Mokolo Catchment receives much more precipitation (800 mm), compared than the northern region (300 mm), its' uneven and undulating topography doesn't make it suitable for cultivation. Consequently, most of the land is covered with forests and woodlands. To a smaller degree, the land is used for dry-land cultivation.

3 Description of data collection

All data, for the specified quaternary catchments, were requested from the National Groundwater Archive/Database (NGA/DB), which is maintained by the Department of Water Affairs and Forestry (DWAF). All water level measurements captured in the NGA from 1970 up to 2006 were used for the interpolation (inverse distance weighting) of the (long-term) average potentiometric surface map. It must be stressed that the map is only used to infer approximate and average regional groundwater flow directions in the catchments (Figure 7). Furthermore, the derived groundwater flow directions assume a homogeneous isotropic aquifer, i.e. they neither consider structural heterogeneities of the underlying geology nor the influence of rivers or dams on local flow directions.

3.1 Accuracy of chemical analysis

The accuracy of the chemical analyses (Appendix B) is calculated according to the plausibility of the electro neutrality, missing field measurements i.e. pH, EC, O_2-readings and redox-potential. The electro neutrality (E.N.) was calculated using equation 1:

$$\text{E.N.}[\%] = \frac{\sum cations[\text{meq}/\ell] - \left|\sum anions[\text{meq}/\ell]\right|}{\sum cations[\text{meq}/\ell] + \left|\sum anions[\text{meq}/\ell]\right|} \cdot 100\% < 5\% \qquad \text{Equation 1}$$

Concentrations below the limit of detection were ignored in the electro-neutrality calculation. All E.N. values (Appendix B) with an error percentage of less than 5% will be considered as acceptable in this report. Interpretations of samples with large errors (> 5%,) in the ion balance will be considered with caution.

4 Hydrogeology

The hydrogeology of the Mokolo Catchment is characterized by aquifers formed by sedimentary rocks of the Karoo Supergroup and Waterberg Formation. To a smaller extent, basement aquifers and alluvial aquifers also occur within the study area. The alluvial aquifers may be significant with respect to its hydraulic connection with the

Mokolo River and the major pools associated with the river. The general geology of the Mokolo Catchment is illustrated in Figure 6.

4.1 General geology

The regional geology of the study area is dominated by the Waterberg Formation. Basement Complex rocks outcrop in the north of the study area, Bushveld Igneous Complex rocks to the east and south of the study area, a very small portion covered by rocks of the Karoo Supergroup with quaternary sediments to the north of the study area.

The Mokolo basin is extremely block faulted with down-throws in a northern direction. The faults strike in SE-NW and SW-NE directions and are targeted for the development of groundwater resources. Faults trending ENE, and subjected to N-S extensional stresses, result in tensional structures ideal for groundwater development.

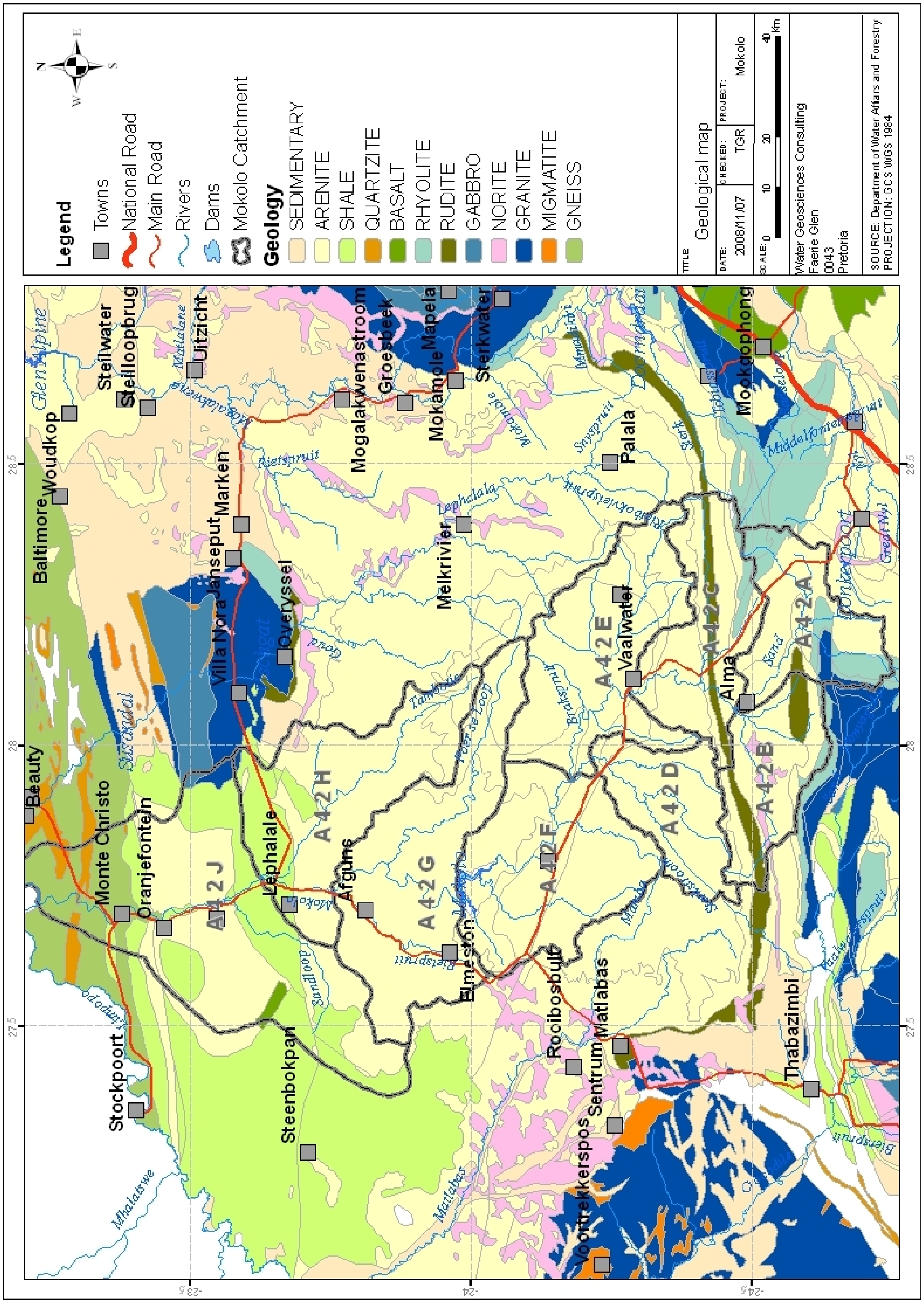

Figure 6: Geological map of the Mokolo Catchment

4.1.1 Lithostratigraphy

4.1.1.1 Basement Complex (Limpopo Mobile Belt)

The north of the study area is underlain by rocks of the Beitbridge Complex and Hout River Gneiss formation forming part of the Basement Complex. According to Barnard (2000) and Foster (1984), the Basement Complex is mainly characterized by granites, granodiorite, migmitites and gneiss but also comprises of metamorphosed sediments, slate, talc schists and sandstone. These Archaean crystalline basement rocks are the oldest rock formations in the study area dated at about 3.1 Ga.

4.1.1.2 Bushveld Igneous Complex (BIC)

Bushveld intrusive igneous rocks are found to the north, south and east of the study area consisting mainly of the Rustenburg layered suite (Rooiberg Group). This 2.06 Ga old rock formation ranges in composition from ultramafic to acidic rocks and includes a large economically (Platinum) important layer comprising mainly of granodoirite, gabbro, norite, anorthosite and granite. Typical intergranular and fractured rock aquifer systems can be expected.

4.1.1.3 Waterberg Formation

The majority of the study area is underlain by the Waterberg formation that consists of three main subgroups; the Setlaole, Makgabeng and Mogalakwena formations. The basal Setlaole Formation rests non-conformably on the basement rocks, and is composed of coarse granulestone and is locally conglomeratic. This formation is interpreted to have been deposited in a fluvial, braided river environment. The Makgabeng Formation is deposited conformably on the Setloale Formation, and consists of large-scale trough and planar cross-bedded fine- to medium-grained sandstone, which is interpreted as an aeolianite (Bumby, 2000). The Mogalakwena Formation, in contrast, lies disconformably above the Makgabeng Formation, and further to the north rests on the Blouberg Formation on a sharp angular unconformity. These strata consist of interbedded sheets of granulestone and conglomerate in proximal areas, grading into trough cross-bedded granulestones and sandstones in distal areas to the southwest (Bumby, 2000).

4.1.1.4 Karoo Supergroup

The Karoo Supergroup, formed during the Paleozoic and Mesozoic era (545 – 65 Ma), consists mainly of sedimentary rocks. The Waterkloof Formation, forming part of the Ellisras basin, comprises of diamictite, mudstone and conglomerates that rest unconformably on the Waterberg Formation (Brandl, 1996). The mudstones are believed to represent glacio-lacustrine deposits where-as the conglomerates and diamictite are believed to have formed as subaqueous outwash deposits formed due to the retreating glacier.

4.1.1.5 Quaternary deposits

Quaternary deposits cover large portions of the Basement Complex (Limpopo Mobile Belt) and the northern reaches of the Waterberg Formation. Sediments such as calcrete, ferricrete, gravel red sand and alluvium are found throughout the northern parts of the Mokolo Catchment. Alluvium of up to 5 meters in thickness with a coarse sand base is present along the Mokolo River and serve as an important local aquifer especially during the summer (rainfall) seasons.

Table 1: Geological units represented in each quaternary catchment

Quaternary Catchment	**Lithostratigraphy**	**Rock Types**
A42A	Bushveld Igneous Complex o Rooiberg Group	Rhyolite, tuff, sandstone, quartzite
	Waterberg Formation	Sandstone, greywacke, siltstone, shale, conglomerate, grit
A42B	Waterberg Formation	Sandstone, greywacke, siltstone, shale, conglomerate, grit
A42C	Bushveld Igneous Complex o Rooiberg Group	Rhyolite, tuff, sandstone, quartzite
	Waterberg Formation	Sandstone, greywacke, siltstone, shale, conglomerate, grit
A42D	Waterberg Formation	Sandstone
A42E	Waterberg Formation	Sandstone
A42F	Waterberg Formation	Sandstone, greywacke, siltstone, shale, conglomerate, grit
A42G	Waterberg Formation	Sandstone, greywacke, siltstone, shale, conglomerate, grit
A42H	Waterberg Formation	Sandstone, greywacke, siltstone, shale, conglomerate, grit
	Karoo Supergroup	Sandstone, mudstone, carbonaceous shale, conglomerate
A42J	Karoo Supergroup	Sandstone, mudstone, carbonaceous shale, conglomerate
	Bushveld Igneous Complex	Gabbro, norite
	Basement Complex	Gneiss, metapelite, amphibolite, granulite, meta-gabbro

4.2 Regional Aquifers

4.2.1 Basement aquifer

The region show relatively low relief where leveled out by overlying deposits of Quaternary age sediments consisting of Kalahari sands, alluvial sand and gravel. Reasonably thick alluvial deposits are found along the Mokolo River. Basement aquifers comprise of deeper fractured (i.e. secondary) aquifers overlain by a weathered horizon of variable thickness. Thicker weathered aquifer zones are expected in areas where the bedrock has been subjected to intense fracturing. The existence of diabase and dolerite dykes forms poor groundwater targets due to the lack of weathering on the margins of these dykes with the basement rocks (gneiss), especially below the static water level. The most noticeable aquifer within the basement rocks are the ENE trending zones of shearing, faulting and brecciation and are usually covered with Quaternary deposits contributing to the aquifer's storage.

4.2.2 Waterberg aquifer

The Waterberg aquifer is predominantly of a fractured and weathered type with alluvial deposits occurring along the Mokolo River. The main groundwater targets are associated with the fractured dyke contacts and fault zones.

The Waterberg formation has steep topography and shows generally poor capability to produce huge amounts of groundwater, unless boreholes intersect NE or SE trending structures (Sami, 2006). Recharge to the aquifer, discharged on the steep slopes, provides baseflow to the rivers. A weathered zone aquifer is found only where deep weathering occurs and provides groundwater storage that feeds the underlying fractured aquifer.

4.2.3 Karoo aquifers

The Karoo aquifer shows similar aquifer properties as the Waterberg aquifer comprising of fractured rocks with a porous matrix. However, groundwater resources and especially the development thereof, are limited due to the low recharge to these aquifers.

4.2.4 Alluvial aquifers

Alluvial aquifers are recharged during periods of high stream-flows and discharge events as well as during the rainfall season. It is an important local, major aquifer and exists in equilibrium with surface water, adjacent groundwater systems and ecosystems along the rivers.

4.3 Surface Water

Two major river systems flow through the study area. The Limpopo River forms the northern boundary of the study area while the Mokolo River flows through the study area. Smaller river systems occurring in the southern part of the study area include the Tambotie River, Rietspriut River and Sandloop River combining to form the Mokolo River. The Hans Strijdom / Mokolo Dam is located on the Mokolo River.

4.4 Borehole Distribution

The distribution of boreholes, as derived from the National Groundwater Database (NGA/DB), reflect patterns of use, positioned close to the main rivers and around towns (Figure 9).A high density of boreholes exist in and near the towns of Vaalwater and Lephalale in the central part of the Mokolo Catchment, as well as along the Mokolo and Limpopo rivers.

4.5 Groundwater Level and Flow Paths

Regional groundwater flow paths in the Mokolo catchments seem to be in a north-west direction away from the Waterberg Mountain Range. However, the interpretation of such trends must take cognizance of the paucity of, and the irregular spatial distribution of, the boreholes used to infer the approximate and average regional groundwater flow directions. However, the inferred regional groundwater flow direction compares well to the topographical map (Figure 7) showing groundwater flowing from elevated areas.

