GROUNDWATER RESERVE DETERMINATION FOR THE MIDDLE VAAL WATER MANAGEMENT AREA

Report to the

Water Research Commission

and the

Chief Directorate: Resource Directed Measures
Department of Water Affairs

by

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This report forms part of a series of two reports. The other report is *Groundwater Reserve Determination for the Upper Vaal River Management Area* (WRC Report No. KV 312/13).

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EXECUTIVE SUMMARY

The Middle Vaal Water Management Area (MVWMA) encompassing ~52 500 km^2 in the north-central portion of the country, occupies a sensitive position within the Vaal River System because of its location downstream of the heavily urbanised and industrialised heartland of South Africa. Although it hosts a mining industry of its own in the form of the Klerksdorp (KOSH area) and Free State (Welkom-Virginia area) gold fields, mining activity is considerably greater and more varied in the neighbouring Upper Vaal WMA, and it is the impact hereof that is of greatest consequence to the MVWMA. This impact, however, is focused mainly on the surface water resources associated with the Vaal River. Groundwater resources typically fulfil a secondary water supply function mainly in agriculture (stock farming), except in the northern portion of the study area where water-rich dolomitic formations yield sufficient water for large-scale irrigated agriculture and municipal water supply locally. Elsewhere in the study area, a number of towns rely either partially or wholly on local groundwater resources for a potable water supply. Under these circumstances, it would appear that ambient groundwater resources largely fulfil a natural supporting role in the maintenance of the biophysical environment of the region. These circumstances dictate the need for a groundwater resource directed measures (GRDM) assessment to give effect to the informed consideration of the Reserve as required by the National Water Act (Act 36 of 1998). The GRDM assessment set out in this report provides a basis for the implementation of the Reserve.

The GRDM assessment identifies five groundwater resource units (GRUs) in the WMA, two of which are subdivided into two subunits each. The GRUs are the foundation on which the GRDM assessment is built. They represent a synthesis of the physical and chemical groundwater hydrology components as informed by the geological environment. The groundwater resources of the WMA are described in terms of the physical and chemical hydrogeological characteristics associated with each of the GRUs and subunits. These characteristics define the quantity and quality components of this resource on the basis of groundwater rest level data, groundwater chemistry data and the trends associated with these components. The description comprises both the reference condition inferred from older (typically pre-1980) data, and the current condition inferred from more recent (typically post-2000) data. The more recent data are also used in an assessment of the present ecological state (PES) of groundwater resources in the study area.

The pattern and trend of groundwater levels in the various GRUs in the long-term does not indicate significant impacts in either a negative or positive direction in regard to the groundwater quantity component of the Reserve. The development of the water supply potential associated with the dolomitic groundwater resources in the northern portion of the WMA (the Schoonspruit Dolomitic Aquifer) requires particular observation and attention. The pattern and trend of groundwater chemistry in the various GRUs in the long-term indicates that, for the most part, groundwater quality is little changed from the reference condition. The exceptions in this regard are associated with the GRUs that host the more vulnerable dolomitic groundwater resources that occur in conjunction with mining activity (the KOSH area) and large-scale irrigated agriculture (the Schoonspruit Dolomitic Aquifer). In the former instance, a trend from a CaMg-HCO_3 type to a Ca-SO_4 type groundwater is evident, and in the latter instance the more recent occurrence of Na-Cl and Na-SO_4 type groundwaters suggest a measure of impact from non-carbonate groundwater.

It is postulated that the resilience of groundwater resources to anthropogenic impacts is substantial,

and masks the mining-related impacts on groundwater quality in the Klerksdorp and Free State goldfields, for example. Where instances of this nature do exist, they are localised and limited in the extent of their hydrogeological footprint. This is in contrast to surface water resources that are much more vulnerable to contamination, and provide rapid conduits for the linear transfer of impacts into the downstream aquatic environment. In essence, the impact of AMD on groundwater quality is largely externalised to the surface water environment.

The present ecological state of groundwater resources in the WMA is assessed as supporting a category B over 52% of the catchment, a category BC over 46% of the catchment, and a category D over the remaining 2%. The category D portion of the catchment comprises the GRU that hosts the mining activity in the Klerksdorp (KOSH area) Goldfield and an associated comparatively large urban and industrial area. The PES categorisation of the groundwater environment shows congruence with that of the surface water resources under circumstances where most of the drainages are assigned a Class C present ecological state classification, and the Vaal River is assigned a Class D classification at best.

The quantity component of the preliminary groundwater Reserve determination was calculated for each quaternary catchment and aggregated to the groundwater resource unit (GRU) level. The outcome indicates that the groundwater component of baseflow amounts to ~202 Mm^3/a (~40% of the estimated total mean annual groundwater recharge of 501 Mm^3). This value is almost twice the 109 Mm^3/a suggested in the National Water Resource Strategy (DWAF, 2004c) be allocated to the ecological Reserve. The basic human needs component of the Reserve amounts to 8.6 Mm^3/a (~2% of the estimated total mean annual groundwater recharge). The total volume of groundwater recommended for allocation to the Reserve therefore amounts to ~211 Mm^3/a.

The quality component of the preliminary groundwater Reserve determination recognises that impacts on this aspect of the resource are largely externalised to the surface water environment. This occurs under circumstances where ~94% of the WMA is underlain by fractured and intergranular aquifers in which the potentiometric surface typically reflects the topographic surface, and the nature of surface water / groundwater interaction over most of the catchment therefore generally represents a reasonably simple gaining hydrologic environment (losing hydrogeological environment). The remaining 6% of the catchment that comprises carbonate strata (dolomite), portions of which are severely compromised by gold mining activity, represents the much more complicated exception to these circumstances.

The preliminary groundwater Reserve determination at quaternary catchment level served to identify those basins which exhibit a risk of experiencing a groundwater deficit. For practical purposes, an allocable volume <5% of the mean annual groundwater recharge of the host catchment identifies a cautionary situation in this regard. Thirteen (~19%) of the 67 quaternary catchments in the study area exhibit this characteristic.

The estimated total annual groundwater use amounts to ~54 Mm^3. After the requirements of the Reserve (~211 Mm^3/a) and this volume are met, ~237 Mm^3/a of groundwater in storage remains for allocation to water users. Not all of this groundwater, however, is available because of limitations imposed by accessibility for abstraction. If it is accepted that not more than 50% of the remaining groundwater in storage is accessible and exploitable, then only ~119 Mm^3 is available for additional allocation annually.

The observation that ~94% of the study area represents a fractured and intergranular aquifer suggests that comparatively simple and uniform RQOs can be applied in regard to groundwater levels across almost the entire WMA. Only the relatively small area of karst hydrosystem needs to be approached differently. Further, the relatively small proportion (~2%) of the study area that reflects a significantly modified category "D" present ecological state, proposed desired status category and management class implies that the remaining ~98% (representing a slightly to moderately modified PES and good to fair proposed desired status category and management class) requires a "closer to natural" set of RQOs in order to protect the ecological Reserve. In the context of groundwater quantity, this will secure the surface water / groundwater interaction that supports the bulk of the ~202 Mm^3/a groundwater contribution to baseflow in the WMA.

CONTENTS

APPENDICES

FIGURES

TABLES

SYMBOLS, ACRONYMS and ABBREVIATIONS

~	approximately
°C	degrees Celsius
%	percent
%ile	percentile
>	greater than
≥	greater than or equal to
<	less than
≤	less than or equal to
AMD	acid mine drainage
amsl	above mean sea level
ARC	Agricultural Research Council

bgl	below ground level
bs	below surface
Ca	calcium
CD:RDM	Chief Directorate: Resource Directed Measures
CGS	Council for Geoscience
Cl	chloride
CMA	Catchment Management Authority
CSIR	Council for Scientific and Industrial Research
DWA	Department of Water Affairs
EC	electrical conductivity
EIA	environmental impact assessment
EMP	environmental management programme
Ga	billion years
GDE	groundwater dependent ecosystem
GDP	gross domestic product
GRA	groundwater resource assessment
GRDM	groundwater resource directed measures
GRU	groundwater resource unit
ha	hectare(s)
HCO_3	bicarbonate
I&AP	interested and affected party
ISP	internal strategic perspective
kg	kilogram(s)
km^2	square kilometre(s)
KOSH	Klerksdorp-Orkney-Stilfontein-Hartbeesfontein
L/d	litre(s) per day
L/s	litre(s) per second
m	metre(s)
m^3/ha	cubic metre(s) per hectare
Ma	million years
MAP	mean annual precipitation
Mg	magnesium
mg/L	milligram(s) per litre
ml	millilitre(s)
MLL	minimum living level
ML/d	megalitre(s) per day
mm	millimetre(s)
Mm^3	million cubic metres
mm/a	millimetre(s) per annum
Mm^3/a	million cubic metres per annum
Mn	manganese
mS/m	milliSiemens per metre
MVWMA	Middle Vaal Water Management Area
n	count
Na	sodium
NGA	National Groundwater Archive
NGDB	National Groundwater Data Base

NFEPA	National Freshwater Ecosystem Priorities Area
n.s.	not specified
PES	present ecological status
Ra	radium
Rn	radon
RQO	resource quality objective
SANBI	South African National Biodiversity Institute
SO_4	sulphate
TDS	total dissolved salts
U	uranium
UGEP	utilisable groundwater exploitation potential
WARMS	water authorisation and registration management system
WMA	Water Management Area
WRC	Water Research Commission

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1 INTRODUCTION

The CSIRs Natural Resources & the Environment (NRE) business unit was appointed by the Department of Water Affairs (DWA) to carry out a groundwater quantity and quality Reserve determination study of the Middle Vaal Water Management Area (WMA). The study was commissioned by the DWAs Chief Directorate: Resource Directed Measures (CD:RDM). The study comprised a Groundwater Resource Directed Measures (GRDM) determination after Parsons and Wentzel (2007). The outcome gives effect to the Reserve in terms of section 17(1) (a) of the National Water Act (Act 36 of 1998), and supports the process of water use licensing in the Middle Vaal WMA.

1.1 Objectives

The study has the following objectives.

- Execute GRDM determinations for the set of groundwater resource units (GRUs), including groundwater dependent ecosystems (GDEs), identified in the study.
- The GRDM determinations must address both the quantity and quality components of groundwater resources.
- Integrate the GRDM determination results with those of the surface water Reserve determination studies in regard to rivers and wetlands following prioritisation of GRUs/GDEs in terms of current use, future potential use and degree impacted.
- Foster the protection of groundwater resources with due consideration to equitable and sustainable use thereof.
- Present the results in a manner that is supportive of the managerial and administrative procedures that inform implementation of the groundwater Reserve.

1.2 Scope

The study meets the requirements of an intermediate level GRDM determination. This is informed by factors such as the significant degree of groundwater use, the measure of negative impact on and threat to groundwater quality, and the uncertainty regarding the importance and sensitivity of GDEs in the Middle Vaal WMA.

The study interrogated various literature sources and databases for groundwater information, including the National Groundwater Data Base / National Groundwater Archive (NGDB/NGA), the Water Authorisation and Registration Management System (WARMS), the Groundwater Resource Assessment (GRA) Phases 1 and 2 products, Internal Strategic Perspective (ISP) and catchment Water Resources Assessment documents, DWAF/DWA and Water Research Commission (WRC) technical reports, Environmental Impact Assessment (EIA) and Environmental Management Programme (EMP) reports, Consultant reports and published scientific papers. The study utilised site-specific information where available, and generated groundwater quality information for GRUs where data in this regard were poorly represented or absent. The study included a comprehensive literature survey aimed at identifying areas where a higher level of GRDM determination might be required. Data assessment methods were tested during this study that may be reviewed and formalised in the on-going development of the GRDM methodology.

1.3 Report

This report presents data assessment methods and GIS data compiled for the Reserve determination. Groundwater resource units (GRUs) have been defined by the project team and technical analysis completed to inform the present status (PS) of the GRUs. Initial discussions with other groups of specialists assessing surface water resources in the Middle Vaal were held to guide integration. The final process of integration, liaison with stakeholders in the WMA and definition of RQOs in participation with stakeholders and other specialists will take place during the final phase of the project.

1.4 Project Implementation

The study was implemented in a phased manner as described hereunder.

1.4.1 Phase 1: Project Inception

This comprised two tasks, viz. a literature review task and compilation of an inception report. Approval of the inception report by the Client triggered the second phase of the project.

1.4.2 Phase 2: Study Implementation

This phase informed the essence of the study and delivered the main product, viz. a preliminary determination of the groundwater component of the Reserve for water quantity and quality in the Middle Vaal WMA, through the sequential execution of seven tasks as described hereunder.

Task 1 Preparation and Re-Assessment of ToR

The Inception Report highlighted the large number of forums and other I&AP groupings in the Middle Vaal WMA. The largely unknown relationship that exists between the groundwater regime and wetlands that might constitute groundwater (or aquifer) dependant ecosystems (GDEs) in the study area was identified as a further challenge to the GRDM determination. Since uncertainty in this regard may also extend to riparian areas (DWAF, 2005), it was envisaged that the level of detail and site specific hydrogeological data available for such settings might be sparse or deficient. Such circumstances would necessarily again be reflected in qualified confidence levels of GRDM assessment and, where necessary, prompt the identification of a higher level confidence GRDM determination.

Task 2 Description of Study Area

This was accomplished on the basis of existing available information obtained from various sources as described previously. Limited provision was made for the sourcing of "new" geohydrological data and information by means of focused field surveys and approaches to organizations such as mines and industries for localised data. This task facilitated a conceptual understanding of the groundwater environment that informed the subsequent tasks within the framework of a GRDM assessment, namely the delineation of GRUs/RUs, classification of groundwater resources, quantification of the Reserve and the setting of RQOs.

Task 3 Delineation of Resource Units

The outcome of Task 2 was applied in the delineation of groundwater resource units (GRUs) and resource units (RUs) in the study area. It was anticipated that the geo-environment would impose the need to consider both physical and functional criteria in such delineation if the groundwater component of the Reserve was to be afforded adequate protection. The 3-tier system of delineation which was followed, drilled down from a primary level based on quaternary basins as the basic building block of a GRDM assessment, through a secondary level based on the identification and recognition of aquifer type and groundwater regimes, to a tertiary level defined, amongst others, by professional geoscientific judgement, expertise and knowledge. The groundwater resource units formed the basis for the GRDM-specific tasks 4 (resource classification), 5 (quantification of the Reserve) and 6 (setting of resource quality objectives).

Task 4 Defining Present Status

The present status category was assessed for each GRU on the basis of factors such as the environmental impacts, level of stress, groundwater usage, groundwater contamination and land use. The present status category, in turn, informed the derivation of a water resource category for each GRU/RU, the setting of the Reserve itself, as well as the derivation of appropriate RQOs.

Task 5 Quantification of the Reserve

This activity sought to establish the volume of groundwater that contributes to sustaining the Reserve. This is a necessary prerequisite to determining the quantity of groundwater potentially available for allocation to users and potential users.

Task 6 Setting of Resource Quality Objectives

This aspect of RDM is generally the most difficult to achieve, since developing a substantive set of objectives requires an holistic appreciation of the groundwater environment that recognises both the requirements of all users and the impacts of some users whilst at the same time being practical, implementable and measurable.

Task 7 Compile a Monitoring Programme for GRUs

This task closed Phase 2 of the study, and drew on the understanding of the groundwater resources gained from the study results to develop a multifunctional groundwater monitoring programme for the Middle Vaal WMA that will meet different demands in terms of variables, frequency, etc. required to implement appropriate management and protection of the various GRUs/RUs.

1.4.3 Data Sources and Software

Significant groundwater and associated data exist for the WMA in data bases managed by the Department of Water Affairs, the Water Research Commission and the Council for Geoscience. Processed data and assessments of groundwater recharge and use such as are contained in the Groundwater Resource Assessment 2 (GRA2) repository (DWAF, 2005) proved invaluable to this study. The various sources used during this Reserve Determination are listed in Table 1-1.

Table 1-1. Data sources used in the GRDM study.

Data	Description	Source
Hydroterrains	Hydroterrains based on aquifer type and characteristics	Reclassified 1:1 Million Geology, CGS
Geology	Geology for the WMA	1:250 000 Geology. CGS
Borehole Yield	1:500 000 Hydrogeological Maps	1:500 000, DWA
Baseflow	K. Sami, Hughes, Schultz and Pittman baseflow estimates	DWAF, [2005]
Groundwater Levels	Interpolated groundwater levels	GRAII (DWAF, [2005])
Groundwater Recharge	Groundwater Recharge as a % of rainfall and as mm/a	GRAII (DWAF, [2005])
National Land Cover 2000	National Land Cover for the year 2000 based on remote sensing imagery.	ARC and CSIR (Van den Berg et al., [2008])
Mean Annual Runoff	Mean Annual Runoff from WR2005	WR2005. Water Research Commission TT 380/08
Mean Annual Precipitation	Precipitation mm/a from Schultze's Atlas of Climatology and Agrohydrology. Based on Lynch 2004 data.	SA Atlas of Climatology and Agrohydrology. WRC report 1489/1/06.
Vegetation	Vegetation classes and biomes	VegMap 2006. Mucina and Rutherford.
Groundwater Levels Point Data	Historic groundwater levels data from the National Groundwater Database.	NGDB, DWA
Chemistry Data	Chemistry data from DWA WMS database including ZQM data	WMS, DWA
Elevation	Shuttle Radar Topology Mission version 4	SRTM v4
Population	Population data from the Geospatial Analysis Platform 2 (GAP 2), with population data for 2004 from StatsSA	GAP2, CSIR
Aspect	Derived from SRTMv4 Elevation data	CSIR
Groundwater Use	Groundwater use in Mm3/a	GRAII (DWAF, [2005])
Groundwater Use	Groundwater use from WARMS	WARMS, DWA

2 OVERVIEW OF THE WATER MANAGEMENT AREA

2.1 Physical Characterisation

2.1.1 Extent

The Middle Vaal WMA is situated in central South Africa, extending across the Free State and North West Provinces (**Figure 2-1**). It is located downstream of the confluence of Vaal and Rietspruit Rivers and upstream of Bloemhof Dam, extending north to the headwaters of the Schoonspruit River and south to the headwaters of the Vet River. The WMA is also referred to as WMA No. 9 and encompasses a surface area of ~52 500 km^2 (DWAF, 2004a). It is bordered by the Upper and Lower Vaal WMAs to the east and west, respectively, as well as the Crocodile West/Marico and the Upper Orange WMAs to the north and south, respectively. Major towns in the WMA include Klerksdorp, Welkom and Kroonstad. Numerous inactive mines are found in the north and west of the WMA, many of which were small diamond claims. The tertiary drainage basins in the WMA comprise C24, C25, C41, C42, C43, C60 and C70. The Vaal River is the main drainage in the WMA, flowing in a westerly direction.

2.1.2 Physiography and Climate

The Middle Vaal WMA is characterised by a relatively flat landscape exhibiting an elevation range from ~2200 m amsl in the hilly upper reaches of the Vals River to about ~1250 m amsl in the vicinity of Bloemhof Dam.

The climate across this WMA can vary considerable from west to east and may be characterised as temperate and generally semi-arid. Mean annual temperature is observed to vary between 18 °C in the west to 14 °C in the east, with an average of approximately 16 °C for the catchment as a whole. Maximum daily temperatures are experienced in January and minimum temperatures in July.

A distinct characteristic of rainfall over the Middle Vaal WMA (**Figure 2-2**) is the uniform decrease westwards from the eastern escarpment regions across the central plateau area. Rainfall mainly occurs in the summer months between October and April, with the peak rainfall months being December and January. Convective thunderstorms generally characterise the rainfall pattern with hail also sometimes evident. Mean annual precipitation (MAP) for the WMA ranges from 700 mm in the east to 500 mm in the west with an average of about 550 mm (DWAF, 2004a).

Average mean annual potential evaporation (class A-pan) is estimated to range from 1 800 mm in the east to 2 600 mm in the drier western parts, which is well in excess of the MAP. Evaporation rates are estimated to be highest in January (200-300 mm) and lowest in June (100-120 mm).

Frost occurs throughout the WMA in winter, typically over the period from mid-May to late-August. The average number of frost days per year for the WMA as a whole ranges from 30 in the northern and eastern parts, and up to 40 in the central plateau areas of the Free State. Humidity is generally observed to be highest in February (the daily mean ranging from 62% in the west to 66% in the east) and lowest in August (the daily mean ranging from 52% in the west to 58% in the east).

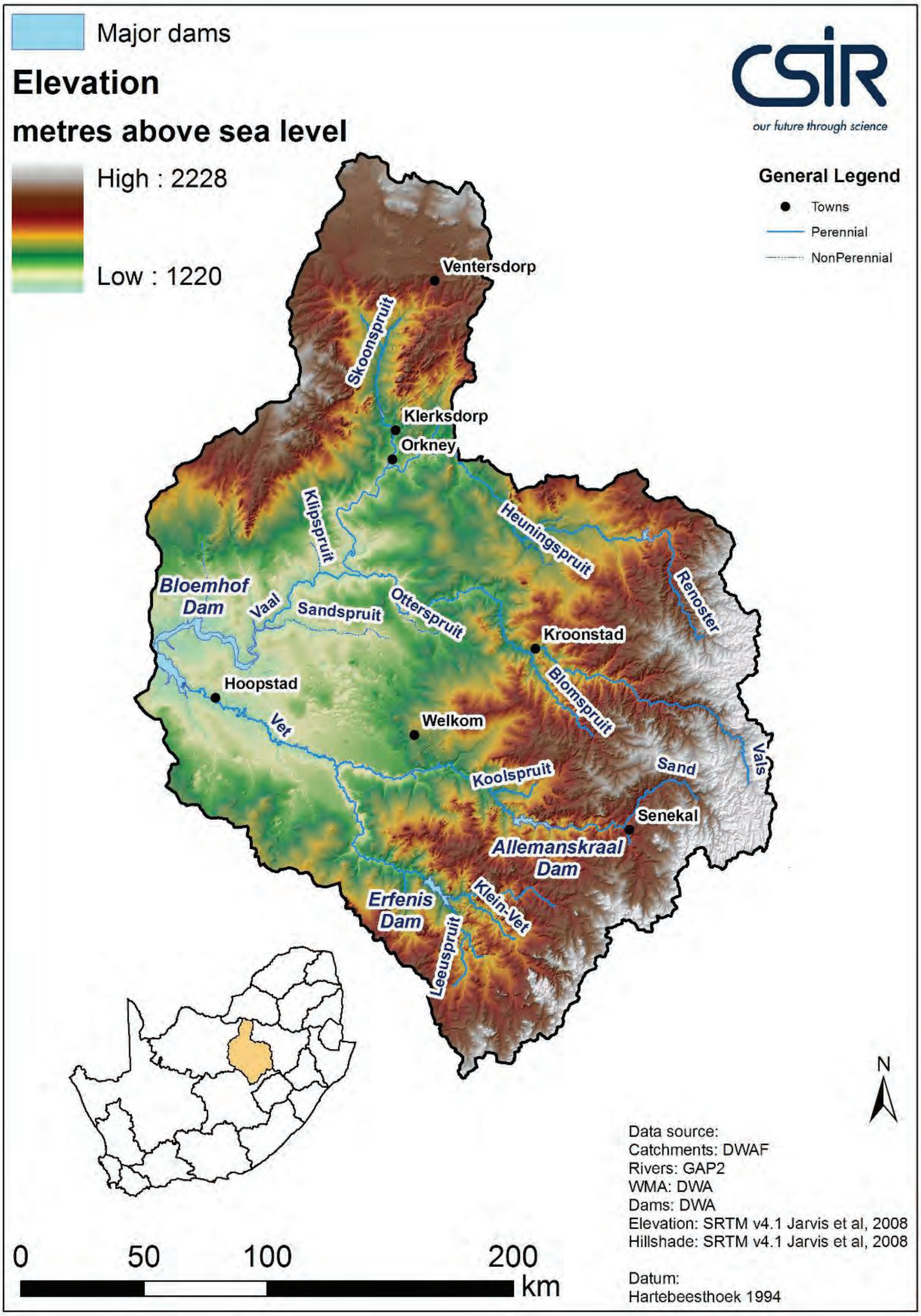

Figure 2-1. Map of the Middle Vaal WMA showing major drainages, dams and towns

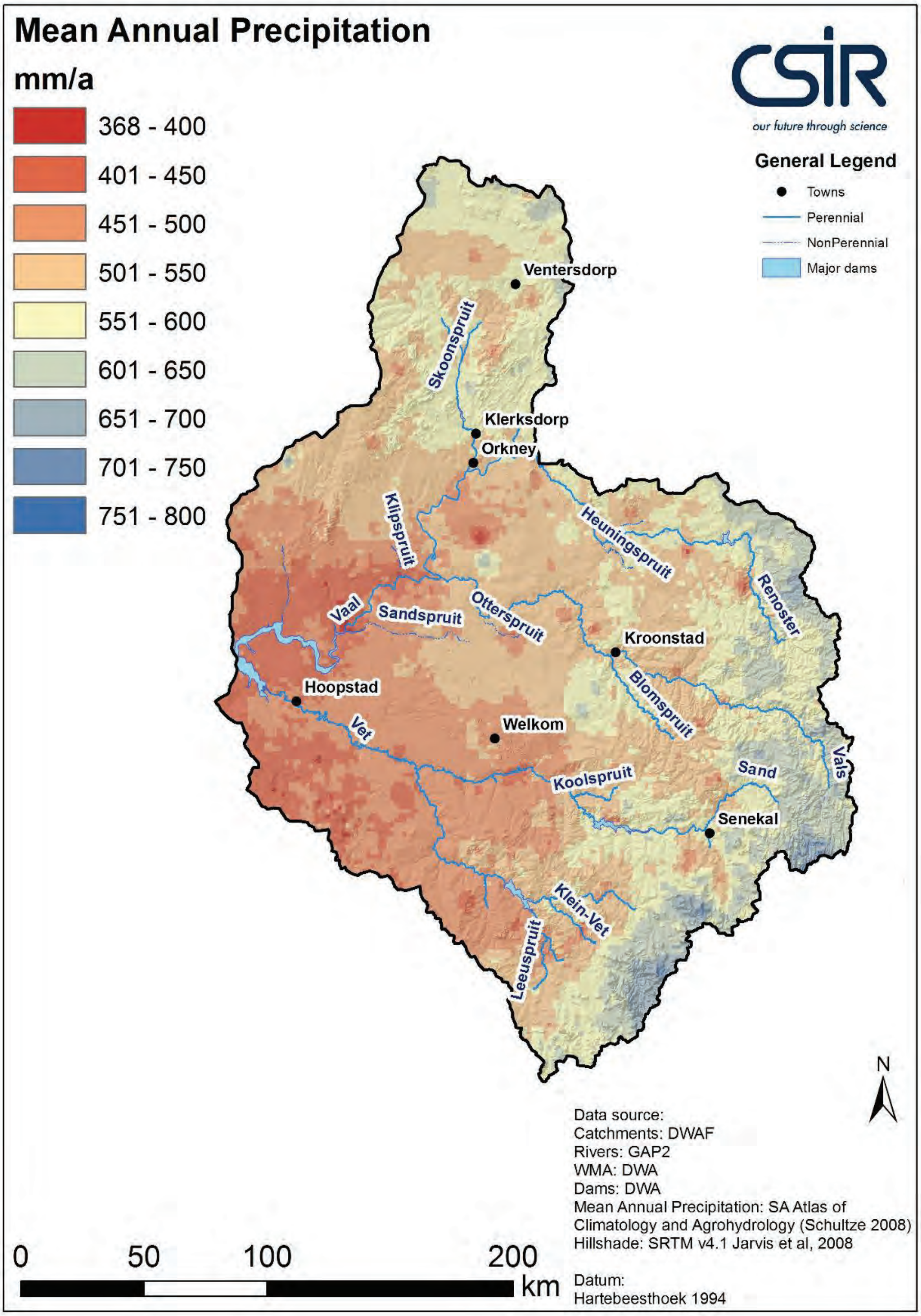

Figure 2-2. Distribution of mean annual precipitation across the Middle Vaal WMA

2.1.3 Vegetation and Soils

Extensive dryland agriculture characterises the land use in the WMA, particularly in the central parts. According to DWAF (2004a), rain-fed cultivation covers about 40% of the 52 500 km^2 of the WMA with the main crops being wheat and fodder pastures (rye and kikuyu). Irrigated agriculture is also practiced over a surface area of ~210 km^2, but mainly downstream of dams and along the Vaal River and its main tributaries. Irrigated crops include maize, groundnuts, sorghum and sunflowers. The third dominant land use is natural veld, which is used for livestock farming (beef, dairy, sheep and game farming). The veld types may be characterised as “pure grassveld” (widespread), “false grassveld” (northern parts) and “tropical bush and savanna” (upstream of Bloemhof Dam). No sugarcane or significant afforestation occurs in the WMA. Infestations of alien vegetation have been observed along the Vaal River, covering an area of ~70 km^2 (DWAF, 2003a).

Soil depths may generally be characterised as moderate to deep with flat to undulating relief over the entire WMA. The dominant soil types (after DWAF, 2004a) are:

- sandy loam, which covers most of the WMA, i.e. from the central portion of the WMA to upstream of Bloemhof Dam;
- clay loam, which extends from the sandy loam area further eastwards into the headwaters of the Sand, Vet, Elandspruit and Renoster rivers; and
- clay soil, which covers a relatively small area at the confluence of the Sand and Vet rivers.

2.1.4 Human Activity

The economy in the WMA is mainly driven by mining and agriculture as primary production sectors. According to DWAF (2004a) approximately 4% of the Gross Domestic Product (GDP) of South Africa originates from the Middle Vaal WMA. Mining is the dominant production sector in the WMA, with the main mining activity being gold mining. Few of the gold mines have a secure long-term life span, although the reserve base could support mining up to the year 2030 (DWAF, 2003a). The future of gold mining will be strongly influenced by the gold price, the rand exchange rate, the industry’s ability to contain operating costs, as well as the tax regime and environmental obligations.

Mining plays a major role in the economic development in the KOSH (Klerksdorp-Orkney-Stilfontein-Hartbeesfontein) area. Extensive gold mining (which also produces uranium and silver as by-products) occurs in the vicinity of Klerksdorp and in the Welkom/Virginia area (the Free State Gold Field). Diamond diggings located in the northern portion of the catchment in the headwaters of the Schoonspruit River around Ventersdorp, and to the west around the towns of Wolmaransstad and Leeudoringstad, represent mining on a much smaller scale, as do the numerous quarries such as those exploited for clay material used in the brick-making industry.

The Middle Vaal WMA is relatively sparsely populated, carrying just over 3% of the national population. Over 75% of the population in the WMA live in urban areas and ~25% in rural areas. Most of the population is concentrated in the main urban and mining centres of Klerksdorp, Orkney and Stilfontein in the Middle Vaal sub-area, Welkom and Virginia in the Sand-Vet sub-area, as well as Kroonstad (which is not a mining town) in the Rhenoster-Vals sub-area (DWAF, 2003a).

2.1.5 Geology

The WMA is underlain by a variety of rock types (**Figure 2-3**). The geology is dominated by four major geological units, namely the Witwatersrand Supergroup, Ventersdorp Supergroup, Transvaal Supergroup and the Karoo Supergroup. The geological age of these strata ranges from >3.1 Ga (billion years) represented by Swazian Era granite gneisses exposed in the northern portion of the WMA, to late Triassic sediments represented by the ~210 Ma (million years) old Clarens and Elliot formations of the Karoo Supergroup along the south-eastern boundary. The Karoo strata also represent the dominant lithology in the study area in terms of spatial extent. The northern portion of the WMA is underlain by rocks of the Witwatersrand Supergroup (~3-2.75 Ga), the volcanic Ventersdorp Supergroup (~2.75-2.65 Ga) and the mainly sedimentary Transvaal Supergroup (~2.65-2.05 Ga) assemblages. The latter include the carbonate Chuniespoort Group strata that host extremely productive dolomitic (karst) aquifers.

A summary of the areal extent of the various simplified lithostratigraphic subdivisions is presented in **Table 2-1**. This shows that more than two-thirds (~70%) of the study area is underlain by Karoo strata, followed in abundance by rocks of the Ventersdorp Supergroup (~13%).

Table 2-1. Summary of areal extent of various simplified lithostratigraphic subdivisions

Simplified Lithostratigraphic Subdivision		**Area**	
		km^2	**%**
Quaternary strata		799.4	1.5
Intrusives	post-Karoo dolerite	2370.5	4.5
	post-Transvaal diabase	111.0	0.2
Karoo Supergroup		36828.9	70.1
Transvaal Supergroup		3323.0	6.3
Ventersdorp Supergroup		6920.7	13.2
Witwatersrand Supergroup		590.0	1.1
Dominion Group		242.3	0.5
Archaean Granite		1078.6	2.1
Undifferentiated strata		261.7	0.5
Total		52526.1	100

A summary of the lithostratigraphy of the study area is presented in **Table 2-2**. The Witwatersrand Supergroup comprises Randian age sedimentary rocks (shale, quartzite and conglomerate). Two groups are identified within this Supergroup, namely the West Rand Group (quartzite, reddish and ferruginous magnetic shales, gritty quartz and conglomerate beds) and the Central Rand Group (arenaceous and rudaceous rocks) (Baran, 2003). Exposures of this supergroup are evident in the vicinity of Klerksdorp in the KOSH area.

The Ventersdorp Supergroup consists mainly of sedimentary and volcanic rocks of Randian age (Baran, 2003). This lithostratigraphic unit is subdivided into the Klipriviersberg Group (mainly andesitic lavas) and the Platberg Group (quartzite, conglomerate, lava, quartz porphyry, andesite, chert and tuff). The Ventersdorp Supergroup outcrops in the vicinity of Orkney and also forms part of the western rim of the Vredefort Dome (Baran, 2003).