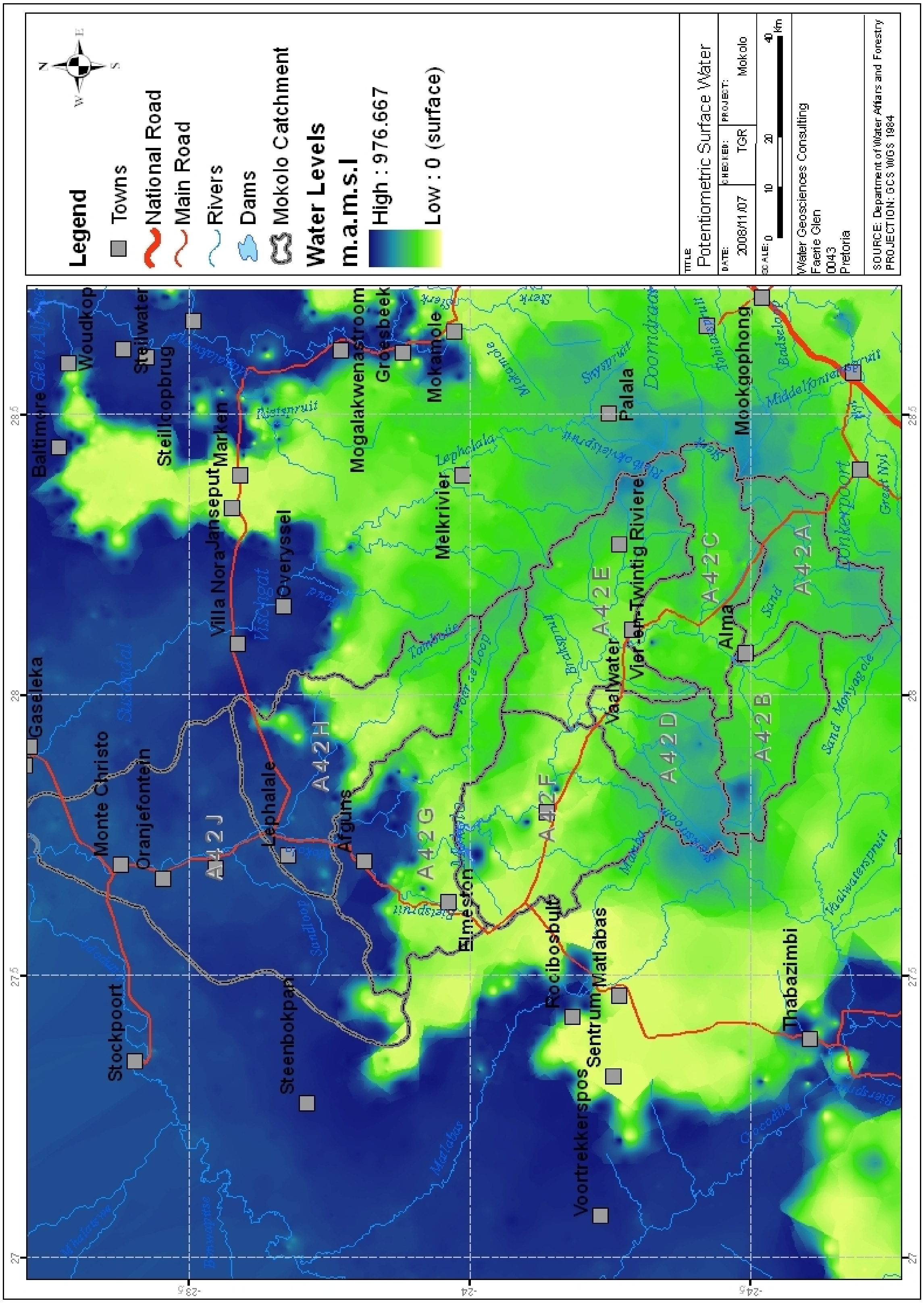

Figure 7: Average Potentiometric Surface Map (mamsl)

4.6 Groundwater Use

Groundwater use can be distinguished in five main categories:

- Rural domestic use
- Livestock/agricultural use
- Bulk water supply
- Irrigation
- Industrial (mining)

Rural domestic use accounts for individual boreholes utilized for primary water supply to rural owners, villages, schools, clinics, hospitals, through water reticulation schemes. Livestock/ agricultural water use refers to individual boreholes utilized for stock watering gardening, etc. Bulk water supply, and irrigation schemes, are provided from well fields in significant aquifer systems consisting of several high yielding boreholes. Industrial (mining) groundwater use accounts for medium to large sized reticulation schemes based on a number of boreholes or well fields. All groundwater use necessitates proper borehole development and resource management.

Irrigation is the dominant groundwater use in the southern part of the Mokolo Catchment with agriculture as the main groundwater use in the northern parts (Table 2).

Table 2: Groundwater use (Mm^3/a) for quaternary catchments and according to different uses (Sami, 2006)

Quaternary catchment	Rural	Agricultural (livestock)	Municipal (water-supply)	Irrigation	Industry and mining	Total
A42A	-	0.0294	-	4.396	0.130	4.55
A42B	-	0.0251	-	4.440	-	4.46
A42C	-	0.0583	-	5.455	-	5.51
A42D	-	0.0089	-	2.922	-	2.93
A42E	-	0.0581	-	8.042	-	8.10
A42F	-	0.0277	-	2.630	-	2.65
A42G	-	0.0648	-	-	-	0.06
A42H	-	0.0571	-	-	-	0.06
A42J	-	0.1886	-	-	-	0.19

Groundwater use in the Mokolo Catchment is relatively low due to the low aquifer yields as well as the abundant surface water available in the Waterberg region. The low population density and low aquifer yields limit large-scale abstraction for irrigation and/or other uses. As a result, the groundwater resources are fairly under-utilized.

4.7 Groundwater Quality and Trends

The typical groundwater types associated with the Waterberg formation (A42E, A42F, A42G, A42H and A42J) consist of a variety of water facies (Appendix B). Quaternary catchment A42E near the Matlabas River are dominated by a Ca-Na-Mg-HCO_3 rich water type where-as quaternary catchments A42H and A42J show a more dominant Na-Cl water facies. The geochemical data obtained from DWAF, in quaternary catchments A42H and A42J, indicate boreholes sampled near the Mokolo and Tamboti rivers.

A distinct HCO_3 water facies dominate the southern part of the Mokolo study area where as a Cl water facies dominate the northern portions of the study area (Figure 8). The HCO_3^- dominated water facies is possibly due to enhanced recharge in the south (i.e. higher rainfall in the Waterberg Mountain Range) while a Cl dominated water facies may indicate samples influenced by return flows irrigation subjected to the effects of evaporation.

A general pattern of elevated total dissolved solids (TDS) with reduced precipitation (or. recharge) can be recognized as well as with increasing TDS along rivers systems (Figure 9). In both situations the groundwater chemistry is influenced by mineralization contributed either by groundwater interacting with the surrounding rock mass and surface (rivers) water (i.e. highly mineralized due to evaporation). A second pattern is a slight decrease of TDS values from the south towards the north. This is due to the localized recharge that occurs in the southern part of the study area and being discharged at the northern part of the study area, showing good correlation between the HCO_3 water facies and lower TDS values in the south and a Cl dominated water facies and higher TDS in the north.

The southern part of the Mokolo Catchment consisting of rocks of the Waterberg Formation present relatively lower concentrations of electrical conductivity (EC) values compared to the northern side consisting of rocks of the Basement Complex and Karoo Supergroup (Figure 10). These differences in EC concentrations can be due to a number of reasons including interaction with different lithologies, mineralization along groundwater flow paths from a recharge area to a discharge area, etc. The evidence for regional groundwater flow paths must still be established taking into account the spatial distribution of the existing boreholes.

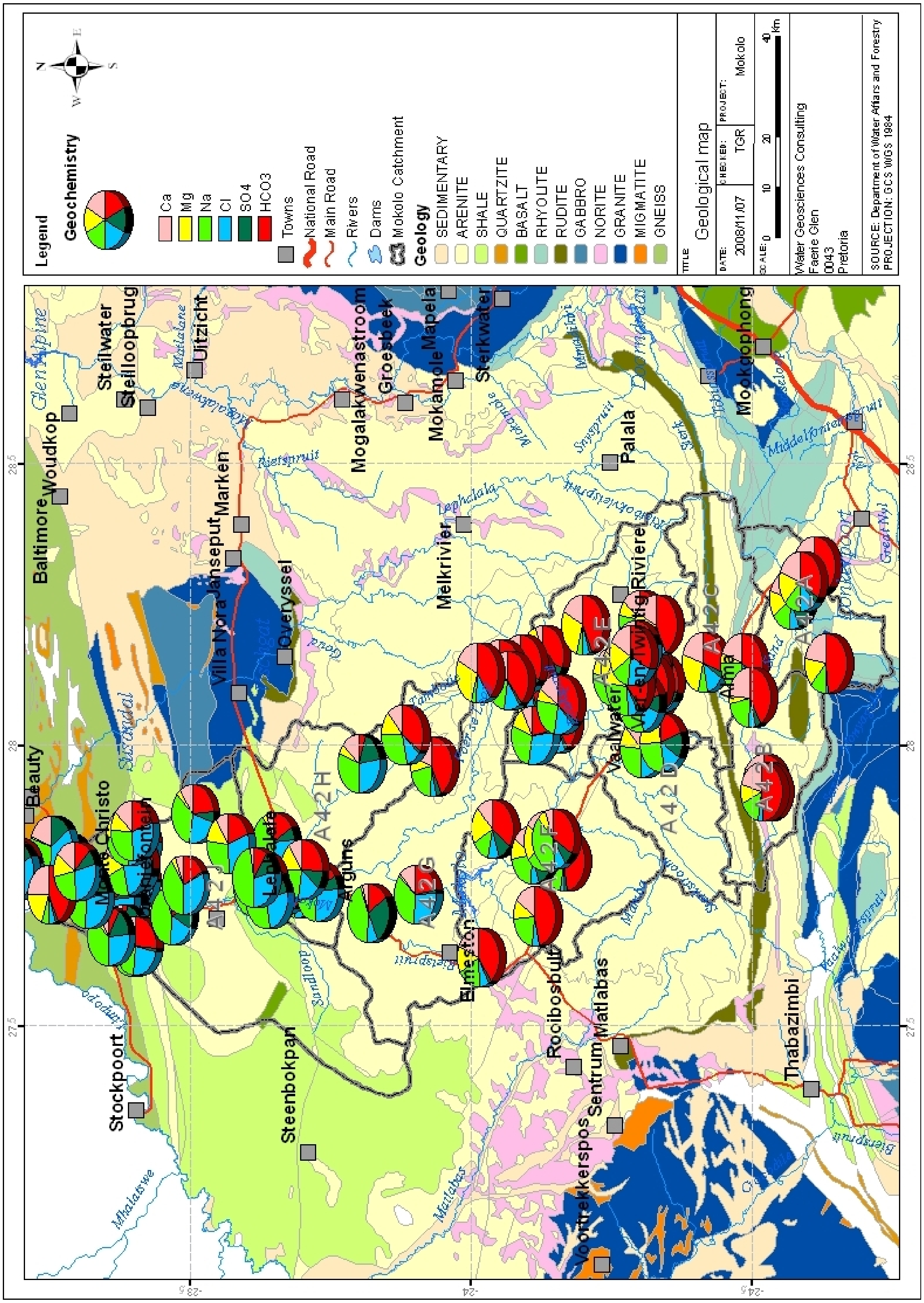

Figure 8: Geological map with groundwater type (parameters in meq/l) distribution.

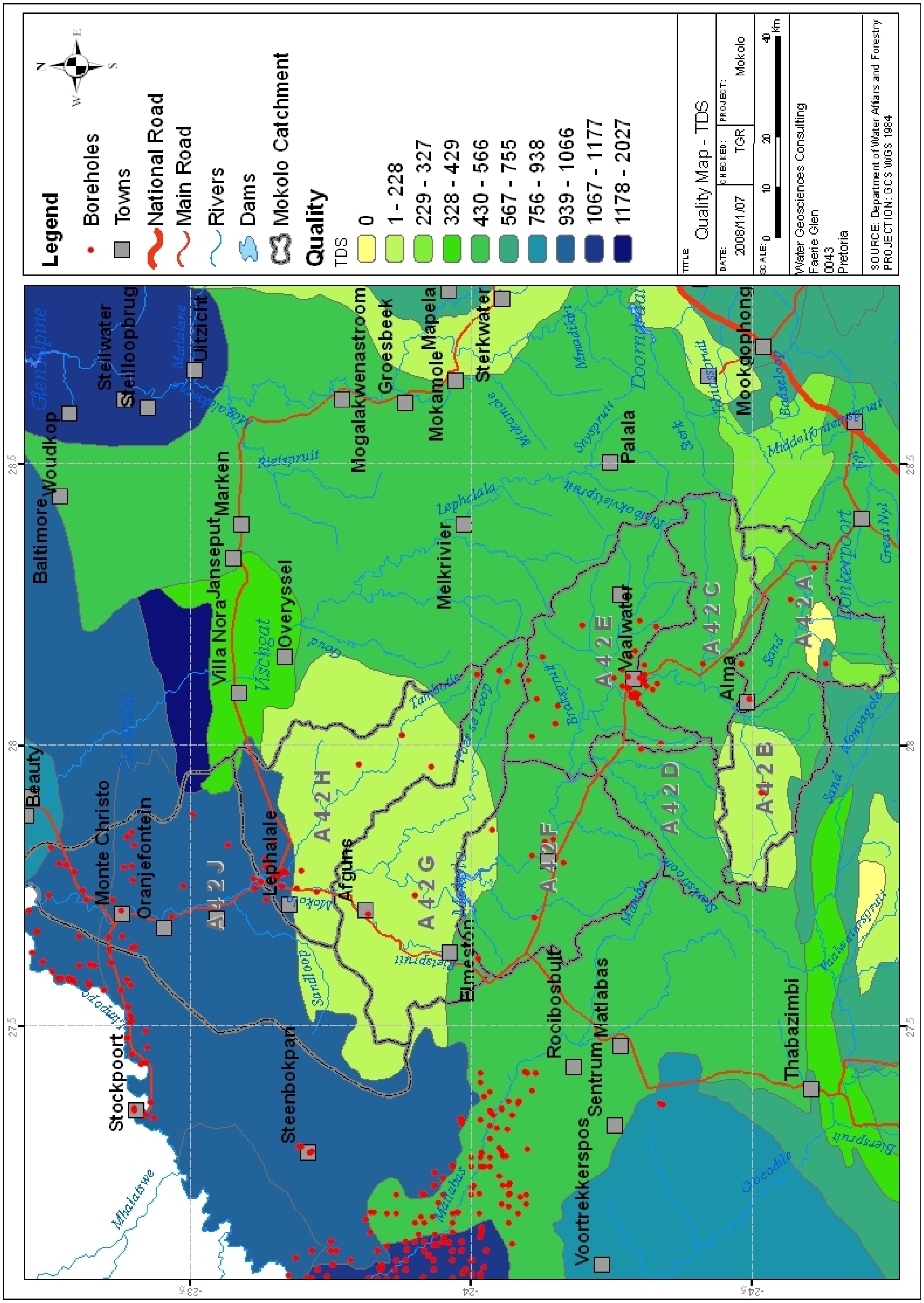

Figure 9: Borehole distribution with regional TDS classification

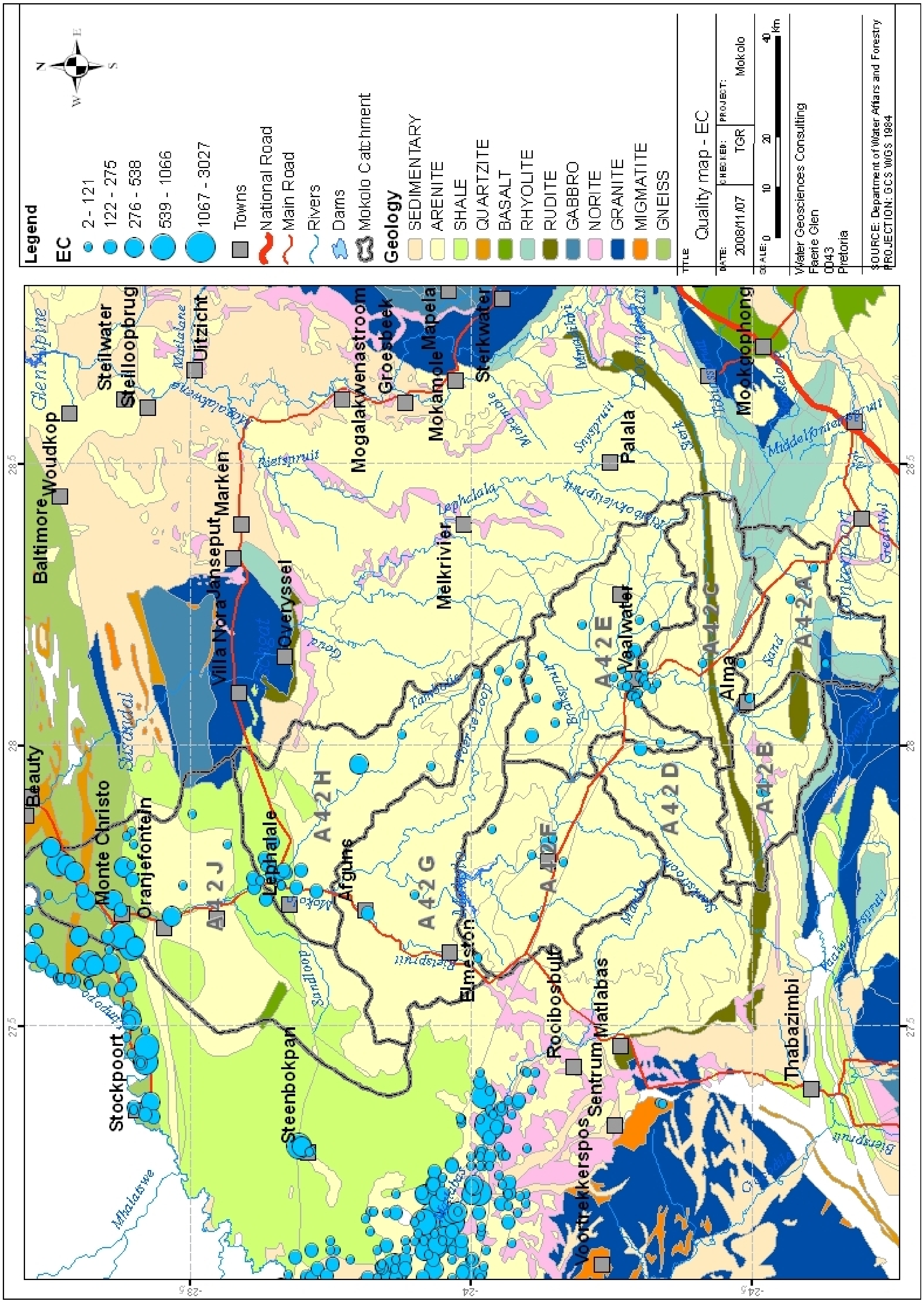

Figure 10: Electrical Conductivity (EC) (mS/m) as a measure of groundwater quality

4.8 Geochemistry

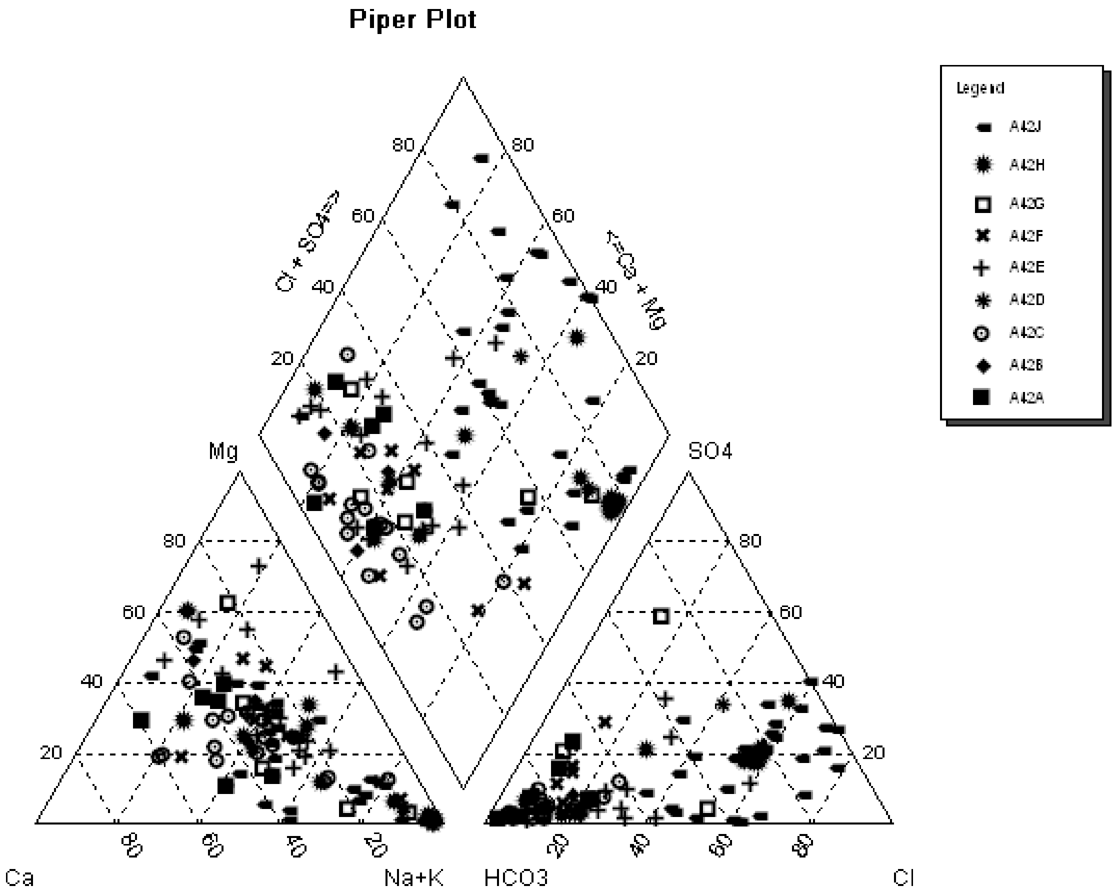

Figure 11: Piper plot showing variation in groundwater chemistry for selected quaternary catchments.

The groundwater samples indicated both HCO_3^- and Cl enriched groundwater subjected to cation exchange processes (Figure 11). Individual piper plots for the different quaternary catchments (Appendix A) show varied water types and are briefly discussed below:

- Quaternary catchment A42A: Only six samples were retrieved for chemical analysis with a dominant Ca-Mg-HCO_3 water facies.
- Quaternary catchment A42B: Three samples were retrieved from the NGDB also showing a Ca-Mg-HCO_3 water facies.
- Quaternary catchment A42C, A42E, A42F, A42G: The groundwater facies differ between Ca-Mg-HCO_3 to Na-HCO_3 water types.

- Quaternary catchment A42H: Two clusters are recognized in the piper plot showing a high concentration in either HCO_3 or Cl. Changes in the ratios of Ca, Mg and Na may indicate cation exchange trends.
- Quaternary catchment A42J: The majority of groundwater samples show an enriched Cl dominated water facies. Changes in the ratios of Ca, Mg and Na again indicate that the groundwater may be subjected to cation exchange processes. This quaternary catchment is underlain by rocks of both the Waterberg formation and the intrusive Bushveld Igneous Complex (BIC) providing a possible explanation for the change from a HCO_3 to a Cl - dominated water facies.

4.9 Groundwater Pollution

Groundwater pollution increases with increasing population and development, especially in areas with a thin regolith and where aquifers with shallow water tables occur. The pollutants contributing to the decreasing groundwater quality may be from:

- Domestic use (especially in high density settlements)
- Agriculture activities
- Industrial and mining activity
- Waste disposal activities

The potential impacts on both the quantity and quality of the groundwater resources due to irrigation in the southern part of the Mokolo Catchment and agriculture in the northern parts should be identified and monitored. Potential impacts due to increased development of the groundwater resources in and near the towns of Vaalwater and Lephalale (Ellisras) in the central part of the Mokolo Catchment, along the Mokolo River as well as along the Limpopo River must also be identified and monitored.

4.10 Recharge

The mean effective recharge show an overall decreasing trend from south to north towards the Limpopo River. The mean annual effective recharge for the entire Mokolo Catchment study area is 170 Mm^3/annum and is expected to decrease during droughts.

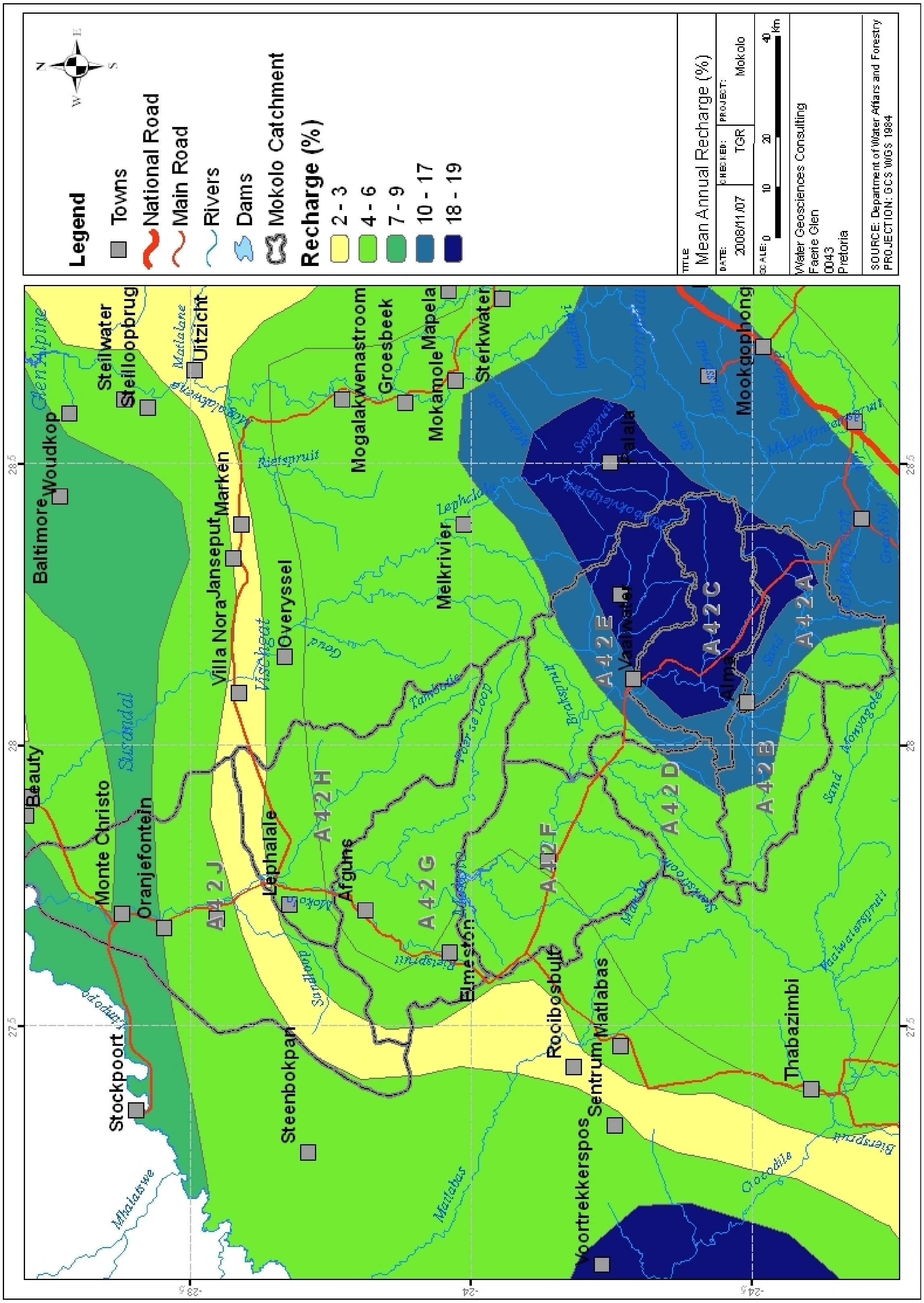

Figure 12: Mean Annual Effective Recharge (mm/a) from Rainfall

The southern part of the Mokolo Catchment (i.e. Waterberg Mountain Range) represents areas of high potential for groundwater development (Figure 12).

However, the mean annual potential recharge doesn't consider the effect of terrain slope on the relationship between rainfall infiltration and runoff nor the hydraulic characteristics of the different lithological units, thus assuming homogeneous, isotropic conditions.

5 Delineation of Resource Units

5.1 Description and delineation of resource units

The Mokolo area consists predominately of four major geological units; the Waterberg formation, Karoo Supergroup, Basement rocks and to a smaller extent alluvial deposits. The delineation of resource units is based on a quaternary catchment level (i.e. primary delineation), according to the major geological units (i.e. secondary delineation) while the alluvial aquifers are highlighted as a focus area for further investigation.

The average characteristics for each of the quaternary catchments were determined by applying the GRDM methodology. A stress index was then determined for each of the quaternary catchments.

The secondary delineation of resource units is based on a combination of the following factors:

- Lithology
- Potentiometric Surface Map (i.e. hydraulic heads) based on elevation / topography
- Geochemical characterization (parameters such as TDS/EC, water type/facies, etc.)

The southern part of the Mokolo Catchment is highly elevated forming the scenic Waterberg Mountain Range where various rivers such as the Mokolo River originate. In this elevated area of the Mokolo Catchment a regional recharge area was delineated for the Waterberg formation, while in central part of the Mokolo Catchment a regional discharge area was delineated. The northern part of the study area is characterized by a relatively flat lying area where the Mokolo enters the Limpopo River.

A third groundwater resource unit was delineated comprising of the Karoo Supergroup and Basement Complex (Figure 13). The two geological units were combined partly due to a lack of groundwater data to clearly distinguish between the geological units. However, aquifer characteristics, and resultant groundwater development approaches, for Karoo sedimentary rocks and basement/crystalline rocks differ significantly to justify two separate groundwater resource units.

The high density of boreholes along the Mokolo River associated with the alluvial deposits and the relatively higher abstraction rates necessitates a more detailed study of these alluvial aquifer systems. As a result, the alluvial aquifers were delineated as a fourth groundwater resource unit.

The water facies show a variation from the south towards the north of the study area. A Ca-HCO_3 water facies characterises the southern dominantly recharge area and a Na-Cl water facies the northern parts of the study area. Although trends in electrical conductivity (EC) and TDS can be observed across the study area, the existence of regional groundwater flow paths must still be established. Water-rock interaction between groundwater and the various lithology units, contributing to the chemical character of groundwater, must also still be characterised.

The borehole yields for the Karoo and Waterberg sediments differ only slightly. Borehole yields of 0.15 ℓ/s is recorded for rocks of the Karoo Supergroup and 0.25 ℓ/s for the Waterberg formation. Only 10% of all boreholes yield more than 2 ℓ/s in both geological units. Limited data exists to compare the borehole yields from rocks of Basement Complex rock in the north of the study area.