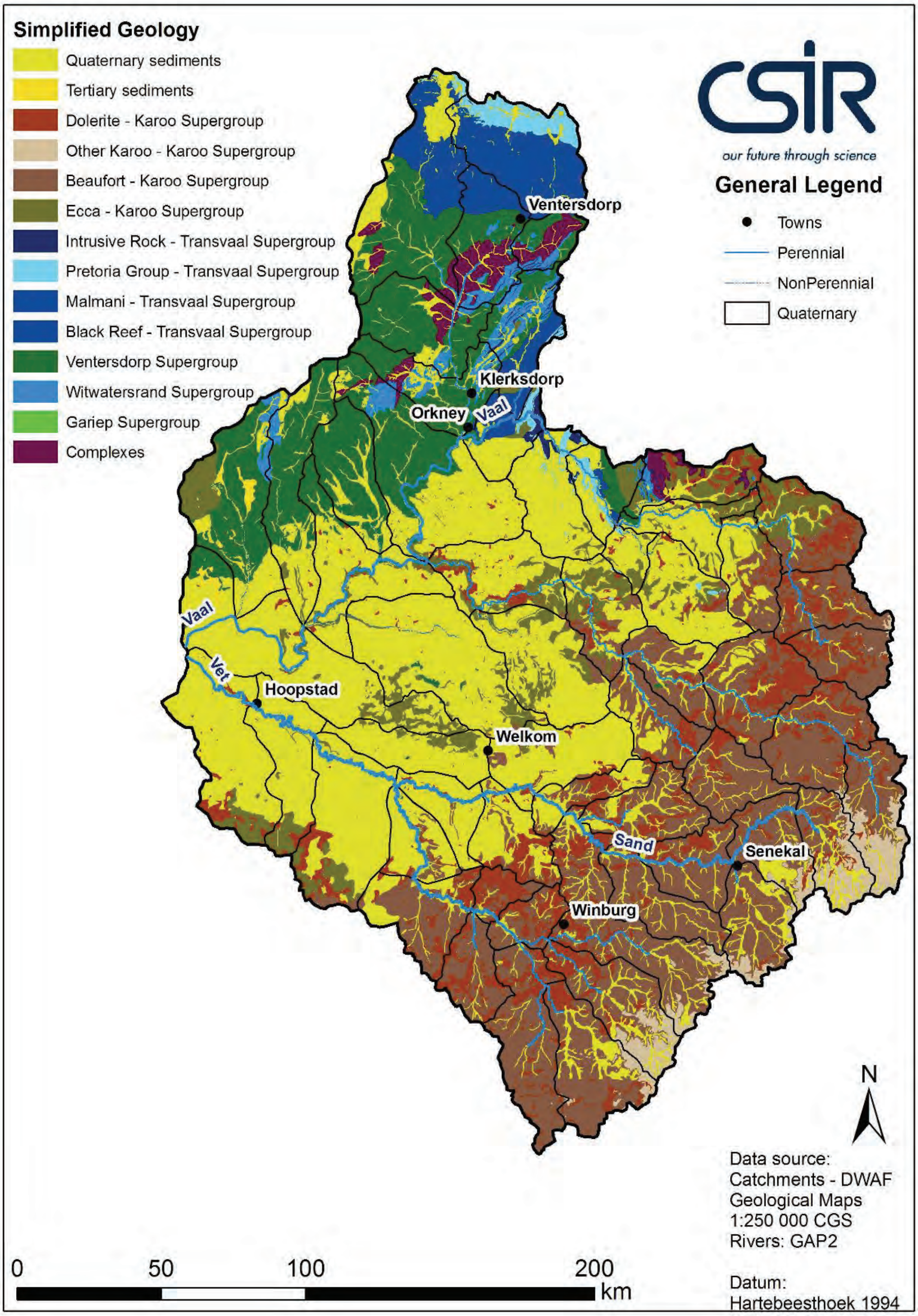

Figure 2-3. Simplified geological map of the Middle Vaal WMA (after CGS 1:250 000)

Table 2-2. Summary of the lithostratigraphy of the Middle Vaal WMA

Basic Lithology	Lithostratigraphic Unit			Era (Age)	
Aeolian sand, calcrete, colluvium, floodplain deposits, alluvium	Quaternary sediments			Late Cenozoic (<10000 yrs)	
Dolerite, diabase, syenite	Dyke / sill intrusive structures			(~144 Ma)	Mesozoic
Basaltic lava		Drakensberg Group	Karoo Supergroup		Mesozoic
Sandstone	Clarens Formation		Karoo Supergroup		Mesozoic
Mudstone & subordinate sandstone	Elliot Formation		Karoo Supergroup		Mesozoic
Sandstone, mudstone & shale	Molteno Formation		Karoo Supergroup	(~250 Ma)	Mesozoic
Mudstone & sandstone	Tarkastad Subgroup	Beaufort Group	Karoo Supergroup	(~250 Ma)	Palaeozoic
Mudstone & subordinate sandstone	Adelaide Subgroup	Beaufort Group	Karoo Supergroup		Palaeozoic
Shale & subordinate sandstone	Volksrust Formation	Ecca Group	Karoo Supergroup		Palaeozoic
Sandstone, shale & coal beds	Vryheid Formation	Ecca Group	Karoo Supergroup		Palaeozoic
Shale	Pietermaritzburg Formation	Ecca Group	Karoo Supergroup		Palaeozoic
Diamictite & shale		Dwyka Group	Karoo Supergroup	(~354 Ma)	Palaeozoic
Alkali granite	Schurwedraai	Intrusive Complexes		(~1000 Ma)	Mokolian
Alkali granite	Baviaanskranz	Intrusive Complexes			Mokolian
Olivine gabbro, wehrite, alkali granite	Rietfontein	Intrusive Complexes			Mokolian
Diorite, albitite	Roodekraal	Intrusive Complexes			Mokolian
Harzburgite, norite, quartz norite/gabbro, granophyre	Losberg	Intrusive Complexes			Mokolian
Basic & ultrabasic rocks	Kaffirskraal	Intrusive Complexes			Mokolian
Diabase	post-Transvaal	Intrusive Complexes		(~2050 Ma)	Mokolian
Quartzite	Magaliesberg Formation	Pretoria Group	Transvaal Supergroup	(~2050 Ma)	Vaalian
Shale	Silverton Formation	Pretoria Group	Transvaal Supergroup		Vaalian
Quartzite & shale	Daspoort Formation	Pretoria Group	Transvaal Supergroup		Vaalian
Shale & Quartzite	Strubenkop Formation	Pretoria Group	Transvaal Supergroup		Vaalian
Andesite	Hekpoort Formation	Pretoria Group	Transvaal Supergroup		Vaalian
Quartzite	Boshoek Formation	Pretoria Group	Transvaal Supergroup		Vaalian
Ferruginous shale & quartzite	Timeball Hill Formation	Pretoria Group	Transvaal Supergroup		Vaalian
Quartzite, chert, conglomerate	Rooihoogte Formation	Pretoria Group	Transvaal Supergroup		Vaalian
Chert-rich dolomite	Eccles Formation	Chuniespoort Group	Transvaal Supergroup		Vaalian
Chert-poor dolomite	Monte Christo Formation	Chuniespoort Group	Transvaal Supergroup		Vaalian
Chert-rich dolomite	Lyttelton Formation	Chuniespoort Group	Transvaal Supergroup		Vaalian
Chert-poor dolomite	Oaktree Formation	Chuniespoort Group	Transvaal Supergroup		Vaalian
Quartzite, conglomerate	Black Reef Formation		Transvaal Supergroup	(~2650 Ma)	Vaalian
Andesite	Alanridge Formation	Platberg Group	Ventersdorp Supergroup	(~2650 Ma)	Randian
Conglomerate, sandstone	Bothaville Formation	Platberg Group	Ventersdorp Supergroup		Randian
Andesite	Rietgat Formation	Platberg Group	Ventersdorp Supergroup		Randian
Quartz porphyry	Makwassie Formation	Platberg Group	Ventersdorp Supergroup		Randian
Andesite	Goedgenoeg Formation	Platberg Group	Ventersdorp Supergroup		Randian
Conglomerate, calcareous shale	Kameeldoorns Formation	Platberg Group	Ventersdorp Supergroup	(~2780 Ma)	Randian
Andesite, tuff		Klipriviersberg Group	Ventersdorp Supergroup		Randian
Arenaceous, rudaceous rocks		Central Rand Group	Witwatersrand Supergroup	(~2780 Ma)	Randian
Quartzite, reddish ferruginous magnetic shale		West Rand Group	Witwatersrand Supergroup		Randian
Quartzite, conglomerate, shale, interbedded lava		Dominium Group	Witwatersrand Supergroup	(~3100 Ma)	Randian
Granite, gneiss		Intrusive Complex		Swazian (>3100 Ma)	

The Transvaal Supergroup comprises volcanic (lava, andesite, tuff, basalt and rhyolite) and sedimentary (quartzite, shale, conglomerate and dolomite) rock types. According to Barnard (2000), diabase intrusions occur near the top of this unit, mainly in the form of sills. The Supergroup consists of the Chuniespoort and Pretoria groups in the study area. The base of the Transvaal Supergroup is represented by the Black Reef Formation, which consists of mainly quartzite with lenses of grit and conglomerate. The overlying Chuniespoort Group consists mainly of carbonate rocks (dolomite) with intercalated chert layers (Baran, 2003). The Pretoria Group comprises shale, quartzite, siltstone, conglomerate, andesitic lava and diabase. An isolated lava outcrop of the Pretoria Group strata occurs north of Koppies in the Free State Province.

The Karoo Supergroup sediments (Carboniferous to Jurassic age) include tillite, mudstone, sandstone and shale. These strata are extensively intruded by dolerite in the form of sills and dykes (Barnard, 2000). The sills often form the cap rock along mountain and hill tops. The Karoo Supergroup comprises the Ecca and Beaufort groups, as well as the Molteno, Elliot, Clarens and Drakensberg formations.

Tertiary and Quaternary deposits, the product of terrestrial sedimentation, are represented by aeolian sands, calcrete, colluvium, floodplain sediments and alluvium. These deposits are generally very thin (only a few meters in thickness, except for some sand dunes that can be up to 20 m high) and localised (Baran, 2003).

2.1.6 Land Use

The results of a provisional assessment of land use activities considered to possess a potentially harmful impact on the environment are summarised in **Table 2-3**. The sub-areas most likely to experience these impacts are also identified.

It is evident from **Table 2-3** that the greatest threats of the listed land use activities are to the groundwater environment in the study area. These are mostly related to the impacts of acid mine drainage (AMD) associated primarily with gold mining activities in the Klerksdorp (KOSH area) and Free State (Welkom-Virginia area) gold fields. The greatest concern in this regard is considered to be the KOSH area, where the impact of AMD on the karst aquifer demands attention. It is understood that the contaminated groundwater situation in the Mahem Spruit, Dankbaarpan and Brakpan area in the Free State Gold Field is being addressed by the relevant mining houses Harmony Gold and AngloGold Ashanti (Harmony, 2006).

2.1.7 Forums and I&APs

It has not been established to what extent forums and I&AP groupings exist or are active in the study area. The Voëlpan Forum in the Free State Gold Field has as focus the impact of mining and sewage effluent on this natural pan (Harmony, 2006).

Table 2-3. Summarised identification of potentially impacting land use activities

Land Use Activity	Sub-area	Nature of Impact
GOLD MINING Klerksdorp Gold Field Free State Gold Field	 C2 All	In active mines, the principal impact is associated with dewatering, and in abandoned mines with groundwater rebound following the cessation of mining. The generation of acid mine drainage (AMD) poses a threat to both the receiving surface and groundwater environments. This is a particular concern where mining operations occur in proximity to dolomite. Additional impacts are associated with mine residue deposits, e.g. rock dumps and tailings dams. The uraniferous nature of the ore-bearing deposits poses an additional environmental concern.
COAL MINING Free State Coal Field	 C2/C4	 Acid mine drainage from defunct mines such as Vierfontein.
DIAMOND MINING Schoonspruit Wolmaransstad & environs	 C2 C2	The principal impact of diamond diggings relates to dewatering of the host alluvial deposits, and the disposal of water containing a high proportion of suspended solids into surface water courses.
AGRICULTURE	All	Generally minor and localised impacts associated with fertiliser-derived nutrients (nitrate and phosphate) from irrigation and cattle feedlots, and pesticide/herbicide contamination, might be expected.
LOCAL GOVERNMENT Municipal waste Sewage effluent Urbanisation	All	Numerous towns in the MVWMA rely to some extent on groundwater for their municipal water supply, and this aspect will necessarily be considered in the study. Further, the potential impacts of municipal landfills on the groundwater environment, especially those facilities that the DWA has not yet licensed, are a concern. Similarly, the discharge of treated waste water effluent to rivers is a concern where such facilities are not compliant in regard to their discharge quality objectives and the receiving drainages are influent, i.e. lose water to permeable substrate, which is of greater concern in karst environments than in intergranular and-fractured environments.

2.2 Overview of Surface Water Resources

The surface water hydrology of the Middle Vaal WMA is dominated by the Vaal River that flows from northeast to southwest across the north-central portion of the WMA before entering the Lower Vaal WMA at Bloemhof Dam (**Figure 2-4**). Major tributaries include the Renoster and Vals rivers in the east, the Sand and Vet rivers in the south, and the Schoonspruit River in the north. The WMA supports three major impoundments, namely the Bloemhof, Allemanskraal and Erfenis dams (**Figure 2-4**). These have a combined full supply capacity of ~1656 Mm^3. Smaller impoundments in the WMA include the Rietspruit, Johan Nesser, Koppies and Serfontein dams.

The WMA is subdivided into three sub-areas based on considerations such as size and location of subcatchments, homogeneity of natural characteristics, location of important water infrastructure and economic development. The three subareas are identified as the following:

- the **Rhenoster/Vals** subarea (encompassing secondary drainage regions C6 and C7) with a natural mean annual runoff (MAR) of 295 Mm^3;

- the **Sand/Vet** subarea (encompassing secondary drainage region C4); with an MAR of 170 Mm^3; and
- the **Middle Vaal** subarea (encompassing a portion of secondary drainage region C2) with an MAR of 423 Mm^3.

A list of the major dams in the WMA is provided in **Table 2-4** together with salient supporting information.

Table 2-4. Summary of the major dams in the Middle Vaal WMA (after DWA, 2003b)

Dam	Quaternary Catchment	River	Year Completed	Purpose	Full Supply Capacity (Mm^3)
Bloemhof	C91A	Vaal	1990	Water supply	1269
Erfenis	C41E	Vet	1976	Irrigation	212
Allemanskraal	C42E	Sand	2002	Industry	175
Koppies	C70C	Rhenoster	1993	Irrigation	42
Rietspruit	C24D	Schoonspruit	1975	Water supply	7
Johan Neser	C24G	Schoonspruit	1954	Irrigation	5.7
Serfontein	C60D		1981	Irrigation	4
				TOTAL	1715

The bulk of the surface water in the Middle Vaal WMA is derived from the Vaal River, most of which originates in the Upper Vaal WMA. Surface water flows that originate within the WMA are highly seasonal and variable, with intermittent flow in many of the tributaries (DWAF, 2004a). There are no natural lakes or swamps in the WMA. Vlei areas and wetlands have been observed along the lower Vet River and in the upper Schoonspruit catchment. Baseflow in the Schoonspruit River is fed from dolomitic (karst) sources in the upper reaches, which also provide water for irrigation and urban use in the Ventersdorp area (DWAF, 2003a; 2004a). According to DWAF (2003a), development of naturally occurring surface water in the WMA has reached its full potential with all the water being fully utilised.

The quality of surface water in the WMA may generally be described as good, although high turbidities have sometimes been observed. Urban runoff and return flows from urban areas in the vicinity of the Vaal River and its main tributaries, e.g. Klerksdorp, also impact the river water quality. In addition, water that enters the Middle Vaal WMA via the Vaal River, may have high concentrations of urban, industrial and mining return flows from the Johannesburg and Ekurhuleni metropoles. This results in high salinities which need to be managed through blending with freshwater typically obtained from the Lesotho Highlands Water Scheme, in order to maintain river water quality of a desired standard. In addition, surface water resources that receive excessive return flows which are high in domestic effluent are vulnerable to algal blooms and eutrophication. According to DWAF (2003a), pollution of the Schoonspruit River has also been experienced, which is interpreted to be a result of poorly managed diamond mining operations on the banks of this river.

Impacts on water quality associated with land use activities have not been quantified in the WMA, however it is interpreted that some influence on the water resources will result from the large areas under cultivation as well as from urban runoff (DWAF, 2003a). In addition, significant quantities of water are estimated to be lost through infestation by alien vegetation, much of which occurs on the banks of the Vaal River.

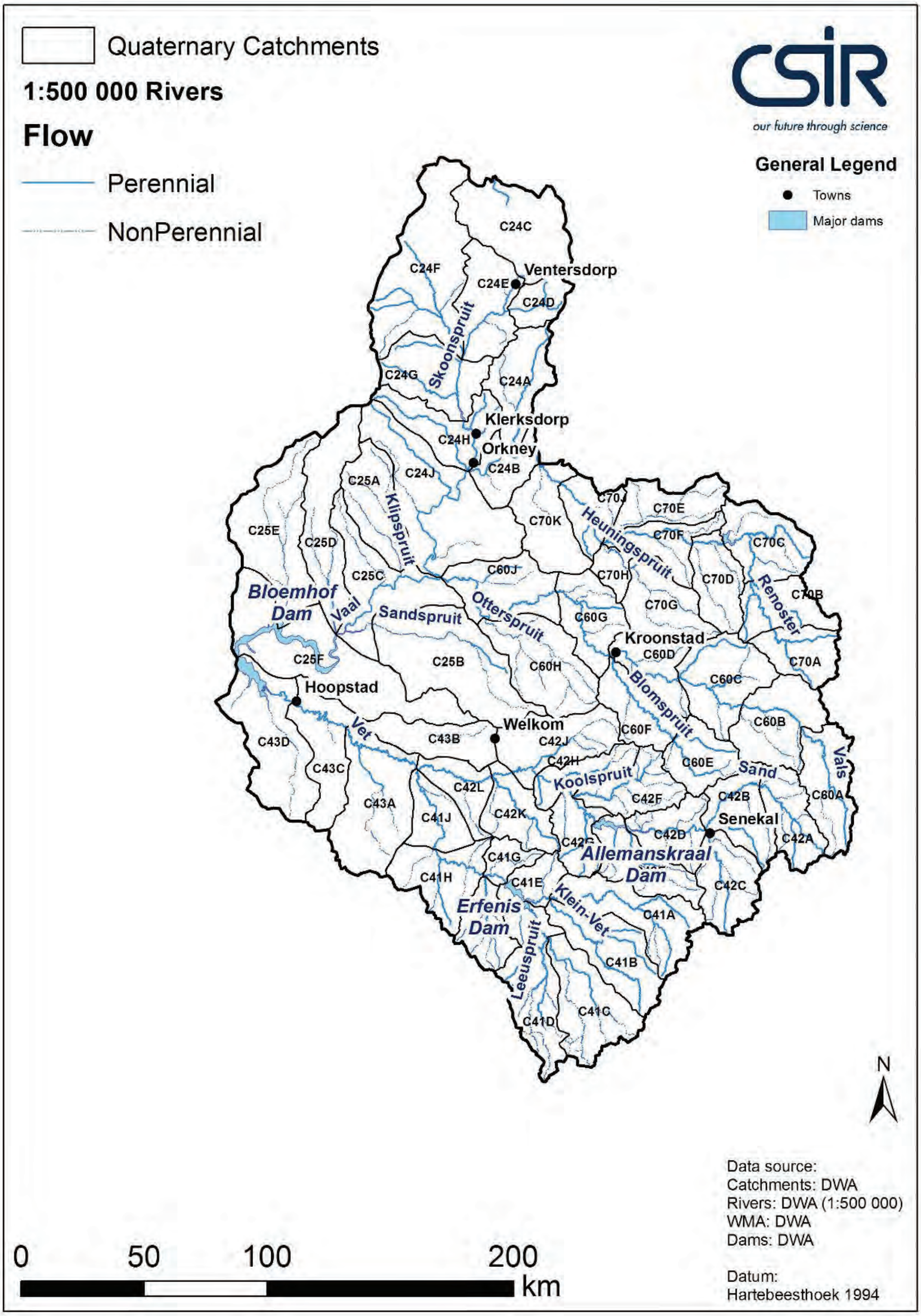

Figure 2-4. Rivers and major dams in the Middle Vaal WMA

2.3 Overview of Groundwater Resources

2.3.1 Hydrostratigraphy

Exploitable aquifers are found in four major geological units, namely the Karoo, Transvaal, Ventersdorp and the Witwatersrand supergroups. There are also limited aquifers found in alluvial deposits along streams and rivers. Extremely productive dolomitic/karst aquifers occur in the northern part of the WMA. These extend from Stilfontein in a northerly direction and from east to west across the extreme northern portion of the WMA in the vicinity of Ventersdorp. The karst aquifer provides water for urban use at Ventersdorp, as well as for large-scale irrigation and rural water supplies.

The remainder of the WMA is mostly underlain by fractured rock aquifers, which are well utilised for rural water supplies and with little undeveloped potential remaining. Groundwater is mainly used for mining, agriculture and domestic use in this WMA. Four types of aquifers are represented in the study area, namely fractured, karst, fractured and intergranular as well as intergranular.

The Witwatersrand, Ventersdorp and Transvaal strata are generally associated with fractured aquifers. These strata and some basement rocks represent the majority of aquifers in the KOSH area. Typical borehole yields vary greatly. According to Barnard (2000) the Witwatersrand Supergroup (West Rand and Central Rand groups) supports median borehole yields of 0.5-2.0 L/s. The depth to groundwater generally varies from 10-25 m below ground level. Groundwater associated with the Witwatersrand strata is typically of good quality as it exhibits an electrical conductivity (EC) in the range 29-37 mS/m. Groundwater also exhibits a calcium-magnesium-bicarbonate character (Baran, 2003).

Within the Ventersdorp Supergroup, the Kameeldoorns and Bothaville formations are the main water bearing formations that are intersected through drilling. These formations have median borehole yields of 0.5-2.0 L/s and 2.0-5.0 L/s, respectively, and a groundwater salinity (EC) of <50 mS/m. The depth to groundwater level generally occurs between 5-20 m in the Kameeldoorns Formation, and 5-15 m in the Bothaville Formation. The andesitic lavas of the Ventersdorp Supergroup are generally regarded as an aquitard since they have widely spaced joint sets and are massive (DWAF, 2008). Slightly elevated borehole yields may be associated with the Ventersdorp Supergroup lavas along major joints, faults and structural lineaments, but borehole yields in these environments rarely exceed 2.0 L/s (DWAF, 2008).

Within the Transvaal Supergroup, the Black Reef, Daspoort and Magaliesberg formations have been extensively explored through drilling. The median borehole yields of these formations generally vary between 0.5-2.0 L/s, whilst the groundwater quality is good (EC <50 mS/m). Although the Black Reef Formation at the base of the Transvaal Supergroup has a negligible primary porosity, localised areas of densely spaced fractures and joints can produce significant borehole yields (DWAF, 2008).

The carbonate rocks of the Malmani Subgroup in the Chuniespoort Group of the Transvaal Supergroup (**Table 2-2**) constitute a generally productive karst aquifer (Barnard, 2000). Outcrops of strata are evident east of Orkney. The occurrence of groundwater in karst aquifers is due to the presence of dissolution openings that result from the solubility of calcium carbonate minerals. These dissolution openings occur along discontinuities such as joints, faults and bedding planes, and may also produce open cavities and caves. The development of karstic features due to preferential solution has served to develop the secondary permeability of the rock mass, particularly in chert-rich units such as the Monte Christo and the Eccles formations (**Table 2-2**). Although the extent of this aquifer in terms of outcrop area is relatively small, it represents the most important groundwater resource in the study area. Groundwater movement within the dolomite aquifer in this area is known to be associated with north-south trending joints and faults which have experienced preferential solution, and flow occurs towards the Vaal River and points of abstraction (DWAF, 2003b).

According to Barnard (2000), the median borehole yield in the Chuniespoort Group is >5.0 L/s, mainly due to the high storativity and permeable nature of the carbonate rocks. Several high yielding springs are associated with the Chuniespoort Group (Barnard, 2000). The groundwater quality is excellent with an average EC of ~60 mS/m. The groundwater is used extensively for irrigation, domestic, mining and municipal/industrial purposes. Continuous abstraction and dewatering of this karst aquifer, however, may also result in the formation of sinkholes.

The majority of the Middle Vaal WMA constitutes a fractured and intergranular aquifer system mainly due to the presence of dolerite sills and dykes. The fractured and interganular aquifer is derived from the dual porosity characteristics that are exhibited at intrusive contact zones. Generally dolerite sills and dykes intrude the host rock (mainly Karoo Supergroup sediments) at fracture and fault zones, but the dolerite itself weathers to a porous intergranular type aquifer. Borehole yields associated with the fractured and intergranular aquifers hosted by the Karoo Supergroup sediments vary considerably, i.e. 0.1-10 L/s, depending on the type and fracturing of the sediments. Yields are normally higher in the Beaufort Group strata than in the Ecca Group strata (Barnard, 2000).

The intergranular type aquifers are generally poorly represented in the WMA, and are limited to the alluvium that occurs in most of the river systems. The alluvial aquifers are generally limited to only a few metres in thickness and only a few hundred metres in width (Baran, 2003). These aquifers have not been extensively explored, and are therefore generally not seen as a major resource.

The geographic distribution of borehole yields as per the hydrogeological map 'classification' presented in **Table 2-5**, is shown in **Figure 2-5**. This indicates that low yielding (<0.5 L/s) boreholes in the intergranular and fractured aquifers (d2 class) characterise the Karoo strata over the greatest extent in the central and southern portion of the study area. However, high yielding boreholes are found in the karst and fractured aquifers in the north and western parts of the WMA. The hydrogeoterrains shown in **Figure 2-6** represent a simplification of the geological environment (**Figure 2-3**) on hydrogeologic grounds.

Table 2-5. Explanation to Figure 2-5

Aquifer Type	**Median Borehole Yield Class (L/s) excluding Dry Boreholes**				
	0.0-0.1	**0.1-0.5**	**0.5-2.0**	**2.0-5.0**	**>5.0**
Intergranular	a1	a2	a3	a4	a5
Fractured	b1	b2	b3	b4	b5
Karst	c1	c2	c3	c4	c5
Intergranular-and-fractured	d1	d2	d3	d4	d5

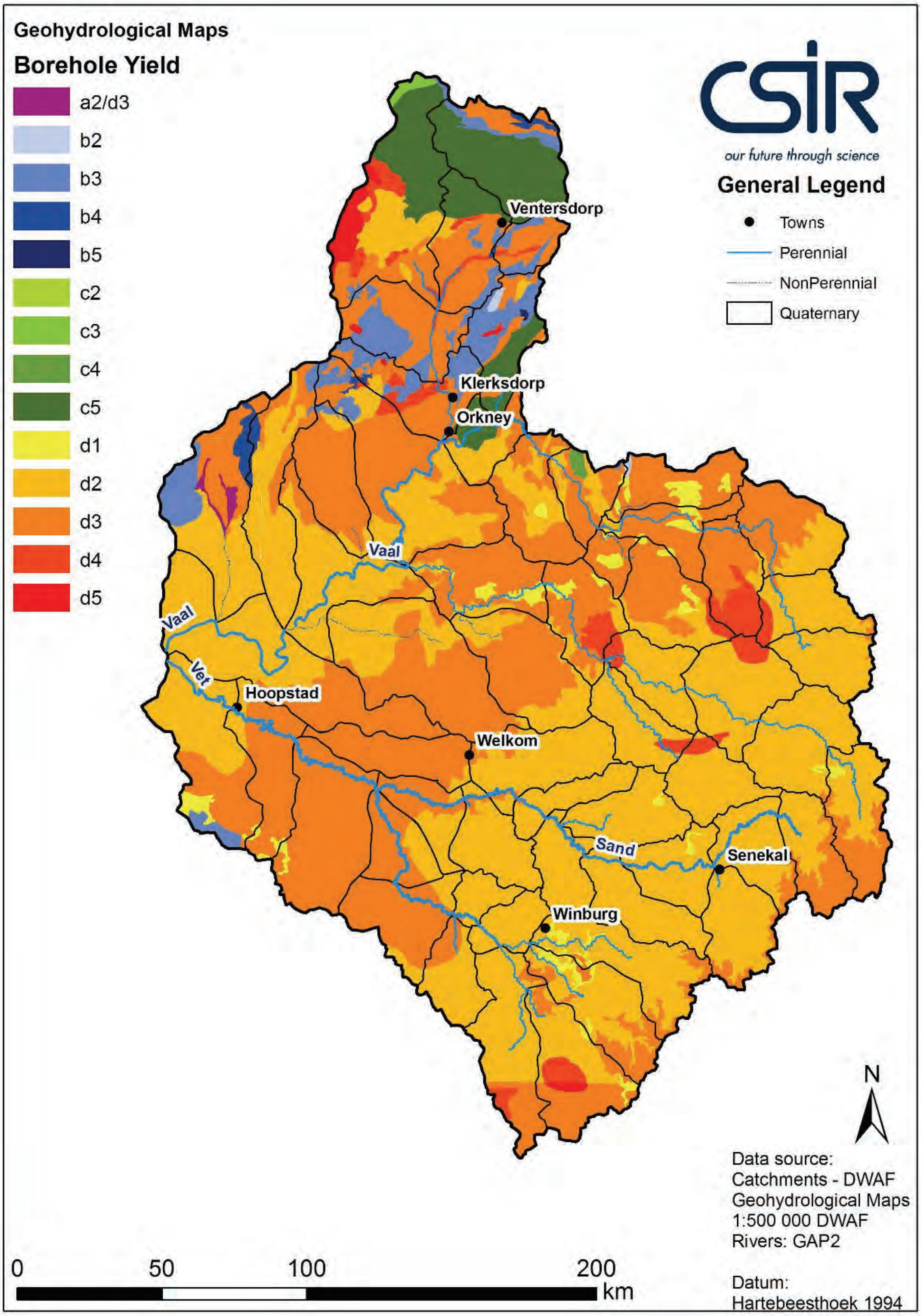

Figure 2-5. Distribution of borehole yields per quaternary catchment in the Middle Vaal WMA (after DWA 1:500 000 geohydrological map series)

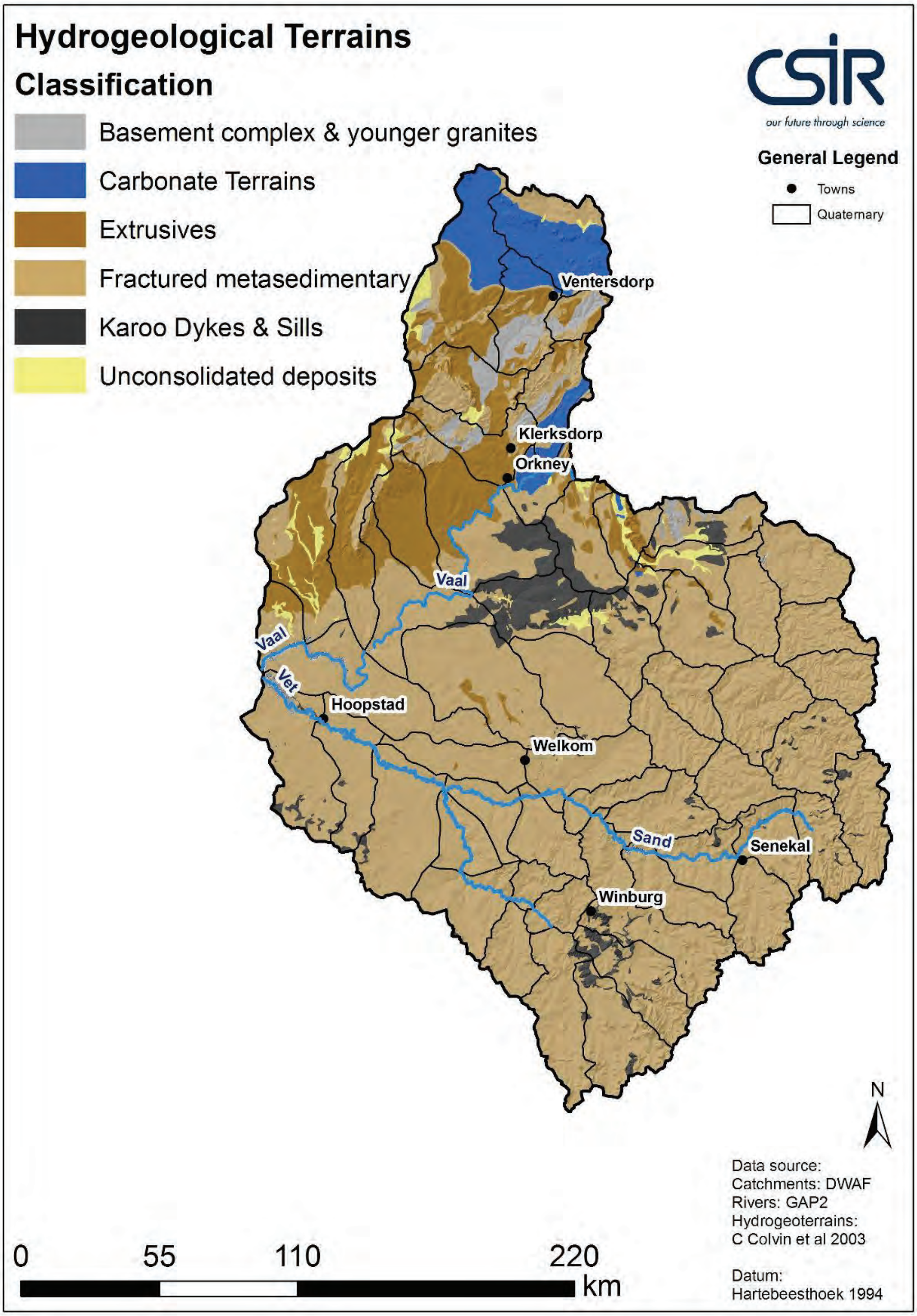

Figure 2-6.Distribution of hydrogeoterrains in the Middle Vaal WMA

2.3.2 Groundwater Recharge

The geographic distribution of estimated groundwater recharge (from the DWAFs GRAII project) is sown in **Figure 2-7**. It is evident that >80% of the area receives <32 mm/a. This is the equivalent of 320 m^3/ha, or 1664 Mm^3 over an area of 52 000 km^2. This is slightly less than the combined capacity of the major impoundments in the study area (**Table 2-4**).

2.3.3 Groundwater Use

The distribution of estimated total groundwater use per quaternary catchment in the WMA is shown in **Figure 2-8**. Almost every farm unit in the Middle Vaal WMA is dependent on groundwater for domestic and stock watering use. The areas where large-scale irrigation takes place from groundwater resources are the Ventersdorp dolomitic compartment and the Karoo aquifers north of Wesselsbron. According to the DWAF (2004a), the Ventersdorp karst aquifer has been subjected to detailed investigations which report abstraction volumes of 41 Mm^3/a for irrigation and 1.3 Mm^3/a for mining activities.

Stilfontein Gold Mine's Margaret Shaft is a point of concentrated groundwater abstraction. Although the mine may be regarded as defunct, pumping continues for the safety of the downstream mines. The volume of water abstracted daily (~32 ML/d) is utilised by a number of users, and any excess is discharged to the Koekemoer Spruit. Groundwater is also abstracted from other operating shafts in the KOSH mining area for safety, and the water is utilised as process water (DWAF, 2004a).

"Scavenger" boreholes on the northern banks of the Vaal River are also interpreted to abstract significant amounts of groundwater. These boreholes serve a remediation function to intercept polluted groundwater originating from mine residue areas (tailings and waste rock deposits) in a high permeability zone of the dolomite. This water is utilised in the gold recovery processes. Additional small-scale abstraction also occurs for irrigation purposes at recreational and sports parks on the mine properties (DWAF, 2004a).

Groundwater is further utilised for individual domestic use in most rural and farming areas. Certain towns in the study area are entirely or partially dependent on groundwater, most notably Ventersdorp, Hartbeesfontein, Coligny, Leeudoringstad, Makwassie, Dominiumville, Bultfontein, Marquard, Verkeerdevlei, Paul Roux, Petrus Steyn, Steynsrus and Edenville, as well as several rural/ tribal villages in the Ventersdorp municipal area. There are also numerous private boreholes in urban areas that are typically utilised for garden irrigation and domestic uses such as filling of swimming pools, car washing, hosing down of paved areas, etc.

The DWA (2005) reports the estimates of total groundwater use per quaternary catchment, subdivided into quantities per economic sector, given in **Table 2-6**. These estimates are expressed as a percentage of the estimated recharge per quaternary catchment in **Figure 2-9**, to obtain an indication of the relative sustainability and geographic distribution of groundwater use in the study area. This exercise identifies four quaternary catchments, namely C24B (mining use ~4.8 Mm^3/a), C24C (irrigation use ~14.2 Mm^3/a), C24E (municipal use ~3.9 Mm^3/a and irrigation use ~3.1 Mm^3/a) and C42H (municipal use ~1 Mm^3/a) as exceeding values of 25%. For much of the study area, estimated groundwater use amounts to less than 5% of the estimated recharge from rainfall.