According to the above, the following groundwater resource units were delineated (Table 3):

1. Primary delineation of groundwater resource units based on:
    - Quaternary catchments (A42A, A42B, A42C, A42D, A42E, A42F, A42G, A42H, A42J)
2. Secondary delineation of groundwater resource units
    - Waterberg Recharge resource unit (A42A, A42B, A42C and A42D)
    - Waterberg Discharge resource unit (A42E and A42F)
    - Karoo/Basement resource unit (A42G, A42H and A42J)
    - Alluvial resource unit (associated with the Mokolo River)

Table 3: Summary of the groundwater resource units and reasons for delineation

Resource Unit s	**Description**	**Origin**
Secondary delineation/resource unit		
Waterberg Formation - Recharge Zone	❖ Geology (Sandstone, greywacke, siltstone, shale, conglomerate, grit) ❖ **Recharge** – Discharge area: Predominantly a recharge zone based on: o Higher Elevation – Waterberg mountain Range o Potentiometric water level map (Hydraulic heads) and groundwater flow paths o Geochemistry (aquifer properties) – Lower TDS and EC, Major ions: Mg-Ca-HCO_3 water facies	Include Quaternary catchments: A42A, A42B, A42C, A42D and A42E
Waterberg Formation - Discharge Zone	❖ Geology (Sandstone, greywacke, siltstone, shale, conglomerate, grit) ❖ Recharge – **Discharge** area: Predominantly a discharge zone based on: o Lower elevation – Waterberg mountain range o Potentiometric water level map (Hydraulic heads) and groundwater flow paths o Geochemistry (aquifer properties) – Higher TDS and EC, Major ions: Na-Cl / HCO_3 water facies	Include Quaternary catchments: A42F, A42G, A42H
Karoo Supergroup & Basement Complex	❖ Geology (Sandstone, Shale and Gneiss) ❖ Geochemistry (aquifer properties) –TDS and EC, Major ions: Na-Cl water type	Include Quaternary catchment: A42J

Alluvial Aquifer Systems	❖ Mokolo and Limpopo rivers are important water resources
	o Alluvial aquifer systems with higher yields
	    o Alluvial deposits (Karoo / Basement)
	o Weathered aquifer systems
	    o Weathered zones (Waterberg / Basement)
		Associated with river systems (i.e. Mokolo River)

Primary delineation/resource unit		
A42A	❖ Quaternary (drainage) catchment level for ‘practical’ water management	Based on surface water drainage patterns
A42B		
A42C		
A42D		
A42E		
A42F		
A42G		
A42H		
A42J		

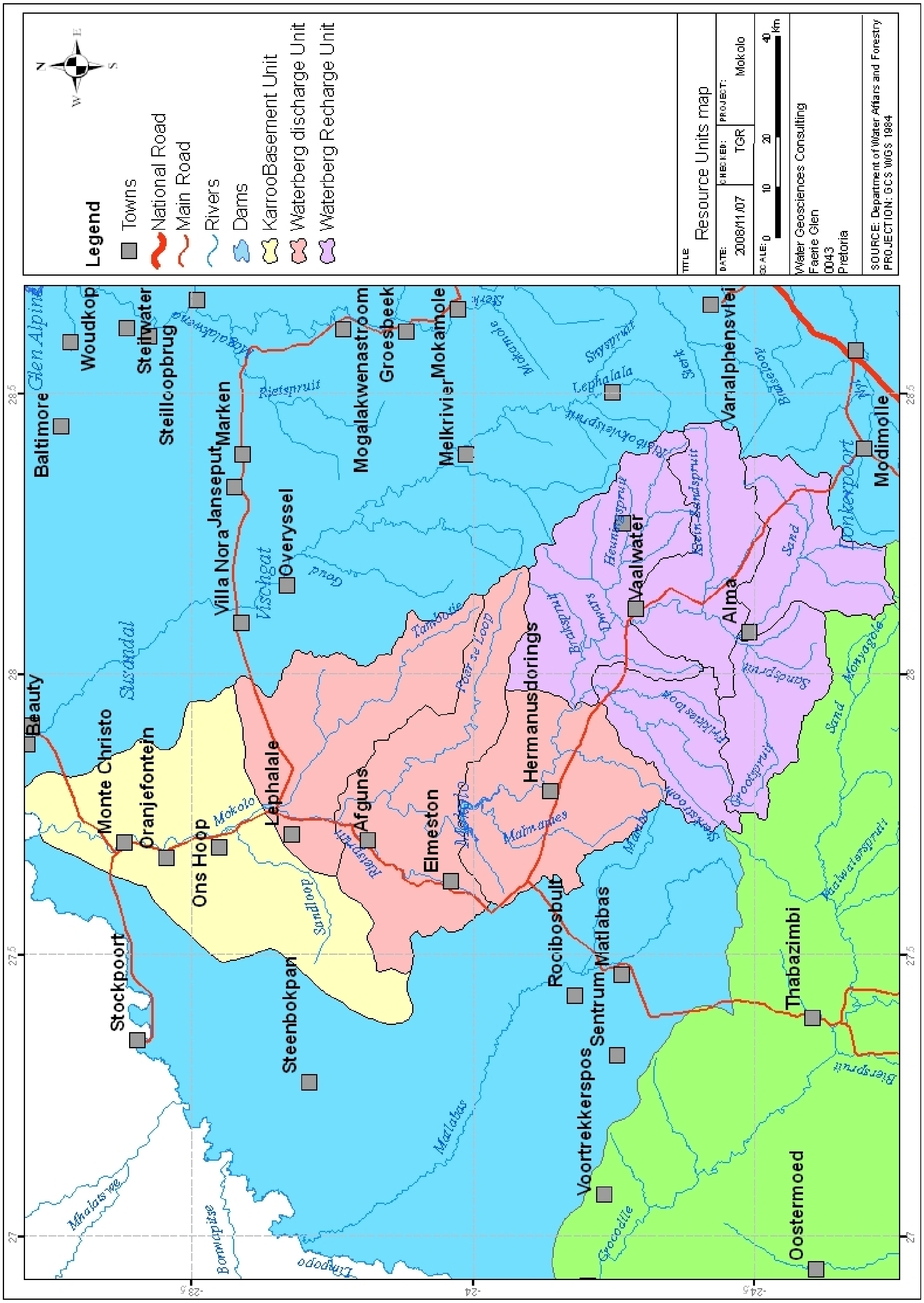

Figure 13: Groundwater Resource Units for the Mokolo Catchment

6 Resource Classification

The National Water Act (Act 36 of 1998) requires that all water resources be classified with reference to the conditions of a resource in terms of impact and the importance of the resource to all users.

6.1 Present Status Category

A category using generic descriptions, in terms of level of impact, needs to be set. It was decided that a stress index based on the volume of groundwater abstraction in relationship to the annual recharge are probably the most appropriate method to determine the category of each resource unit.

Table 4: Present Status Category according to Stress Index (Source: Parsons et al., 2006)

Present Status Category	Description	Stress Index (Abstraction/Recharge)	Water Resource Category
A	Unstressed levels or low levels of stress	<0.05	Natural
B		0.05 – 0.20	Good
C	Moderate levels of stress	0.20 – 0.40	
D		0.40 – 0.65	Fair
E	Stressed	0.65 – 0.95	
F	Critically stressed	>0.95	Poor

A stress index was calculated by dividing groundwater abstraction (i.e. groundwater use) by mean annual potential recharge. The stress index is then used to classify the resource units in terms of its present status category and water resource category.

However, the stress index is determined for the entire quaternary drainage catchment (and geological units) and there might be local hot-spots requiring a higher stress index, typically around large-scale abstraction areas.

6.1.1 Present status category and water resource category

Moderate stress levels were categorized for quaternary catchment A42A, A42B, A42C and A42E. All these quaternary catchments are in the southern part of the Mokolo Catchment in the recharge area. Unstressed to low levels of stress characterize the northern parts of the Mokolo Catchment (Table 5, Figure 14).

The three major resource units, excluding the alluvial aquifer systems, delineated show either moderate stress levels or unstressed to low levels of stress (Table 5):

- **Waterberg Recharge resource unit** shows moderate levels of stress indicating a relatively *Good* water resource unit.
- **Waterberg Discharge resource unit** shows unstressed to low levels of stress indicating a *Natural* water resource unit.

- **Karoo/Basement resource unit** shows unstressed to low levels of stress indicating a *Natural* water resource unit.

All the groundwater resource units in the Mokolo Catchment are presently being used sustainably according to GRDM determinations. However, correct management from a socio-economical as well as an ecological protective point should be implemented, observed and maintained to insure that these groundwater resource units won't be over-utilized over a long-term basis. Indications of over-utilization include factors such as reduction in spring and river flows, reduced biodiversity, vegetation die-off, land subsidence and long term declination of water levels where it is not related to natural influences. The data used for the GRDM determinations should be updated to include current groundwater use.

Table 5: Present Status and Water Resource Categories according to Stress Index for the Mokolo Catchment

Resource Units	Total abstraction (Mm^3/a)	Recharge (Mm^3/a)	Stress Index	Description	Present Status Category	Water Resource Category
Secondary delineation/resource unit						
Waterberg Recharge	25.57	94.29	0.27	Moderate levels of stress	C	Good
Waterberg Discharge	2.78	63.23	0.04	Unstressed levels or low levels of stress	A	Natural
Karoo/Basement	0.19	13.15	0.014	Unstressed levels or low levels of stress	A	Natural
Alluvial aquifers	X	X	X	X	X	X
Primary delineation/resource unit						
A42A	4.56	16.1	0.28	Moderate levels of stress	C	Good
A42B	4.47	16.85	0.27	Moderate levels of stress	C	Good
A42C	5.51	21.82	0.25	Moderate levels of stress	C	Good
A42D	2.93	17	0.17	Unstressed levels or low levels of stress	B	Good
A42E	8.1	22.52	0.36	Moderate levels of stress	C	Good
A42F	2.66	22.27	0.12	Unstressed levels or low levels of stress	B	Good
A42G	0.06	25.32	0.0024	Unstressed levels or low levels of stress	A	Natural
A42H	0.06	15.64	0.0038	Unstressed levels or low levels of stress	A	Natural
A42J	0.19	13.15	0.0144	Unstressed levels or low levels of stress	A	Natural

Please Note: X – Lack of data

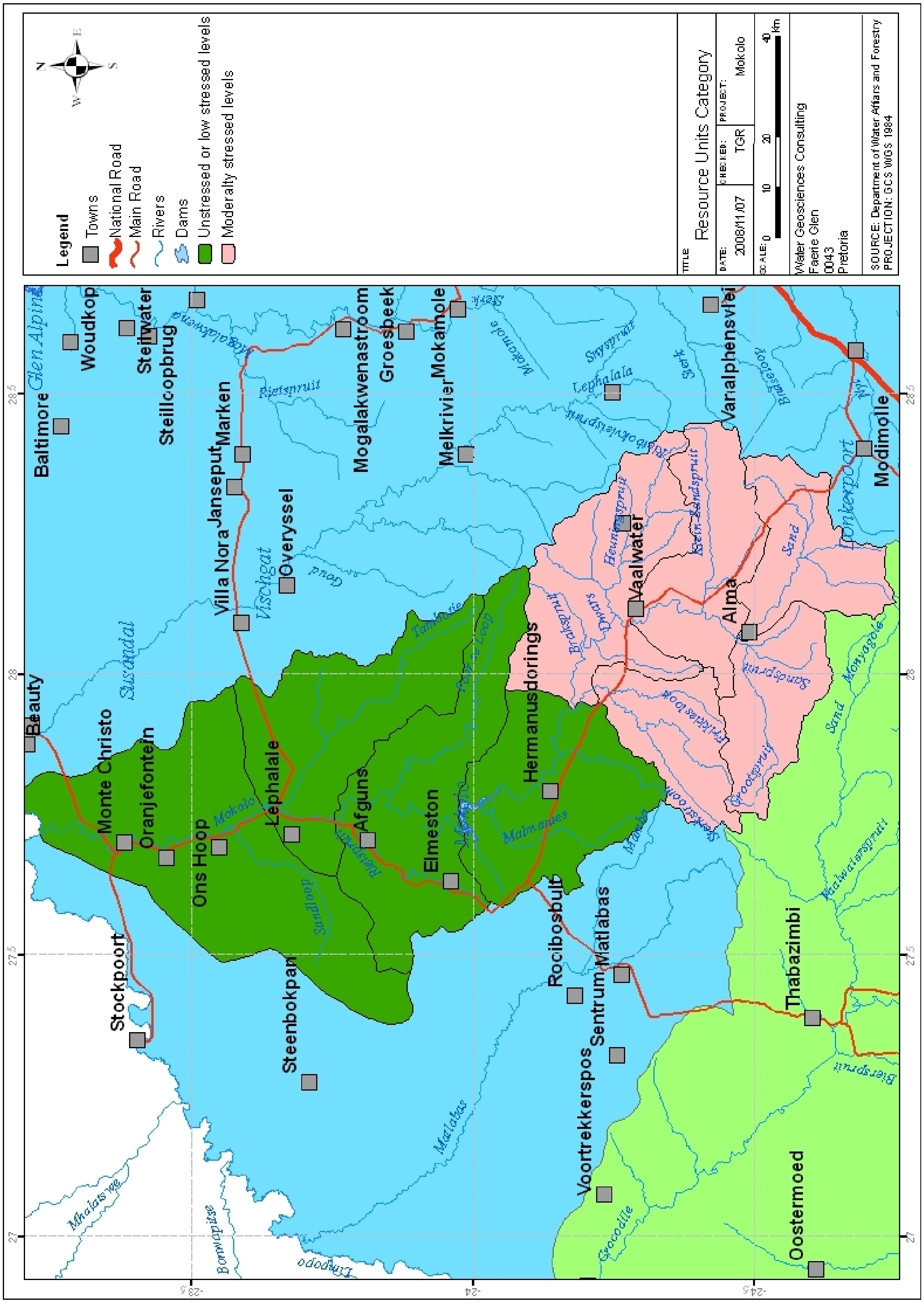

Figure 14: Present status category for geological resource units (secondary delineation)

7 GRDM Assessment

7.1 Geological resource units (secondary delineation)

7.1.1 Waterberg recharge resource unit

This resource unit covers an areal extent of approximately 3300 km^2 forming part of the scenic Waterberg Mountain Range. A few conservation/protected areas are located within the resource unit covering approximately 300 km^2. The resource unit is underlain by rocks of the Waterberg formation and to a very small extent by rocks of the Rooiberg Group (Bushveld Igneous Complex). NE-SW and NW-SE trending faults and dykes occur that is probably related to the Limpopo Mobile Belt Orogeny.

The most important aquifer in this resource unit is a dual porosity aquifer comprising primarily of sedimentary rocks. TDS values range from 600 to 1700 mg/l from south to north in the study area with a dominant Ca-Mg-HCO_3 water facies.

The total average recharge is estimated to be 94.64 Mm^3/annum and the total groundwater usage (i.e. abstraction) estimated to be 25.57 Mm^3/annum (Tables 5, 6). The estimated total volume of water stored in the aquifer is 3976 Mm^3/annum. The groundwater is mainly used for irrigation purposes.

7.1.2 Waterberg discharge resource unit

The Waterberg discharge resource unit falls within the middle portion of the Mokolo Catchment and covers an area of approximately 3200 km^2 including protected areas of approximately 150 km^2. The resource unit is also underlain by rocks of the Waterberg formation with similar NE-SW and NW-SE trending faults and dykes.

This unit is described as a discharge area with TDS values ranging between 60 and 200 mg/l with both Ca-Mg-HCO_3 and Na-HCO_3 water facies.

The total average recharge is estimated to be 63.24 Mm^3/annum with the total groundwater usage (i.e. abstraction) estimated to be 2.78 Mm^3/annum (Tables 5, 6). The estimated total volume of water stored in the aquifer is 3846 Mm^3/annum. The groundwater is mainly used for irrigation purposes.

7.1.3 Karoo/Basement resource unit

The northern part of the Mokolo Catchment is delineated as the Karoo/Basement resource unit covering an area of approximately 1800 km^2 with very small protection areas. The unit is underlain by rocks of both the Karoo Supergroup and Basement Igneous Complex. Prominent NE-SW and NW-SE trending faults and dykes similarly occur that is related to the Limpopo Mobile Belt Orogeny.

Fractured and integranular aquifers are present in the unit with TDS values ranging from 700 to 1100 mg/l and a dominant Na-Cl water facies.

The total average recharge is estimated to be 13.15 Mm^3/annum with the total groundwater usage (i.e. abstraction) estimated to be 0.19 Mm^3/annum (Table 6). The estimated total volume of water stored in the aquifer is 1011 Mm^3/annum. The groundwater use is mainly used for irrigation.

7.1.4 Alluvial Aquifer resource unit

The alluvial aquifer is one of the most important groundwater resource units in the Mokolo Catchment. Most of the groundwater abstraction, especially in the north, occurs along the confluence of the Mokolo and Limpopo Rivers. The alluvial deposits fingers out from north to south along the Mokolo Rivers and its branches. The most prominent alluvial aquifer is found in the north of the study area. Towards the south and into the Waterberg mountain range, the alluvial aquifer thins out and vanishes between the hills.

A study by de Jager et al (2006) on the characterization of the alluvial deposits along the Mokolo River resulted in the following conclusions:

- The alluvial deposits of the Mokolo River, south of Lephalale, have an average thickness of 9.1 m with a saturated volume of 13.3 Mm^3 (at 37% storage). The abstraction is 8.9 Mm^3/annum.
- The lower reaches of the Mokolo River, north of Lephalale, have an average alluvial thickness of 4.5 m with a saturated volume of 14.4 Mm^3 (at 37% storage). The abstraction volume is estimated to be 9.8 Mm^3/annum.
- The most northern part of the Mokolo Catchment has an average alluvial thickness of 4.0 meter with a saturated volume of 2.5 Mm^3 (at 37% storage).

The total volume of groundwater abstracted was estimated to be 17.7 Mm^3/annum. Abstraction from the Mokolo River varies between 7 and 10 Mm^3/annum.