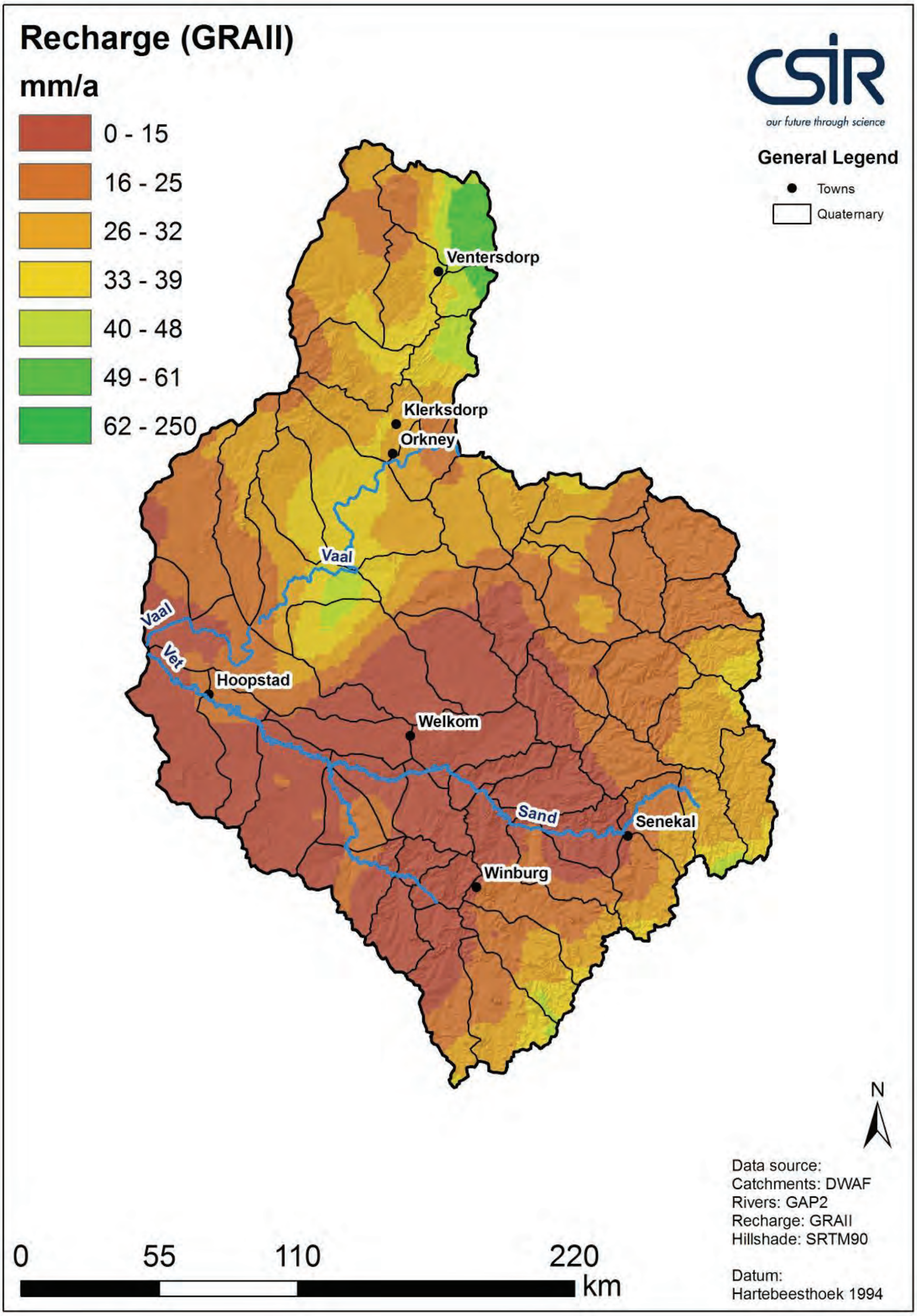

Figure 2-7. Distribution of estimated recharge (mm/a) per quaternary catchment (after DWAF, 2005 GRAII)

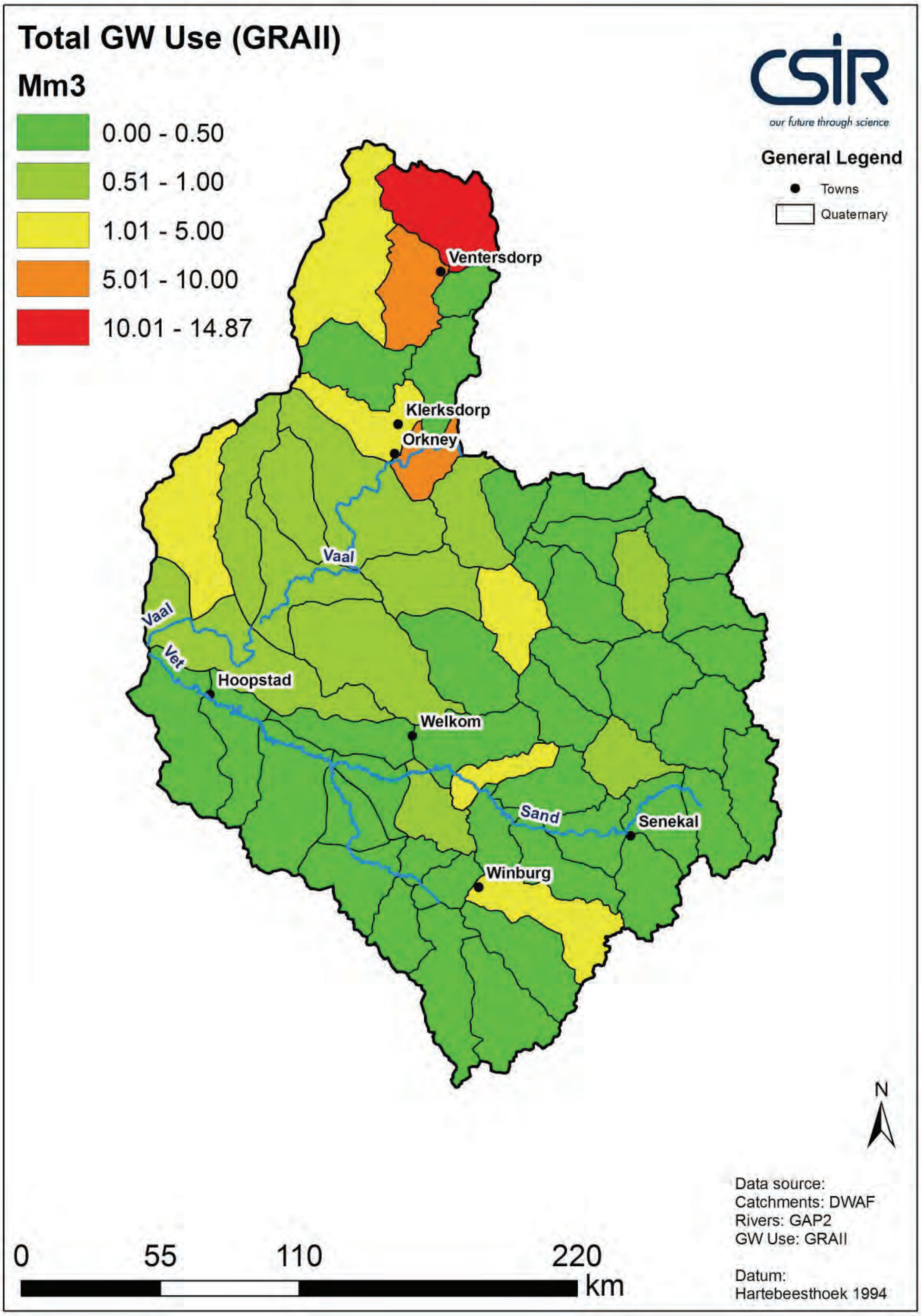

Figure 2-8. Distribution of estimated total groundwater use per quaternary catchment in Mm3/a (after DWAF, 2005 GRAII)

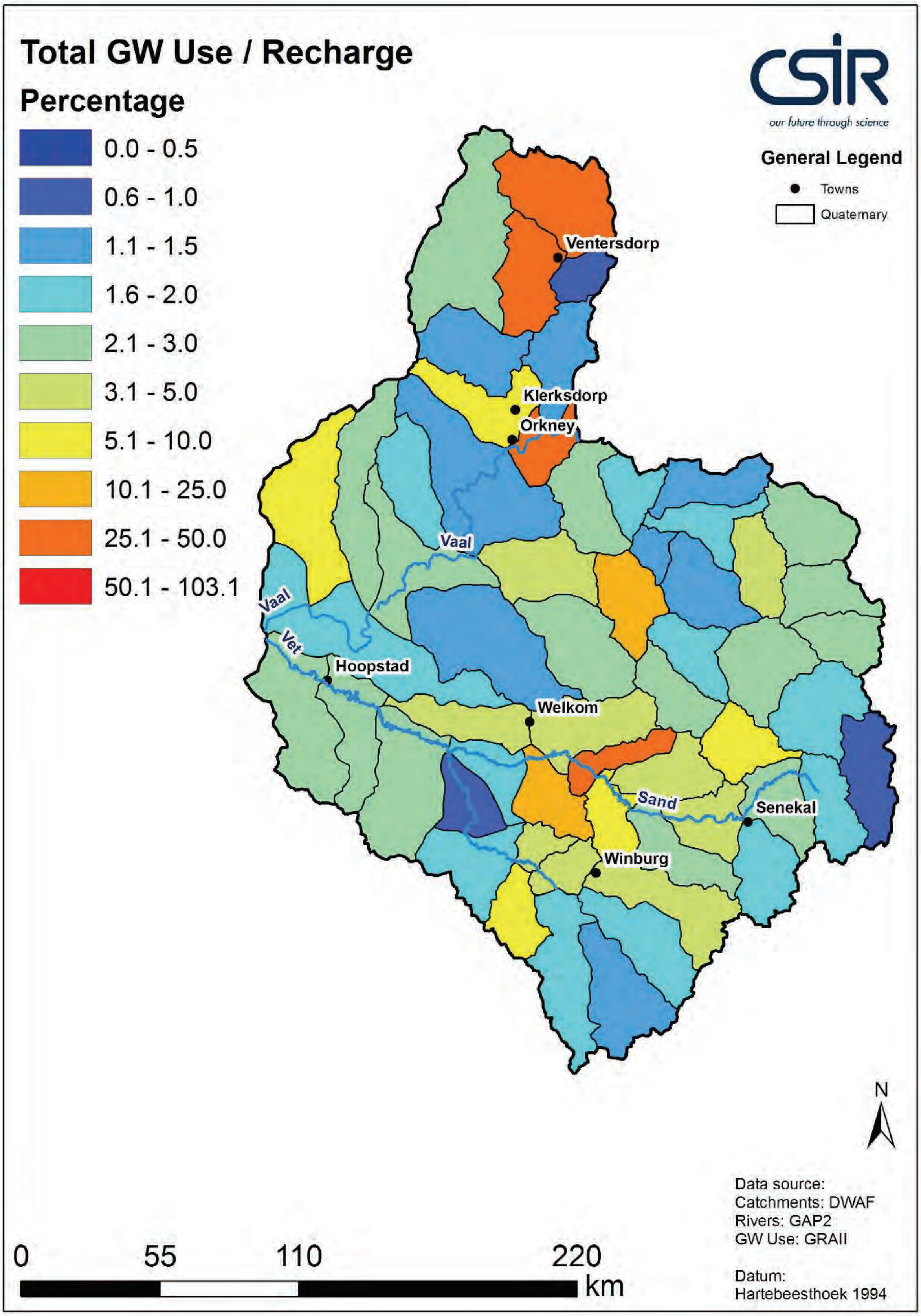

Figure 2-9. Distribution of estimated groundwater use as a percentage of recharge per quaternary catchment

Table 2-6. Summary of groundwater use in the Middle Vaal WMA (DWA, 2005) (values in Mm^3/a)

Quaternary Catchment	Total	Rural	Municipal	Agriculture		Mining	Industry	Aquatic
				Irrig.	Livestock			
C24A	0.3	0.0	0.0	0.0	0.3	0.0	0.0	0.0
C24B	5.1	0.0	0.0	0.0	0.2	4.8	0.1	0.0
C24C	14.9	0.0	0.0	14.2	0.4	0.2	0.1	0.0
C24D	0.2	0.0	0.0	0.0	0.1	0.0	0.0	0.0
C24E	7.5	0.0	3.9	3.1	0.3	0.0	0.2	0.0
C24F	1.3	0.2	0.1	0.3	0.6	0.0	0.1	0.0
C24G	0.3	0.0	0.0	0.0	0.2	0.0	0.1	0.0
C24H	1.4	0.0	0.3	0.6	0.2	0.2	0.1	0.0
C24J	0.8	0.0	0.0	0.1	0.7	0.0	0.1	0.0
C25A	0.5	0.0	0.1	0.0	0.2	0.0	0.2	0.0
C25B	0.6	0.0	0.0	0.0	0.4	0.1	0.0	0.0
C25C	0.8	0.0	0.0	0.0	0.3	0.0	0.4	0.0
C25D	0.6	0.0	0.1	0.0	0.3	0.1	0.1	0.0
C25E	1.9	0.0	0.0	0.0	0.4	1.4	0.0	0.0
C25F	0.6	0.0	0.0	0.0	0.3	0.1	0.2	0.0
C41A	1.1	0.0	0.3	0.0	0.5	0.0	0.2	0.0
C41B	0.4	0.0	0.0	0.0	0.4	0.0	0.0	0.0
C41C	0.3	0.0	0.0	0.0	0.3	0.0	0.0	0.0
C41D	0.3	0.1	0.0	0.0	0.2	0.0	0.0	0.0
C41E	0.1	0.0	0.0	0.0	0.1	0.0	0.0	0.0
C41F	0.2	0.0	0.0	0.0	0.2	0.0	0.0	0.0
C41G	0.1	0.0	0.0	0.0	0.1	0.0	0.0	0.0
C41H	0.2	0.0	0.0	0.0	0.2	0.0	0.0	0.0
C41J	0.1	0.0	0.0	0.0	0.1	0.0	0.0	0.0
C42A	0.3	0.0	0.1	0.0	0.2	0.0	0.0	0.0
C42B	0.3	0.0	0.0	0.0	0.3	0.0	0.0	0.0
C42C	0.3	0.0	0.0	0.0	0.3	0.0	0.0	0.0
C42D	0.3	0.0	0.0	0.0	0.3	0.0	0.0	0.0
C42E	0.3	0.0	0.0	0.0	0.3	0.0	0.0	0.0
C42F	0.2	0.0	0.0	0.0	0.2	0.0	0.0	0.0
C42G	0.2	0.0	0.0	0.1	0.2	0.0	0.0	0.0
C42H	1.1	0.0	1.0	0.0	0.1	0.0	0.0	0.0
C42J	0.4	0.1	0.0	0.0	0.3	0.0	0.0	0.0
C42K	0.9	0.0	0.0	0.0	0.2	0.7	0.0	0.0
C42L	0.1	0.0	0.0	0.0	0.1	0.0	0.0	0.0
C43A	0.3	0.0	0.1	0.0	0.2	0.0	0.0	0.0
C43B	0.2	0.0	0.0	0.0	0.1	0.0	0.1	0.0
C43C	0.3	0.0	0.0	0.0	0.3	0.0	0.0	0.0
C43D	0.4	0.0	0.0	0.0	0.4	0.0	0.0	0.0
C60A	0.2	0.0	0.0	0.0	0.2	0.0	0.0	0.0
C60B	0.5	0.0	0.0	0.0	0.5	0.0	0.0	0.0
C60C	0.4	0.0	0.0	0.0	0.4	0.0	0.0	0.0
C60D	0.2	0.0	0.0	0.0	0.1	0.0	0.0	0.0
C60E	0.6	0.0	0.1	0.0	0.3	0.0	0.2	0.0
C60F	0.2	0.0	0.0	0.0	0.2	0.0	0.1	0.0
C60G	2.1	0.0	0.4	0.0	0.2	1.4	0.0	0.0
C60H	0.3	0.0	0.0	0.0	0.3	0.0	0.0	0.0
C60J	0.8	0.0	0.0	0.0	0.4	0.0	0.4	0.0
C70A	0.5	0.0	0.1	0.0	0.3	0.0	0.0	0.0

Quaternary Catchment	Total	Rural	Municipal	Agriculture		Mining	Industry	Aquatic
				Irrig.	Livestock			
C70B	0.4	0.0	0.0	0.0	0.4	0.0	0.0	0.0
C70C	0.4	0.0	0.1	0.0	0.3	0.0	0.0	0.0
C70D	0.6	0.0	0.0	0.0	0.3	0.0	0.4	0.0
C70E	0.2	0.0	0.0	0.0	0.2	0.0	0.0	0.0
C70F	0.2	0.0	0.0	0.0	0.2	0.0	0.0	0.0
C70G	0.3	0.0	0.0	0.0	0.3	0.0	0.0	0.0
C70H	0.1	0.0	0.0	0.0	0.1	0.0	0.0	0.0
C70J	0.2	0.0	0.0	0.0	0.2	0.0	0.0	0.0
C70K	0.7	0.0	0.0	0.0	0.4	0.0	0.2	0.0
TOTAL	54.1	0.4	6.7	18.4	15.8	9.0	3.3	0.0

2.3.4 Basic Human Needs

Population data were sourced from the Geospatial Analysis Platform 2 (GAP2) developed by the CSIR. The data were disseminated per mesozone (~50 km^2). The population data are for 2004 and were obtained from the StatSA population census data, extracted from the so-called Small Area Layer (SAL) and the sub-place population profiles. The data were summarised per quaternary catchment and is shown in **Table 2-7**.

Table 2-7. Summary per quaternary catchment of population and population below the minimum living level (GAP CSIR)

Quaternary Catchment	Population (2004)	Population below MLL	Quaternary Catchment	Population (2004)	Population below MLL
C24A	7 050	5 017	C42F	71 955	39 809
C24B	53 243	31 256	C42G	8 608	6 876
C24C	127 400	25 663	C42H	81 504	41 319
C24D	18 681	3 079	C42J	15 133	12 391
C24E	116 134	51 439	C42K	961	587
C24F	139 917	29 827	C42L	1 867	1 182
C24G	32 786	20 852	C43A	69 395	26 707
C24H	6 803	5 225	C43B	3 272	1 854
C24J	22 249	17 403	C43C	17 170	9 364
C25A	4 378	2 998	C43D	32 156	24 645
C25B	79 903	63 942	C60A	3 692	2 340
C25C	6 871	5 004	C60B	14 374	10 790
C25D	85 274	60 167	C60C	13 109	8 469
C25E	13 720	10 597	C60D	3 818	2 567
C25F	5 615	3 706	C60E	8 850	7 788
C41A	78 440	54 136	C60F	171 594	96 217
C41B	29 722	20 033	C60G	2 019	1 300
C41C	34 267	21 292	C60H	9 748	6 274
C41D	42 182	29 024	C60J	9 860	6 169
C41E	2 936	2 629	C70A	2 828	2 218
C41F	12 077	8 630	C70B	8 339	6 715
C41G	122	130	C70C	5 627	4 114
C41H	12 635	8 669	C70D	5 293	2 012

Quaternary Catchment	Population (2004)	Population below MLL	Quaternary Catchment	Population (2004)	Population below MLL
C41J	16 567	11 390	C70E	17 100	13 034
C42A	7 353	5 110	C70F	2 908	2 141
C42B	2 875	1 903	C70G	3 617	2 745
C42C	20 210	8 731	C70H	4 317	3 081
C42D	30 888	21 992	C70J	4 580	3 602
C42E	7 532	6 150	C70K	4 394	3 050
TOTAL				1 017 830	535 994

2.3.5 Groundwater Threats

There are several sources of point and diffuse groundwater pollution in the Middle Vaal WMA. Most of these sources are, however, related to mining activities (e.g. abandoned mines), although agriculture and urban activities also influence the quality of groundwater. In the Middle Vaal subarea, the following sources contribute to the degradation of the groundwater quality (DWAF, 2003b):

- gold in the KOSH (Klerksdorp Gold Field) area (acid mine drainage);
- mine residue (waste) deposits, e.g. tailings dams and waste rock dumps;
- recirculation of process water , i.e. between metallurgical plants, mine residue areas and underground;
- return water dams;
- pipe bursts and spills at gold metallurgical plants; and
- decant from abandoned mines.

Typically, the groundwater exhibits higher than normal salinity with a $CaMgNa/SO_4$ or $CaMgNa/HCO_3$ chemical composition. The pH, however, is generally in the neutral to slightly basic range (7-8) due to the neutralising effect of the dolomitic strata. High concentrations of certain metals are sometimes evident, e.g. Fe, Mn and Al (DWAF, 2003b). Dewatering of dolomitic compartments for mining purposes, for example in the vicinity of Stilfontein, may also have an impact on the groundwater. Problems have also been experienced with seepage of groundwater containing manganese from mining areas into the Vaal River (DWAF, 2003a).

The impacts from agricultural activities on groundwater quality at a local scale are typically fairly small, but the contribution on a catchment scale needs to be included in assessing any pollution situation. In cities and towns, poor operation and management of wastewater treatment works (WWTWs) contribute to groundwater pollution through the discharge of sewage into evaporation pans. In addition, pollution also emanates from landfill sites, on-site sanitation facilities (especially in informal settlements), and spills resulting from accidents or leaking underground storage tanks.

3 PRESENT STATUS OF GROUNDWATER

3.1 Groundwater Level

Groundwater level monitoring data were assessed to indicate trends in groundwater 'quantity' and the present status of this resource.

3.1.1 Method

The average water level was calculated for each geosite (borehole) enumerated in the DWAs National Groundwater Data Base / National Groundwater Archive (NGDB/NGA) for the Middle Vaal WMA. This value was imported into the Aquachem data management software package, and the data grouped in terms of geological unit penetrated according to surface geology, and quaternary catchment underlain by such geological unit. Further analysis was performed to establish the statistical characteristics of groundwater levels associated with each lithological unit as distributed between quaternary catchments. Depth to groundwater level data are available for 5026 stations in the Middle Vaal WMA. Of these, 88 support >100 measurements.

3.1.2 Geological Unit Assessments

3.1.2.1 Adelaide Subgroup

The Adelaide Subgroup is penetrated in quaternary basins C41C, C41D, C42B, C42C, C60B, C60C, C60D, C60E, C60F, C70A, and C70D. Five of these catchments contain an insufficient amount of data to perform statistical analyses. Catchment C70A has the smallest range in water level measurements, while C60D and C60F have the largest range in water level measurements. An overall minimum close to 0 m bs (below surface) occurs in catchment C60B, while an overall maximum of close to 70 m bs occurs in catchment C60D. Minimum, maximum and median water level values vary significantly between the different catchment areas (**Figure 3-1**).

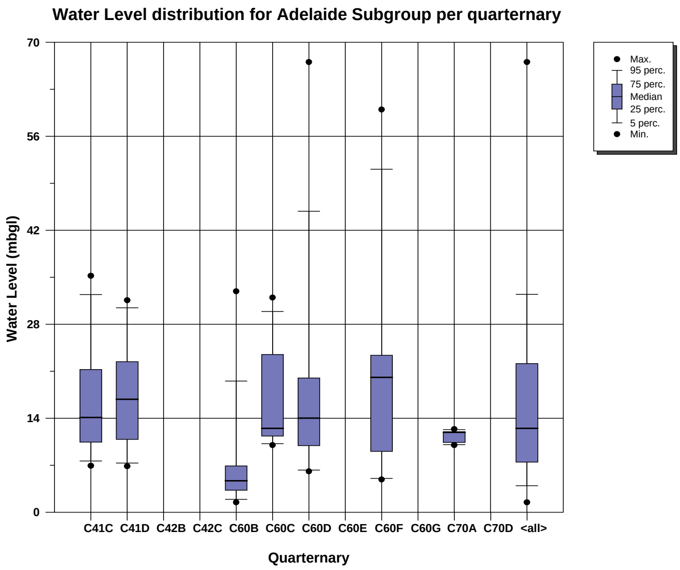

Figure 3-1. Groundwater level statistics for the Adelaide Subgroup per quaternary catchment

3.1.2.2 Allanridge Formation

The Allanridge Formation occurs in 10 quaternary catchments, of which only 8 have a sufficient amount of data to evaluate statistically (**Figure 3-2**). Groundwater levels demonstrate a similar attitude everywhere in this lithological unit, typically located between 9 and 18 m bs with minimum values of <5 m bs. Maximum depths seldom exceed 30 m bs (**Figure 3-2**).

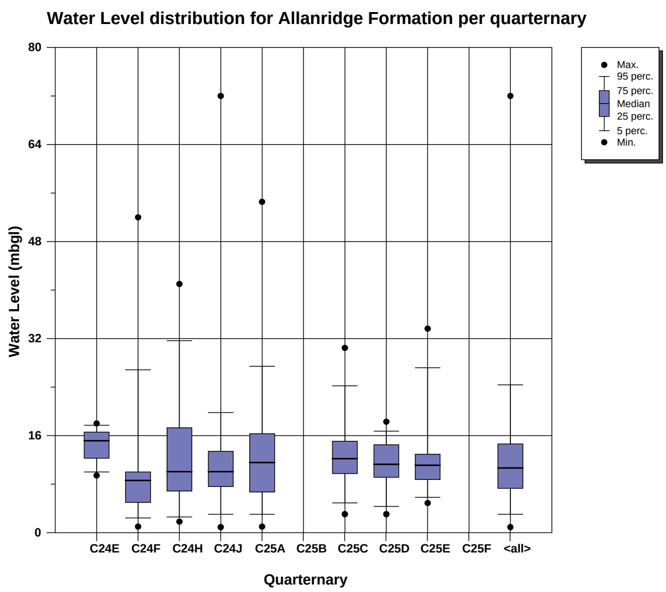

Figure 3-2. Groundwater level statistics for the Allanridge Formation per quaternary catchment

3.1.2.3 Black Reef Formation

This lithostratigraphic unit occurs in six quaternary catchments (**Figure 3-3**), and is characterised by a significantly greater variation in depth to groundwater level between quaternary catchments than observed in the case of the Allanridge Formation (**section 3.1.2.2**).

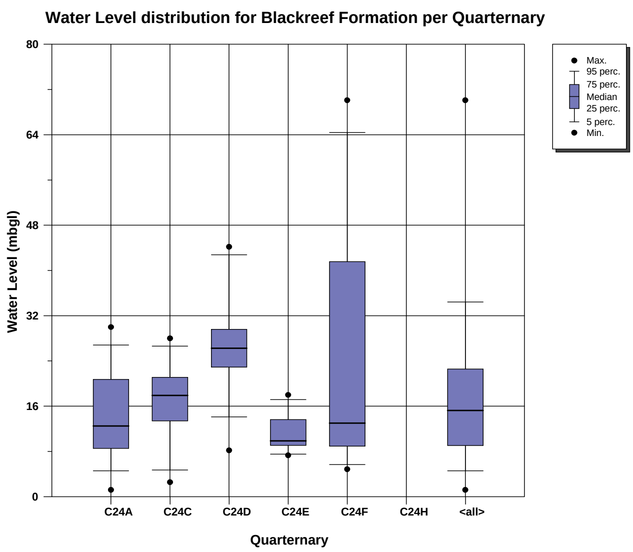

Figure 3-3. Groundwater level statistics for the Black Reef Formation per quaternary basin

3.1.2.4 Bothaville Formation

Quaternary catchment C24C, which is mainly underlain by dolomitic strata, reflects a significantly different depth to groundwater level (**Figure 3-4**) than that which characterises this hydrogeologic parameter in the other three catchments where sandstone and conglomerate of the Bothaville Formation occurs.

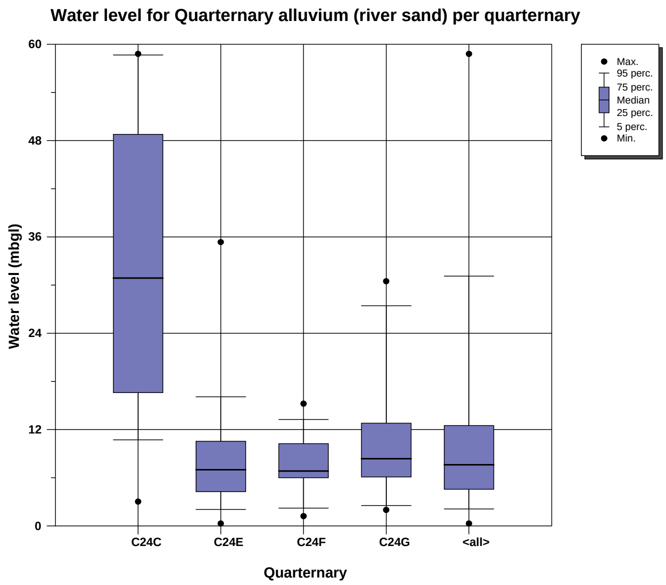

Figure 3-4. Groundwater level statistics for the Bothaville Formation per quaternary basin

3.1.2.5 Ecca Group

The Ecca Group only occurs in catchments C24A and C24B, the latter having insufficient data to analyse statistically. The depth to groundwater rest level is characterised by a relatively shallow mean value of ~16 m bs, although a significant number of stations indicate a substantially greater depth with a 75%ile value of ~54 m bs (**Figure 3-5**).

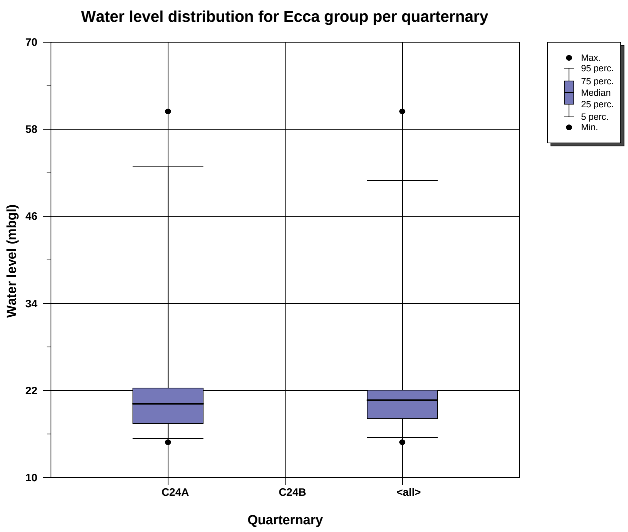

Figure 3-5. Groundwater level statistics for the Ecca Group per quaternary basin

3.1.2.6 Elliot Formation

The Elliot Formation only occurs in catchments C42A and C80A, respectively the headwaters of the Sand and Vals rivers in the south-eastern corner of the WMA (**Figure 2-4**). The relatively shallow median depth to groundwater level of ~13 m bs (**Figure 3-6**) is matched by moderate extreme values (~32 m bs).

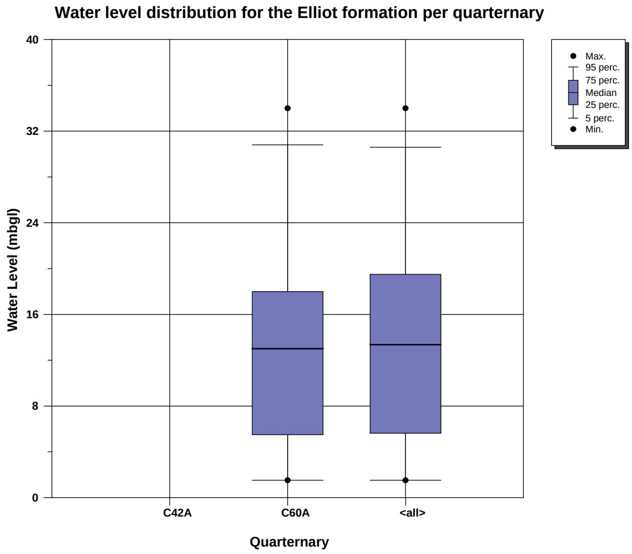

Figure 3-6. Groundwater level statistics for the Elliot Formation per quaternary basin

3.1.2.7 Government Subgroup

The Government Subgroup occurs in the KOSH area (catchments C24A and C24H, **Figure 2-4**), and supports significant differences in groundwater level characteristics between the two host catchments (**Figure 3-7**). Catchment C24H is characterised by a median depth to groundwater level (~25 m bs) that is twice as deep as that which characterises C24A. The similarity of the box-and-whisker plots for the whole data set and C24A indicates the strong bias exercised by the C24A data in characterising groundwater levels associated with the Government Subgroup strata.

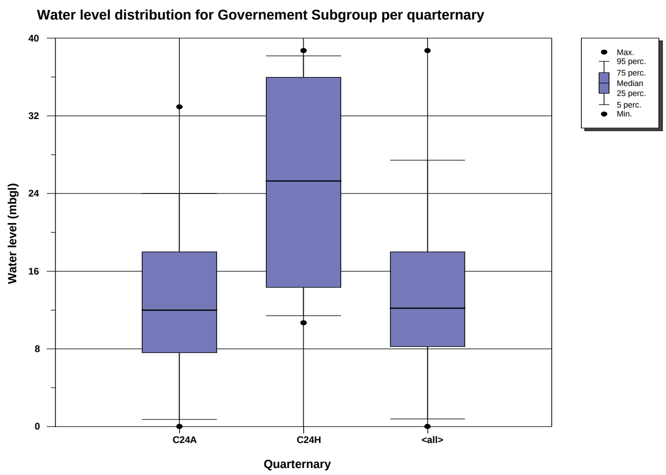

Figure 3-7. Groundwater level statistics for the Government Subgroup per quaternary basin

3.1.2.8 Hekpoort Formation

The Hekpoort Formation is characterised by shallow depths (median <5 m bs) to groundwater level (**Figure 3-8**). The more extreme 95%ile and maximum values significantly exceed the median value.

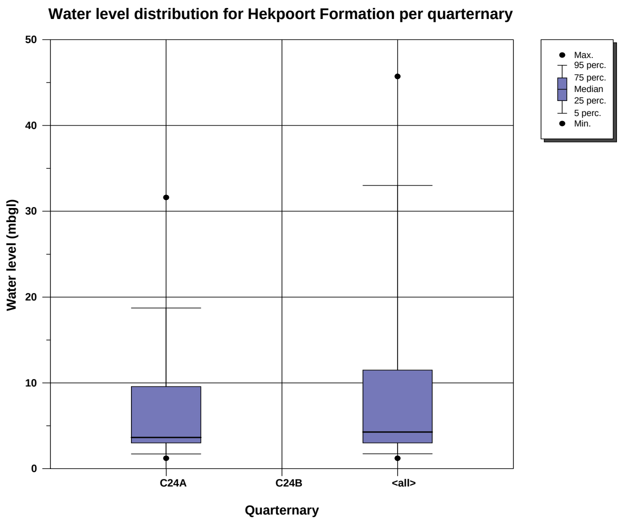

Figure 3-8. Groundwater level statistics for the Hekpoort Formation per quaternary catchment

3.1.2.9 Hospital Hill Formation

The groundwater level associated with Hospital Hill Formation strata reflects reasonably similar characteristics across the seven quaternary catchments (**Figure 3-9**) located along the north-western margin of the WMA.