Table 6: GRDM determination for the resource units (calculated using GRDM software)

Quaternary catchment	Present status category	Water resource category	Annual recharge (Mm^3/a)	Baseflow – main. low flow (Mm^3/a)	Population	Basic Human needs (Mm^3/a)	Reserve (%)	Ground-water allocation	Ground water use
Secondary delineation/resource unit									
Waterberg Recharge	C	Good	94.29	33.57	1500	0.014	35.49	61.07	25.57
Waterberg Discharge	A	Natural	63.23	5.8	26500	0.242	9.55	57.18	2.78
Karoo/ Basement	A	Natural	13.15	0.36	0	0	2.74	12.79	0.19
Alluvial systems	X	X	X	X	X	X	X	X	X
Primary delineation/resource unit									
A42A	C	Good	16.1	4.07	0	0	25.28	12.03	4.56
A42B	C	Good	16.85	8.18	0	0	48.55	8.67	4.47
A42C	C	Good	21.82	3.95	1500	0.014	18.17	17.86	5.51
A42D	B	Good	17	9.19	0	0	52.97	8.16	2.93
A42E	C	Good	22.52	8.18	0	0	36.32	14.34	8.1
A42F	B	Good	22.27	2.48	0	0	11.14	19.79	2.66

A42G	A	Natural	25.32	2.7	0	0	10.66	22.62	0.06
A42H	A	Natural	15.64	0.63	26500	0.242	5.57	14.77	0.06
A42J	A	Natural	13.15	0.36	0	0	2.74	12.79	0.19

8 Quantification of the Resource

8.1 Basic Human Needs

According to the National Water Act (Act 36 of 1998) each person are entitled to 25 liters per day. The basic human needs (BHN) component of the Reserve is calculated taking in account the population in each quaternary catchment and assuming that the population is entirely or partially dependent on groundwater as a source of water supply (i.e. 25 litres per person per day). The BHN component of the groundwater Reserve was calculated in table 6 (see section 7) for two of the quaternary catchments.

8.2 Groundwater contribution to Baseflow

Baseflow:

> Baseflow is that part of stream flow that derives from groundwater and shallow subsurface storage. During the dry season, the stream flow is typically composed entirely of baseflow.

Groundwater component of baseflow:

> This is the component of Baseflow that derives from the aquifer adjacent to a surface water body, and excludes interflow in the vadose zone or short–term storm events which saturate the subsurface soil and discharge to a surface water body before reaching the aquifer.

The groundwater contribution to baseflow is much higher for the southern, higher lying parts of the Mokolo catchment (delineated as Waterberg recharge unit) compared to the middle, lower lying parts of the Mokolo catchment (delineated as Waterberg discharge unit). The groundwater contribution to baseflow in the northern parts (i.e. Karoo/Basement resource unit) is significantly lower compared to the southern and middle sections of the Mokolo catchment (Table 7).

Table 7: Baseflow according to Schultz, Pitman and Hughes (Source: Sami, 2006)

Resource unit	MAR (Mm^3/a)	Base flow Schultz (mm/a)	Base flow Pitman (mm/a)	Base flow Hughes (mm/a)	Base flow - Main. Low flow (Mm/a)	GW contribution to base flow (mm/a)
Secondary delineation/resource unit						
Waterberg recharge	203.61	73.85	153.1	153.9	33.57*	61.99
Waterberg discharge	104.5	1.68	13.1	27.17	5.8*	1.68
Karoo/Basement	7.42	0	0	0.05	0.36*	0
Alluvial aquifers	X	X	X	X	X	X
Primary delineation/resource unit						
A42A	25.89	16.75	31.4	27.26	4.07*	15.18
A42B	25.97	17.76	32.3	29.49	8.18*	12.57
A42C	34.06	17.49	32.1	29.03	3.95*	12.65
A42D	46.51	11.9	30.7	38.44	9.19*	11.64
A42E	71.18	9.95	26.6	29.68	8.18*	9.95
A42F	36.79	0.62	4.6	10.28	2.48*	0.62
A42G	39.97	0.55	4.4	9.39	2.7*	0.55
A42H	27.74	0.51	4.1	7.5	0.63*	0.51
A42J	7.42	0	0	0.05	0.36*	0
* Calculated using Spatsim software						

9 Management Objectives

The Mokolo area consists predominately of four major geological units; the Waterberg formation, Karoo Supergroup, Basement rocks and to a smaller extent alluvial deposits. The delineation of groundwater resource units is based on a quaternary catchment level (i.e. primary delineation), according to the major geological units (i.e. secondary delineation) while the alluvial aquifers are highlighted as a focus area for further investigation.

The alluvial aquifer system is one of the most important groundwater resource units in the Mokolo Catchment. Most of the groundwater abstraction, especially in the north, occurs along the confluence of the Mokolo and Limpopo Rivers. The high density boreholes along the Mokolo River associated with the alluvial deposits and the relatively higher abstraction rates necessitates a more detailed study of these alluvial aquifer systems.

A present status category or stress index, based on the volume of groundwater abstraction in relationship to the annual recharge, was set for each of the quaternary catchments. Moderate stress levels were categorized for quaternary catchments A42A, A42B, A42C and A42E which are all located in the southern part of the Mokolo Catchment. Unstressed to low levels of stress characterize the northern parts of the Mokolo Catchment. The water resource category thus varies from *GOOD* in the south to

NATURAL in the middle and northern parts of the catchment. The groundwater contribution to baseflow (i.e. maintenance low flow component) is also much higher for the southern, higher lying parts of the Mokolo catchment compared to the middle and northern, lower lying parts of the Mokolo catchment. The above characteristics could not be determined for the alluvial aquifer systems due to a lack of data.

As a result, current and future water uses that impact (or may impact) on groundwater dependant ecosystems must be identified to set protection zones for these groundwater dependant ecosystems.

All the groundwater resource units in the Mokolo Catchment are being used sustainably according to GRDM determinations. However, correct groundwater management procedures, from a socio-economical as well as an ecological protection perspective, should be implemented, observed and maintained to insure that these groundwater resource units won't be over-utilized over a long-term basis. Indications of over-utilization include factors such as reduction in spring and river flows, reduced biodiversity, vegetation die-off, land subsidence and long term declination of water levels where it is not related to natural influences. The data used for the GRDM determinations should be updated to include current groundwater use.

Further studies are required focusing on:

- Developing a conceptual understanding of the varied aquifer systems and the groundwater domains through more site specific geohydrology studies.

- The information available is not adequate to characterize the alluvial aquifer systems and/or to assess the potential impacts of the development activities on the groundwater resources in these alluvial systems.

The following generic resource quality objectives are proposed based on the level of understanding of the aquifer system(s):

- Develop the aquifer system(s) at a sustainable rate, especially the alluvial aquifers. Determine the optimal yield of the borehole and the sustainable yield of the aquifer system through conducting aquifer tests.
- Maintain groundwater levels and groundwater gradients with specific reference to maintaining the groundwater contribution to baseflow. Implement a groundwater level monitoring programme and specifically monitor the quantity and quality of groundwater.
- Continuously assess the potential impacts of the development activities, and associated land-use activities, on the quality of the groundwater resources. Implement a periodic groundwater quality sampling programme prior to and during development operations. Set resource quality objectives based on the ambient groundwater quality.

Implement the above activities to generally prevent the following:

- To prevent and/or manage potential decreasing groundwater level trends.
- To prevent the deterioration of the groundwater quality.
- To prevent stress on groundwater dependent ecosystems and to maintain the groundwater component of baseflow.
- To manage groundwater optimally within the catchment taking into account (where appropriate):
  - Increasing groundwater use in the catchment
  - Increasing disputes around groundwater use
  - The increasing numbers of boreholes completed and/or failing
  - The increasing number of potential groundwater pollution sources
  - Increasing groundwater pollution from existing sources

Effective monitoring programmes are required to determine if or when the sustainable groundwater abstraction limits are being approached or exceeded.

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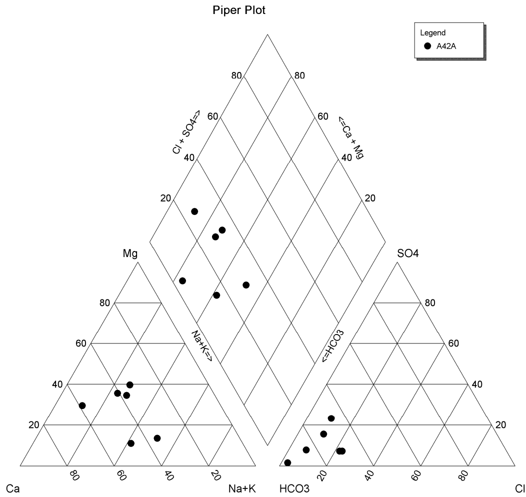
APPENDIX A
PIPER PLOTS



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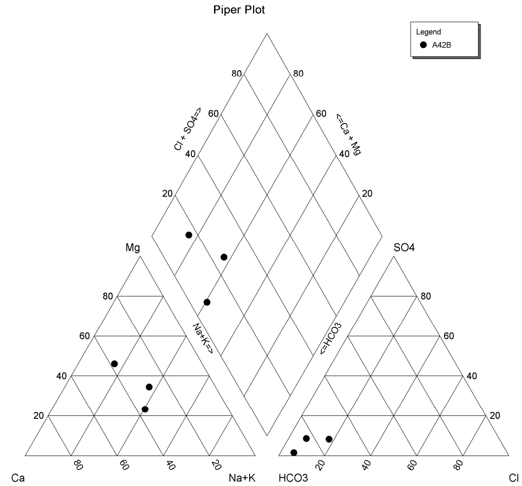

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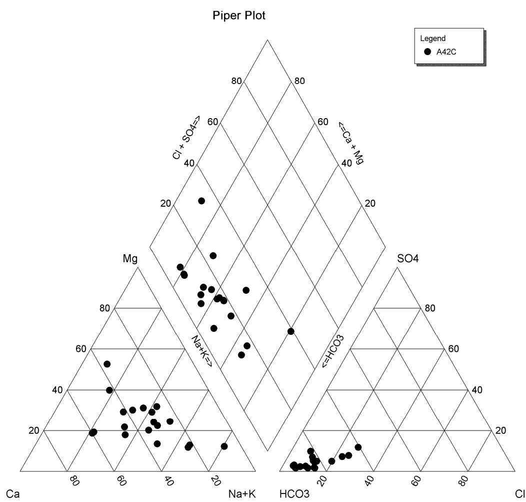

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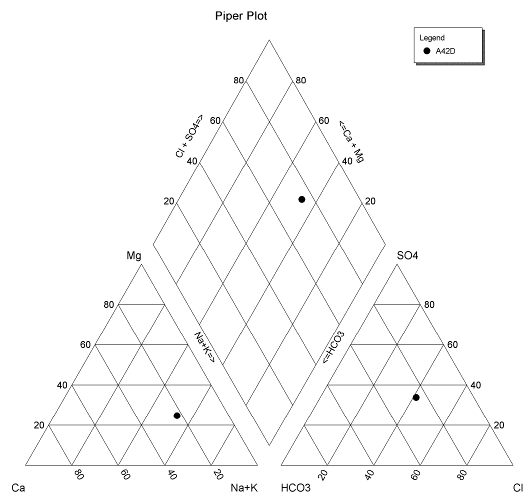

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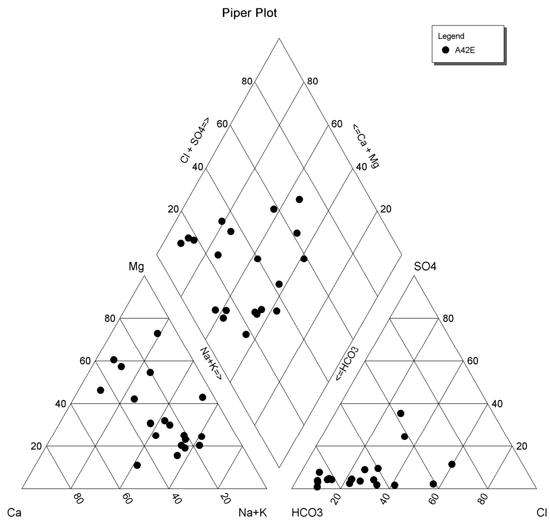
APPENDIX A
PIPER PLOTS



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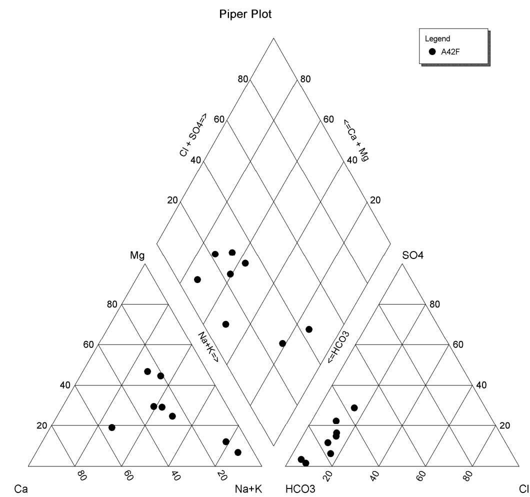

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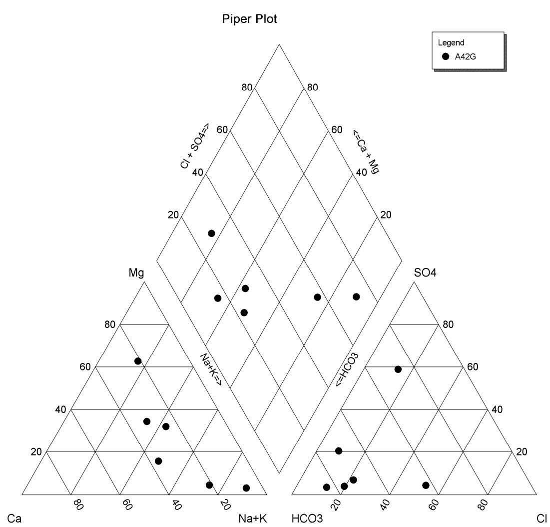

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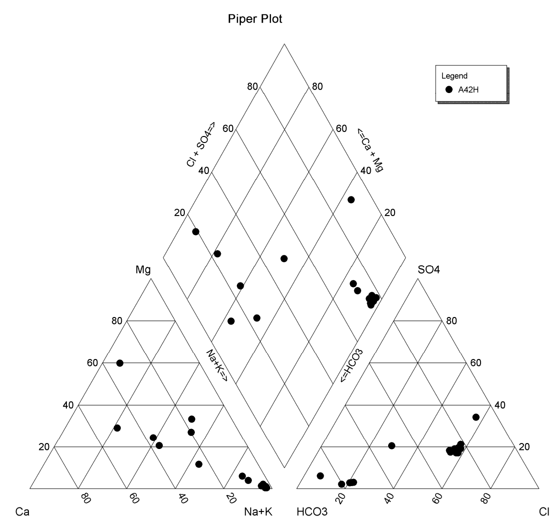

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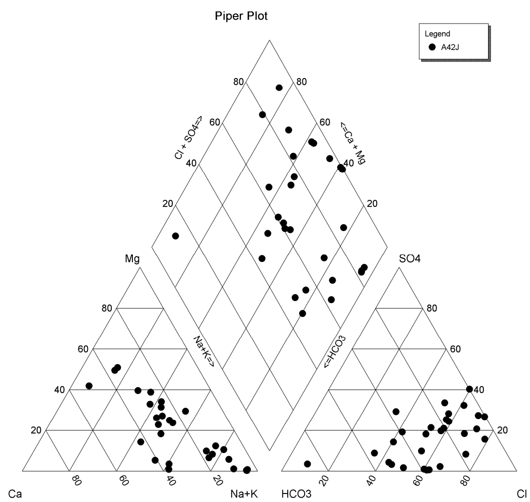
APPENDIX A
PIPER PLOTS