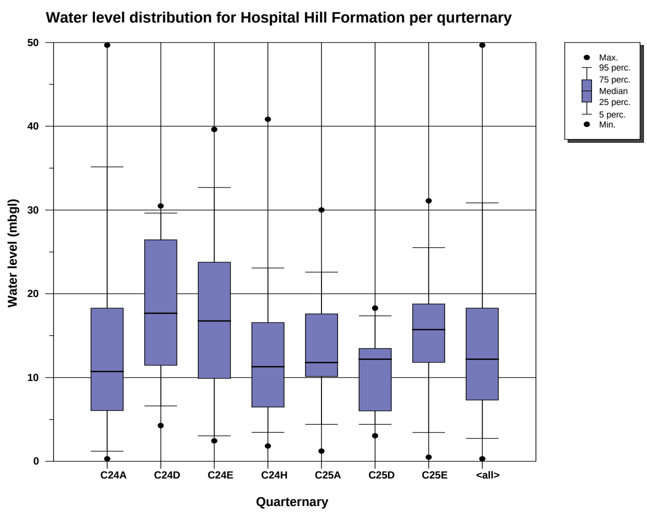

Figure 3-9. Groundwater level statistics for the Hospital Hill Formation per quaternary basin

3.1.2.10 Kameeldoorns Formation

The Kameeldoorns Formation occurs in six catchments (**Figure 3-10**) in the northern portion of the study area. The available data indicate median depths to groundwater level in the range 10-20 m bs.

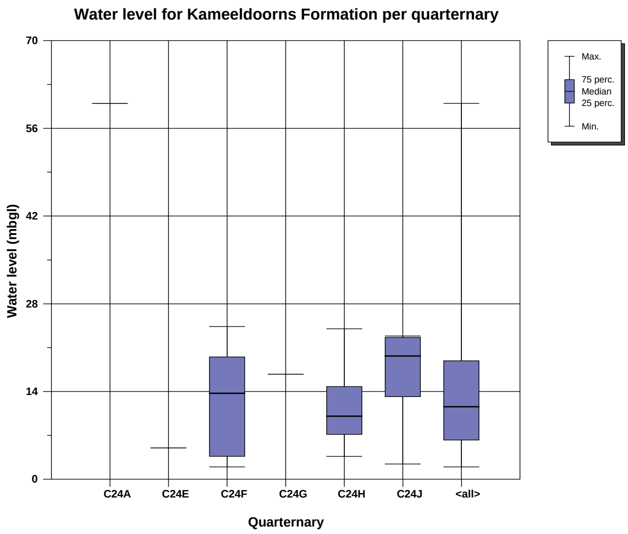

Figure 3-10. Groundwater level statistics for the Kameeldoorns Formation per quaternary catchment

3.1.2.11 Karoo Dolerite intrusions

Groundwater level data associated with boreholes intersecting dolerite intrusions (dykes and sills) in the WMA indicate the wide distribution of intrusive-related groundwater occurrences. The pattern of groundwater level statistics (**Figure 3-11**) indicates relatively shallow (<10 m) depths below surface across most of the catchments. As might be expected, slightly greater depths are observed in catchments C41C and C41D encompassing the headwaters of the Leeu Spruit in the higher lying southern portion of the WMA.

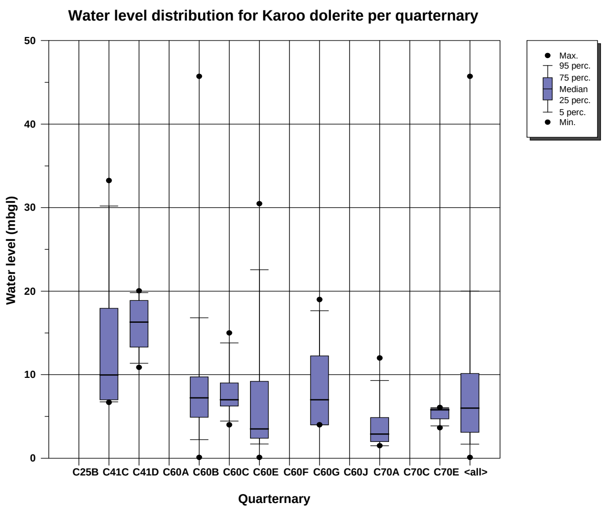

Figure 3-11. Groundwater level statistics for Karoo Dolerite intrusions per quaternary basin

3.1.2.12 Klipriviersberg Group

The Klipriviersberg Group strata are again characterised by quite shallow (<12 m bs) depths to groundwater level (**Figure 3-12**). This is also true for the 95%ile values (<30 m bs), although maximum values of ~50 m bs or greater occur.

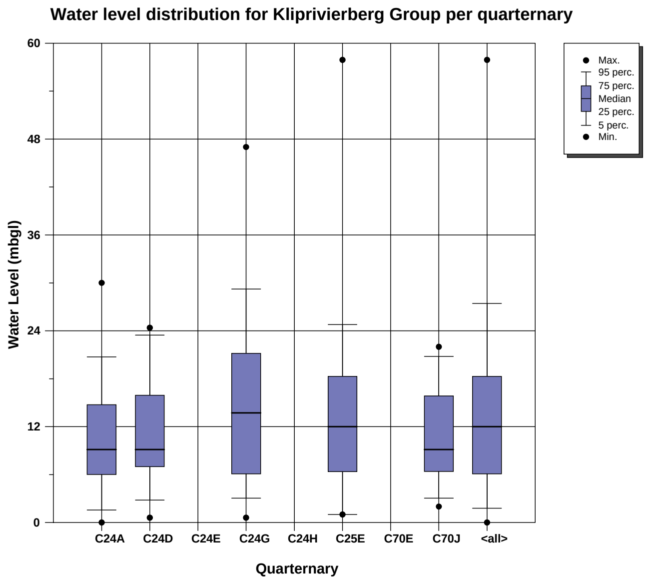

Figure 3-12. Groundwater level statistics for the Klipriviersberg Group per quaternary basin

3.1.2.13 Makwassie Formation

Except for catchment C24E with a median depth to groundwater level of ~21 m bs (**Figure 3-13**), this hydrogeologic variable typically occupies a shallower depth (<10 m) below surface. Excessive depths are uncommon, with 95%ile values typically <30 m bs and maximum values of <50 m bs (**Figure 3-13**).

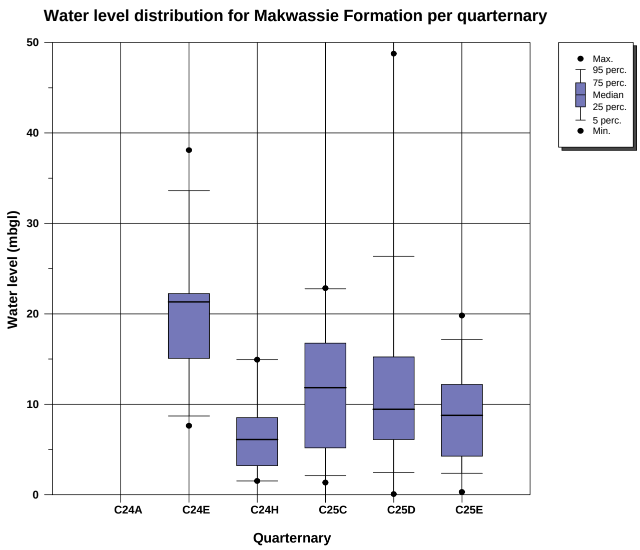

Figure 3-13. Groundwater level statistics for the Makwassie Formation per quaternary catchment

3.1.2.14 Malmani Subgroup

The Malmani Subgroup strata are limited to six catchments in the northern part of the WMA (**Figure 3-14**). The very shallow minimum water levels indicate the influence of springs in this karst environment. The relatively deep maximum values (e.g. the 155 m bs in catchment C24A) are not uncommon in karst aquifers, reflecting very low hydraulic gradients over significant distances.

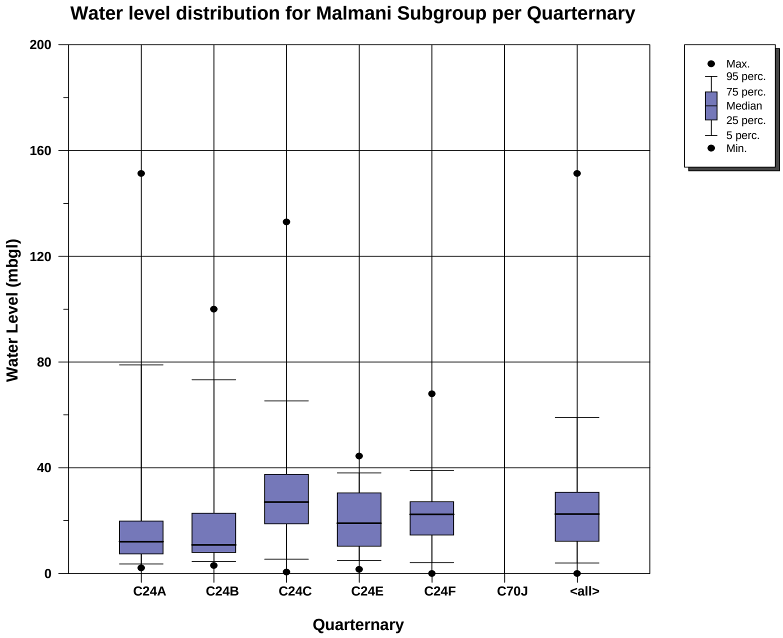

Figure 3-14. Groundwater level statistics for the Malmani Subgroup per quaternary basin

3.1.2.15 Molteno Formation

The Molteno Formation occupies the higher lying terrain along the eastern margin of the WMA in catchments C42A, C42B, C70A and C80A (**Figure 2-4** and **Figure 3-15**). Despite the elevated geographic location, median depths to groundwater level remain comparatively shallow (<14 m bs), and with 75%ile values <20 m bs.

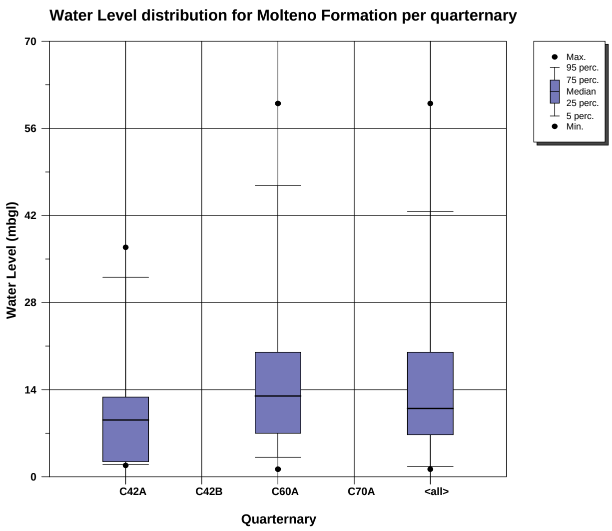

Figure 3-15. Groundwater level statistics for the Molteno Formation per quaternary catchment

3.1.2.16 Alluvial Sediments

Unconsolidated alluvial deposits occur in 14 catchments of the WMA (**Figure 3-16**), and are characterised by shallow median (<9 m bs) and 75%ile (<18 m bs) depths to groundwater level. The anomalously deep maximum value of 81 m bs in catchment C24A is unlikely for this groundwater setting, and is therefore regarded with caution.

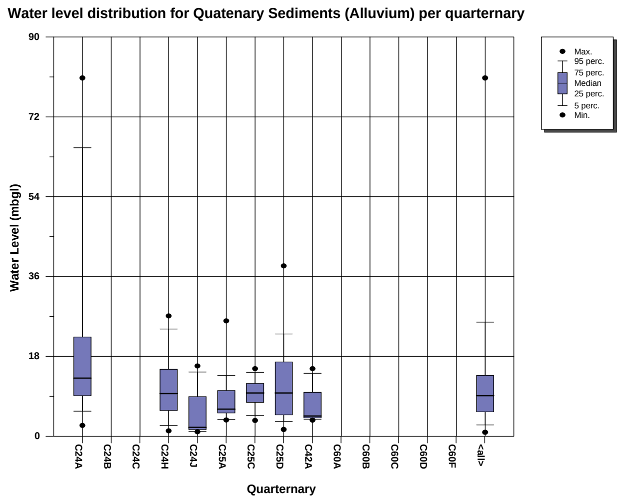

Figure 3-16. Groundwater level statistics for alluvial sediments per quaternary catchment

3.1.2.17 Vryheid Formation

Characterisation of the depth to groundwater level associated with Vryheid Formation strata is foiled by an insufficiency of data (**Figure 3-17**). Nevertheless, the median value of ~22 m bs returned by the full data set is in good agreement with the value of ≤20 m bs obtained for the Ecca Group strata in the Upper Vaal WMA (CSIR, 2012).

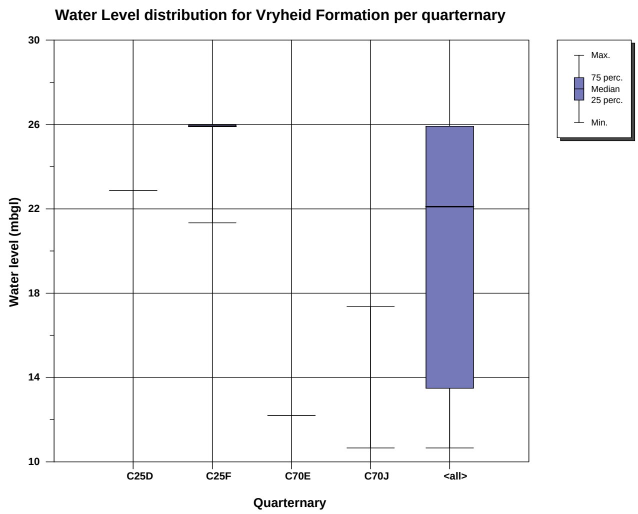

Figure 3-17. Groundwater level statistics for the Vryheid Formation per quaternary basin

3.1.2.18 Quaternary Surface Deposits

This lithology only occurs in 2 catchments, namely C24C and C24F (**Figure 3-18**). Water level values range from ~9 to ~18 m bs in catchment C24F (10 measurements), and from ~4 to ~37 m bs in C24C (17 measurements), with a median value of ~12 m bs.

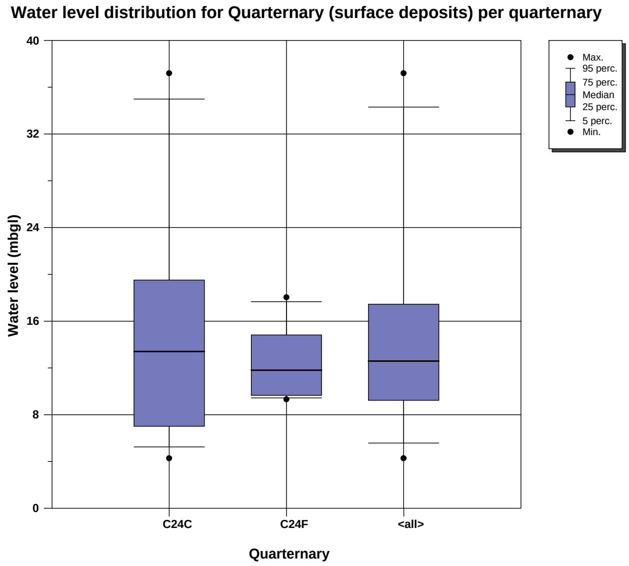

Figure 3-18. Groundwater level statistics for quaternary surface deposits per quaternary catchment

3.1.2.19 Quaternary Gravel Deposits

Quaternary gravels in catchment C24C are characterised by a median depth to groundwater level of ~26 m bs and a maximum value of ~36 m bs (**Figure 3-19**).

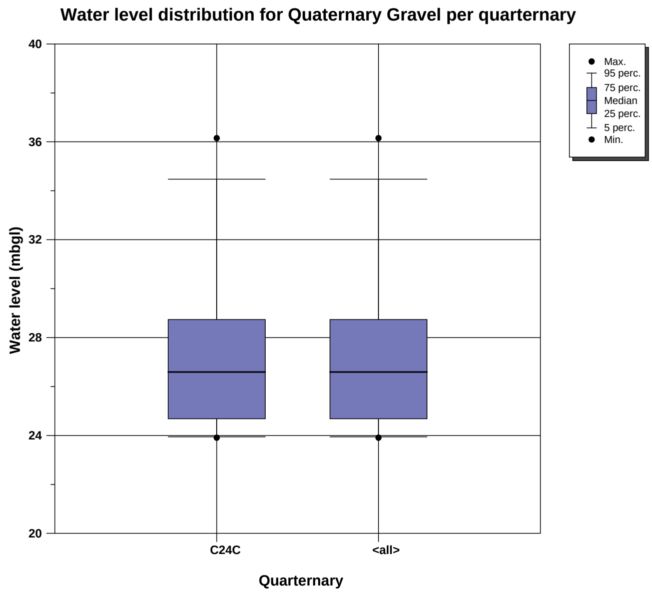

Figure 3-19: Groundwater level statistics for Quaternary gravels per quaternary basin

3.1.2.20 Quaternary Soil Cover

The soil cover in catchments C24C, C24F, C24G, C24H, C24J, C25D and C25E masks underlying bedrock represented by a variety of strata comprising mainly dolomite or lava. The groundwater level data associated with this surface geology therefore represents that of the bedrock rather than that of the surficial soils. These circumstances explain the >7 m bs median values reflected in **Figure 3-20**.

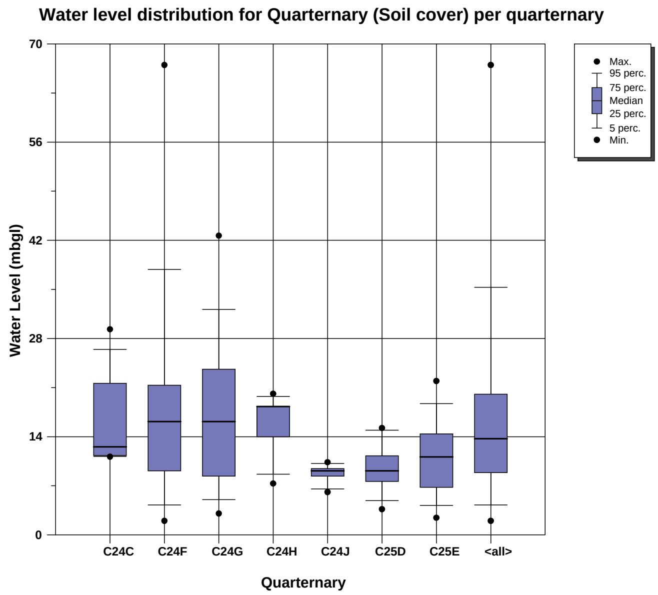

Figure 3-20. Groundwater level statistics for Quaternary soil cover per quaternary catchment

3.1.2.21 Aeolian Sands

Aeolian sand occurs in 18 quaternary catchments, of which 9 have insufficient data to evaluate statistically (**Table 3-1**). A minimum water level of ~1 m bs occurs in catchment C24J, and a maximum value of ~46 m bs in C25C (**Figure 3-21**).

Table 3-1. Depth to groundwater level characteristics for aeolian sand deposits

Quaternary Catchment	N	Minimum (m bs)	Maximum (m bs)	Range (m)
C60J	1	8	8	0
C43D	2	9.1	11.3	2.2
C60D	21	2.6	36.6	34
C60G	1	20	20	0
C70E	1	13	13	0
C70F	2	10.4	21.3	11
C70H	2	21	30	9
C60F	3	22.9	29.3	6.4
C25A	9	2.1	21.3	19.2
C24B	5	10.7	18.3	7.6
C24J	53	0.91	93	92.1
C25B	2	15	65	50
C25C	11	7.6	45.7	38.1
C25D	40	3	32.5	29.5
C25E	25	4.6	24.4	19.8
C25F	26	3.1	42.7	39.6
C41J	2	10	10	0
C70K	3	12	20	8

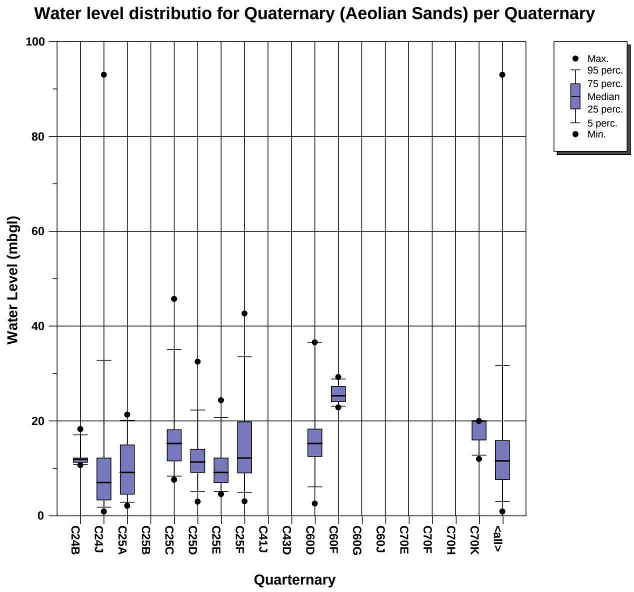

Figure 3-21. Groundwater level statistics for aeolian sands deposits per quaternary catchment

3.1.2.22 Rhenosterhoek Formation

The Rhenosterhoek Formation of the Dominium Group is characterised by a median depth to groundwater level of ~17 m bs, and a maximum depth that rarely exceeds ~28 m bs (**Figure 3-22**).

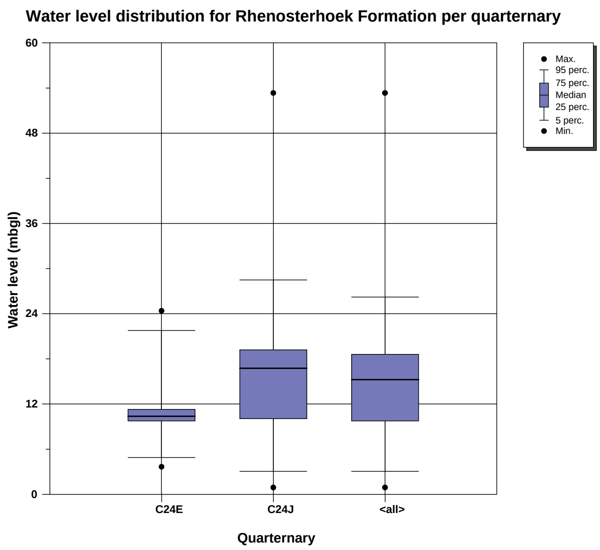

Figure 3-22. Groundwater level statistics for the Rhenosterhoek Formation per quaternary basin

3.1.2.23 Rietgat Formation

Groundwater level data from 814 boreholes unequally distributed across 11 quaternary catchments (**Table 3-2**) are available for characterising this hydrogeologic variable associated with Rietgat Formation (Platberg Group) strata. Catchments C24G and C25D support ~58% of the stations for which data are available (**Table 3-2**). Recognising this bias, the median depth to groundwater level falls in the relatively narrow range 10-15 m bs (**Figure 3-23**), with 75%ile values typically <30 m bs.

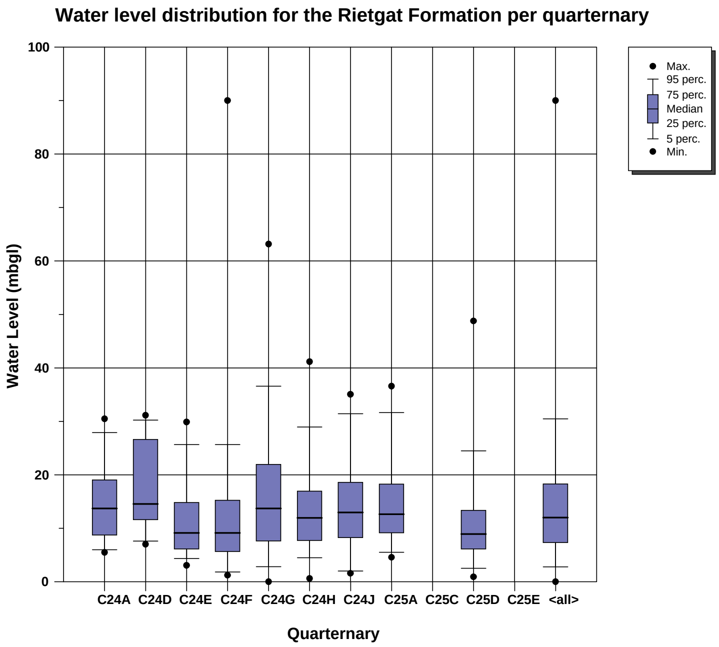

Figure 3-23. Groundwater level statistics for the Rietgat Formation per quaternary catchment

Table 3-2. Water level summary statistics for the Rietgat Formation

Quaternary Catchment	N	Minimum (m bs)	Median (m bs)	95%ile (m bs)	Maximum (m bs)	Range (m)
C25A	10	4.6	12.7	31.6	36.6	32
C24A	18	5.5	13.7	27.9	30.5	25
C24D	17	7	14.5	30.2	31.1	24.1
C24E	27	3.1	9.1	25.7	29.9	26.8
C24F	79	1.2	9.1	25.6	90	88.8
C24G	328	0.01	13.7	36.6	63.2	63.1
C24J	60	1.6	13	31.4	35.1	33.5
C25C	1	25	N/A	N/A	25	
C25D	146	0.91	8.9	24.5	48.8	47.9
C25E	2	17.7	N/A	N/A	21.1	3.4
C24H	126	0.61	11.9	29	41.2	40.5

3.1.2.24 Rooihoogte Formation

The Rooihoogte Formation, unlike the Rietgat Formation, only occurs in two quaternary catchments. Although catchment C24C shows a greater range of values than does catchment C24F, this is attributed to the greater number of sites (88) in this area compared to the seven of C24F. This finds support in the similar box-and-whisker plots of the C24C data and the combined data set (**Figure 3-24**).

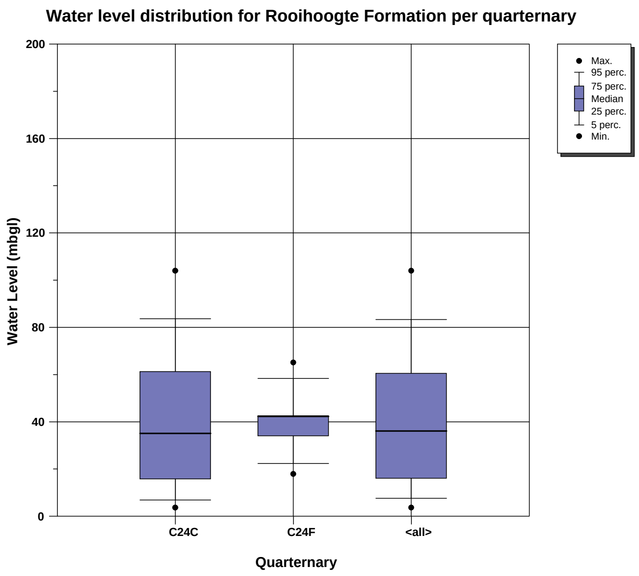

Figure 3-24. Groundwater level statistics for the Rooihoogte Formation per quaternary catchment

3.1.2.25 Swazian Granite and Gneiss

The Swazian granite and gneiss strata occur in six quaternary catchments that share a total of 107 boreholes for which water level data are available. The plots in **Figure 3-25** suggest that the greater range of inter-quartile values associated with catchments C24F and C70E are uncharacteristic compared to that of the other basins. The range represented by the combined data set (excluding the minimum and maximum values) is considered to better reflect the typical depth to water level encountered in these lithologies. In this regard , a median depth to groundwater level of ~9 m bs is indicated.

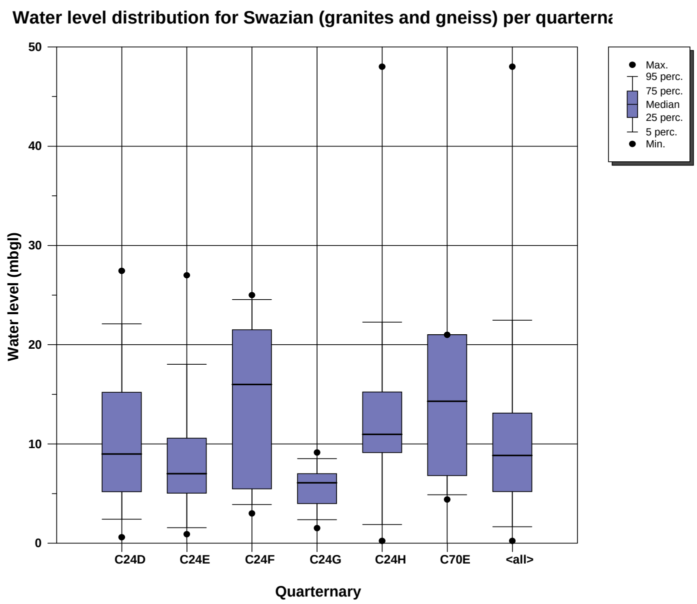

Figure 3-25. Groundwater level statistics for Swazian granite and gneiss per quaternary basin

3.1.2.26 Syferfontein Formation

The Syferfontein Formation data set of 26 boreholes for which water level data are available spans quaternary catchments C24E and C24J. Although the latter supports too few data (2 values) to evaluate statistically, the influence on the 95%ile and maximum values of the combined data set is evident (**Figure 3-26**). A median water level depth of ~9 m bs and narrow inter-quartile range of 4-10 m bs characterises this lithology.

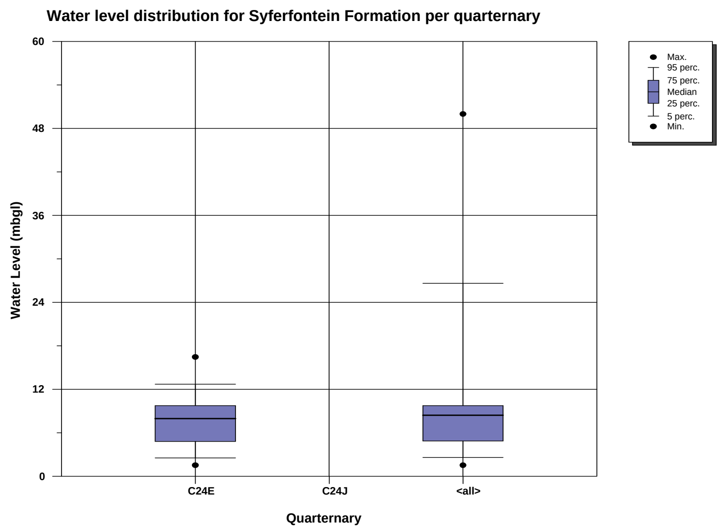

Figure 3-26. Groundwater level statistics for the Syferfontein Formation per quaternary catchment

3.1.2.27 Tarkastad Subgroup

The groundwater level associated with the Tarkastad Subgroup strata is characterised on the basis of data for 101 stations. These occur in nine quaternary catchments in the area, although **Figure 3-27** indicates that four of these have too few data for a statistical analysis. The 'anomalous' range of water level data associated with catchments C24C and C80E compared to the other catchments is evident in **Figure 3-27**. The complete data set indicates a median water level depth of ~9 m bs.

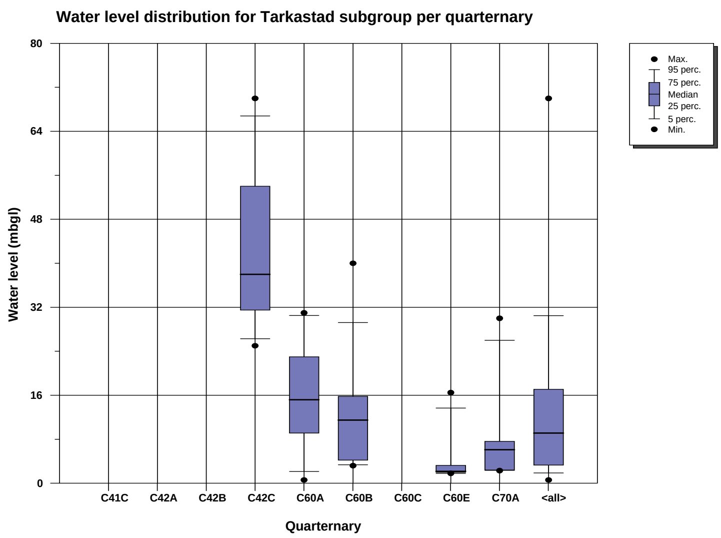

Figure 3-27. Groundwater level statistics for the Tarkastad Subgroup per quaternary catchment

3.1.2.28 Tertiary Deposits

Data for 50 boreholes drilled through and into calcified Tertiary strata in catchment C26E serve to characterise the water level associated with these strata. **Figure 3-28** indicates a shallow depth to groundwater level with a median value of ~6 m bs in a narrow inter-quartile range of 4-8 m bs.

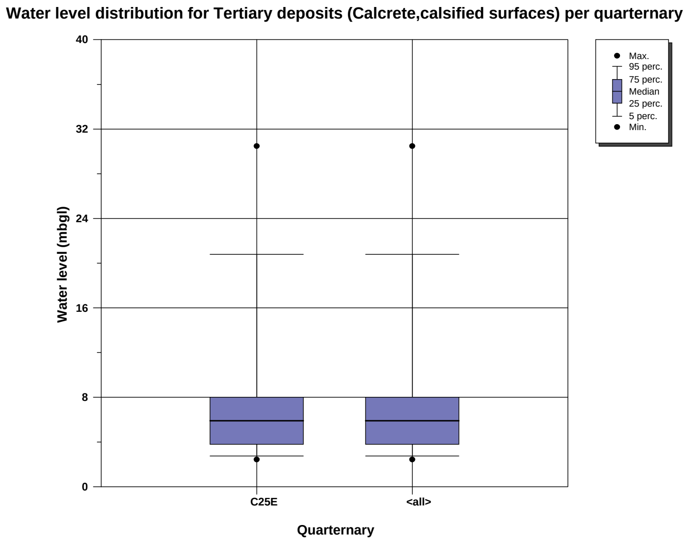

Figure 3-28. Groundwater level statistics for Tertiary deposits per quaternary basin

3.1.2.29 Timeball Hill Formation

The groundwater level associated with the Timeball Hill Formation strata is characterised on the basis of data for 59 stations which occur in catchments C24A (7 stations) and C24C (52 stations). The similar inter-quartile range associated with these catchments (**Figure 3-29**) indicates the uniformity that characterises this hydrogeologic parameter of the Timeball Hill Formation. The median values of ~14 m bs again indicate a comparatively shallow depth to groundwater rest level.

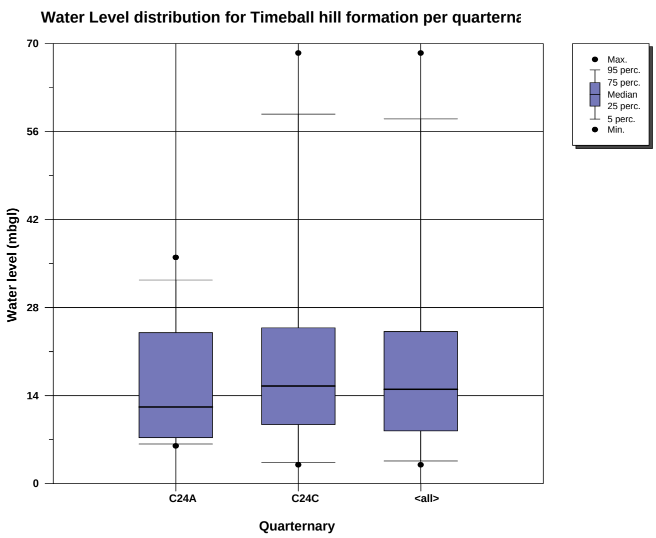

Figure 3-29. Groundwater level statistics for the Timeball Hill Formation per quaternary catchment

3.1.2.30 Volksrust Formation

The Volksrust Formation set of groundwater level measurements comprises 64 stations spread across six quaternary catchments, of which only three have sufficient data for statistical evaluation. The similarity between the inter-quartile ranges of catchments C25E and C25F and the combined data set (**Figure 3-30**) indicates that characterisation of the water level associated with this formation is biased by the data of these catchments. Nevertheless, the median value of ~18 m bs indicates a moderate depth to groundwater rest level.

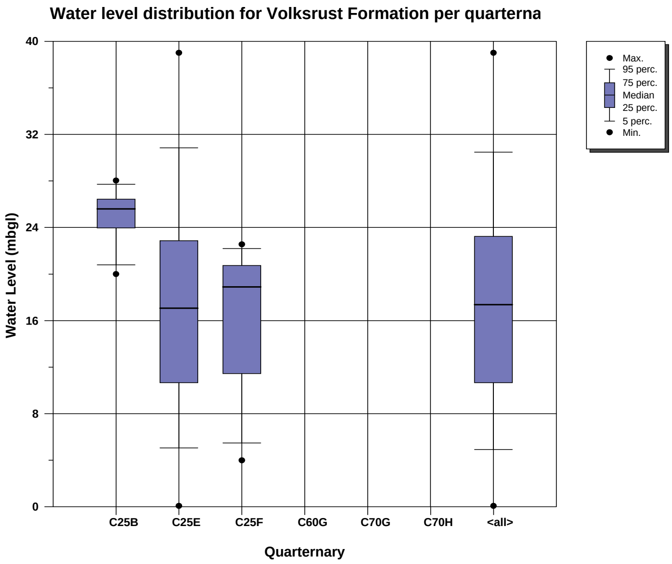

Figure 3-30. Groundwater level statistics for the Volksrust Formation per quaternary catchment

3.1.2.31 Exclusions

The following lithologic units are excluded from the preceding analysis and discussion of depth to groundwater level characteristics because of the insufficiency of available data.

- Clarence Formation:One station with water level data.
- Quaternary river terrace gravels:Five stations each with only one water level reading.
- Tertiary calcrete deposits:One station with a single water level measurement.
- Goedgenoegd Formation:Four stations each with only one water level measurement.
- Daspoort Formation: One station with a single water level measurement.
- Jeppestown Formation:Four stations each with a single water level measurement.
- Vaalian diabase:Five stations with one water level reading each.

3.2 Groundwater Chemistry

3.2.1 Sources of Data

Chemical data were sourced from the Department of Water Affairs as the custodian of all hydrologic and hydrogeologic data in South Africa. Physical and chemical water quality data were obtained from the NGDB/NGA and the ZQM data bases. The latter forms part of the central and overarching Water Management System (WMS) database, while the NGDB/NGA serves as repository for physical hydrogeologic data. The WMS and the NGDB/NGA are not linked at present.

Monitoring stations that support the ZQM database are used to monitor "temporal changes under natural conditions". Even though the ZQM data represents natural conditions, it is not suitable as a measure of virgin/reference conditions due to the comparatively short (<10 years) length of this record. The complete hydrochemistry data set informs the groundwater quality assessment component of this study, using the older portion of this record as a proxy for virgin/reference conditions, together with other sources such as Bond (1947).

3.2.2 History, Availability and Quality of Data

The Middle Vaal WMA is served by 984 geosites providing groundwater quality data amounting to 1758 chemical analyses spanning the period 1970 to 2007. The distribution of these data by quaternary catchment is shown in **Figure 3-31**.

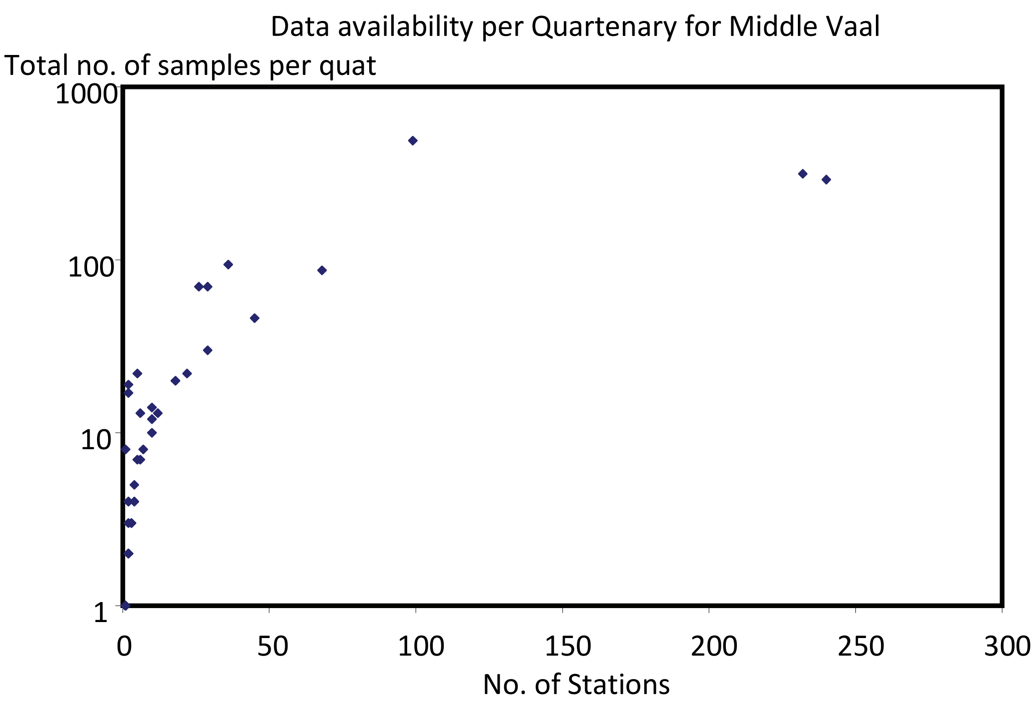

Figure 3-31. Plot of number of stations versus number of analyses per station for each quaternary catchment in the Middle Vaal WMA

The ion (or electrical) balance error was used as a screening technique to evaluate the reliability and integrity of each analysis in the data set. An error of ≤5% is generally considered acceptable for fresh water (Appelo and Postma, 2009), and was applied to this study. This resulted in 49.9% of the analyses passing this criteria, the remainder either exceeding this limit or being incomplete (in terms of major ions reported) for this calculation. This result is illustrated in **Figure 3-32**. As a consequence, a number of quaternary catchments have necessarily been excluded from the groundwater quality assessment component of this study.

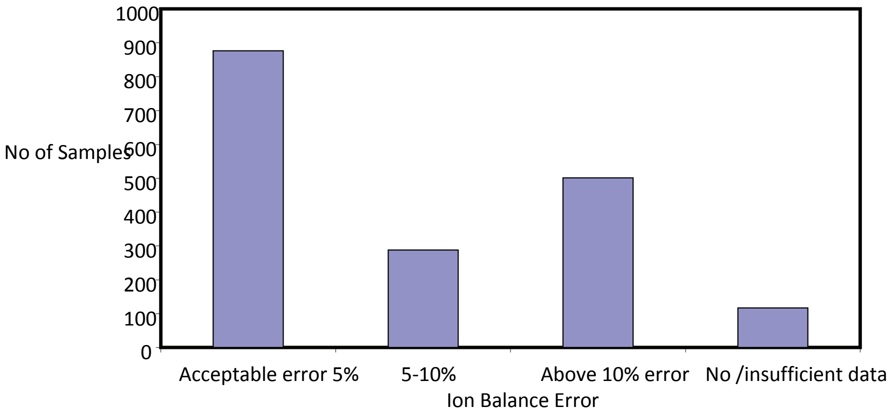

Figure 3-32. Ion balance error for the Middle Vaal groundwater chemistry data set.

3.2.3 Temporal Distribution of the Data

Figure 3-33 shows the distribution of hydrochemical data according to the date sampled, grouped by decade. The assessment applies to the full data set, and not the subset considered acceptable in terms of the ion balance error.

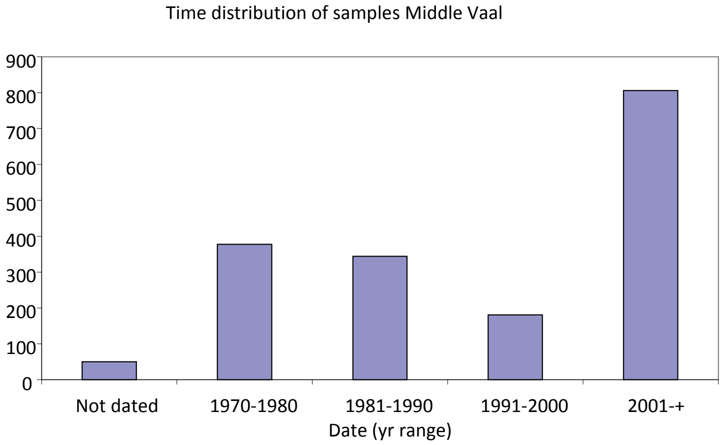

Figure 3-33. Temporal distribution of analyses to evaluate data availability for reference and current conditions

The assessment reveals the gradual decline in 'availability' across the last three decades of the 20th century, followed by a significant increase in the period from 2000 to 2010. The latter period witnessed almost as many analyses (~800) being undertaken as in the previous four decades combined (~1000). The implication is that the earlier records, which represent the 'reference' conditions, are data-poor. By comparison, the youngest records representing the 'current' conditions are well represented.

A summary description of the outcome of the data verification exercise is presented in **Table 3-3**.

Table 3-3. Summary of hydrochemical data screening exercise outcome, ≤5% error balance

Tertiary Catchment	No. of Quaternary Catchments	No. of Stations	No. of Analyses	Ratio of Analyses/Station	No. of pre-1985 Analyses	No. of post-1985 Analyses
C24	9	461	919	1.99	301	618
C25	5	24	25	1.04	11	14
C41	4	18	31	1.72	2	29
C42	7	20	25	1.25	21	4
C43	2	9	16	1.78	9	7
C60	7	21	22	1.05	13	9
C70	5	9	20	2.22	3	17

3.2.4 Hydrochemical Characterisation

The screened hydrochemical data set for the study area was evaluated in terms of its chemistry and dominant water types, using the geological unit intersected as a grouping category, to characterise the groundwater resources in the study area. Hydrochemical characterisation was made using the trilinear Piper diagram. A statistical evaluation of the data per geological unit considered the minimum, mean and maximum values in order to compare groundwater chemical composition. This was done to assess whether any of the lithologies could be grouped in terms of water types or dominant ions.

The information provided in **Table 3-4** represents a synthesis of this evaluation. Average concentrations per lithology or formation seem to vary considerably. This may be due to a multitude of reasons ranging from type of formation (rock composition) to age of the water (residence time) to level of impact from surrounding land use activities in the area (anthropogenic impacts).

Table 3-4. Mean concentrations of chemical and physical parameters per geological unit or formation in the Middle Vaal WMA

Geological Unit	No. of stations	No. of samples	Mean chemical variable value										
			pH	EC (mS/m)	Ca (mg/L)	Na (mg/L)	K (mg/L)	Mg (mg/L)	Cl (mg/L)	SO_4 (mg/L)	$CaCO_3$ (mg/L)	F (mg/L)	NO_3 (mg/L)
Malmani Subgroup	45	195	7.7	181	199.8	54.4	11.2	117.9	49.4	775.8	239.6	0.166	3
Black Reef Formation	12	22	8.0	66.2	72	12.8	1.2	35.5	23.2	38.1	245.6	0.19	8.6
Allanridge Formation	32	36	7.9	90.4	65.1	79.9	3.7	26.9	113.4	54.3	194.3	0.255	12.5
Karoo Dolerite	13	23	8.0	117.1	97.4	73.3	8	54.4	130.5	113.4	296.9	0.384	7.2
Molteno Formation	2	2	8.5	41	14	95.6	1.9	2.7	15.5	12.3	211	1.4	0.5
Bothaville Formation	9	9	7.1	32.9	30.3	13.4	2.7	13	22	4.6	99.4	0.263	7
West Rand Group	13	57	7.5	39.5	25.3	9.2	2.3	21.6	10.3	45.5	87.6	0.144	6.9
Hospital Hill Formation	7	50	7.6	32.1	16.2	6.5	1.2	17.3	9	3.8	87.7	0.126	6.6
Government Subgroup	6	7	7.0	92	90.4	27.8	10.3	52.3	20.1	343.4	87	0.267	9.1
Klipriviersberg Group	3	42	7.8	58.8	39.2	26.5	3.1	31.1	27.8	13.7	165.1	0.177	19.7
Central Rand Group	2	7	7.7	60.8	62.1	12.6	2.3	36.7	21.6	74.6	213.4	0.254	4
Rietgat Formation	25	77	7.6	85.3	75.8	33.1	1.7	59.5	21.5	322.3	128.2	0.298	4.7
Adelaide Subgroup	11	12	8.2	74.3	54.7	86	3.5	19	35.1	29.6	297.1	0.55	5.4
Rooihoogte Formation	13	20	7.9	28.8	25.9	4.7	1.6	16.2	14.3	3.7	115.1	0.143	1.3
Makwassie Formation	2	2	7.8	44.3	45.5	6.7	3.3	25.5	22.1	4.7	182.4	0.09	4.8
Ecca Group		12	8.0	139.7	48.7	242.6	3.9	29.5	319.5	58.9	284.1	0.87	1.2
Monte Christo Formation	118	169	8.1	55.3	50.4	5.1	1.4	36.2	16.6	5.5	239.8	0.127	4.6
Lyttelton Formation	24	36	8.2	54.7	47.9	6.2	1.3	37.5	20.2	6.1	227.3	0.104	6.4
Tarkastad Subgroup	15	25	8.1	67.6	52	63.6	2.6	23.9	18.2	30.7	299.8	0.54	2.4
Eccles Formation	38	54	8.0	38.2	34.8	7.1	2.4	22.7	24	3.8	152.7	0.119	2.1
Normandien Formation	7	17	8.0	83	63.5	79.3	5.6	27.6	39.7	106.5	269.5	0.72	3.5
Timeball Hill Formation	2	2	8.0	386.2	179.5	522.9	19.2	135.8	1012	441.9	207.6	0.393	8.3
Oaktree Formation	46	47	8.1	68.5	60.4	9.6	2.2	43.4	39.7	26.3	221.1	0.105	12.6
Alluvium	60	131	7.8	70.5	66.4	30.1	3.4	40.4	23.1	168.2	177.7	0.178	5.1

3.2.4.1 Quaternary Sediments

The alluvial deposits that represent the majority of these (very young) sediments in the study area, are also the least protected or most vulnerable groundwater resource to pollution due to factors such as shallow depth to groundwater rest level and generally more transmissive hydraulic properties. These circumstances militate against an assessment of reference conditions, since potential impacting activities such as mining commenced much earlier than groundwater quality monitoring programmes. Nevertheless, the pre-1980 (**Figure 3-34**) data reveal a distribution that reflects a Ca-HCO_3 chemical composition, whereas the post-2000 data set clearly shows a second grouping characterised by a Ca-SO_4 type groundwater. This is considered an unequivocal indication of negative impacts from primarily the mining industry and associated land use activities.

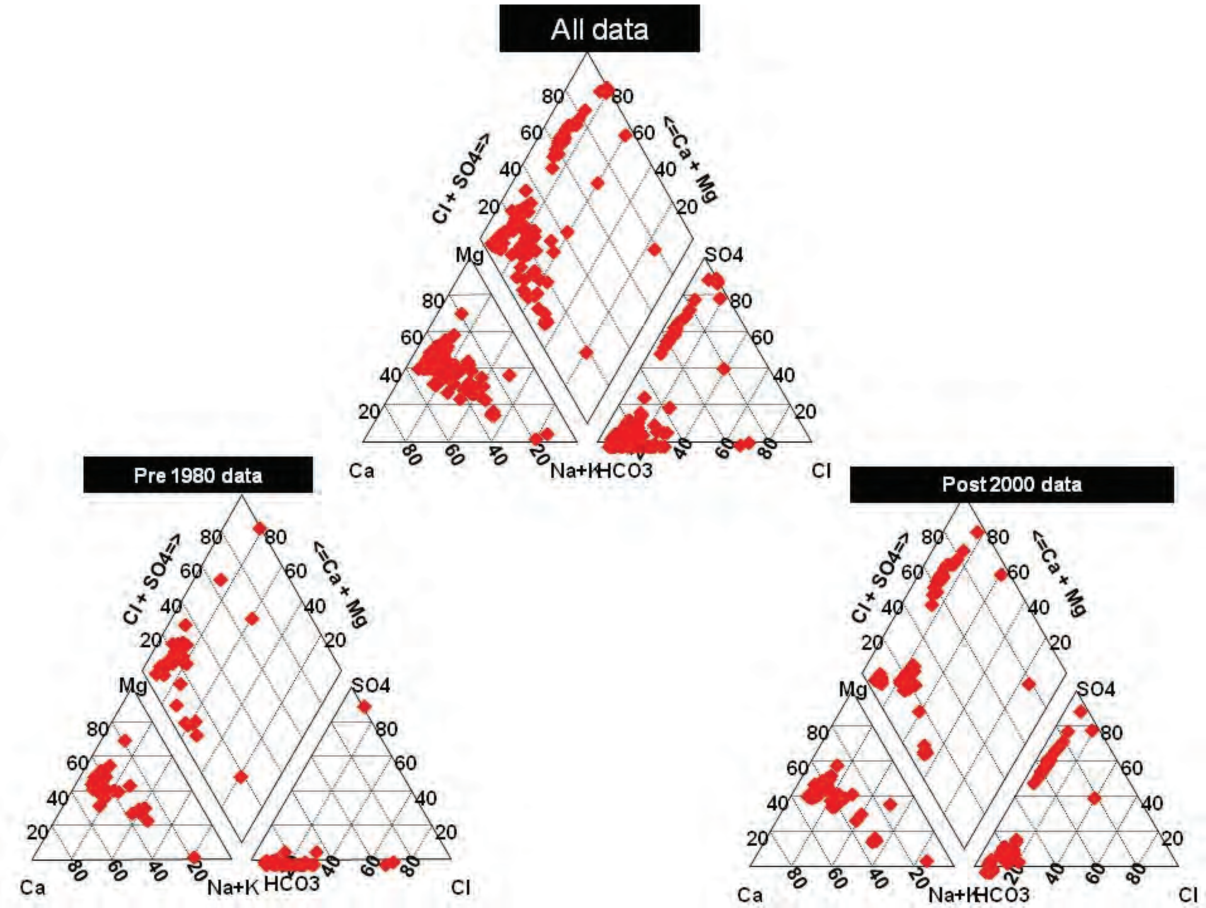

Figure 3-34. Trilinear diagram of alluvial groundwater chemistry

The aeolian sand deposits, much like alluvium, are prone to impacts from surface land use activities. **Figure 3-35** indicates that pre-1986 groundwater chemistry data comprised a variety of hydrochemical types, whereas the post-2000 data set shows a bias that is distributed between a Na-HCO_3 and a Na-Cl type groundwater chemistry.

Figure 3-36 indicates a Na-HCO_3 chemical character for a single groundwater sample associated with the Kalahari sand deposits in the study area. This composition is typical of the sodium carbonate enrichment that characterises the groundwater associated with these sediments (Mazor et al., 1980).

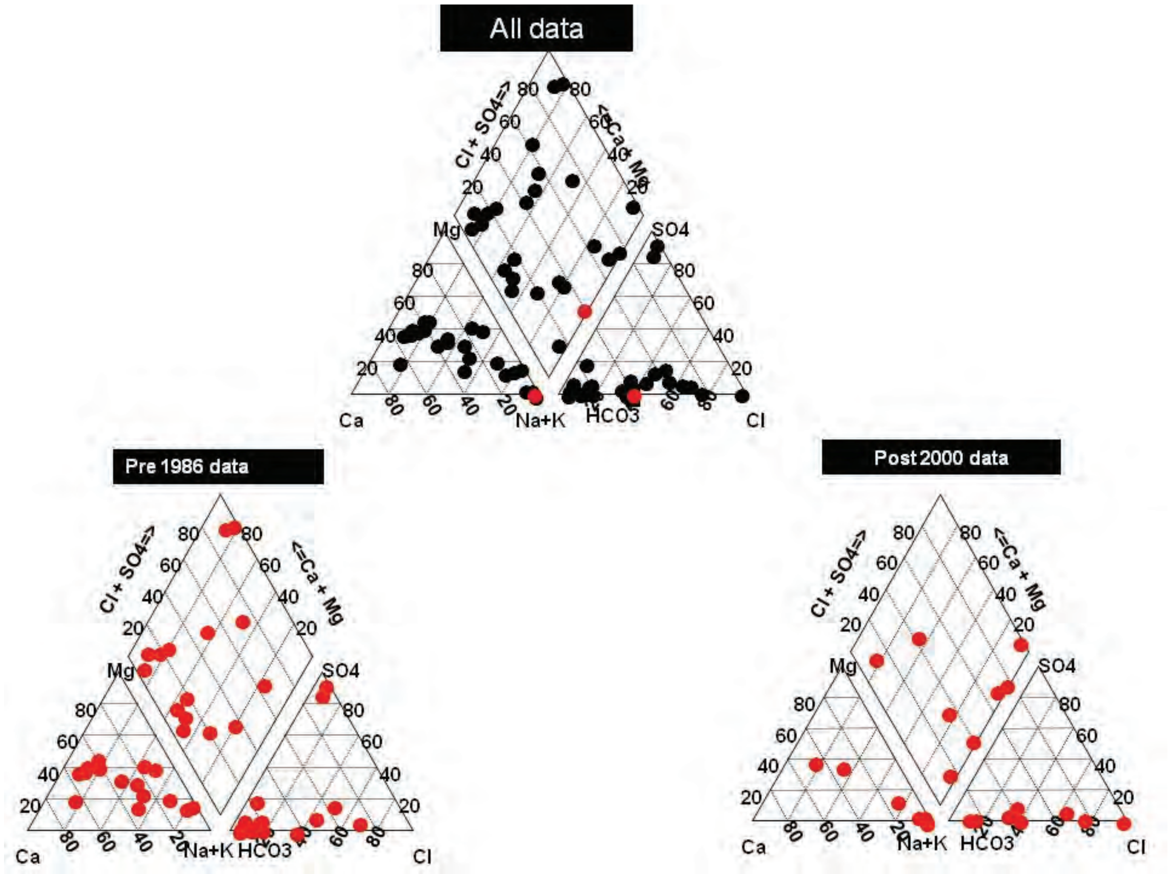

Figure 3-35. Trilinear diagram of groundwater chemistry associated with aeolian sand deposits

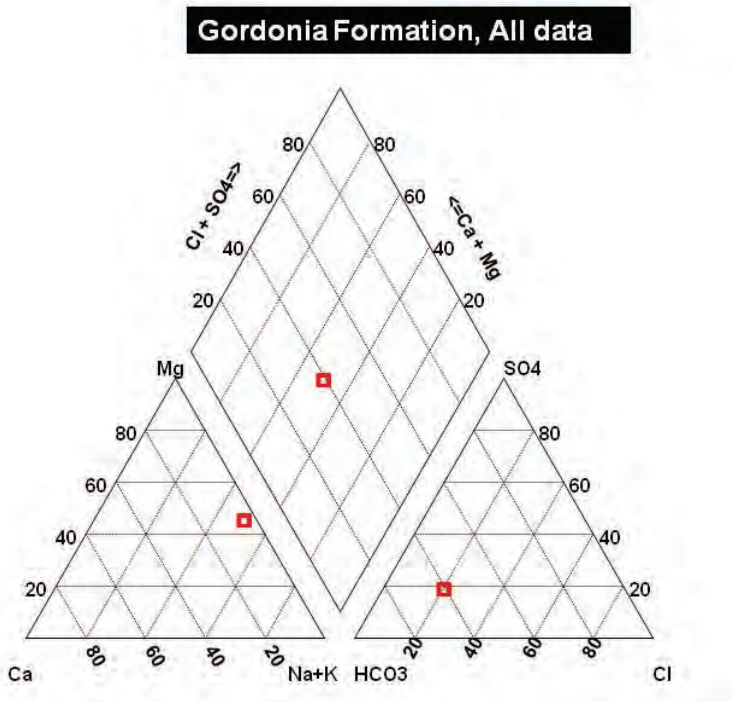

Figure 3-36. Trilinear diagram for groundwater associated with Kalahari sand deposits

3.2.4.2 *Undifferentiated Karoo Strata*

These strata are identified by Baran and Dziembowski (2003) as representing sedimentary strata of the Molteno, Elliot and Clarens formations together with basalt of the Drakensberg Group. The sparse pre-1986 data set (**Figure 3-37**) indicates a Ca-HCO_3 chemistry associated with this groundwater, whereas the more recent post-2000 data reflect a bias toward a Ca-Cl chemical composition.

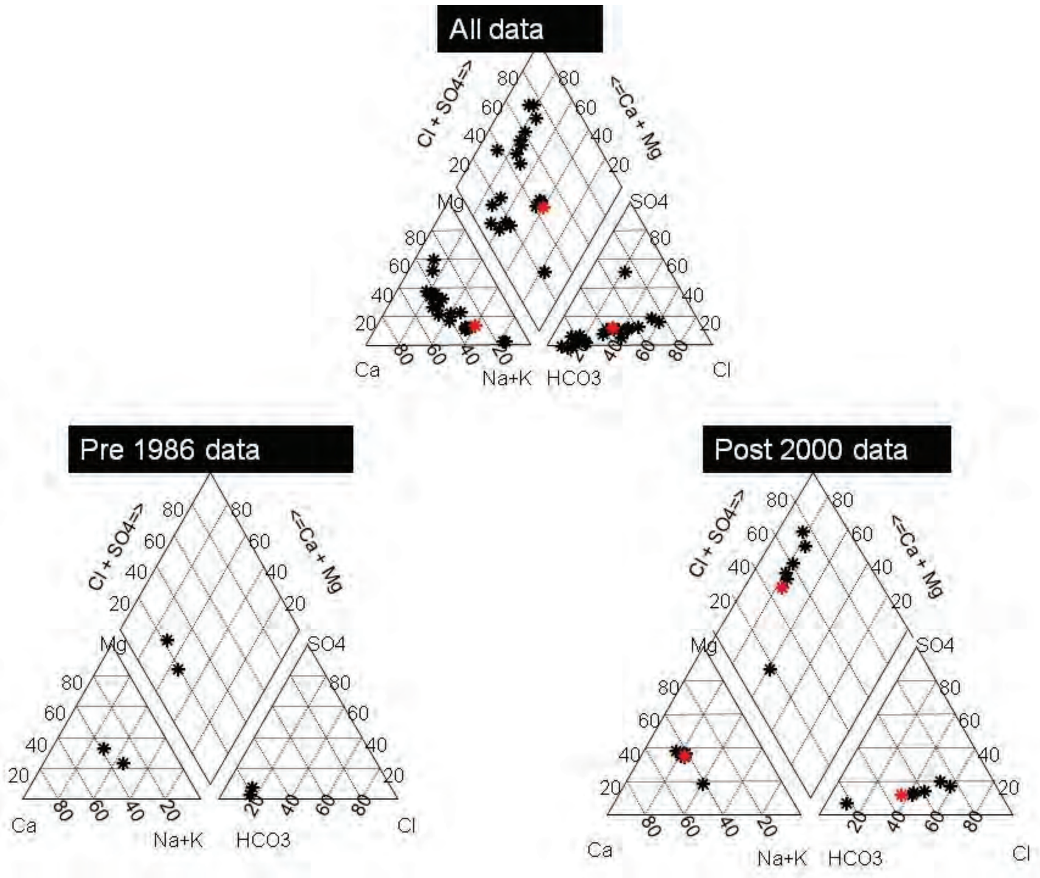

Figure 3-37. Trilinear diagram of groundwater chemistry associated with undifferentiated Karoo strata

3.2.4.3 *Molteno Formation*

The Molteno Formation groundwater exhibits a Na-HCO_3 chemical composition (**Figure 3-38**). Although this is based on only two analyses, it finds support in the similar evaluation reported for this lithological unit in the Upper Vaal WMA GRDM assessment (CSIR, 2012).

3.2.4.4 *Beaufort Group*

This unit is represented by analyses associated with the Normandien Formation and the Tarkastad and Adelaide subgroups. **Figure 3-39** reveals a distinct similarity in the chemical composition of groundwater associated with these lithological units. Whereas the anion component is dominated by bicarbonate (HCO_3), the cation component in especially the Tarkastad and Adelaide subgroups represents a continuum between Ca and Na as end members. These circumstances might be indicative of cation exchange processes in these groundwaters.

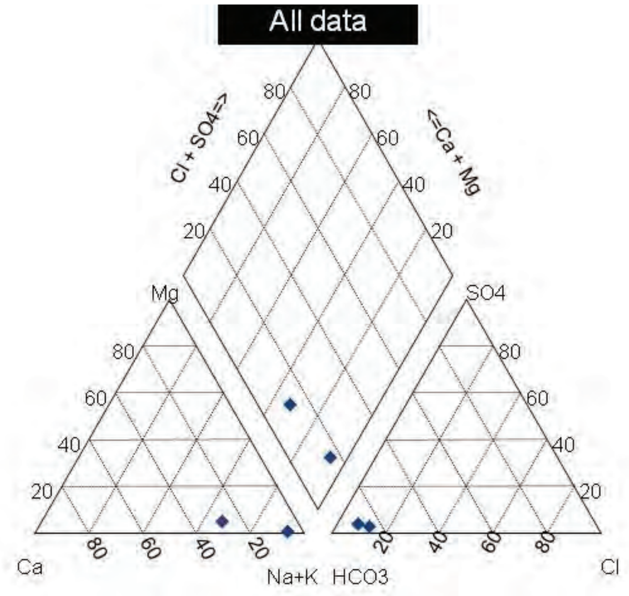

Figure 3-38. Trilinear diagram of groundwater chemistry associated with Molteno Formation strata

The groundwater associated with the Normandien Formation reflects a NaCa-HCO_3 chemical composition that might represent a transitional groundwater along the cation exchange pathway between Ca and Na dominance. These observations in regard to the Normandien Formation and the Tarkastad Subgroup groundwater, find support in the similar evaluation reported for these lithological units in the Upper Vaal WMA GRDM assessment (CSIR, 2012).

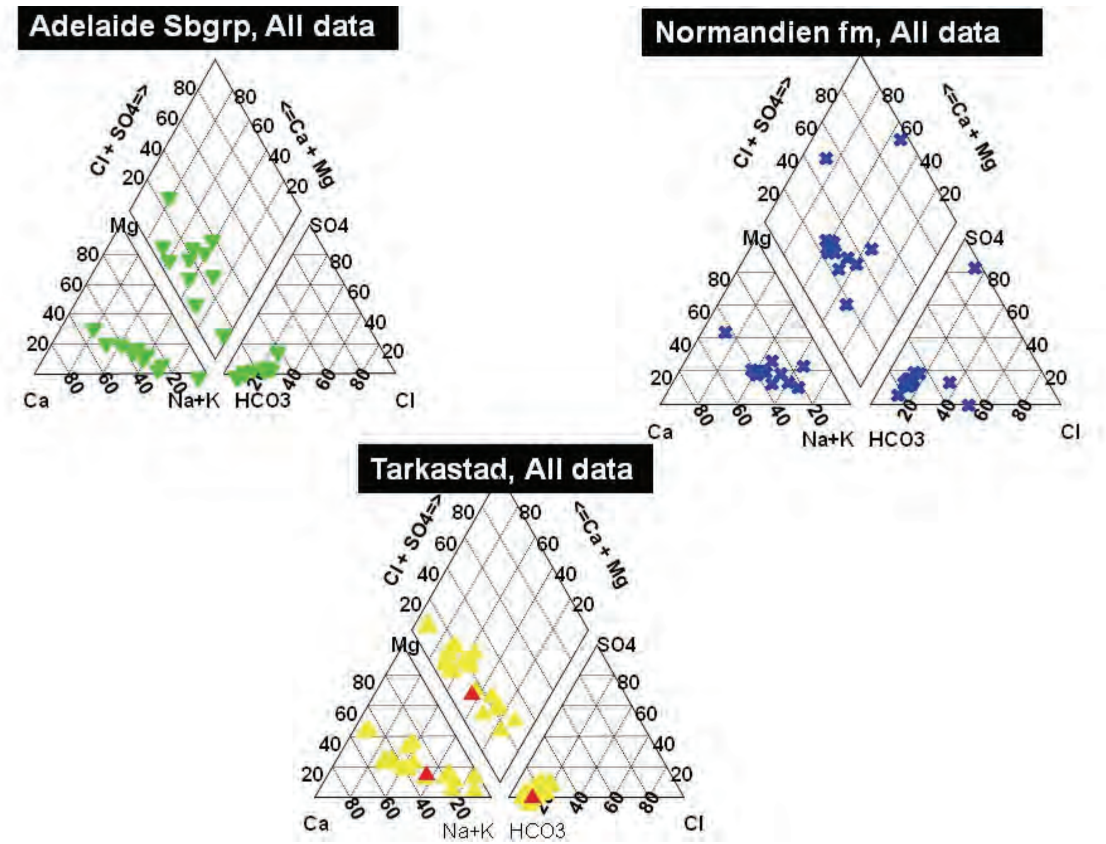

Figure 3-39. Trilinear diagram of groundwater chemistry associated with Beaufort Group strata

3.2.4.5 Ecca Group

The chemistry of Ecca Group groundwater is represented by analyses associated with the Volksrust and Vryheid formations (**Figure 3-40**). The latter is represented by a single analysis for which reliable data are available. Whereas the single Vryheid Formation analysis reflects an unequivocal Na-HCO_3 chemical composition, the Volksrust Formation data set indicates a bias toward a Ca-HCO_3 composition, with one analysis clearly exhibiting a Na-Cl composition.

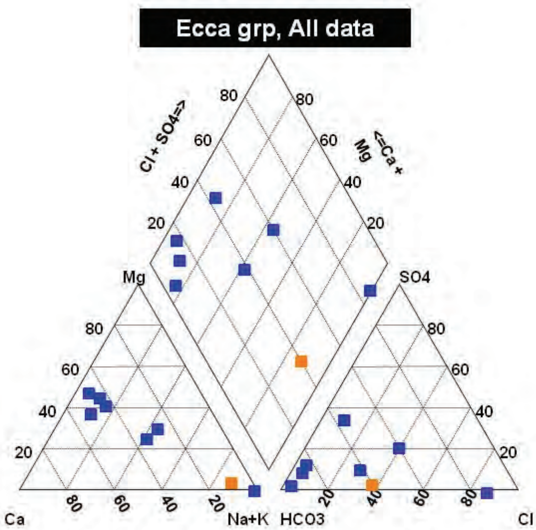

Figure 3-40. Trilinear diagram of groundwater chemistry associated with Ecca Group strata

3.2.4.6 Pretoria Group

Groundwater chemistry data are only available for the two oldest formations in the Pretoria Group succession of mainly sedimentary strata. These are the Rooihoogte Formation at the base, and the overlying Timeball Hill Formation (**Table 2-2**). The trilinear diagrams (**Figure 3-41**) show a predominantly CaMg-HCO_3 chemical composition, with a single Mg-CL type groundwater evident in the Rooihoogte Formation data set, and a Na-Cl analysis in the Timeball Hill Formation data set.