A42J

APPENDIX B
GROUNDWATER FACIES

Sample ID	Quaternary catchment	Water facies	E.N. [‰]
143 BA WQ 3.23	A42G	Mg-Ca-HCO_3-Cl	0.1
144 BA WQ 4-15	A42E	Mg-HCO_3-Cl	-1.4
180 BA WQ 14.29	A42H	Mg-Ca-HCO_3	-2.2
2326DD00105 MOOIVLEI	A42H	Na-Ca-Cl-SO_4	0.1
2427BB00155 GROENFONTEIN PTN. WELGEVONDEN - H24-FH	A42F	Na-Ca-Mg-HCO_3	-0.1
2427BB00156 HERMANUSDORINGS PTN. LALINGWE RANCH -H	A42F	Na-HCO_3-SO_4	-3.3
2427BB00157 HERMANUSDORINGS PTN. LALINGWE RANCH -	A42F	Ca-Na-HCO_3	-4.5
2427BB00158 WELGEVONDEN PTN. WELGEVONDEN - H24-FVD	A42F	Na-Mg-Ca-HCO_3-SO_4	-1.9
2427BB00159 GROENFONTEIN PTN. WELGEVONDEN - H24-FV	A42F	Mg-Na-Ca-HCO_3	-0.1
2427BB00160 GROENFONTEIN PTN. WELGEVONDEN - H24-FV	A42F	Na-HCO_3	0.1
2428AC00265 GROENFONTEIN	A42E	Na-Mg-HCO_3-SO_4-Cl	-0.4
2428AC00441 VAALWATER H240024	A42C	Ca-Mg-Na-HCO_3-Cl	-3.4
2428AC00442 VAALWATER H240023	A42C	Ca-Na-HCO_3	-4.0
2428AC00444 VAALWATER H240029	A42C	Na-Ca-Mg-HCO_3	-2.8
2428AC00445 ZANDRIVIER VAALWATER - H240031	A42E	Ca-Na-Mg-HCO3-Cl-SO_4	-10.2
2428AC00448 HARTBEESTPOORT - HT05	A42C	Na-Mg-Ca-HCO_3	-0.8
2428AC00449 LEEUWDRIFT - LT01	A42E	Na-Mg-HCO_3-Cl	0.6
2428AC00450 LEEUWDRIFT - LT02	A42E	Na-Ca-Mg-HCO_3-Cl	0.7
2428AC00451 LEEUWDRIFT - LT03	A42E	Na-Mg-Ca-HCO_3-Cl	0.1
2428AC00452 LEEUWDRIFT - LT06	A42E	Na-Mg-Ca-HCO_3-Cl	-2.9
2428AC00453 HAARTBEESTPOORT - HT03	A42E	Na-Mg-Ca-HCO_3	0.6
2428AC00454 SLYPSTEENDRIFT - ST01	A42E	Na-Mg-Ca-Cl-HCO_3	-2.3
2428AC00455 SLYPSTEENDRIFT - ST03	A42E	Mg-Ca-Na-HCO_3-Cl	-4.3
2428AC00457 NOOITGEDACHT - NT02	A42C	Na-Ca-Mg-HCO_3	-4.9
2428AC00458 VAALWATER - VR03	A42C	Ca-Na-Mg-HCO_3	1.0
2428AC00459 VAALWATER - VR04	A42C	Na-Ca-HCO_3	-0.9
2428AC00460 VAALWATER - VR05	A42C	Na-Ca-Mg-HCO_3	0.8
2428AC00468 ZANDRIVIER H240047	A42C	Ca-HCO_3	-4.6
2428AC00469 ZANDRIVIER H240050	A42C	Ca-Na-Mg-HCO_3	0.2
2428AC00470 ZANDRIVIER H240048	A42C	Ca-Na-HCO_3	-2.7

APPENDIX B
GROUNDWATER FACIES

Sample ID	Quaternary catchment	Water facies	E.N. [‰]
2428AC00471 KNOPFONTEIN H240062	A42C	Na-Ca-HCO_3-Cl	0.1
2428AC00477 VAALWATER PTN. VAALWATER - H24-VLW-01	A42C	Na-Mg-Ca-HCO_3	-1.8
2428AC00479 VAALWATER PTN. VAALWATER - H24-VLW-03	A42C	Na-Ca-Mg-HCO_3	-4.1
2428AC00495 KNOPPIEFONTEIN H240067	A42E	Ca-Na-HCO_3	-2.3
2428BB00449 MACALACASKOP H032605	A42E	Mg-Na-Ca-HCO_3-Cl	-0.8
2428CB00496 LEEUPOORT PTN. LEEUPOORT - H24-LEE-02	A42A	Mg-Ca-Na-HCO_3-Cl	2.4
2429AA00077 LANSBERGHOEK PTN. LANSBERGHOEK - H29-L	A42G	Na-Ca-HCO_3-Cl	-4.5
ALFRED	A42J	Na-Cl-SO_4	1.6
BATH (DUP NAME 24721)	A42J	Na-Mg-Ca-Cl-HCO_3	2.0
BOESMANSFONTEIN 112 (DUP NAME 15858)	A42E	Mg-Ca-HCO_3	-1.5
BOESMANSFONTEIN 112 (DUP NAME 15859)	A42E	Mg-Ca-HCO_3	-0.2
BOSCHOEK (DUP NAME 20504)	A42A	Ca-Mg-Na-HCO_3-SO_4	-0.4
BRAKFONTEIN (DUP NAME 22991)	A42G	Na-Mg-Ca-HCO_3	4.6
BULGE RIVIER	A42F	Na-Ca-Mg-HCO_3	1.6
BULTFONTEIN (DUP NAME 21565)	A42G	Mg-Ca-Na-HCO_3	3.3
BUURMANSHULP (DUP NAME 24720)	A42J	Na-Mg-Cl-HCO_3	1.5
BUURMANSHULP (DUP NAME 3828)	A42J	Na-Ca-Mg-Cl-HCO_3	0.5
DONDERBOSCHFONTEIN1	A42E	Mg-Ca-HCO_3	-0.7
EENDRACHT (DUP NAME 9042)	A42J	Ca-Mg-HCO_3	-1.6
EHRENBREITSTEIN (DUP NAME 27383)	A42H	Na-Cl-HCO_3	-2.9
GORKUM	A42J	Na-Cl-SO_4	-0.6
GRIETASVLAKTE (DUP NAME 27396)	A42H	Na-Cl-HCO_3	0.3
GRIETASVLAKTE (DUP NAME 27397)	A42H	Na-Cl-HCO_3	-0.6
GROENFONTEIN (DUP NAME 20499)	A42C	Na-HCO_3-Cl	-4.3
GROOTVLEY (DUP NAME 26567)	A42G	Na-SO_4-HCO_3	-2.7
GUNFONTEIN	A42E	Na-Ca-Mg-HCO_3	-0.3
JACOBSLOOP	A42J	Na-Ca-Mg-Cl-HCO_3	-1.6
JUPITER	A42H	Na-Mg-Ca-HCO_3	3.4
KAMEELFONTEIN (DUP NAME 3830)	A42J	Na-Ca-HCO_3-Cl	1.5
KAMEELFONTEIN (DUP NAME 3831)	A42J	Na-Mg-Ca-Cl	3.7

APPENDIX B
GROUNDWATER FACIES

Sample ID	Quaternary catchment	Water facies	E.N. [‰]
KLIPFONTEIN (DUP NAME 3829)	A42J	Na-HCO_3-Cl	1.4
KROMDRAAI (DUP NAME 8995)	A42C	Mg-Ca-HCO_3-Cl	2.1
MAGENTA	A42J	Na-Ca-Cl-SO_4	-1.2
MAKLAK	A42J	Na-Cl-HCO_3	-0.4
MONTE CHRISTO	A42J	Na-Ca-Mg-Cl-HCO_3	3.4
MONTEVIDEO	A42J	Na-Cl-HCO_3	-0.2
MORGENZON (DUP NAME 20917)	A42D	Na-Mg-Ca-Cl-SO_4-HCO_3	0.5
OLIEVENHOUFONTEIN	A42E	Na-Ca-HCO_3-Cl	-2.5
ORANJEFONTEIN (DUP NAME 8936)	A42J	Na-HCO_3-Cl-SO_4	-0.9
RHENOSTERFONTEIN (DUP NAME 22248)	A42B	Mg-Ca-HCO_3	-1.9
RHENOSTERFONTEIN (DUP NAME 22249)	A42B	Ca-Na-Mg-HCO_3	2.3
RHENOSTERPOORT (DUP NAME 20276)	A42A	Ca-Mg-Na-HCO_3	1.0
RIETVALEY (DUP NAME 3840)	A42J	Na-Ca-Cl-SO_4	0.8
RIETVALEY (DUP NAME 3841)	A42J	Mg-Ca-Cl-SO_4	1.0
ROOIBOKVALE	A42B	Na-Mg-Ca-HCO_3	-0.2
RUSTENBURG (DUP NAME 3849)	A42J	Mg-Ca-Cl-SO_4	1.8
RUSTENBURG (DUP NAME 8937)	A42J	Na-Mg-Ca-Cl-SO_4	-3.1
SMITHFIELD (DUP NAME 24703)	A42J	Na-Ca-Mg-Cl-HCO_3	1.2
SMITHFIELD (DUP NAME 3832)	A42J	Na-Ca-Mg-Cl-HCO_3	0.5
SPECULATIE (DUP NAME 3846)	A42J	Mg-Na-Ca-Cl-HCO_3	3.5
SPECULATIE (DUP NAME 3851)	A42J	Mg-Ca-Na-Cl	2.2
SPRUITSKLOOF	A42G	Na-Ca-Cl-HCO_3	-2.4
STELLENBOSCH (DUP NAME 20503)	A42J	Na-HCO_3-Cl	-2.5
STERKFONTEIN (DUP NAME 21578)	A42E	Na-Ca-Mg-HCO_3	1.1
STERKSTROOM (DUP NAME 3865)	A42J	Na-Ca-Cl-SO_4	2.3
STERKSTROOM (DUP NAME 3866)	A42J	Na-HCO_3-Cl	-2.7
TAUNFONTEIN	A42H	Na-Mg-HCO_3-Cl-SO_4	-1.3
VAALWATER (DUP NAME 28914)	A42C	Na-Ca-HCO_3	-0.3
VENTERSHOEK	A42H	Na-Ca-Mg-HCO_3	-0.5
VOGELSTRUISFONTEIN (DUP NAME 27384)	A42J	Na-Cl-SO_4	1.2

APPENDIX B
GROUNDWATER FACIES

Sample ID	Quaternary catchment	Water facies	E.N. [‰]
VOGELSTRUISFONTEIN (DUP NAME 27385)	A42J	$Na-Cl-SO_4$	2.2
WATERKLOOF (DUP NAME 9051)	A42H	$Ca-Mg-Na-HCO_3-Cl$	-4.2
WATERKLOOF (DUP NAME 9051)	A42H	$Ca-Mg-Na-HCO_3-Cl$	-3.5
WERKENDAM (DUP NAME 27386)	A42H	$Na-Cl-HCO_3$	-2.8
WERKENDAM (DUP NAME 27387)	A42H	$Na-Cl-HCO_3$	0.1
WERKENDAM (DUP NAME 27388)	A42H	$Na-Cl-HCO_3$	0.3
WERKENDAM (DUP NAME 27389)	A42H	$Na-Cl-HCO_3$	-3.1
WERKENDAM (DUP NAME 27390)	A42H	$Na-Cl-HCO_3$	-0.9
WERKENDAM (DUP NAME 27391)	A42H	$Na-Cl-HCO_3$	-0.1
WERKENDAM (DUP NAME 27392)	A42H	$Na-Cl-HCO_3$	-2.4
WERKENDAM (DUP NAME 27393)	A42H	$Na-Cl-HCO_3$	-2.9
WERKENDAM (DUP NAME 27393)	A42H	$Na-Cl-HCO_3$	1.5
WERKENDAM (DUP NAME 8935)	A42H	$Na-Ca-Mg-HCO_3-Cl$	-2.4
WINDHOEK (DUP NAME 3864)	A42J	Ca-Na-Cl	0.3
WITKLIP (DUP NAME 20502)	A42E	$Na-Ca-HCO_3-Cl$	-0.7
WITKLIP (DUP NAME 22009)	A42A	$Ca-Mg-HCO_3$	-3.8
ZANDPUT WATERBERG	A42F	$Mg-Na-Ca-HCO_3$	-0.8
ZQMELS1 2327DA00034 RIETSPRUIT ELLISRAS/WITKOP	A42H	$Na-Cl-HCO_3-SO_4$	-4.4
ZQMVAW1 2428AC00394 ZANDRIVIER/VAW WELDING	A42C	$Na-Ca-HCO_3$	0.4
ZQMVAW2 2428AC00406 GROENFONTEIN PLOT NO 5 VAALWAT	A42C	$Ca-Mg-HCO_3$	-0.4

APPENDIX C
GEOCHEMISTRY

Sample ID	Latitude	Longitude	Ca	Cl	DMS	EC	F	K	Mg	NH_4	NO_3	Na	PO_4	SO_4	Si	TAL	HCO3	pH
RHENOSTERPOORT (DUP NAME 20276)	-24.6305560	28.1444440	25.7	3	232	29.4	0.44	4.36	13.5	0.02	0.04	14.4	0.005	2	17.69	137.9	178.0703	7.64
BOSCHOEK (DUP NAME 20504)	-24.5675000	28.2588890	7	3.4	67	10	0.31	0.64	3.9	0.02	0.05	5.6	0.011	10.2	6.04	28.9	37.31857	6.36
WITKLIP (DUP NAME 22009)	-24.6097220	28.3166670	20.1	7	133	18.2	0.38	3.19	6.1	0.02	0.99	2.7	0.016	13.2	9.81	62.1	80.18973	7.4
2428AC00471 KNOPFONTEIN H240062	-24.4811900	28.1447200	26.751	29.951	272.507	35.3	2.213	2.2	6.172	0.02	0.241	43.749	0.025	12.54	17.729	121.19	156.4926	7.713
2428AC00495 KNOPPIEFONTEIN H240067	-24.4957700	28.0838200	17.872	5	146.214	18.4	1.51	1.918	2.492	0.02	0.398	16.846	0.026	6.919	13.139	75.283	97.21294	8.255
2428CB00496 LEEUPOORT PTN. LEEUPOORT - H24-LEE-02	-24.5851600	28.2896600	4.296	4.617	45.273	6.35	0.18	1.603	3.067	0.02	0.393	2.98	0.197	2	6.913	19.816	25.5884	7.648
ROOIBOKVALE	-24.5194440	27.9305560	51.8	55.3	653	84.5	0.74	4.27	37.3	0.02	4.97	72.7	0.011	34.3	23.99	306.9	396.3	
RHENOSTERFONTEIN (DUP NAME 22248)	-24.5250000	27.9166670	14.4	5.3	139	17.8	0.39	1.23	10.5	0.02	0.07	6.1	0.046	7.9	9.61	76.3	98.52619	
RHENOSTERFONTEIN (DUP NAME 22249)	-24.5166670	27.9166670	23.3	6.4	239	29.7	0.75	19.16	9	0.23	0.02	18.5	0.073	2	11.57	132.6	171.2264	
ZQMVAW1 2428AC00394 ZANDRIVIER/VAW WELDING	-24.2944440	28.0911110	17.569	16.267	312.395	40.5	0.438	1.041	6.327	0.02	2.739	60.595	0.012	9.788	9.268	154.342	199.3018	8.122
ZQMVAW2 2428AC00406 GROENFONTEIN PLOT NO 5 VAALWATER	-24.3233330	28.0986110	21.489	5.632	188.934	26	0.142	1.336	12.297	0.02	0.212	9.74	0.014	2	15.085	110.962	143.2852	8.473
KROMDRAAI (DUP NAME 8995)	-24.4127780	28.1458330	96	106		111.1	0.1		83		23.72	32		43		369.9	477.6519	7.6
GROENFONTEIN (DUP NAME 20499)	-24.3305560	28.1102780	0.5	3.5	28	2.2	0.17	0.51	0.5	0.02	0.14	6	0.017	2	4.45	10.3	13.30039	5.62
VAALWATER (DUP NAME 28914)	-24.2972220	28.0911110	18.4	13.9	307	39.2	0.94	1.48	5.7	0.02	0.528	59.5	0.008	4.6	9.06	164.5	212.4189	8.26
2428AC00441 VAALWATER H240024	-24.2869440	28.0921100	25.726	22.83	234.21	30.6	0.141	0.827	10.932	0.02	0.849	20.245	0.034	7.665	19.875	116.428	150.3435	8.009
2428AC00442 VAALWATER H240023	-24.2846900	28.0878000	25.842	5	224.355	25.8	0.231	1.049	6.005	0.043	0.086	22.142	0.124	4.412	15.04	130.291	168.2448	8.172
2428AC00444 VAALWATER H240029	-24.3087800	28.1163600	18.501	5	240.963	28.6	0.24	0.952	8.188	0.02	0.504	32.185	0.036	4.152	12.835	138.919	179.3861	8.048
2428AC00468 ZANDRIVIER H240047	-24.2860200	28.0880500	26.092	5	176.339	22.4	0.142	1.415	4.894	0.02	0.432	9.753	0.021	2	11.818	102.555	132.4293	8.264
2428AC00469 ZANDRIVIER H240050	-24.2938800	28.0852700	16.84	5	141.469	19.8	0.196	1.078	4.919	0.02	0.473	13.754	0.051	2	14.426	78.249	101.0429	8.211
2428AC00470 ZANDRIVIER H240048	-24.2877700	28.0869400	27.161	5	181.154	22.7	0.13	0.996	5.345	0.02	0.339	10.892	0.021	2	12.288	105.014	135.6046	8.236
2428AC00471 KNOPFONTEIN H240062	-24.4811900	28.1447200	26.751	29.951	272.507	35.3	2.213	2.2	6.172	0.02	0.241	43.749	0.025	12.54	17.729	121.19	156.4926	7.713
2428AC00448 HARTBEESTPOORT - HT05	-24.2816600	28.1013800	30.064	25.835	429.019	55.5	0.537	0.977	22.166	0.044	1.7	54.961	0.021	12.006	12.688	225.405	291.0655	8.258
2428AC00457 NOOITGEDACHT - NT02	-24.3075000	28.1433300	43.159	35.882	531.455	67	0.225	1.372	25.303	0.02	1.928	55.681	0.015	6.108	14.838	291.258	376.1015	8.291
2428AC00458 VAALWATER - VR03	-24.3005500	28.1194400	47.195	24.143	467.203	57.5	0.388	0.925	23.056	0.02	3.479	46.898	0.021	4.584	14.487	249.761	322.5164	8.393
2428AC00459 VAALWATER - VR04	-24.2919400	28.0925000	29.303	19.537	314.806	39.8	0.287	2.559	10.079	0.02	1.672	40.746	0.015	9.674	11.726	160.055	206.679	8.437
2428AC00460 VAALWATER - VR05	-24.3091600	28.1261100	37.478	29.86	482.305	59.7	0.208	1.28	22.416	0.02	8.586	59.564	0.012	4.562	14.388	236.92	305.9348	8.315
2428AC00477 VAALWATER PTN. VAALWATER - H24-VLW-01	-24.3065000	28.1116100	16.01	12.345	261.313	33.8	0.281	1.143	9.821	0.043	3.339	38.399	0.006	11.021	12.151	129.126	166.7404	8.392

APPENDIX C
GEOCHEMISTRY

Sample ID	Latitude	Longitude	Ca	Cl	DMS	EC	F	K	Mg	NH_4	NO_3	Na	PO_4	SO_4	Si	TAL	HCO3	pH
2428AC00479 VAALWATER PTN. VAALWATER - H24-VLW-03	-24.3116900	28.1066300	10.736	5.378	138.747	19.1	0.202	1.228	5.013	0.054	1.134	16.856	0.017	8.523	9.385	70.264	90.7319	7.872
MORGENZON (DUP NAME 20917)	-24.3022220	27.9944440	92	295	1324	194.5	2.72	4.94	61.5	0.02	0.9	246.9	0.003	326.5	15.65	237.8	307.0711	7.9
144 BA WQ 4-15	-24.1269440	28.1586110	18.8	103.4	778	94.6	0.44	11.53	100.2	0.14	3.71	42.2	0.032	49.4	20.13	356.9	460.865	8.3
DONDERBOSCHFONTEIN1	-24.1977780	28.2136110	52.3	24.4	592	78.9	0.22	1.04	59.2	0.02	5.44	12.9	0.007	14.6	14.41	331.1	427.5494	7.43
BOESMANSFONTEIN 112 (DUP NAME 15858)	-24.1175000	28.0838890	51.3	43	597	77.9	0.38	5.75	57.7	0.02	0.69	19.3	0.003	17.4	22.14	327.6	423.0299	7.51
BOESMANSFONTEIN 112 (DUP NAME 15859)	-24.1500000	28.0386110	91.7	45.2	729	88.8	0.46	0.86	57.4	0.02	0.02	20.7	0.003	21	24.36	403	520.3939	7.8
GUNFONTEIN	-24.1027780	28.1166670	21.4	10.5	245	32	0.16	5.72	9.8	0.02	0.04	28	0.006	4.8	4.05	134.9	174.1964	7.81
VOGELVLEI POTGIETER (DUP NAME 20495)	-24.1080560	28.0166670	54	402.8	1278	189.8	0.43	15.09	55.5	0.02	0.07	253.8	0.006	21.4	9.78	389.2	502.574	7.97
2428AC00265 GROENFONTEIN	-24.3377780	28.0041670	0.5	4.3	40	4.7	0.32	1.05	2.7	0.04	1.66	5.6	0.01	7.7	5.07	8.1	10.45953	5.53
OLIEVENHOUFONTEIN	-24.1541670	28.0708330	30.1	50.7	391	55.7	0.24	5.34	9.8	0.2	0.04	63.5	0.158	9.4	12.35	181.6	234.5001	7.45
WITKLIP (DUP NAME 20502)	-24.2994440	28.2222220	30.4	93.4	440	62	0.68	5.89	14.6	0.1	0.02	79.5	0.069	4.9	11.58	172.4	222.6201	7.6
STERKFONTEIN (DUP NAME 21578)	-24.3291670	28.2125000	33.7	18.1	381	49	0.45	1.58	19.6	0.02	0.67	43.7	0.012	2	17.44	213.6	275.8217	7.9
2428AC00445 ZANDRIVIER VAALWATER - H240031	-24.2986100	28.0744440	3.121	5	52.558	5.79	0.208	1.056	1.792	0.02	5.147	3.498	0.062	4.894	5.298	8.192	10.57833	6.605
2428AC00449 LEEUWDRIFT - LT01	-24.2683300	28.1063800	28.166	86.694	577.173	76.5	0.558	1.753	19.87	0.049	4.938	114.19	0.022	15.345	11.103	236.707	305.6597	8.367
2428AC00450 LEEUWDRIFT - LT02	-24.2533300	28.1213800	28.308	43.876	411.187	54	0.35	1.324	14.014	0.02	1.376	71.021	0.022	11.806	11.968	192.169	248.1478	8.336
2428AC00451 LEEUWDRIFT - LT03	-24.2786100	28.1216600	38.344	70.152	644.765	81.8	0.427	1.75	27.244	0.02	0.115	109.462	0.06	18.195	10.253	310.412	400.835	8.382
2428AC00452 LEEUWDRIFT - LT06	-24.2688800	28.1341600	43.197	93.453	620.773	85.7	0.317	1.927	32.608	0.02	7.236	80.214	0.022	39.117	13.224	244.259	315.4116	8.251
2428AC00453 HAARTBEESTPOORT - HT03	-24.2777700	28.1047200	24.145	24.984	412.175	52	0.453	1.344	15.654	0.051	1.192	69.813	0.006	12.361	10.997	211.654	273.3088	8.443
2428AC00454 SLYPSTEENDRIFT - ST01	-24.2905500	28.1677700	59.212	264.129	769.835	134	0.955	2.038	43.579	0.02	0.054	123.495	0.015	68.045	11.604	170.654	220.3655	8.317
2428AC00455 SLYPSTEENDRIFT - ST03	-24.2836100	28.1583300	52.932	104.429	577.294	81.8	0.204	2.031	40.911	0.02	0.717	44.508	0.012	7.066	15.13	264.076	341.0013	8.222
2428AC00495 KNOPPIEFONTEIN H240067	-24.4957700	28.0838200	17.872	5	146.214	18.4	1.51	1.918	2.492	0.02	0.398	16.846	0.026	6.919	13.139	75.283	97.21294	8.255
2428BB00449 MACALACASKOP H032605	-24.1469100	28.9513300	46.048	86.934	828.885	109.2	0.988	0.866	74.879	0.015	15.265	64.815	0.038	13.009	32.397	388.462	501.621	8.42
ZANDPUT WATERBERG	-24.0380560	27.8500000	4.7	5.4	81	10.7	0.32	4.46	6	0.02	0.16	6.2	0.007	8.6	3.82	36.7	47.39071	7.08
BULGE RIVIER	-24.1125000	27.6944440	15.8	8.3	227	25.5	0.68	11.04	9.1	0.43	0.1	28	0.262	2	20.4	125.3	161.7999	8.25
2427BB00155 GROENFONTEIN PTN. WELGEVONDEN - H24-FH-01	-24.1352200	27.8206300	32.955	22.266	390.295	49.3	0.574	1.568	18.555	0.02	4.146	45.88	0.034	27.666	11.123	182.363	235.4853	7.673
2427BB00156 HERMANUSDORINGS PTN. LALINGWE RANCH -H24-FH-02	-24.1424700	27.8190500	7.954	31.254	431.822	59.7	3.659	0.871	4.61	0.045	0.797	111.581	0.015	80.019	10.209	154.391	199.3651	8.156
2427BB00157 HERMANUSDORINGS PTN. LALINGWE RANCH - H24-	-24.1651100	27.7919700	43.809	7.928	323.349	39.4	0.198	1.913	9.098	0.042	0.159	23.092	0.006	6.795	18.497	188.426	243.3145	8.398

APPENDIX C
GEOCHEMISTRY

Sample ID	Latitude	Longitude	Ca	Cl	DMS	EC	F	K	Mg	NH_4	NO_3	Na	PO_4	SO_4	Si	TAL	HCO3	pH
FH-03																		
2427BB00158 WELGEVONDEN PTN. WELGEVONDEN - H24-FVDM-01	-24.1088600	27.8038800	25.027	16.99	332.345	46.6	0.439	1.679	15.595	0.02	1.457	42.474	0.017	48.388	12.02	143.715	185.5792	8.112
2427BB00159 GROENFONTEIN PTN. WELGEVONDEN - H24-FVDM-03	-24.1306300	27.8281300	8.512	8.855	127.184	18.4	0.155	0.721	9.381	0.02	3.58	10.145	0.094	4.47	11.447	56.414	72.8474	7.833
2427BB00160 GROENFONTEIN PTN. WELGEVONDEN - H24-FVDM-04	-24.1461600	27.8328000	14.175	36.472	544.387	64.1	3.988	1.98	10.636	0.048	0.427	132.311	0.02	50.11	13.007	240.066	309.9972	8.253
SPRUITSKLOOF	-23.9000000	27.7333330	4	18		66	0.3		0.5		0.02	16		2		19.7	25.43861	6.6
143 BA WQ 3.23	-24.0886110	28.1425000	45.2	80.4	723	91.1	0.48	5.65	80.2	0.16	2.8	35.6	0.04	34.1	29.22	351.7	454.1502	8.12
BULTFONTEIN (DUP NAME 21565)	-24.0125000	27.6208330	8.6	5.6	93	12.9	0.05	1.86	5.6	0.07	0.35	9.4	0.03	2	18.01	49.6	64.04848	7.2
BRAKFONTEIN (DUP NAME 22991)	-24.0500000	28.1333330	8.9	5.1	123	16	0.21	4.17	6.8	0.1	0.13	14.8	0.671	15.5	15.34	53	68.4389	6.5
GROOTVLEY (DUP NAME 26567)	-23.8166670	27.7000000	17.7	64.4	924	140	7.3	3.2	4.6	0.02	0.02	258.9	0.003	364.4	2.74	166.5	215.0015	7.93
2429AA00077 LANSBERGHOEK PTN. LANSBERGHOEK - H29-LAN-01	-24.0651800	28.1143800	42.165	43.32	457.294	56.3	0.374	1.084	10.849	0.075	2.057	62.871	0.015	11.529	11.116	226.247	292.1528	8.438
ZQMELS1 2327DA00034 RIETSPRUIT ELLISRAS/WITKOP	-23.6905560	27.7452780	6.629	308.575	1002.216	168	11.349	3.786	0.5	0.02	0.177	324.29	0.013	154.907	7.771	156.924	202.636	8.264
2326DD00105 MOOIVLEI	-23.8000000	27.9666670	175.4	715.7	2237	354.9	1.02	7.78	50.1	0.07	0.46	519.2	0.012	582.9	20.04	149.7	193.3076	7.56
WERKENDAM (DUP NAME 8935)	-23.6333330	27.7833330	10	11		88.8	0.1		4		0.02	12		2		50	64.565	7.4
WATERKLOOF (DUP NAME 9051)	-23.6625000	27.7500000	14	11		13.3	0.4		5		0.02	7		2		55	71.0215	7.9
WATERKLOOF (DUP NAME 9051)	-23.6625000	27.7500000	14	11		13.3			5		0.02	7		2		55	71.0215	7.4
180 BA WQ 14.29	-24.0113890	28.1272220	43.3	42.2	472	55.9	0.24	1.28	47.6	0.12	1.12	10.2	0.025	6.4	19.68	258.8	334.1884	8.08
EHRENBREITSTEIN (DUP NAME 27383)	-23.7250000	27.7391670	20.6	251.3	865	143	10.79	5.82	6	0.02	0.02	254.6	0.008	107.5	10.67	170.5	220.1667	8.16
WERKENDAM (DUP NAME 27386)	-23.6430560	27.7872220	7.5	296.8	1010	168	14.32	4.81	2	0.44	0.02	327.2	0.011	136.5	7.75	180.7	233.3379	8.28
WERKENDAM (DUP NAME 27387)	-23.6538890	27.7655560	6.4	281.5	947	162	15.64	3.18	1.6	0.445	0.02	324.9	0.014	130.2	7.59	150.3	194.0824	8.29
WERKENDAM (DUP NAME 27388)	-23.6558330	27.7644440	7.8	280.1	939	160	16.06	3.44	1.2	0.358	0.02	322.3	0.013	125.3	8.58	149.2	192.662	8.07
WERKENDAM (DUP NAME 27389)	-23.6569440	27.7680560	7.1	276.5	921	159	14.77	3.4	0.5	0.358	0.02	301.8	0.014	128.2	8.89	154	198.8602	8.18
WERKENDAM (DUP NAME 27390)	-23.6725000	27.7725000	7.4	257.2	873	143	17.25	3.62	0.5	0.322	0.02	294.8	0.013	103.7	9.47	153.7	198.4728	7.99
WERKENDAM (DUP NAME 27391)	-23.6463890	27.7716670	7.2	284.7	945	156	15.86	3.17	1.2	0.161	0.258	323.6	0.01	126.4	7.55	148.8	192.1454	7.83
WERKENDAM (DUP NAME 27392)	-23.6333330	27.7983330	8.8	308.8	1016	153	11.89	3.78	3.6	0.358	0.532	328.4	0.019	144.7	7.25	166.3	214.7432	8.13
WERKENDAM (DUP NAME 27393)	-23.6611110	27.7725000	7	268	898	143	14.68	3.45	1.1	0.347	0.02	293.8	0.015	123.1	9.17	152.4	196.7941	8.25