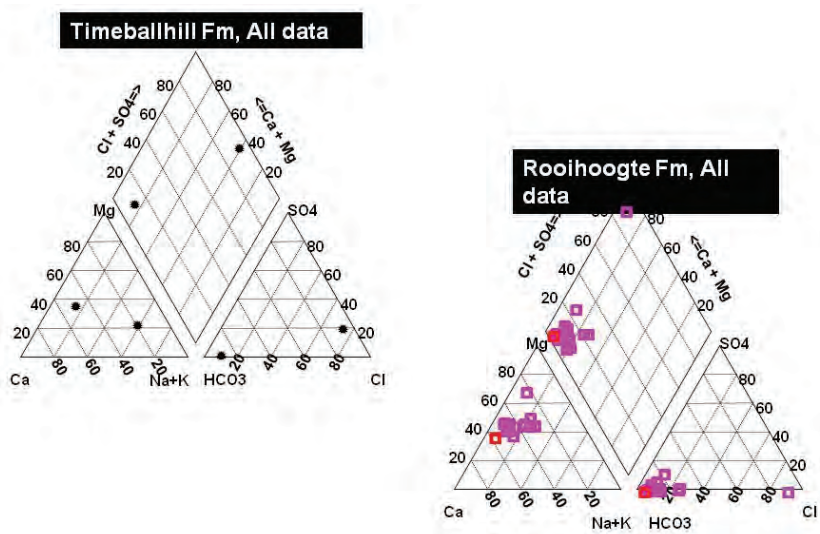

Figure 3-41. Trilinear diagram of groundwater chemistry associated with Pretoria Group strata

3.2.4.7 Chuniespoort Group

The information presented in **Figure 3-42** represents the groundwater chemistry of those formations within the Malmani Subgroup which are differentiated in the DWA data base and occur in the study area. Unsurprisingly, the data (**Figure 3-42**) reflect the CaMg-HCO_3 composition that characterises natural dolomitic groundwater. It is also evident from the trilinear diagrams in Figure 3-42 that the cation composition ranges between Ca and Mg as end members, and the anion composition between bicarbonate (HCO_3) and Cl as end members.

The undifferentiated Malmani Subgroup analyses (**Figure 3-43**) show compositions that range between the CaMg-HCO_3 (natural) and the Ca-SO_4 (impacted) end-members. The latter composition undoubtedly reflects the impact of mine water discharge on this environment. In contrast to the differentiated data sets (**Figure 3-42**), the undifferentiated set shows that the anion composition ranges between bicarbonate (HCO_3) and SO_4 as end members, with Ca and Mg as the cation end members.

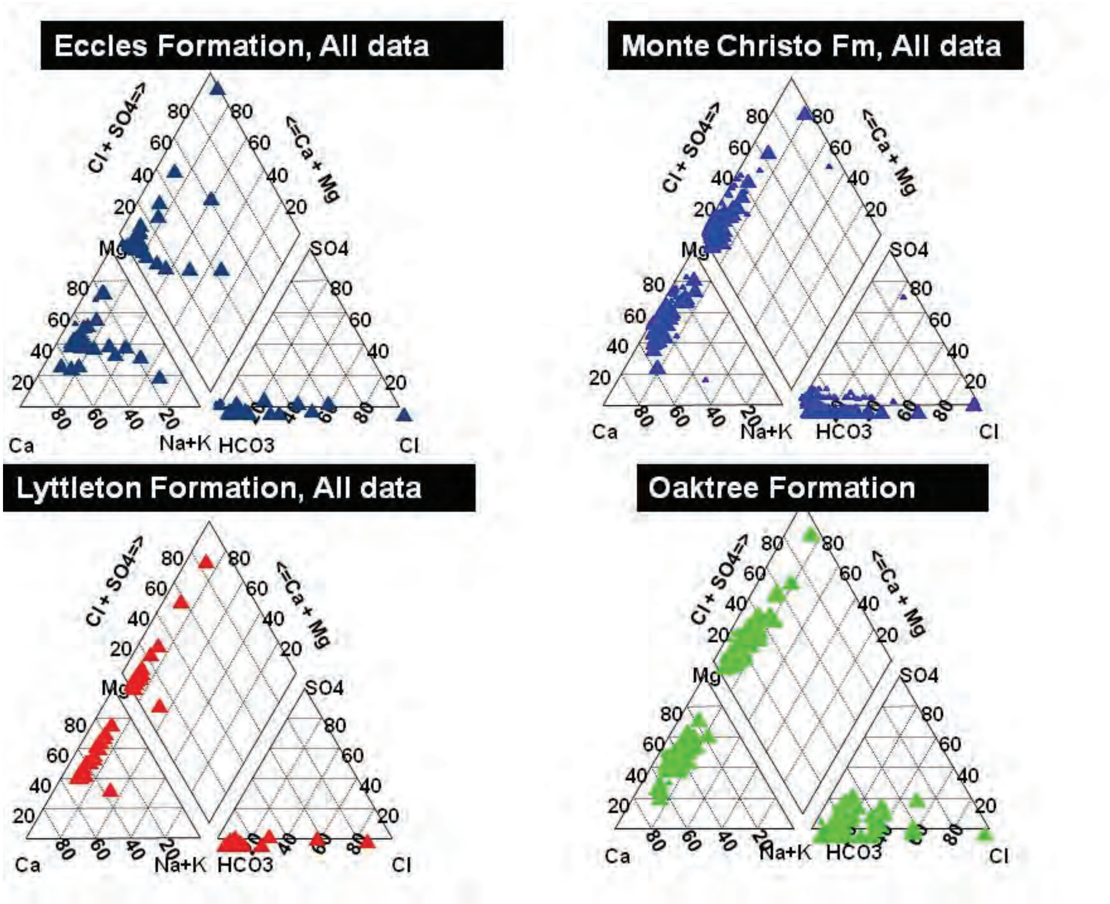

Figure 3-42. Trilinear diagram of groundwater chemistry associated with Chuniespoort Group strata

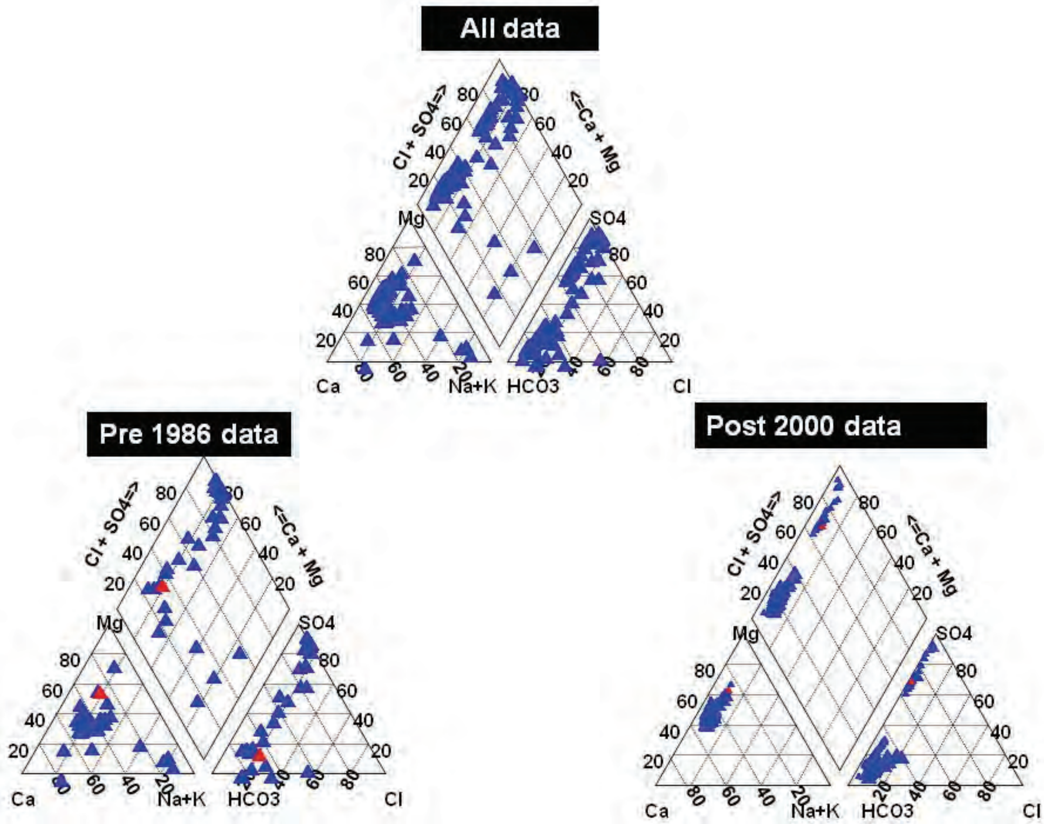

Figure 3-43. Trilinear diagram of groundwater chemistry associated with undifferentiated Malmani Subgroup strata

3.2.4.8 Black Reef Formation

The Black Reef Formation (**Figure 3-44**) typically produces fresh groundwater with a Ca-HCO_3 chemical composition. Unsurprisingly, this is similar to that of the Malmani Subgroup carbonate strata (**Figure 3-42**) which overlie this formation.

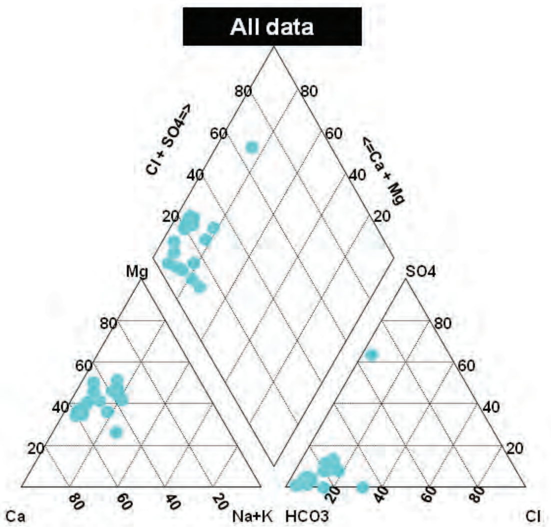

Figure 3-44. Trilinear diagram of groundwater chemistry associated with Black Reef Formation strata

3.2.4.9 Allanridge Formation

It is evident from the trilinear diagrams in **Figure 3-45** that the cation composition of Allanridge Formation groundwater is dominated by Ca, whereas the anion composition ranges between bicarbonate (HCO_3) and Cl as end members. Further, that the more recent post-2000 data set reveals a slightly greater Na influence on the chemical composition of this groundwater.

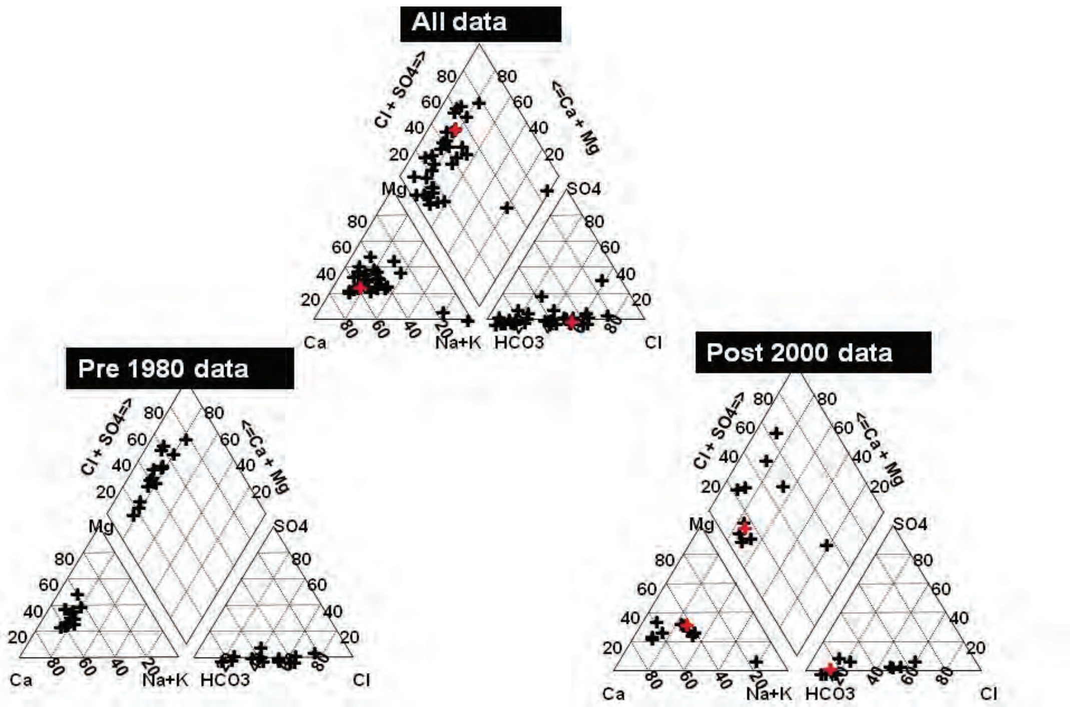

Figure 3-45. Trilinear diagram of groundwater chemistry associated with Allanridge Formation strata

3.2.4.10 Bothaville Formation

The chemical composition of groundwater associated with this formation reflects a similarity to that of the overlying Allanridge Formation (**Figure 3-45**), i.e. mainly having a Ca-HCO_3 composition but with a Ca-Cl type groundwater also present.

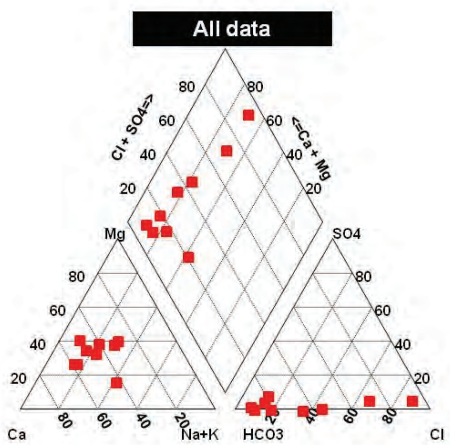

Figure 3-46. Trilinear diagram of groundwater associated with the Bothaville Formation

3.2.4.11 Platberg Group

The trilinear diagrams presented in **Figure 3-47** reveal the dearth of groundwater chemistry information for the Makwassie, Kameeldoorns and Goedgenoeg formations within the Platberg Group. Only the Rietgat Formation is suitably characterised in this regard. Nevertheless, all four these units would appear to produce a similar type of groundwater characterised by a CaMg-HCO_3 composition. In addition, the Rietgat Formation exhibits a second comparatively tight grouping of groundwater that is characterised by a CaMg-SO_4 composition.

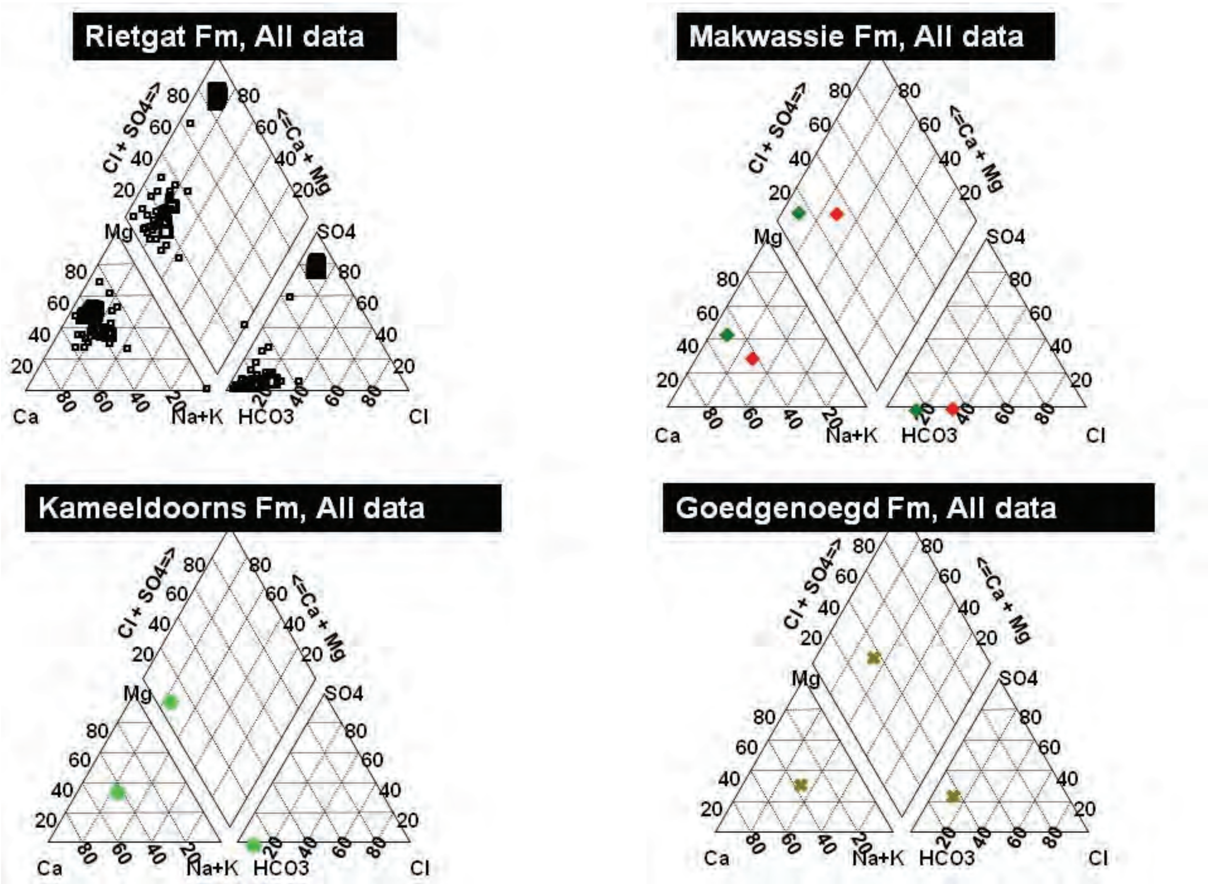

Figure 3-47. Trilinear diagram of groundwater associated with the Platberg Group strata

3.2.4.12 Klipriviersberg Group

The Klipriviersberg Group of the Ventersdorp Supergroup hosts a predominantly Ca-HCO_3 type water (**Figure 3-48**). The grouping of this groundwater for the Middle Vaal WMA is much tighter than that observed for the Upper Vaal WMA (CSIR, 2012), which observation suggests that little if any influence from mining activities is manifested on this groundwater in the Middle Vaal WMA.

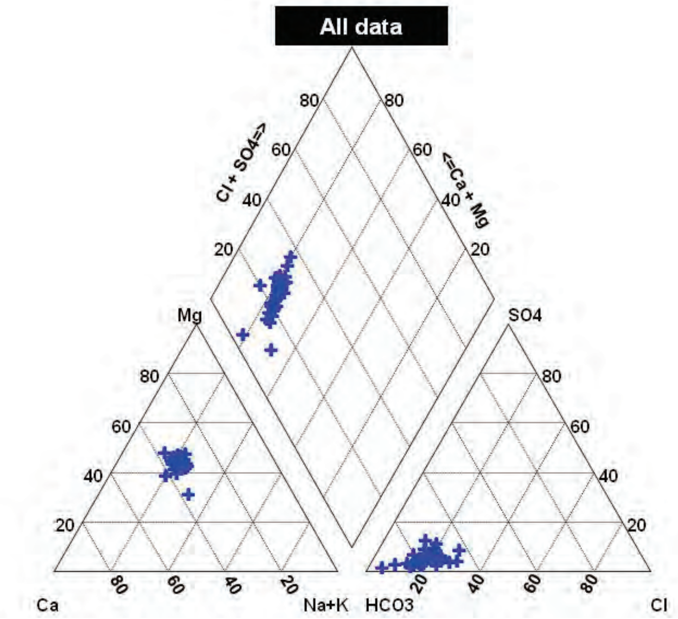

Figure 3-48. Trilinear diagram of groundwater associated with the Klipriviersberg Group

3.2.4.13 Central Rand Group

Represented by quartzite, conglomerate and shale of the Johannesburg and Turffontein subgroups, the chemical composition of groundwater in these strata is poorly characterised due to a paucity of data (**Figure 3-49**). Nevertheless, the CaMg-HCO_3 composition evident in **Figure 3-49** finds support in the similar evaluation of this groundwater for the Upper Vaal WMA (CSIR, 2012). Notable in **Figure 3-49** is the absence of groundwater with a MgCa-SO_4HCO_3 composition as observed for the Upper Vaal WMA, where the impact of mining activity is much more widespread.

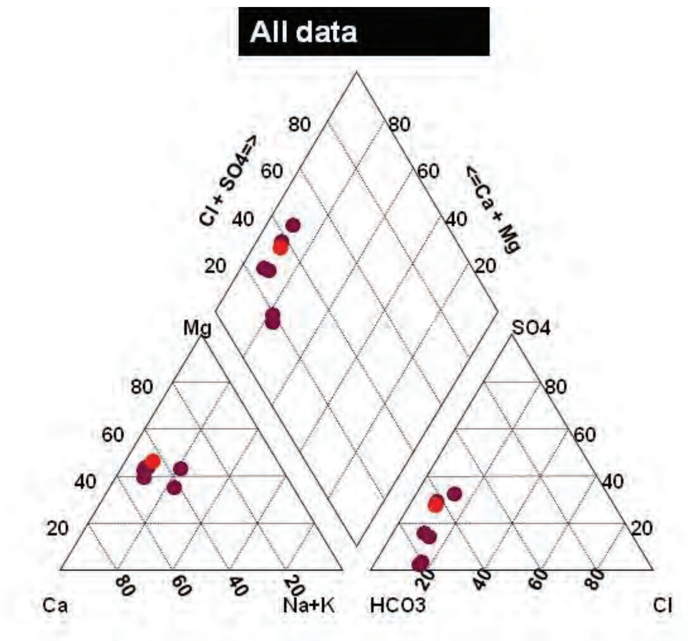

Figure 3-49. Trilinear diagram of groundwater associated with Central Rand Group strata

3.2.4.14 West Rand Group

The trilinear diagrams presented in **Figure 3-50** illustrate the circumstances where the older Hospital Hill Subgroup strata reflect a tight grouping of groundwater chemistry with a dominant MgCa-HCO_3 composition compared to the greater variation in groundwater chemistry associated with the overlying Government Subgroup strata. The latter includes groundwater exhibiting the Ca-SO_4 composition that typifies the impact of acid mine water.

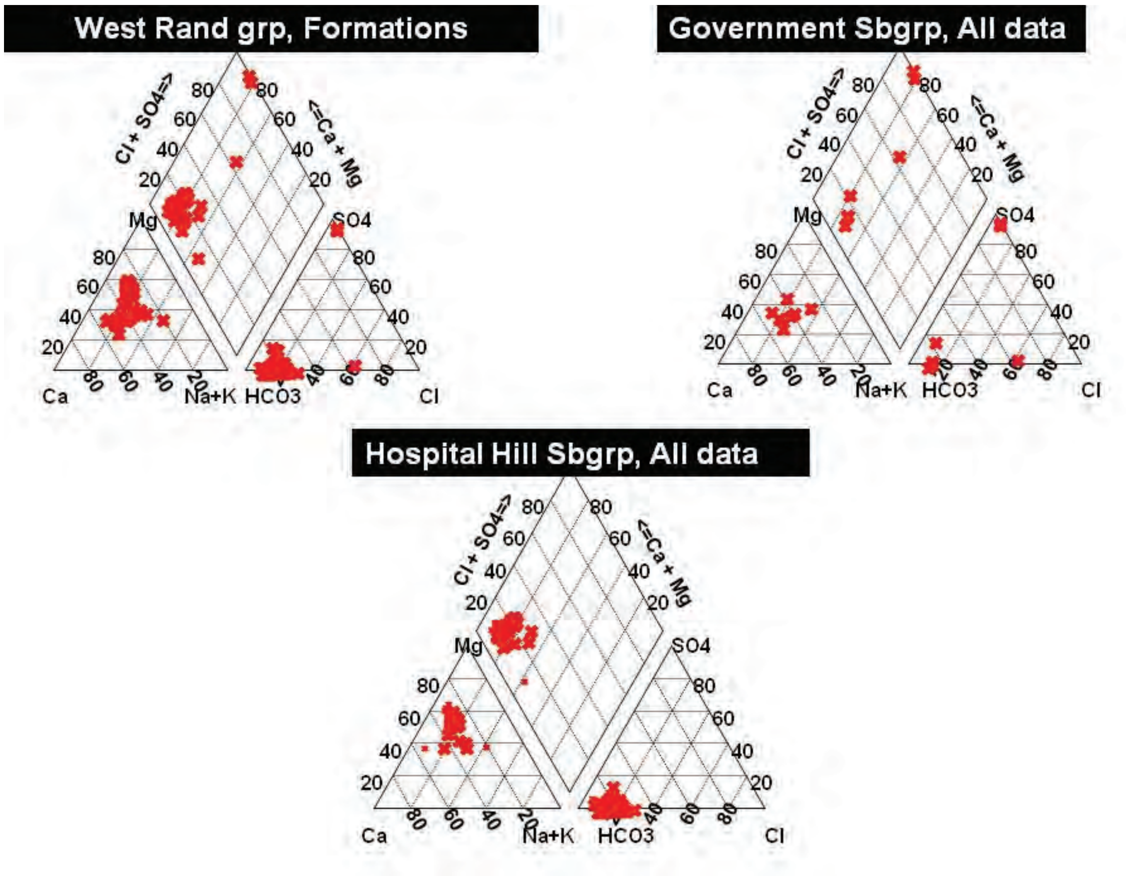

Figure 3-50. Trilinear diagram of groundwater associated with West Rand Group strata

Analyses of West Rand Group groundwater sourced in the Western Basin of the Witwatersrand Goldfield reveal a generally very weakly mineralised water with EC values <20 mS/m and TDS values <120 mg/L, together with a low pH typically in the range 5.5-6.0. The acidic nature is attributed to the very low alkalinity of this groundwater, with total alkalinity typically <10 mg $CaCO_3$/L offering very little neutralising capacity.

3.2.5 Bacteriological Quality

None of the 976 boreholes listed in the DWAs microbiological monitoring database are located in the Middle Vaal WMA. It would appear that much greater focus is placed on the active sampling of surface water resources and other pathways more directly linked to this source, e.g. wastewater treatment works, resulting in a dearth of bacteriological quality data in regard to groundwater resources.

3.2.6 Summary Overview of GRU Characterisation

A summary of the occurrence of the various lithologies in the study area in relation to the groundwater resource units is presented in **Table 3-5**. The summary reflects the association of the younger lithologies primarily with GRUs 3, 4 and 5, and that of the older lithologies mainly with GRUs 1 and 2. Similarly, a summary of the availability of groundwater chemistry data for characterising this aspect of the various lithologies in the study area is presented in **Table 3-6**. Disappointingly, this reveals the insufficiency of data for ~56% of the 43 lithostratigraphic units. Thirteen of these (~30%) exhibit a paucity of data. In some instances, the scarcity of data does not present a concern because of the very localised occurrence or the availability of data in other areas of occurrence outside the study area.

Table 3-5. Summary of the lithology per groundwater resource unit in the study area

<table>
<tr><th rowspan="3">Basic Lithology</th><th colspan="8">Groundwater Resource Unit</th><th rowspan="3" colspan="2">Era
(Age)</th></tr>
<tr><th colspan="2">1</th><th rowspan="2">2</th><th colspan="2">3</th><th colspan="2">4</th><th rowspan="2">5</th></tr>
<tr><th>a</th><th>b</th><th>a</th><th>b</th><th>a</th><th>b</th></tr>
<tr><td>Aeolian sand, calcrete, colluvium, floodplain deposits, alluvium</td><td style="background:#d9d9d9"></td><td style="background:#d9d9d9"></td><td style="background:#d9d9d9"></td><td style="background:#d9d9d9"></td><td style="background:#d9d9d9"></td><td style="background:#d9d9d9"></td><td style="background:#d9d9d9"></td><td style="background:#d9d9d9"></td><td colspan="2">Late Cenozoic
(<10000 yrs)</td></tr>
<tr><td>Dolerite, diabase, syenite</td><td></td><td></td><td></td><td></td><td style="background:#d9d9d9"></td><td style="background:#d9d9d9"></td><td style="background:#d9d9d9"></td><td></td><td rowspan="5">(~144 Ma)

(~250 Ma)</td><td rowspan="5">Mesozoic</td></tr>
<tr><td>Basaltic lava</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td style="background:#d9d9d9"></td></tr>
<tr><td>Sandstone</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td style="background:#d9d9d9"></td></tr>
<tr><td>Mudstone & subordinate sandstone</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td style="background:#d9d9d9"></td></tr>
<tr><td>Sandstone, mudstone & shale</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td style="background:#d9d9d9"></td></tr>
<tr><td>Mudstone & sandstone</td><td></td><td></td><td></td><td></td><td></td><td style="background:#d9d9d9"></td><td style="background:#d9d9d9"></td><td></td><td rowspan="6">(~250 Ma)

(~354 Ma)</td><td rowspan="6">Palaeozoic</td></tr>
<tr><td>Mudstone & subordinate sandstone</td><td></td><td></td><td></td><td></td><td></td><td style="background:#d9d9d9"></td><td style="background:#d9d9d9"></td><td></td></tr>
<tr><td>Shale & subordinate sandstone</td><td></td><td></td><td style="background:#d9d9d9"></td><td style="background:#d9d9d9"></td><td style="background:#d9d9d9"></td><td></td><td></td><td></td></tr>
<tr><td>Sandstone, shale & coal beds</td><td></td><td></td><td style="background:#d9d9d9"></td><td style="background:#d9d9d9"></td><td style="background:#d9d9d9"></td><td></td><td></td><td></td></tr>
<tr><td>Shale</td><td></td><td></td><td style="background:#d9d9d9"></td><td style="background:#d9d9d9"></td><td style="background:#d9d9d9"></td><td></td><td></td><td></td></tr>
<tr><td>Diamictite & shale</td><td></td><td></td><td></td><td style="background:#d9d9d9"></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Alkali granite</td><td></td><td></td><td style="background:#d9d9d9"></td><td></td><td style="background:#d9d9d9"></td><td></td><td></td><td></td><td rowspan="6">(~1000 Ma)

(~2050 Ma)</td><td rowspan="6">Mokolian</td></tr>
<tr><td>Olivine gabbro, wehrite, alkali granite</td><td></td><td></td><td style="background:#d9d9d9"></td><td></td><td style="background:#d9d9d9"></td><td></td><td></td><td></td></tr>
<tr><td>Diorite, albitite</td><td></td><td></td><td style="background:#d9d9d9"></td><td></td><td style="background:#d9d9d9"></td><td></td><td></td><td></td></tr>
<tr><td>Harzburgite, norite, quartz norite/gabbro, granophyre</td><td></td><td></td><td style="background:#d9d9d9"></td><td></td><td style="background:#d9d9d9"></td><td></td><td></td><td></td></tr>
<tr><td>Basic & ultrabasic rocks</td><td></td><td></td><td style="background:#d9d9d9"></td><td></td><td style="background:#d9d9d9"></td><td></td><td></td><td></td></tr>
<tr><td>Diabase</td><td></td><td></td><td style="background:#d9d9d9"></td><td></td><td style="background:#d9d9d9"></td><td></td><td></td><td></td></tr>
<tr><td>Quartzite</td><td style="background:#d9d9d9"></td><td style="background:#d9d9d9"></td><td></td><td></td><td style="background:#d9d9d9"></td><td></td><td></td><td></td><td rowspan="11">(~2050 Ma)

(~2650 Ma)</td><td rowspan="11">Vaalian</td></tr>
<tr><td>Shale</td><td style="background:#d9d9d9"></td><td style="background:#d9d9d9"></td><td></td><td></td><td style="background:#d9d9d9"></td><td></td><td></td><td></td></tr>
<tr><td>Quartzite & shale</td><td style="background:#d9d9d9"></td><td style="background:#d9d9d9"></td><td></td><td></td><td style="background:#d9d9d9"></td><td></td><td></td><td></td></tr>
<tr><td>Shale & Quartzite</td><td style="background:#d9d9d9"></td><td style="background:#d9d9d9"></td><td></td><td></td><td style="background:#d9d9d9"></td><td></td><td></td><td></td></tr>
<tr><td>Andesite</td><td style="background:#d9d9d9"></td><td style="background:#d9d9d9"></td><td></td><td></td><td style="background:#d9d9d9"></td><td></td><td></td><td></td></tr>
<tr><td>Quartzite</td><td style="background:#d9d9d9"></td><td style="background:#d9d9d9"></td><td></td><td></td><td style="background:#d9d9d9"></td><td></td><td></td><td></td></tr>
<tr><td>Ferruginous shale & quartzite</td><td style="background:#d9d9d9"></td><td style="background:#d9d9d9"></td><td></td><td></td><td style="background:#d9d9d9"></td><td></td><td></td><td></td></tr>
<tr><td>Quartzite, chert, conglomerate</td><td style="background:#d9d9d9"></td><td style="background:#d9d9d9"></td><td></td><td></td><td style="background:#d9d9d9"></td><td></td><td></td><td></td></tr>
<tr><td>Chert-rich dolomite</td><td style="background:#d9d9d9"></td><td style="background:#d9d9d9"></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Chert-poor dolomite</td><td style="background:#d9d9d9"></td><td style="background:#d9d9d9"></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Quartzite, conglomerate</td><td style="background:#d9d9d9"></td><td style="background:#d9d9d9"></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Andesite</td><td></td><td></td><td style="background:#d9d9d9"></td><td></td><td></td><td></td><td></td><td></td><td rowspan="9">(~2650 Ma)

(~3100 Ma)</td><td rowspan="9">Randian</td></tr>
<tr><td>Conglomerate, sandstone</td><td></td><td></td><td style="background:#d9d9d9"></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Andesite</td><td></td><td></td><td style="background:#d9d9d9"></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Quartz porphyry</td><td></td><td></td><td style="background:#d9d9d9"></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Andesite</td><td></td><td></td><td style="background:#d9d9d9"></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Conglomerate, calcareous shale</td><td></td><td></td><td style="background:#d9d9d9"></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Arenaceous, rudaceous rocks</td><td></td><td></td><td style="background:#d9d9d9"></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Quartzite, reddish ferruginous magnetic shale</td><td></td><td></td><td style="background:#d9d9d9"></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Quartzite, conglomerate, shale, interbedded lava</td><td></td><td></td><td style="background:#d9d9d9"></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Granite, gneiss</td><td></td><td></td><td style="background:#d9d9d9"></td><td></td><td style="background:#d9d9d9"></td><td></td><td></td><td></td><td colspan="2">Swazian
(>3100 Ma)</td></tr>
</table>

Table 3-6. Summary of groundwater quality data availability per lithostratigtraphic unit in the study area

Basic Lithology	Lithostratigraphic Unit			Chemical Data
Aeolian sand, calcrete, colluvium, floodplain deposits, alluvium	Quaternary sediments			SUFFICIENT
Dolerite, diabase, syenite	Dyke / sill intrusive structures			SUFFICIENT
Basaltic lava		Drakensberg Group	Karoo Supergroup	VERY SCARCE
Sandstone	Clarens Formation			VERY SCARCE
Mudstone & subordinate sandstone	Elliot Formation			VERY SCARCE
Sandstone, mudstone & shale	Molteno Formation			VERY SCARCE
Mudstone & sandstone	Tarkastad Subgroup	Beaufort Group		SUFFICIENT
Mudstone & subordinate sandstone	Adelaide Subgroup			
Shale & subordinate sandstone	Volksrust Formation	Ecca Group		SPARSE
Sandstone, shale & coal beds	Vryheid Formation			
Shale	Pietermaritzburg Formation			
Diamictite & shale		Dwyka Group		VERY SCARCE
Alkali granite	Schurwedraai	Intrusive Complexes		VERY SCARCE
Alkali granite	Baviaanskranz			
Olivine gabbro, wehrite, alkali granite	Rietfontein			
Diorite, albitite	Roodekraal			
Harzburgite, norite, quartz norite/gabbro, granophyre	Losberg			
Basic & ultrabasic rocks	Kaffirskraal			
Diabase	post-Transvaal			
Quartzite	Magaliesberg Formation	Pretoria Group	Transvaal Supergroup	SPARSE
Shale	Silverton Formation			
Quartzite & shale	Daspoort Formation			
Shale & Quartzite	Strubenkop Formation			
Andesite	Hekpoort Formation			
Quartzite	Boshoek Formation			
Ferruginous shale & quartzite	Timeball Hill Formation			
Quartzite, chert, conglomerate	Rooihoogte Formation			
Chert-rich dolomite	Eccles Formation	Chuniespoort Group		SUFFICIENT
Chert-poor dolomite	Monte Christo Formation			
Chert-rich dolomite	Lyttelton Formation			
Chert-poor dolomite	Oaktree Formation			
Quartzite, conglomerate	Black Reef Formation			SUFFICIENT
Andesite	Alanridge Formation	Platberg Group	Ventersdorp Supergroup	SUFFICIENT
Conglomerate, sandstone	Bothaville Formation			
Andesite	Rietgat Formation			
Quartz porphyry	Makwassie Formation			
Andesite	Goedgenoeg Formation			
Conglomerate, calcareous shale	Kameeldoorns Formation			
Andesite, tuff		Klipriviersberg Group		SUFFICIENT
Arenaceous, rudaceous rocks		Central Rand Group	Witwatersrand Supergroup	SUFFICIENT
Quartzite, reddish ferruginous magnetic shale		West Rand Group		
Quartzite, conglomerate, shale, interbedded lava		Dominium Group		
Granite, gneiss		Intrusive Complex		VERY SCARCE

4 AQUIFER DEPENDENT ECOSYSTEMS

4.1 Aquifer Dependence and Vegetation Types

The primary information sources for assessing the occurrence, extent and importance of groundwater dependence are river flow data, particularly baseflow, ecological information and geology (lithology and structure). The best available ecological information at the scale of the Water Management Area is for vegetation and wetlands. Unfortunately the best available wetland data at present only indicates the occurrence and extent of a wetland. A project aimed at developing a more detailed classification using the national wetlands classification system (Ewart-Smith et al., 2006; SANBI, 2009) is underway but the results were not available for this assessment.

The most detailed vegetation map of the entire area that is available at present is the recently completed national vegetation map (Mucina and Rutherford, 2006). This map groups vegetation into biomes which are suites of vegetation types with similar controlling factors. The biomes are sub-divided into bioregions and the bioregions into vegetation types. There are 23 vegetation types in the Middle Vaal WMA which are grouped into 3 biomes, the dominant biome being Grassland (**Table 4-1**). The wetlands data were taken from the current wetlands database maintain by the South African National Biodiversity Institute (http://bgis.sanbi.org/nwi/project.asp). In areas where the Highveld Salt Pans occur, their area has been excluded from that of the wetlands in the vegetation type which will minimise double counting. Differences in the estimates of wetland areas between the vegetation map and the wetlands data set are due to refinements in the wetland dataset since the version that was used for the national vegetation map.

The national vegetation map shows that the Highveld Alluvial Vegetation (Azonal biome) in this WMA only occurs on the downstream sections of the major rivers. The mapped extent of this vegetation type is based largely on the extent of the alluvial deposits mapped for the land type classification developed by the Agricultural Research Council (Schoeman et al., 2002). This mapping was done at a scale of 1:250 000 and excludes the smaller alluvial systems within the floodplains of many rivers and river reaches, particularly those in the eastern part of the study area. This means that the riverine alluvial systems are far more extensive than is shown by the national vegetation map. We have not attempted to map the occurrence and extent of these additional alluvial ecosystems. Their ecology and sensitivity to changes in the groundwater will be very similar to that of the Highveld Alluvial Vegetation. Local-scale groundwater assessments will be needed to establish the resource quality objectives to apply at the local scale to ensure that these ecosystems are properly managed.

Most of the biomes are easily distinguished by the dominance or combination of certain plant growth forms. Grasslands are dominated by grasses and woody vegetation is absent or relatively rare and largely confined to fire refugia. The dominant ecological factor is the frequent fires with the frequency decreasing as the rainfall decreases. Riparian and wetland vegetation is characterized by grasses and reeds. Savanna is characterized by an understorey of grasses and the presence of woody plants. Sometimes the woody plants are widespread but in other cases the woody plants are confined to certain areas such as rocky outcrops. Fire frequencies can be similar to grasslands but are generally less frequent. Riparian and wetland vegetation can include shrub and tree species together with grasses and reeds. The Forest biome is characterized by a dense overstorey of tall trees and the forest are generally confined to kloofs and other fire refugia.

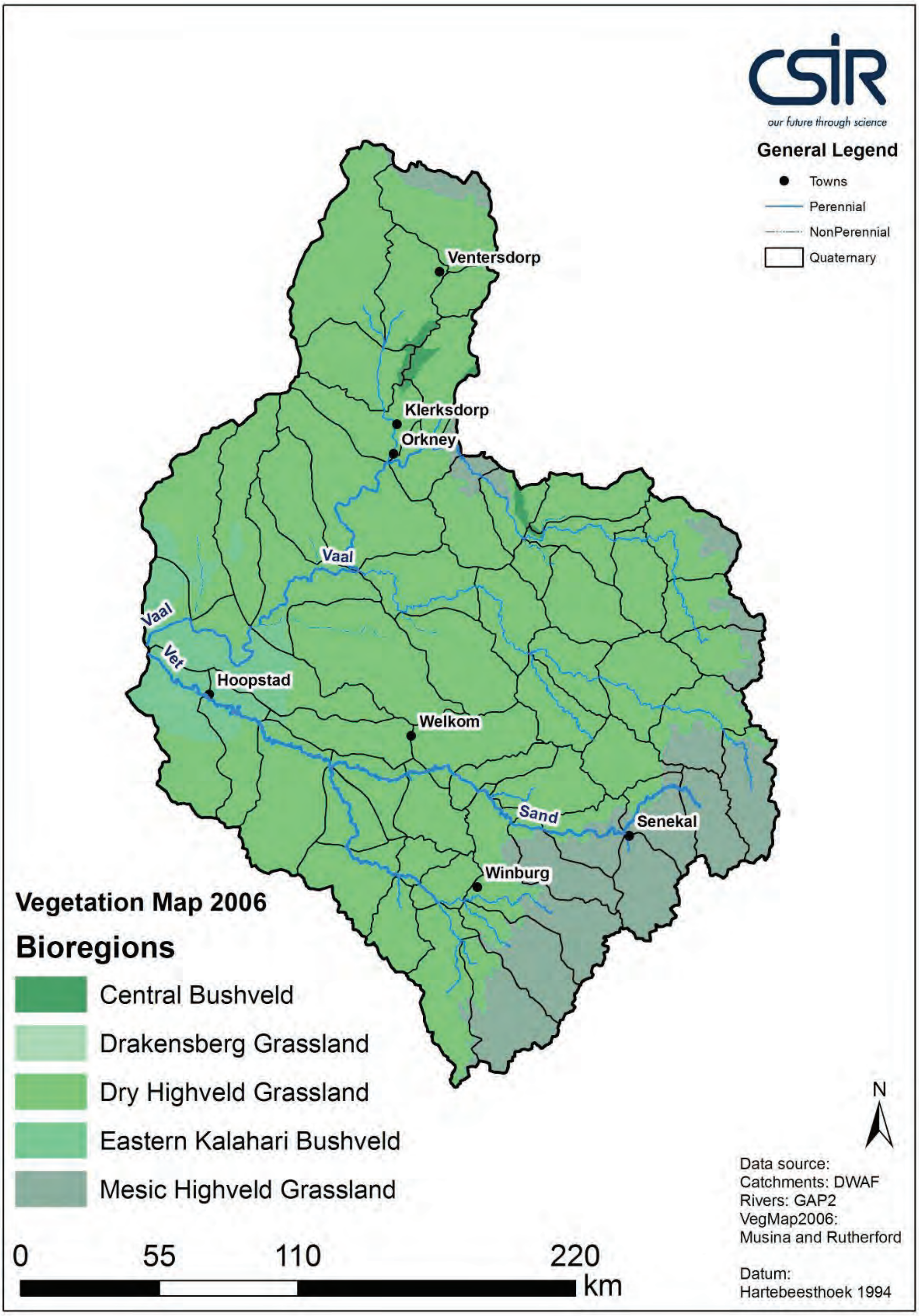

Figure 4-1. Bioregion map for the Middle Vaal WMA (Mucina and Rutherford, 2006)

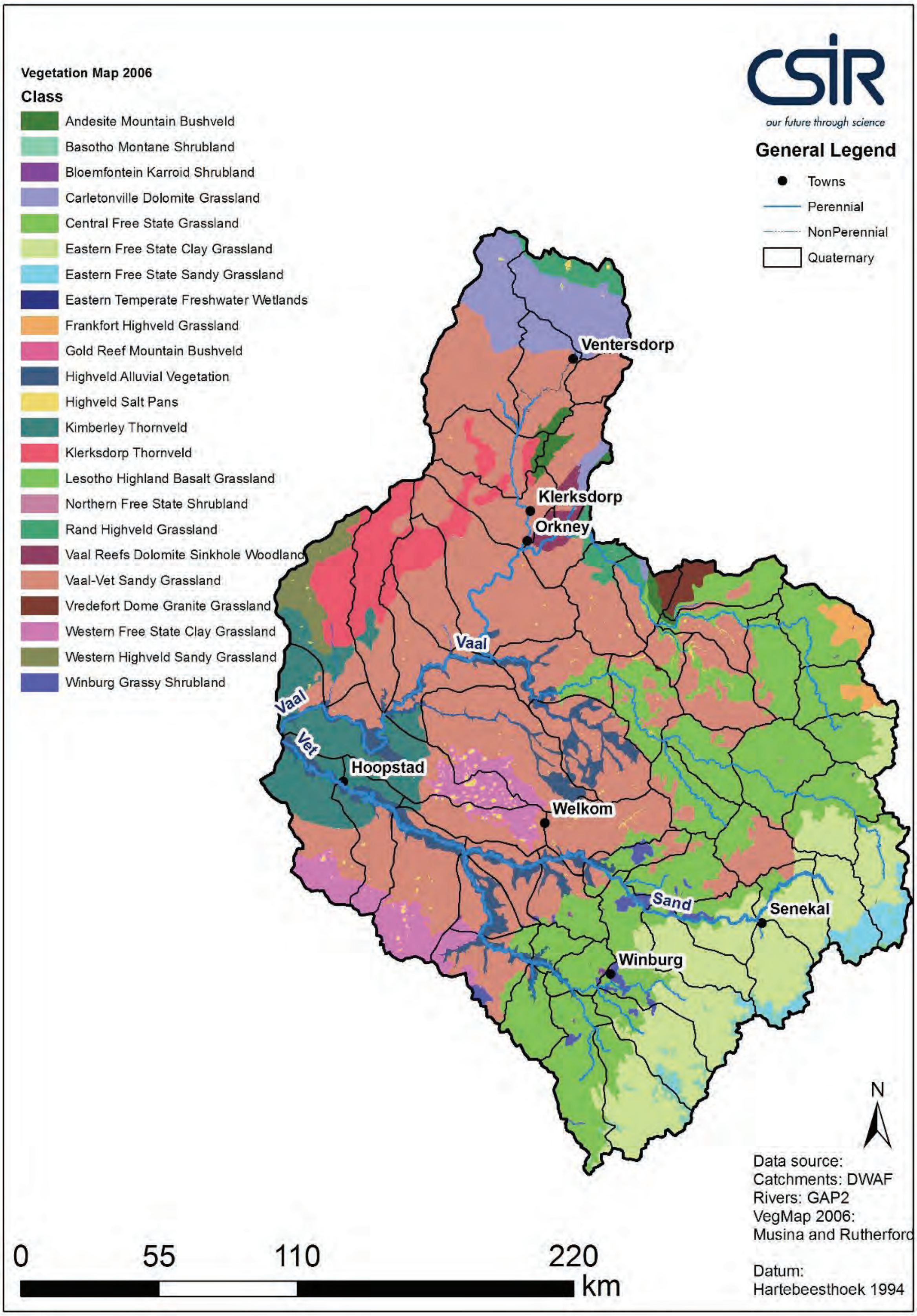

Figure 4-2. Vegetation map for the Middle Vaal WMA (Mucina and Rutherford, 2006)

Table 4-1. The biomes, bioregions and vegetation types of the Middle Vaal WMA based on data from the National Vegetation Map (Mucina and Rutherford 2006). Wetland areas were extracted from the national wetlands dataset

Biome	Bioregion	Vegetation type	Area (ha)	Percentage of WMA	Wetlands (% of veg. type)
Azonal	Alluvial Vegetation	Highveld Alluvial Vegetation	239113	4.55	7.90
Azonal	Freshwater Wetlands	Eastern Temperate Freshwater Wetlands	169	0.00	99.84
Azonal	Inland Saline Vegetation	Highveld Salt Pans	24331	0.46	99.73
Grassland	Drakensberg Grassland	Lesotho Highland Basalt Grassland	1144	0.02	0.00
Grassland	Dry Highveld Grassland	Bloemfontein Karroid Shrubland	2624	0.05	0.16
Grassland	Dry Highveld Grassland	Carletonville Dolomite Grassland	211349	4.02	0.16
Grassland	Dry Highveld Grassland	Central Free State Grassland	1169779	22.26	0.53
Grassland	Dry Highveld Grassland	Klerksdorp Thornveld	212550	4.04	0.93
Grassland	Dry Highveld Grassland	Vaal Reefs Dolomite Sinkhole Woodland	34694	0.66	1.97
Grassland	Dry Highveld Grassland	Vaal-Vet Sandy Grassland	1933846	36.80	1.26
Grassland	Dry Highveld Grassland	Vredefort Dome Granite Grassland	29158	0.55	0.26
Grassland	Dry Highveld Grassland	Western Free State Clay Grassland	187323	3.56	3.21
Grassland	Dry Highveld Grassland	Western Highveld Sandy Grassland	53920	1.03	2.98
Grassland	Dry Highveld Grassland	Winburg Grassy Shrubland	35643	0.68	0.61
Grassland	Mesic Highveld Grassland	Basotho Montane Shrubland	34844	0.66	0.07
Grassland	Mesic Highveld Grassland	Eastern Free State Clay Grassland	624759	11.89	0.47
Grassland	Mesic Highveld Grassland	Eastern Free State Sandy Grassland	64339	1.22	0.34
Grassland	Mesic Highveld Grassland	Frankfort Highveld Grassland	34817	0.66	0.32
Grassland	Mesic Highveld Grassland	Northern Free State Shrubland	859	0.02	0.00
Grassland	Mesic Highveld Grassland	Rand Highveld Grassland	72514	1.38	1.67
Savanna	Central Bushveld	Andesite Mountain Bushveld	31464	0.60	0.02
Savanna	Central Bushveld	Gold Reef Mountain Bushveld	322	0.01	0.00
Savanna	Eastern Kalahari Bushveld	Kimberley Thornveld	255516	4.86	1.18
Total area			5255078		

The Azonal biome includes all the vegetation types which are strongly controlled by factors which extend across biome boundaries and distinguish them ecologically from the biomes in which they are situated (Mucina et al., 2006). For example, alluvial vegetation is controlled by the presence of alluvial deposits along rivers and the hydrological regime in those alluvial deposits. This gives the alluvial vegetation features which differ markedly from the adjacent vegetation such as non-alluvial grasslands. The characteristics of the different biomes, bioregions and vegetation types allow us to describe the kinds of interactions there may be with groundwater and the extent and importance of their potential groundwater dependence.

4.2 Biomes, Bioregions and Vegetation Types

4.2.1 Azonal Biome

This biome is represented by three bioregions and vegetation types and occupies ~5.0% of the WMA. All three types are controlled primarily by their hydrological regime (Mucina et al., 2006a).

Highveld Alluvial Vegetation (4.55%):This vegetation occurs on the alluvial deposits found along drainage lines, streams and rivers and their floodplains. The alluvial deposits along the river systems cross all the aquifer types in the WMA and extensive alluvial deposits may be found where the rivers cross erosion-resistant structures like dykes. The topography is generally flat and the hydrological regime in the alluvium is determined by a combination of surface flows and lateral drainage of groundwater from the adjacent areas. These areas are typically flooded during the wet season with the duration and depth of the flooding depending on the elevation of the different floodplain relative to the water levels during floods. The main rivers are perennial with the tributaries ranging from perennial to seasonal and ephemeral depending on the rainfall and the extent of their catchments. The alluvial sediments are generally dynamic with ongoing erosion and deposition. The rivers often have multiple, anastomosing channels and the flows in the smaller channels are often seasonal. The vegetation is quite variable, ranging from seasonally flooded grasslands to extensive reedbeds and riparian thickets with woody species. The most widespread woody tree species are Acacia karoo (Sweet thorn), Salix species (Willow), Celtis africana (White stinkwood), Rhus species (Karees) and Diospyros species. There are also shrub species and woody and herbaceous species and a number of grass and sedge species characteristic of seasonally and perennially inundated wetlands.

The vegetation map shows that 7.9% of this vegetation type is *Eastern Temperate Freshwater Wetlands*. The dominant hydrological driver is probably the surface water level and flooding regime with lateral groundwater inflows, potentially, playing a smaller role. There is lateral groundwater drainage which is thought to be important particularly in the interfaces between the floodplain alluvium and the adjacent hillslopes. The quantity of the groundwater drainage is likely to be greatest in the areas with high rainfall but groundwater drainage following wet periods in dry areas could also be ecologically important. The alluvial vegetation has been extensively disturbed by ploughing and intensive grazing of the floodplains, altered river flows and invasion by a range of alien plant species including trees (e.g. Willow, Poplars, Eucalypts, Brazilian pepper), shrubs, herbs and grasses. In areas of intensive cultivation the water quality is likely to be influenced by nutrients from fertilizers, pesticides and herbicides in the runoff and groundwater drainage from the adjacent areas.

Eastern Temperate Freshwater Wetlands (<0.01%):These comprise a range of wetland types including perennial and seasonal lakes and vleis with aquatic and hygrophilous vegetation, temporarily inundated grasslands and ephemeral herblands. They are found mainly in depressions and in various settings on hillslopes and bottomlands and are often characterised by a clear zoning of the vegetation which is controlled by the fluctuations in the (often perched) water table. The gentle topography of the Highveld grasslands results in the occurrence of numerous seasonal wetlands where surface water accumulates. In the fractured Karoo sediments, and some dolomitic areas, wetlands occur where sediments have accumulated upslope of erosion-resistant features such as dolerite intrusions. Wetlands are also found on areas with basement rocks where water is stored in the weathered profile and in fracture systems. The vegetation of these wetlands is diverse but is typically dominated by grass and sedge species, sometimes with reed beds and with aquatic plants where there is seasonal or perennial open water. Woody species are generally absent. The wetlands include some large and ecologically important examples which are regarded as important for waterbirds and for water flow regulation. Some of them have been designated as internationally and/or nationally important protected areas. Many of the small wetlands have been disturbed by being ploughed, intensively grazed and invaded by alien plant species. The hydrological regime in these wetlands ranges from surface water controlled through the whole range to groundwater controlled. There is insufficient information available at present to characterise the surface-groundwater interactions, degree of groundwater dependence or sensitivity to surface or groundwater abstraction. Only the larger wetlands were included in the national vegetation map but many smaller wetlands have been mapped for the wetlands dataset that is being used in the National Freshwater Ecosystems Priority Areas (NFEPA) project.

Highveld Salt Pans (0.5%):Saltpans form in closed depressions in the landscape where surface runoff accumulates, bringing in dissolved salts which remain behind when the water evaporates. The salts have accumulated over long periods of time and the salinity, together with the flooding regime, control the vegetation dynamics. The salt pans occur primarily on fractured shales but the bottoms of the pans are usually formed from impermeable clays which disconnect them from the underlying aquifers and their hydrological regime. The vegetation varies with the degree and duration of the inundation and with the salinity levels in the water. In the wet season ephemeral or seasonal freshwater species may be an important component with salt-tolerant species replacing them as the pan dries out and the salinity increases. Groundwater dependence is unlikely.

4.2.2 Grassland Biome

The Grassland biome is divided into four bioregions, namely the Drakensberg, Sub-escarpment, Mesic Highveld and Dry Highveld grasslands (Mucina et al., 2006b), and comprises 89.5% of the WMA. The grasslands occur over a range of altitude and rainfall as well as a range of lithologies, hydrogeological units and soil types.

Drakensberg grassland bioregion (0.02%):The *Northern Drakensberg Highland Grassland* is found on the Clarens sandstone and mudstones of the Elliot Formation on the crest of the escarpment. The vegetation is dominated by grasslands with shrub (e.g. *Protea caffra*) and small tree species (*Leucosidea sericea*) occurring at higher altitudes in rocky areas and on south facing slopes. The slopes are generally moderate to steep and the soils shallow and well-drained. Wetlands occur in areas where drainage is impeded or where changes in slope result in sediment and water accumulation. Groundwater dependent ecosystems are highly localized, occurring where alluvium accumulates along rivers and in terrain forms where water accumulates or there are geological contacts which control groundwater movement.

Mesic Highveld Grassland bioregion (15.8%):These vegetation types include a range of grassland types, primarily on the shales of the Karoo Supergroup but also on granites and other basement rocks and on the dolomites. They are all sourveld grasslands where the growing season is determined primarily by the duration of the frost-free period. Communities with a woody shrub component are found in rocky habitats which provide some protection from fire. Woody plant communities also occur in some situations where there is access to groundwater. The vegetation dynamics are determined by the frequent fires which occur mainly during the winter.

Basotho Montane Shrubland (0.7%):Occurs on the upper layers of the mudstones and sandstones of the Molteno, Elliot and Clarens formations mainly in the Free State and Lesotho. It occurs on the coarse talus found on steep slopes of mesas and incised valleys where it receives some protection from fire. The vegetation is dominated by shrubs (e.g. Rhus species, Olea, Euclea) which can become dense and tall. The *Northern Free State Shrubland* (0.02%) occurs in similar situations but on the Adelaide Subgroup (Beaufort Group) sandstones and in association with dolerite sills in the Free State and marginally into Mpumalanga. Wetlands occur in the few gently sloping areas and along streamlines. Groundwater discharges from the underlying fractured aquifer and along geological contacts are generally highly localised, as are the associated groundwater dependent communities.

The Frankfort Highveld Grasslands (0.66%):Occur mainly on the mudstones, shales and occasional sandstones of the Adelaide Subgroup (Beaufort Group) and dolerite intrusions in the Free State. *Eastern Free State Clay Grassland* (11.9%) occurs on the mudstones and shales of the Adelaide Subgroup (in the north) and the Tarkastad Subgroup (in the south) in the Free State and adjacent parts of Lesotho. The landscape is flat to gently rolling and punctuated by dolerite and sandstone outcrops which form isolated hills and ridges with shrubland vegetation (e.g. *Basotho Montane Shrubland*). The vegetation is a dense, tall grassland. The similar *Eastern Free State Sandy Grassland* (1.2%) occurs on the same lithologies but the soils are somewhat sandier and better drained.

In all these mesic grassland vegetation types there are hygrophilous grasslands and wetlands in level or gently-sloping areas, low-lying areas and along the wide and moist valley bottoms. The wetlands belong to the *Eastern Temperate Freshwater Wetlands* vegetation type but only the larger ones were included in the vegetation map. Groundwater-surface water interactions occur along the drainage lines and in wetlands but are localised rather than widespread. The drainage lines are often invaded by Acacia mearnsii (Black wattle), willows, poplars and other invasive alien species.

Dry Highveld Grassland bioregion (73.7%): Most of these grasslands are similar to the mesic grasslands but the rainfall is lower and fires are less frequent, occurring at intervals of more than 1-2 years. The *Central Free State Grassland* (22.3%) is found on clayey soils derived from the mudstones and sandstones of the Adelaide Subgroup in the Free State and extending a little into Gauteng. The dense, short grasslands are often overgrazed resulting in encroachment by shrubs and Acacia karoo. The *Western Free State Clay Grassland* (WFSCG) (3.6%) is found on the sandstones, mudstones and shales of the Volkrust Formation where it is restricted to flat bottomlands embedded with salt pans (i.e. endorheic drainages). The *Vaal-Vet Sandy Grassland* (36.8%) occurs on aeolian and colluvial sands overlying the Ecca Group and Ventersdorp Supergroup (andesite, basement gneiss). These form gently undulating plains and hills which divide the WFSCG into sections. The *Vredefort Dome*

Granite Grassland (0.6%) is a short grassland which occurs on slightly undulating plains on a range of soil types derived from the granites and gneisses. The granites form prominent domes which provide relatively fire-free habitats for scattered shrub and tree species. Surface runoff from the domes may enhance recharge in their immediate surrounds. The *Western Highveld Sandy Grassland* (1.0%) occurs in North West Province where it occurs on sands or calcretes on the flat plains formed by the basaltic lavas of the Klipriviersberg Group and andesitic lavas of the Allanridge Formation. It is a short grassland with scattered bush clumps. Many endorheic Highveld salt pans are embedded in this grassland and many of the additional wetlands (comprising 3.0% of the area) probably in many small salt pans. In these dry grasslands, groundwater-dependent ecosystems will be rare and localised and often associated with drainage lines or settings where sediments and water accumulate, but where there is sufficient flushing to prevent salt accumulation.

The Klerksdorp Thornveld (4.0%):Is characterised by open to dense Acacia karoo bush clumps in dry grassland on undulating plains formed from the shale, slate and quartzite of the Pretoria Group and the Ventersdorp Group volcanics and sediments in North West Province. The Pretoria Group is intercalated with the diabase sills and Hekpoort Formation lavas which give rise to shallow, rocky soils. The bush clumps support a variety of deep-rooted shrub and tree species and a rich understorey flora in these species-rich grasslands.

The Vaal Reefs Dolomite Sinkhole Woodland (0.7%): Almost confined to this WMA, it is associated with sinkholes in the undulating landscape and prominent, rocky, chert ridges formed from dolomites of the Malmani Subgroup. It includes a number of deep-rooted tree species (Acacia karoo, A. erioloba, Celtis africana, Rhus lancea) which may be using the groundwater in the karst aquifer. The tree clumps contain a number of understorey species which may also be sustained by "hydraulic lift" of groundwater by the deep-rooted trees (Caldwell and Richards, 1989). The surrounding *Carletonville Dolomite Grassland* (4.0%) extends into Gauteng and is characterised by the same undulating plains and rocky ridges, and a high diversity of grass species. There are numerous wetlands (0.78% of this vegetation type) in these dolomites which are divided into compartments, and springs occur where groundwater discharges from a higher lying compartment to a lower one (Nel et al., 1995; Colvin et al., 2007). The dolomitic aquifers support rare or endemic flora and fauna, and a range of specialised subterranean invertebrate species (Stephens et al., 2002). Groundwater dependence of the woodlands and the spring ecosystems may be high and sensitive to changes in water levels and discharge rates.

Winburg Grassy Shrubland (0.7%):Occurs on the dolerite outcrops (sills and dykes) in the Adelaide Subgroup across a range of grassland types in the Free State. The rocky outcrops provide protection from fire and frost for a number of woody shrub and small tree species (Olea, Rhus, Euclea, Diospyros). *Bloemfontein Karroid Shrubland* (0.1%) occurs as isolated patches on the dolerite dykes and sills intruding into the Adelaide Subgroup in the Free State in this WMA. The vegetation structure ranges from a low to medium height shrubland and contains a very diverse flora of geophytes. Wetlands are rare and groundwater dependent ecosystems are unlikely to occur.

4.2.3 Grassland Wetlands

In addition to the wetlands mapped as part of the Eastern Temperate Freshwater Wetlands, there are many smaller wetlands. These wetlands are relatively extensive, comprising >1% of the area, in the following dry grasslands types: Vaal Reefs Dolomite Sinkhole Woodland, Vaal-Vet Sandy Grassland, Western Free State Clay Grassland and Western Highveld Sandy Grassland. In the mesic grasslands they are relatively frequent only in the Rand Highveld Grassland.

4.2.4 Savanna Biome

The descriptions below are based on information from the background information and vegetation type descriptions given by Rutherford et al., (2006).

Central Bushveld bioregion (5.5%):The Andesite Mountain Bushveld (0.6%) occurs in the Gauteng, North West, Mpumalanga and Free State provinces on hillslopes and ridges formed from the tholeitic basalt of the Klipriviersberg Group, shale, sandstone and siltstone of the Madzaringwe Formation and conglomerate of the Pretoria Group. The soils are rocky and shallow overlying the fractured rocks. The vegetation is a dense, medium tall, thorny bushveld with a dense grass layer. *Gold Reef Mountain Bushveld* (0.01%) occurs only marginally in this WMA. It is associated with rocky ridges formed from the quartzites, conglomerates and some shale horizons of the Silverton, Daspoort and Magaliesberg formations and the Hospital Hill, Turffontein and Government subgroups. The soils are shallow, generally gravelly lithosols and well drained. The woody vegetation is generally dense, particularly on the south-facing slopes, and the understorey is dominated by grasses.

These vegetation types all include a number of tree and shrub species with the potential to form deep root systems which can tap into groundwater. There may be groundwater-dependence where the area has a shallow (<10 m) water table, particularly where the rainfall is low. Drainage lines within these vegetation types often contain alluvial deposits where there may be groundwater-dependant ecosystems.

Eastern Kalahari Bushveld bioregion (4.9%):The *Kimberley Thornveld* occurs in the North West, Free State and Northern Cape provinces on the sediments of the Karoo Supergroup (south and east) and the andesitic lavas of the Allanridge Formation (north and west). The terrain comprises plains with deep, sandy soils. The vegetation has an overstorey of tall, deep-rooted trees (Acacia erioloba, A. tortilis, A. karoo, Boscia albitrunca), a well-developed shrub layer and an open understorey of grasses. The deep-rooted tree species are probably tapping into groundwater so there may be some groundwater-dependence in addition to the potentially groundwater-dependent ecosystems associated with alluvial environments. More than 1% of the landscape has been mapped as wetlands.

4.3 Synthesis of Groundwater Ecosystem Dependence

The preceding sections describe the types of GDEs based on the features of the vegetation types as given in the descriptions prepared for the national vegetation map (Mucina and Rutherford, 2006). This section presents the groups arranged according to the likelihood of GDEs being present and the nature of their occurrence in the different groups of vegetation types (**Table 4-2**). The nature and distribution of GDEs is strongly controlled by the nature of the underlying aquifers and the spatial patterns of groundwater movement, discharge and water table depths (Colvin et al., 2007). Most of the geological formations in the WMA form fractured hard-rock aquifers where water movements are controlled by the fractures and by large-scale structures such as faults and contacts between rock formations with different properties (e.g. fractured versus massive, aquifer versus aquiclude).

Unconsolidated formations are found in areas where sediments accumulate such as river alluvium, colluvium and talus on slopes. These formations are typically highly heterogeneous with coarse sediments which can store relatively large volumes of groundwater, and have high transmissivities, and fine sediments acting as aquitards. This means that GDEs are likely to be a general feature of unconsolidated sediments and that these ecosystems are likely to be sensitive to groundwater abstraction. The GDEs may also not look like "typical" wetlands, the only indication may be the presence of deep-rooted trees and a water table which is within reach of these root systems.

The WMA also includes some Malmani Subgroup carbonate strata which contain large quantities of groundwater in solution cavities. Their high storage capacity enables these formations to retain large volumes of groundwater recharge and to discharge this more slowly, resulting in sustained spring flows throughout the dry season (Le Maitre and Colvin, 2008). Groundwater levels and discharges in the dolomites are the main controls on the occurrence and dynamics of GDEs in these formations, which makes them potentially highly sensitive to groundwater abstraction.

In conclusion, however, it is worth considering the weakness of the RDM protocol in regard to groundwater as formulated in Brown and Louw (2011), namely that "*The role of groundwater in supporting aquatic ecosystems and the implications for them of abstraction are still poorly understood. This threatens successful inclusion of the groundwater component in the RDM determination for a catchment.*"

Table 4-2. A synthesis of the probability of occurrence, likely extent and characteristics of groundwater-dependence and groundwater dependent ecosystems in the various vegetation types in the WMA

Probability	Extent	Vegetation type	Description
Low	Localised, occurring in specific settings	Basotho Montane Shrubland	Grassland with a significant shrub component, on rocky slopes and areas which are well drained and overlie Drakensberg basalts. Marshes and wetlands form on level patches and riparian vegetation is found on streamlines. Dependence locally high.
		Bloemfontein Karroid Shrubland Northern Free State Shrubland Winburg Grassy Shrubland	Shrubland with grasses, found primarily on well-drained rocky slopes and rocky areas. Groundwater interactions and dependence low except along streamlines or in rare wetlands
		Western Free State Clay Grassland	Occurs in close association with the Highveld Salt Pans and in the same closed (endorheic) drainage systems. GDEs unlikely to occur.
	Limited, if any	Highveld Salt Pans	Closed salt pan systems, disconnected from groundwater if there is any.
Medium	Localised, occurring in specific settings	Lesotho Highland Basalt Grassland	Ground-surface water interactions occur in specific settings determined by terrain, water flow and accumulation on and below the surface and soil accumulation and depth (e.g. streamlines and depressions). The weathering on the basalts can be deep with substantial groundwater storage potential. Groundwater dependence probably only seasonal due to the high rainfall, low temperatures and frequent fog and mist
Medium	Localised, occurring in specific settings	Eastern Free State Clay Grassland Eastern Free State Sandy Grassland Frankfort Highveld Grassland Rand Highveld Grassland	Mesic grasslands on a range of hydrogeological terrains. The landscape is generally gently undulating or rolling with hills and low to prominent ridges where more resistant formations (e.g. dolerites, sandstones) occur. Ground-surface water interactions occur in specific settings determined by terrain, water flow and accumulation on and below the surface and soil accumulation and depth (e.g. streamlines and depressions) including the depth of the weathering. Alluvial deposits and formations occur along water courses and in floodplains and flooding and lateral groundwater inflow determine the hydrogeological regime. In these settings groundwater dependence can be high. Hygric grasslands common in bottomlands and depressions. Groundwater dependence variable but moderated by the relatively high rainfall and the low temperatures in the higher parts of the Highveld.
Medium	Localised, occurring in specific settings	Central Free State Grassland Vaal-Vet Sandy Grassland Vredefort Dome Granite Grassland Western Highveld Sandy Grassland	Dry grasslands which have GDEs in the same settings as the mesic grasslands but because of the lower rainfall are likely to have fewer and less extensive groundwater systems. At the same time, the drier conditions would make GDEs more sensitive to the impacts of changes in the groundwater regime.
Medium	Localised, occurring in specific settings	Gold Reef Mountain Bushveld Andesite Mountain Bushveld Gauteng Shale Mountain Bushveld Klerksdorp and Kimberly Thornveld	Woodland with a tree and shrub layer comprising a number of species which are known to de deep rooted and potentially using groundwater and may be sensitive to lowering of the water table. Groundwater dependent ecosystems otherwise similar to those of the grasslands with a range from surface to groundwater driven types. Most wetlands shown in Kimberly Thornveld are salt pans

Probability	Extent	Vegetation type	Description
High	Localised, occurring in specific settings	Carletonville Dolomite Grassland	Dry grasslands on the Malmani dolomites characterised by numerous highly groundwater-dependent ecosystems, including springs and seeps. These frequently occur along dolomitic compartment divides. GDEs sensitive to changes in water table depth and discharge regimes.
		Vaal Reefs Dolomite Sinkhole Woodland	Species-rich woodland patches in dolomite grasslands, characterised by deep-rooted tree species which may be sensitive to changes in the water table depth.
High	General, a typical feature of these ecosystems and to be expected unless there is evidence that it is not groundwater dependent	Eastern Temperate Freshwater Wetlands	These wetlands occur throughout the WMA across a wide variety of rock, aquifer and vegetation types. Most of them are typical wetlands formed where water and sediment or peat has accumulated and they range from alluvial systems to extensive bottom or valley wetlands where erosion resistant structures have trapped sediments. The water sources vary from surface water dominated to groundwater dominated and there is a range of groundwater dependence.
		Highveld Alluvial Vegetation	Alluvial & riparian vegetation, mixture of surface and groundwater dependent types, only large (wide) units shown in the national vegetation map but alluvial systems are present along most river reaches.