APPENDIX C
GEOCHEMISTRY

Sample ID	Latitude	Longitude	Ca	Cl	DMS	EC	F	K	Mg	NH_4	NO_3	Na	PO_4	SO_4	Si	TAL	HCO3	pH
WERKENDAM (DUP NAME 27393)	-23.6611110	27.7725000	7.3	274.3	945	156	11.88	3.92	1.3	0.02	0.185	326.5	0.017	124.8	8.11	159.5	205.9624	8.07
GRIETASVLAKTE (DUP NAME 27396)	-23.6669440	27.7777780	10.8	263.4	878	135	14.15	3.38	2	0.148	0.02	295	0.013	104.8	10.74	150.6	194.4698	8.09
GRIETASVLAKTE (DUP NAME 27397)	-23.6494440	27.8263890	28.2	287	994	155	1.97	5.1	10.7	0.21	0.02	287.9	0.011	131.1	7.79	198.2	255.9357	8.38
VENTERSHOEK	-23.9302780	27.9613890	19.3	6.4	202	27.6	0.58	4.05	6.6	0.126	0.062	23.8	0.017	7.6	9.98	109.1	140.8808	7.56
TAUNFONTEIN	-23.6977780	27.7775000	78.5	249	1668	206	0.48	54.72	95.7	0.546	1.266	240.2	0.016	238.1	5.1	578.1	746.5005	7.89
JUPITER	-23.8780560	28.0180560	36.2	61.3	652	72.1	0.36	6.8	29.7	0.02	10.722	106.1	0.017	10.8	28.32	289.9	374.3479	8.05
BUURMANSHULP (DUP NAME 3828)	-23.4008330	27.8236110	49.8	162.1	608	92.4	0.44	4.22	30.2	0.04	3.41	94.4	0.008	6.6	34.44	201.3	259.9387	6.9
KLIPFONTEIN (DUP NAME 3829)	-23.3988890	27.7597220	46.1	203.4	911	135.7	8.15	4.41	16.2	0.07	1.95	226	0.015	19.4	25.43	310.4	400.8195	7.7
MONTE CHRISTO	-23.3777780	27.7072220	127	353.9	1346	226.1	2.24	7.58	67.1	0.02	23.88	209.1	0.029	192	39.45	230.5	297.6447	7.47
MONTEVIDEO	-23.3644440	27.7255560	66.9	518.7	1883	296.6	2.31	7.45	41.9	0.02	8.36	489	0.025	242.3	36.91	391.7	505.8022	7.67
KAMEELFONTEIN (DUP NAME 3830)	-23.3975000	27.7861110	48.7	91.3	517	78.4	0.58	6.06	16.7	0.61	0.32	83.1	0.023	30.7	20.71	194.7	251.4161	7.25
KAMEELFONTEIN (DUP NAME 3831)	-23.3827780	27.7833330	227.8	896.7	2345	377.6	0.93	7.91	154.7	0.02	55.15	331.5	0.011	133.4	27.37	285	368.0205	7.6
SMITHFIELD (DUP NAME 3832)	-23.3888890	27.8375000	54.5	228.3	710	114.4	0.29	4.87	32.8	0.02	7.26	121.9	0.011	2	33.61	189.5	244.7014	6.9
RIETVALEY (DUP NAME 3840)	-23.2800000	27.7883330	331.2	917.2	2723	437.8	3.67	5.21	4.2	0.04	0.37	624.7	0.005	835.3	7.64	2	2.5826	5.9
RIETVALEY (DUP NAME 3841)	-23.2675000	27.7897220	613.6	2259.7	4956	770	0.29	17.61	553.4	0.05	0.2	298.5	0.011	864.6	23.43	284.7	367.6331	7.42
MAGENTA	-23.2533330	27.8194440	181.9	664.1	1554	280.4	1.26	2.46	10.5	0.04	2.34	349.1	0.014	328.6	6.19	4.9	6.32737	5.96
SPECULATIE (DUP NAME 3846)	-23.1905560	27.7797220	106.2	353.9	1269	217.1	1.21	3.14	95.9	0.04	19.13	162.4	0.031	85.5	43.79	308.2	397.9787	7.61
RUSTENBURG (DUP NAME 3849)	-23.3091670	27.7425000	180.3	489.6	1495	241.9	0.39	4.55	150.2	1.51	15.53	80.5	0.006	237.1	23.75	230.6	297.7738	7.34
SPECULATIE (DUP NAME 3851)	-23.1850000	27.7766670	320.8	1180	2959	492.2	1.31	6.8	246.6	0.02	14.28	342.9	0.007	427.4	36.47	303.5	391.9096	7.4
WINDHOEK (DUP NAME 3864)	-23.3808330	27.6613890	499.6	1611.7	3471	588.2	2.1	33.44	100.8	0.06	7.46	562.1	0.012	432.9	30.05	160.3	206.9954	7.24
STERKSTROOM (DUP NAME 3865)	-23.3972220	27.6402780	513	1474	3682	638.8	2.63	13.26	39.6	0.1	0.05	764.6	0.01	778	6.73	79.1	102.1418	7.36
STERKSTROOM (DUP NAME 3866)	-23.4025000	27.6419440	68.5	599.3	2675	345.6	3.31	21.82	47.1	0.49	3.47	671.3	0.023	77.5	9.85	960	1239.648	7.75
ALFRED	-23.3541670	27.6583330	59.5	351.5	1238	182.4	1.49	9.92	19.5	0.02	0.32	338.9	0.03	304	8.65	124.1	160.2503	6.9
ORANJEFONTEIN (DUP NAME 8936)	-23.4666670	27.6958330	80	497		388.9	2.8		5		5.65	835		576		715.2	923.5378	7.7
RUSTENBURG (DUP NAME 8937)	-23.3166670	27.7250000	208	994		466.7	0.8		180		13.78	419		708		139.4	180.0072	7.5
EENDRACHT (DUP NAME 9042)	-23.2500000	27.7333330	12	4		10.6	0.1		6		0.02	2		2		50	64.565	7.4
STELLENBOSCH (DUP NAME 20503)	-23.5041670	27.8769440	32.8	140	669	94.1	1.3	7.82	7.4	0.06	0.05	158.6	0.051	66.3	5.09	208.8	269.6234	7.71
JACOBSLOOP	-23.6250000	27.7583330	17.7	42.3	204	29.1	0.7	3.98	7.9	0.32	2.36	28.1	0.637	26.1	29.68	52.8	68.18064	6.75
MAKLAK	-23.4875000	27.7500000	17.3	210.1	618	96.8	0.36	3.72	6.3	0.04	7.1	175.8	0.026	9.5	6.99	133.7	172.6468	7.41
SMITHFIELD (DUP NAME	-23.3966670	27.8461110	53.2	221.9	711	116	0.3	4.88	31.3	0.09	7.43	127.7	0.033	4.4	34.18	191.8	247.6713	7.33

APPENDIX C
GEOCHEMISTRY

Sample ID	Latitude	Longitude	Ca	Cl	DMS	EC	F	K	Mg	NH_4	NO_3	Na	PO_4	SO_4	Si	TAL	HCO3	pH
24703)																		
BUURMANSHULP (DUP NAME 24720)	-23.5675000	27.8236110	26.4	174.7	517	89.4	0.38	4.18	29.4	0.04	2.17	100.6	0.028	2	35.56	138.2	178.4577	7.75
BATH (DUP NAME 24721)	-23.2944440	27.7750000	205.9	787.5	2493	379.4	1.26	11.79	154.8	0.06	17.26	396.4	0.077	362.8	20.14	406.9	525.43	7.98
VOGELSTRUISFONTEIN (DUP NAME 27384)	-23.6161110	27.7463890	13.6	316.5	1058	186	11.33	3.63	1.4	0.442	0.047	363.3	0.012	212.4	9.34	111.2	143.5926	7.91
VOGELSTRUISFONTEIN (DUP NAME 27385)	-23.6358330	27.7258330	14.2	289.6	979	168	14.23	3.95	0.5	0.196	0.194	339.9	0.02	172.6	12.55	116.6	150.5656	8.1
GORKUM	-23.6133330	27.7630560	13.7	306.4	958	171	2.33	2.43	0.5	0.473	0.162	317.4	0.017	171.2	6.21	116.5	150.4365	8.22

APPENDIX D

QUATERNARY CATCHMENT PROPERTIES

Table 6: Aquifer properties according to quaternary catchments (Source: Sami, 2006)

Quaternary Catchments	**Area (km^2)**	**Area (km^2) within SA**	**% Area within SA boundaries**	**Average Water level (m.bgl)**	**Average Thickness Saturated Weathered Zone (m)**	**Average Thickness Saturated Fractured Zone (m)**	**Average Specific Yield Weathered Zone**	**Average Storativity Fractured Zone**	**Average Storativity Aquifer**	**Volume Weathered Zone of Water (m^3)**	**Volume Fractured Zone of Water (m^3)**	**Total Volume Aquifer (m^3)**
A42A	573.42	573.42	100.00%	18.00	15.8	225.8	0.036080	0.000908	0.004917	404,248,000	144,748,000	548,996,000
A42B	521.61	521.61	100.00%	18.09	16.8	269.4	0.048280	0.001211	0.006534	495,370,000	178,869,000	674,239,000
A42C	698.36	698.36	100.00%	19.79	16.5	262.8	0.046875	0.001176	0.006345	576,047,000	229,083,000	805,130,000
A42D	496.61	496.61	100.00%	17.12	17.0	280.0	0.051425	0.001289	0.006950	517,953,000	178,355,000	696,308,000
A42E	1007.25	1007.25	100.00%	20.42	17.0	280.0	0.051425	0.001289	0.006950	887,273,000	364,293,000	1,251,566,000
A42F	1021.70	1021.70	100.00%	18.55	17.0	280.0	0.051425	0.001289	0.006950	998,584,000	368,986,000	1,367,570,000
A42G	1206.22	1206.22	100.00%	20.25	17.0	280.0	0.051425	0.001289	0.006950	1,068,060,000	434,696,000	1,502,756,000
A42H	1056.65	1056.65	100.00%	25.01	16.2	255.4	0.049460	0.001127	0.008206	655,156,000	321,191,000	976,347,000
A42J	1810.51	1810.51	100.00%	26.20	12.8	169.3	0.038414	0.000539	0.011300	820,722,000	190,898,000	1,011,620,000

Table 7: Quaternary catchments harvest potential, borehole yield and exploitation potential (Source: Sami, 2006)

Quaternary catchments	**Harvest potential (m^3/km^2/annum)**	**Harvest potential (mm)**	**Harvest potential ($X10^6 m^3$/annum)**	**Average yield borehole (l/s,8hrs/day)**	**Average yield borehole (l/s,24hrs/day)**	**Exploitation factor**	**Exploitation potential (m^3/km^2/annum)**	**Exploitation potential (mm)**	**Exploitation potential ($X10^6 m^3$/annum)**
A42A	15178	15.2	8.7	1.52	0.51	0.6	9107	9.1	5.22
A42B	12566	12.6	6.56	1.02	0.34	0.5	6283	6.3	3.28
A42C	12652	12.7	8.83	1.46	0.49	0.5	6326	6.3	4.42
A42D	11642	11.6	5.79	1.12	0.37	0.5	5821	5.8	2.89
A42E	12700	12.7	12.79	1.41	0.47	0.5	6350	6.4	6.39
A42F	12405	12.4	12.68	1.47	0.49	0.5	6203	6.2	6.34
A42G	10234	10.2	12.35	0.96	0.32	0.5	5117	5.1	6.18
A42H	9826	9.8	10.39	1.09	0.36	0.5	4913	4.9	5.19
A42J	7451	7.5	13.5	1.1	0.37	0.5	3725	3.7	6.75

APPENDIX D
QUATERNARY CATCHMENT PROPERTIES

Table 8: Water use and borehole yields (Source: Sami, 2006)

Quaternary catchments	Sum of yields (l/s)	Sum of borehole yields (X10^6 m^3/annum)	Municipal use (X10^6 m^3/annum)	Rural use (X10^6 m^3/annum)	Livestock use (X10^6 m/annum)	Irrigation use (X10^6 m^3/annum)	Total use (X10^6 ^{m3}/annum)	Total use (mm/annum)
A42A	253.31	2.66	0	0	0.0331	0	0.0331	0.1
A42B	148.2	1.56	0	0	0.0281	0	0.0281	0.1
A42C	340.72	3.58	0	0	0.0655	0	0.0655	0.1
A42D	47.19	0.5	0	0	0.0101	0	0.0101	0
A42E	462.84	4.87	0	0	0.0654	0	0.0654	0.1
A42F	201.9	2.12	0	0	0.0313	0	0.0313	0
A42G	258.99	2.72	0	0	0.0731	0	0.0731	0.1
A42H	316.34	3.33	0	0	0.0641	0	0.0641	0.1
A42J	509.97	5.36	0	0	0.2167	0	0.2167	0.1

Table 9: Mean annual runoff and base flow of quaternary catchments (Source: Sami, 2006)

Quaternary catchments	MAR (X10^{6}m^3/annum)	Base flow index	Base flow Schultz (mm/annum)	Base flow Pitman (mm/annum)	Base flow Hughes (mm/annum)	GW contributing to base flow (X10^{6}m^3/annum)	GW contributing to base flow (mm/annum)
A42A	25.89	0.3708	16.75	31.4	27.26	8.7	15.18
A42B	25.97	0.357	17.76	32.3	29.49	6.56	12.57
A42C	34.06	0.3585	17.49	32.1	29.03	8.83	12.65
A42D	46.51	0.1272	11.9	30.7	38.44	5.79	11.64
A42E	71.18	0.1407	9.95	26.6	29.68	10.02	9.95
A42F	36.79	0.0171	0.62	4.6	10.28	0.63	0.62
A42G	39.97	0.0165	0.55	4.4	9.39	0.66	0.55
A42H	27.74	0.0195	0.51	4.1	7.5	0.54	0.51
A42J	7.42	0	0	0	0.05	0	0

APPENDIX D
QUATERNARY CATCHMENT PROPERTIES

Table 10: Harvest potential, exploitable potential and groundwater utilization (Source: Sami, 2006)

Quaternary catchments	**Harvest pot – base flow ($X10^6m^3$/annum)**	**Exploitable portion (X10*6m3/annum)**	**Harvest potential – total use ($X10^6m^3$/annum)**	**Exploitable pot – use ($X10^6m^3$/annum)**	**Estimated Groundwater utilization**	**Impact of groundwater Water abstraction on surface water**	**Max utilizable groundwater ($X10^6m^3$/annum)**
A42A	0	0	8.66	5.18	UNDER-UTILISED	HIGH	3.65
A42B	0	0	6.53	3.25	UNDER-UTILISED	HIGH	1.64
A42C	0	0	8.77	4.35	UNDER-UTILISED	HIGH	2.94
A42D	0	0	5.78	2.88	UNDER-UTILISED	HIGH	1.45
A42E	2.77	1.39	12.72	6.33	UNDER-UTILISED	MODERATE	5.9
A42F	12.05	6.02	12.65	6.31	UNDER-UTILISED	LOW	3.17
A42G	11.69	5.85	12.28	6.1	UNDER-UTILISED	LOW	5.23
A42H	9.84	4.92	10.32	5.13	UNDER-UTILISED	LOW	1.22
A42J	13.5	6.75	13.28	6.53	UNDER-UTILISED	NEGLIGABLE	2.19