5 GROUNDWATER BASEFLOW EVALUATION

Various data sources provide different estimates for baseflow. Presented in **Table 5-1** are values showing the different estimates of baseflow based on Hughes (**Figure 5-1**), Pitman (**Figure 5-2**), Schultz (**Figure 5-3**) and Sami (**Figure 5-4**). The full baseflow calculations are shown in **Appendix B**. The summary results are shown in **Table 5-1**. Hydrograph separation was done using Herold's method based on the stream flow data from WRP. The hydrograph separation results are hereafter referred to as WRP baseflow, and are given in **Table 5-1** and **Figure 5-5**.

Table 5-1. Comparison of groundwater baseflow values from different sources

QUAT	AREA (km^2)	MAP (mm/a)	MAR (WR2005) (Mm^3/a)	BASEFLOW WRP (Mm^3/a)	QUAT	AREA (km^2)	MAP (mm/a)	MAR (WR2005) (Mm^3/a)	BASEFLOW WRP (Mm^3/a)
C24A	839	584	32.13	3.26	C42F	734	567	23.33	1.36
C24B	530	562	19.71	2.32	C42G	555	549	15.75	1.26
C24C*	1350	587	See footnote	14.3	C42H	445	540	11.73	0.68
C24D	364	584	10.97	0.72	C42J	1014	530	25.04	0.02
C24E	925	560	14.63	0.88	C42K	668	521	15.51	0.71
C24F	2020	577	28.12	3.08	C42L	511	506	11.73	0.67
C24G	985	581	23.86	2.59	C43A	1491	483	2.46	0
C24H	840	576	13.73	0.51	C43B	723	495	3.82	0
C24J	2110	552	10.54	0.73	C43C	913	470	1.35	0
C25A	864	542	3.36	0.63	C43D	1476	465	2.45	0
C25B	1888	509	2.52	0.65	C60A	860	625	35.23	2.58
C25C	1210	522	4.14	0.01	C60B	1022	610	37.27	3.85
C25D	1203	525	10.06	0.66	C60C	1048	571	28.63	3.57
C25E	1537	510	3.89	0.63	C60D	645	550	16.66	2.1
C25F	2219	481	3.45	0	C60E	664	557	16.07	2.13
C41A	1078	598	37.32	2.3	C60F	659	556	17.87	2.14
C41B	1005	598	34.88	1.18	C60G	782	537	18.53	2.15
C41C	1095	595	37.13	1.11	C60H	1232	513	1.13	0
C41D	1155	549	28.04	1.11	C60J	959	548	6.77	0
C41E	391	519	9.93	0.03	C70A	613	627	18.52	1.78
C41F	555	496	12.34	0.02	C70B	660	612	17.76	1.04
C41G	272	516	6.36	0.01	C70C	887	615	24.45	1.9
C41H	887	500	20.44	0.02	C70D	675	586	13.51	1.03
C41J	556	495	12.35	0.01	C70E	693	578	16.76	1.02
C42A	695	633	22.43	3.95	C70F	564	574	13.05	0.97
C42B	727	582	19.79	2.56	C70G	901	577	16.91	1.86
C42C	793	626	24.32	2.22	C70H	251	568	5.48	0.76
C42D	663	556	12.63	3.45	C70J	521	575	12.54	1.54
C42E	750	565	15.23	3.37	C70K	891	565	8.07	1.4

* This entire quaternary catchment is an endoreic area and there is no natural surface runoff from this catchment. All outflow is from the Schoonspruit Eye.

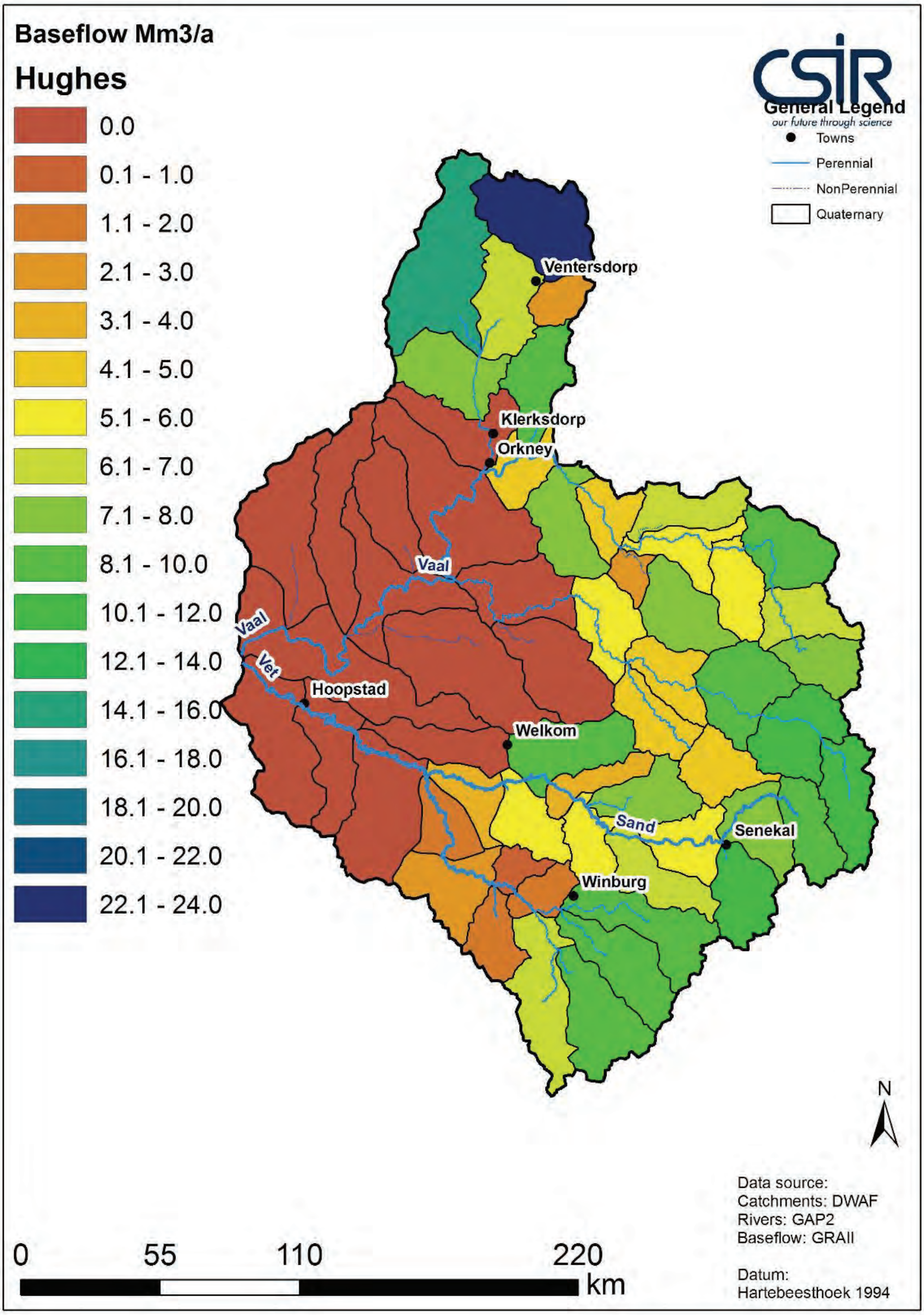

Figure 5-1. Baseflow estimate for the Middle Vaal WMA per quaternary catchment by Hughes (values in Mm^3/a)

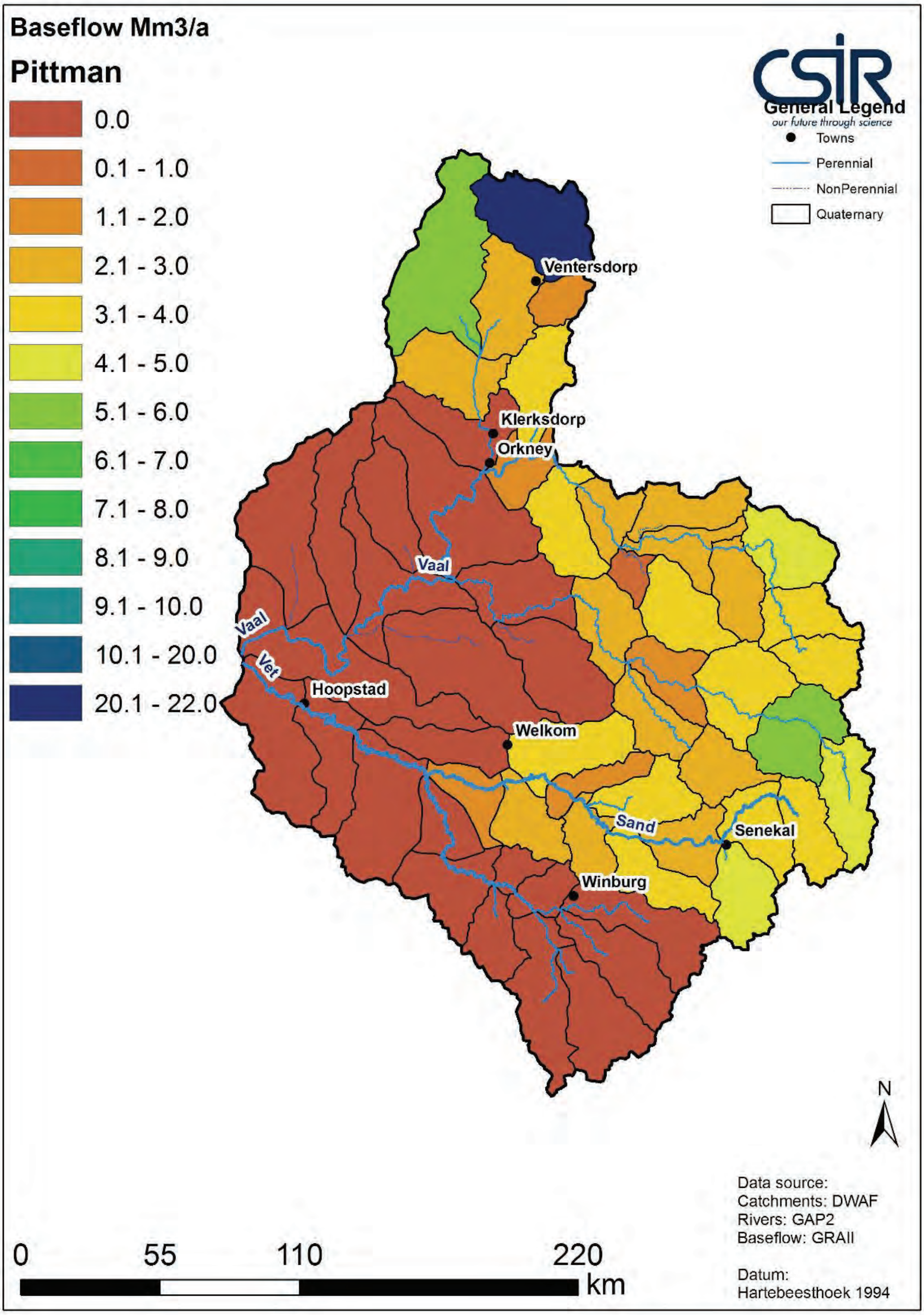

Figure 5-2. Baseflow estimate for the Middle Vaal WMA per quaternary catchment by Pitman (values in Mm^3/a)

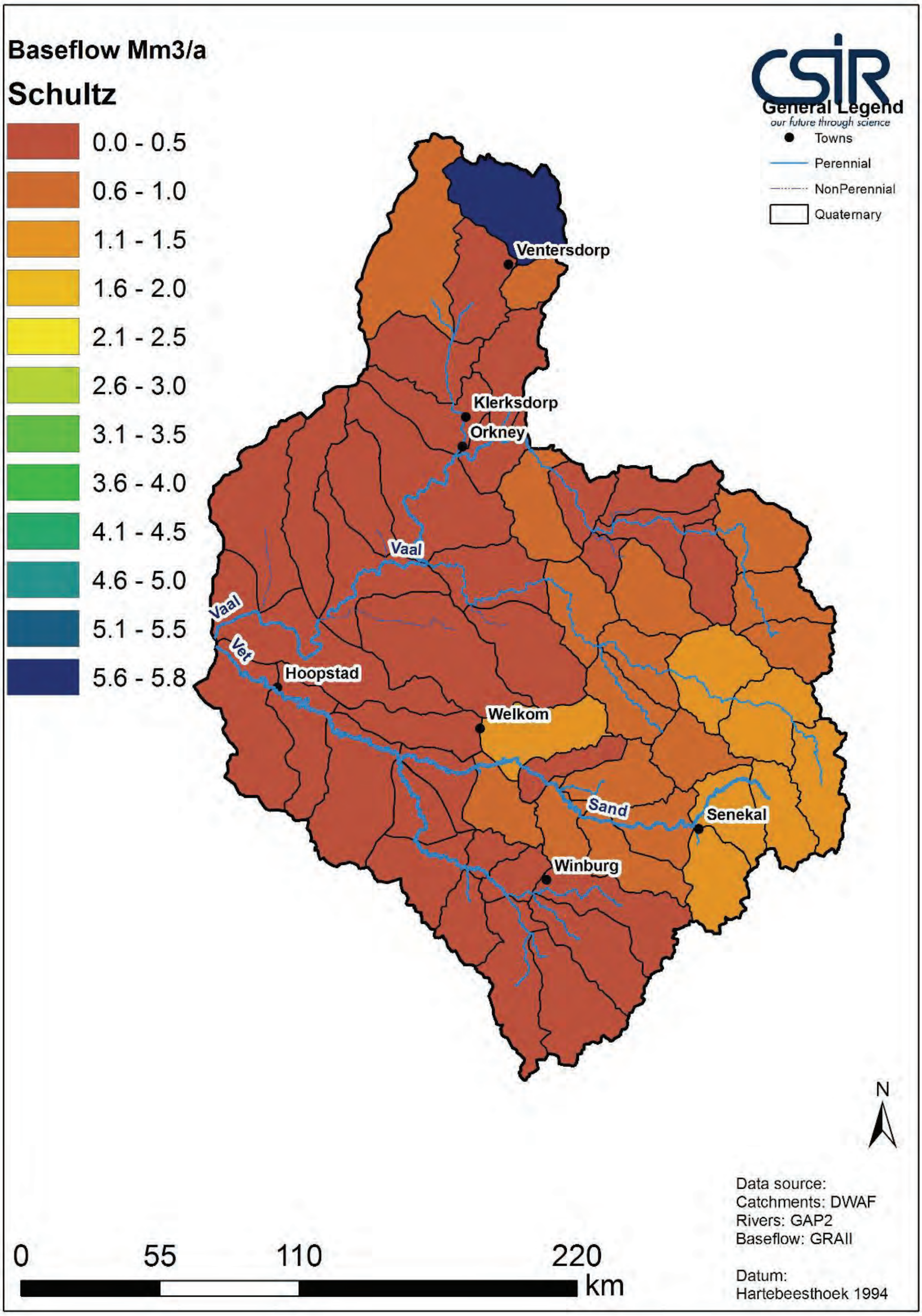

Figure 5-3. Baseflow estimate for the Middle Vaal WMA per quaternary catchment by Schultz (values in Mm^3/a)

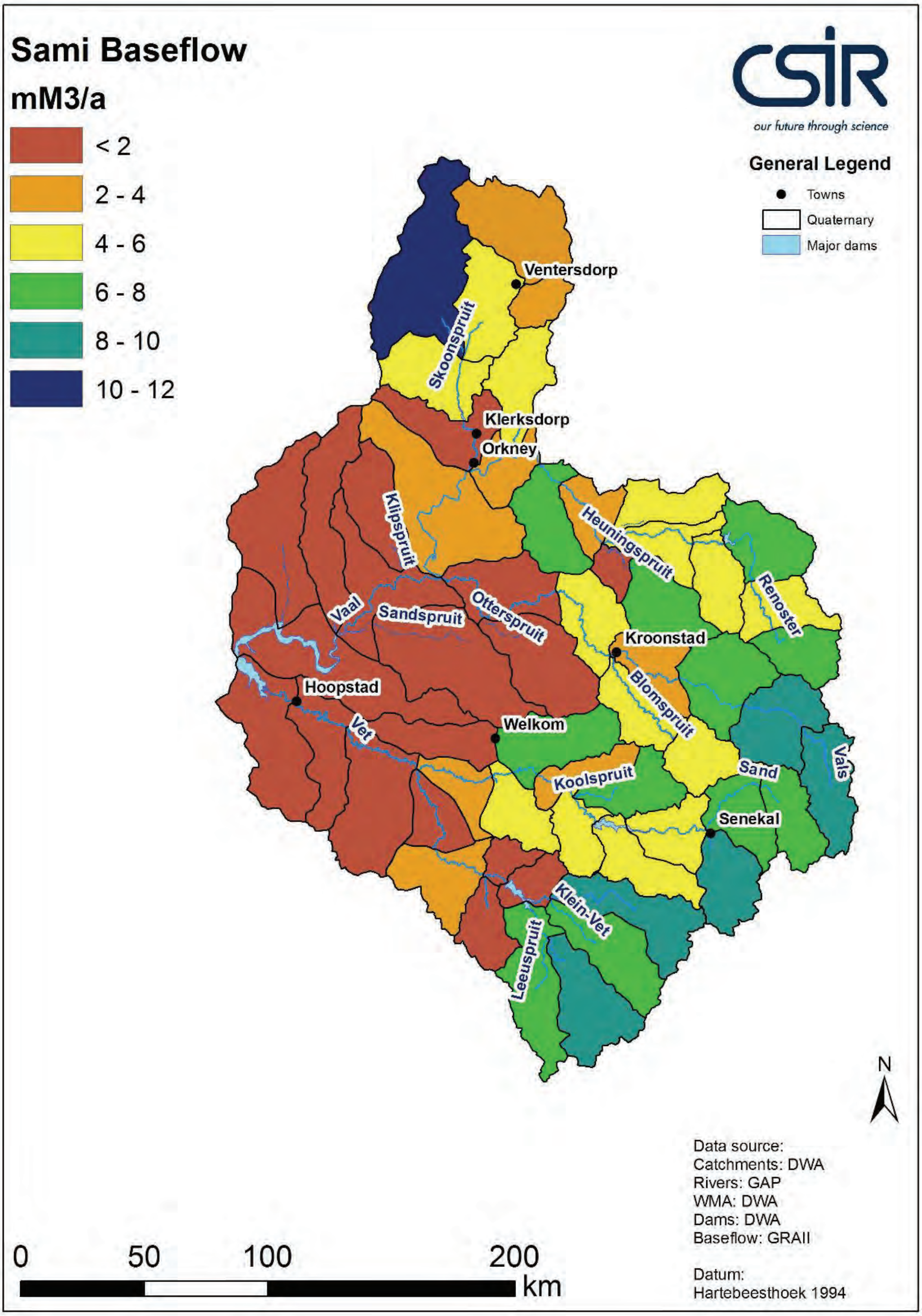

Figure 5-4. Baseflow estimate for the Middle Vaal WMA based on Sami from GRAII (values in Mm^3/a)

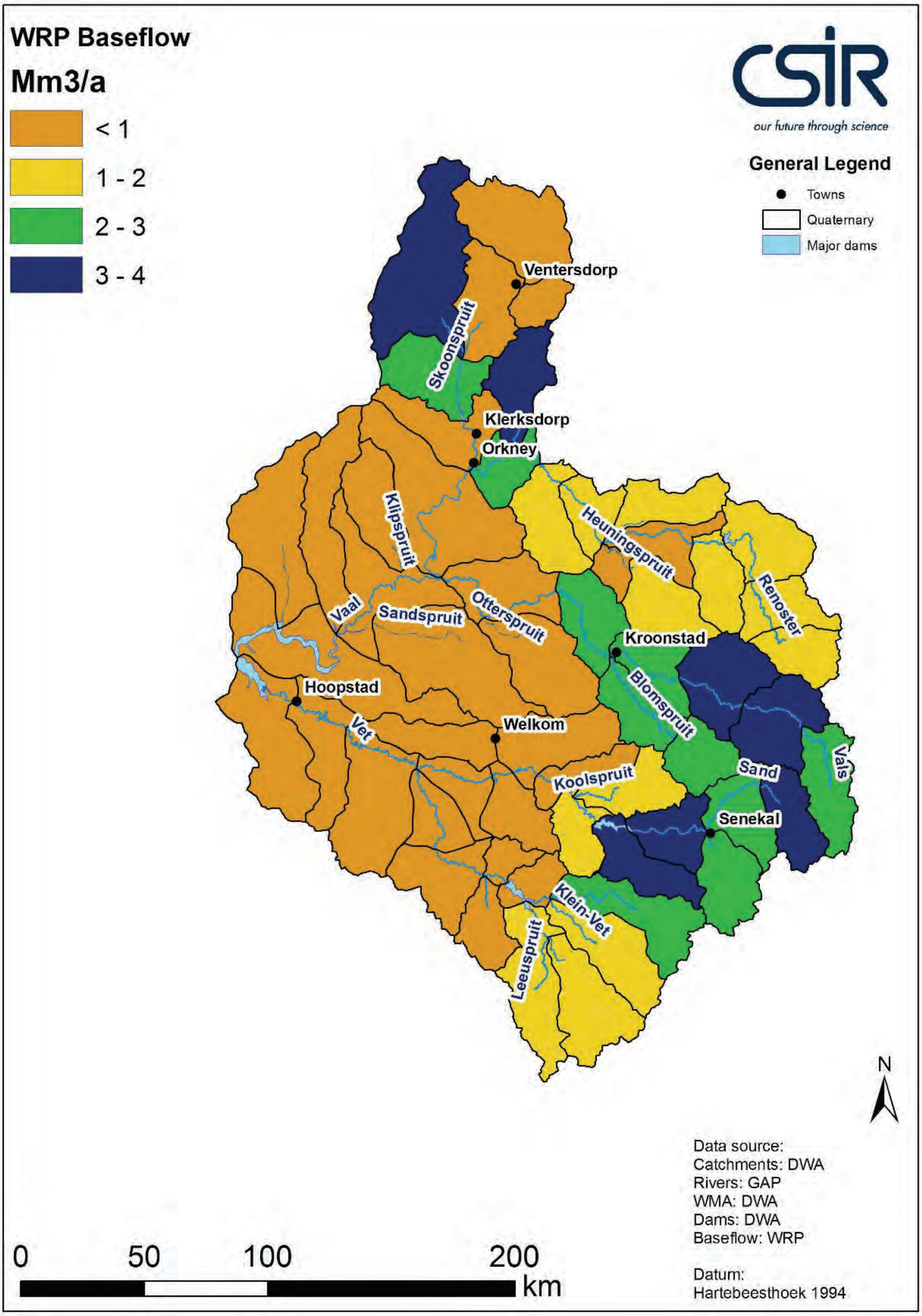

Figure 5-5. Baseflow estimate for the Middle Vaal WMA based on hydrograph separation using WRP streamflow data (values in Mm^3/a)

Baseflow data reported by Van Tonder and Dennis (2003) provide a further source for comparison with the afore-mentioned estimates. This is presented in **Table 5-2**.

Table 5-2. Groundwater baseflow estimates after Herold and Van Tonder and Dennis (2003)

Quaternary Catchment	**GRU**	**Baseflow (Mm^3/a)**		**Quaternary Catchment**	**GRU**	**Baseflow (Mm^3/a)**	
		Herold	**Van Tonder & Dennis (2003)**			**Herold**	**Van Tonder & Dennis (2003)**
C24A	2	3.26	3	C42F	4a	1.36	3
C24B	1b	2.32	2	C42G	4a	1.26	2
C24C	1a	14.3	14	C42H	3a	0.68	1
C24D	2	0.72	1	C42J	3a	0.02	3
C24E	2	0.88	2	C42K	3a	0.71	2
C24F	2	3.08	5	C42L	3a	0.67	1
C24G	2	2.59	2	C43A	3a	0	
C24H	2	0.51		C43B	3a	0	
C24J	2	0.73		C43C	3a	0	
C25A	2	0.63		C43D	3a	0	
C25B	3a	0.65		C60A	5	2.58	4
C25C	2, 3	0.01		C60B	4b	3.85	4
C25D	3a, 2	0.66		C60C	4b	3.57	3
C25E	3a, 2	0.63		C60D	4b	2.1	2
C25F	3a	0		C60E	4b	2.13	2
C41A	4a, 5	2.3		C60F	4b	2.14	2
C41B	4a, 5	1.18		C60G	3a	2.15	2
C41C	4a	1.11		C60H	3a	0	
C41D	4a	1.11		C60J	3a	0	
C41E	4a	0.03		C70A	4b	1.78	3
C41F	4a	0.02		C70B	4b	1.04	3
C41G	4a	0.01		C70C	4b	1.9	3
C41H	4a	0.02		C70D	3b	1.03	2
C41J	3a	0.01		C70E	3b	1.02	2
C42A	5	3.95	3	C70F	3b	0.97	2
C42B	5	2.56	3	C70G	3b	1.86	3
C42C	5	2.22	4	C70H	3a	0.76	1
C42D	4a	3.45	2	C70J	3a	1.54	2
C42E	3a, 4a	3.37	3	C70K	3a	1.4	3

6 DELINEATION OF GROUNDWATER RESOURCE UNITS

6.1 Method

The identification of groundwater resource units (GRUs) in the study area is based on the consideration of a combination of various factors such as rock type, magnitude of recharge, nature of land use impact and conservation status. A further important consideration is the need to keep this as simple and manageable as possible both in terms of number and in terms of geospatial definition. The outcome for the study area is illustrated in **Figure 6-1** and **Figure 6-2**, which reflect the distribution of the five GRUs identified in the Middle Vaal WMA.

The association (as far as possible) of GRUs with the footprint of quaternary catchments facilitates the geospatial definition of each GRU. This convenience necessarily sacrifices a measure of hydrogeological accuracy, because it is common cause that the distribution of geological strata seldom follows the hydrological boundaries that define surface water catchments. Nevertheless, the extent to which the GRU footprints honour their underpinning geological framework is shown in **Figure 6-1**. The discrepancy of GRU numbering between **Figure 6-1** and **Figure 6-2** illustrates the refinement that derives from the recognition of similar lithologies as representing quasi-homogeneous hydrogeological environments. For example, GRU 2 in **Figure 6-1** is identified as GRU 1b in **Figure 6-2** to reflect the karst environment that is mutual to these GRUs as subcomponents of GRU 1.

6.2 Physical Description of the GRUs

6.2.1 GRU 1

6.2.1.1 GRU 1a

GRU 1a encompasses that portion of the Malmani Subgroup dolomitic strata (type *c* aquifers as per **Table 2-5**) which host extensive irrigated agriculture that is based on the karst groundwater resources. Also known as the Schoonspruit Dolomitic Aquifer located in the northern-most portion of the WMA around Ventersdorp, the sustainable utilisation of these groundwater resources in terms of both their socio-economic and ecological importance is a critical aspect of GRDM that needs to be considered. This GRU is drained by the Schoonspruit Eye which discharges on average at ~50 Mm^3/a (~1600 L/s) (Maré et al., 2007) via the Schoonspruit stream southwards to join the Vaal River at Orkney. This flow is more than enough to supply the current Ventersdorp municipal demand of ~1.9 Mm^3/a and the Schoonspruit Irrigation Scheme demand of 16.8 Mm^3/a, the balance contributing to the Klerksdorp water supply drawn from the Johan Neser Dam (WRP, 2011a).

6.2.1.2 GRU 1b

GRU 1b encompasses that portion of the Malmani Subgroup dolomitic strata which hosts the extensive mining activity associated with the gold mining industry in the Klerksdorp Gold Field. The impact of mining is manifested in the form of underground mine workings and extensive mine residue deposits on surface. A portion of this GRU has been severely impacted by intentional dewatering of the karst aquifer in order to facilitate mining at depth beneath this resource. The threat of contamination associated with acid mine drainage (AMD) is a real concern, and the complexity of issues that attend these concerns pose extreme challenges for a GRDM assessment. Among these issues is the concern for the presence of radionuclides (e.g. ^{238}U, ^{226}Ra, ^{222}Rn) associated with mine water discharges resulting from mining activity and related land uses (see Winde et al., 2004). Concerns in this regard, however, are directed at sediment and surface water quality rather than at groundwater quality.

6.2.2 GRU 2

This GRU encompasses the older (Randian) geologic strata that underlie the north-western portion of the WMA. After unimproved natural grassland as the principal land use (~63%), cultivated agriculture in the form of commercial dryland farming (~29%) represents the second most extensive land use (**Table 7-1**) in this GRU. The hydrogeologic environment represents a moderately productive resource that comprises mainly intergranular-and-fractured (type *d*) with subordinate fractured (type *b*) aquifer types supporting borehole yields in the range 0.5-2 and 2-5 L/s (yield classes *3* and *4*, respectively, as described in **Table 2-5**). These circumstances describe the reliance of numerous towns in this GRU (e.g. Wolmaransstad, Leeudoringstad and Coligny) on groundwater resources for a significant proportion of their municipal water supply. The Wolmaransstad Town Area, which includes the four main urban centres in the Maquassi Hills Local Municipality, namely Wolmaransstad, Makwassie, Witpoort and Leeudoringstad, obtains 30% (~0.8 Mm^3) of its current annual water requirement of 2.6 Mm^3 from groundwater resources (WRP, 2011b).

6.2.3 GRU 3

6.2.3.1 GRU 3a

This GRU covers most of the central portion of the WMA receiving a mean annual precipitation (MAP) of <500 mm (with a lower limit of 450 mm along the western margin), and underlain by older strata of the Karoo Supergroup. These are represented by the argillaceous rocks (shale, siltstone, mudstone) of the Ecca Group located mainly west, north-west and north of Welkom, and the arenaceous rocks (sandstone) of the Beaufort Group located to the south-east of Welkom. The hydrogeological environment represents a moderately productive resource that comprises mainly intergranular-and-fractured (type *d*) aquifers supporting borehole yields in the range 0.5-2 and 2-5 L/s (yield classes *3* and *4* respectively, as described in Table 2-5). The relative economic importance of this GRU is shown by the ~47% of surface area that supports cultivated commercial dryland agriculture as the principal land use activity, followed by natural unimproved grassland comprising ~42% of the area (**Table 7-1**). The distribution of coal fields (largely undeveloped) in the study area, mainly across GRUs 3a and 3b, is shown in **Figure 6-3**.

6.2.3.2 GRU 3b

Defined by similar geologic and hydrogeological characteristics as those which describe GRU 3a (section 6.2.3.1), this GRU is recognised as a separate entity on the basis of its slightly higher MAP of >550 mm. Although ~40% of the area supports cultivated commercial dryland agriculture, natural unimproved grassland (~53% of the area) represents the dominant land use in this GRU.

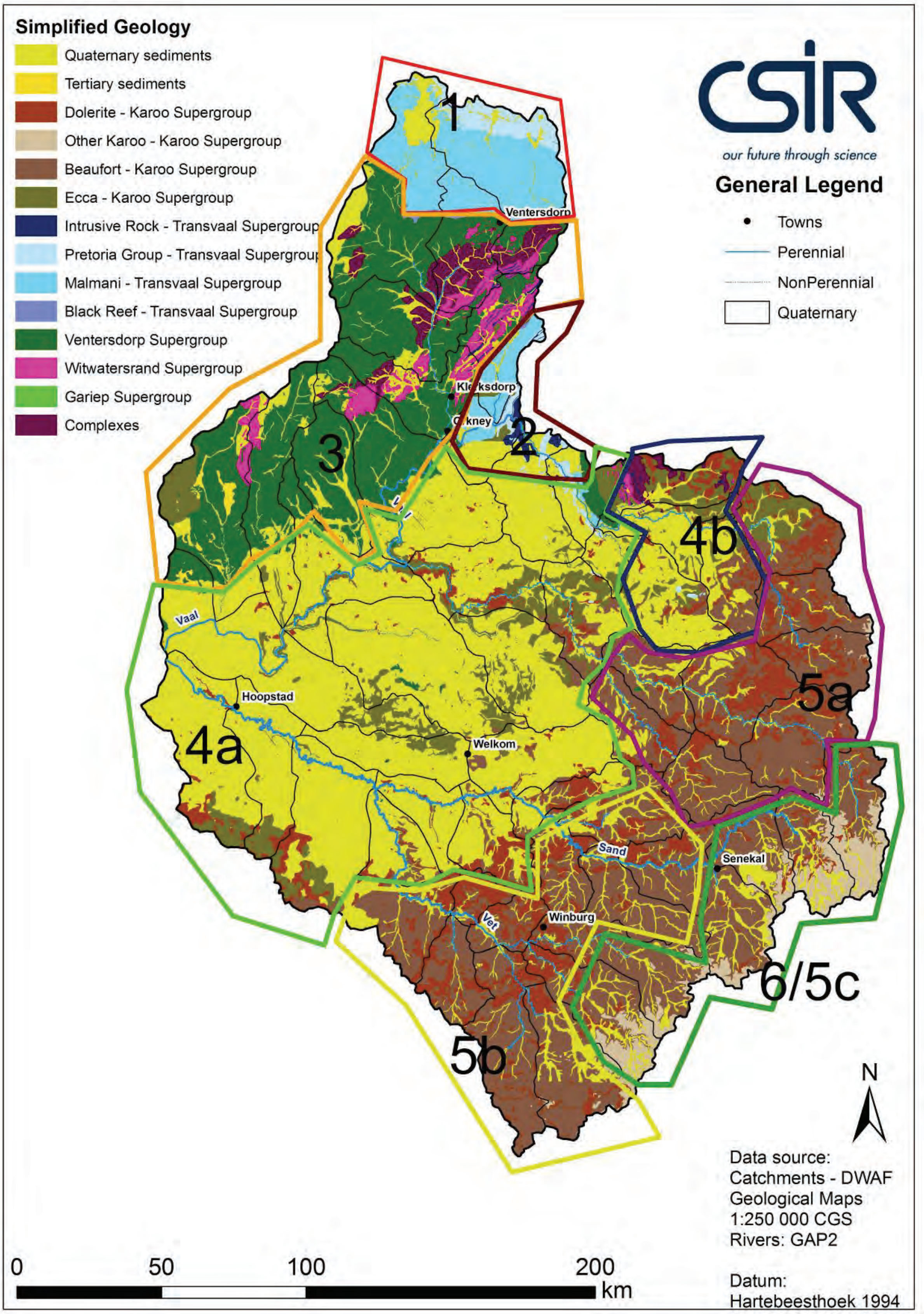

Figure 6-1. Original conceptual demarcation of groundwater resource units (GRUs) in the study area on the basis of mainly geological criteria

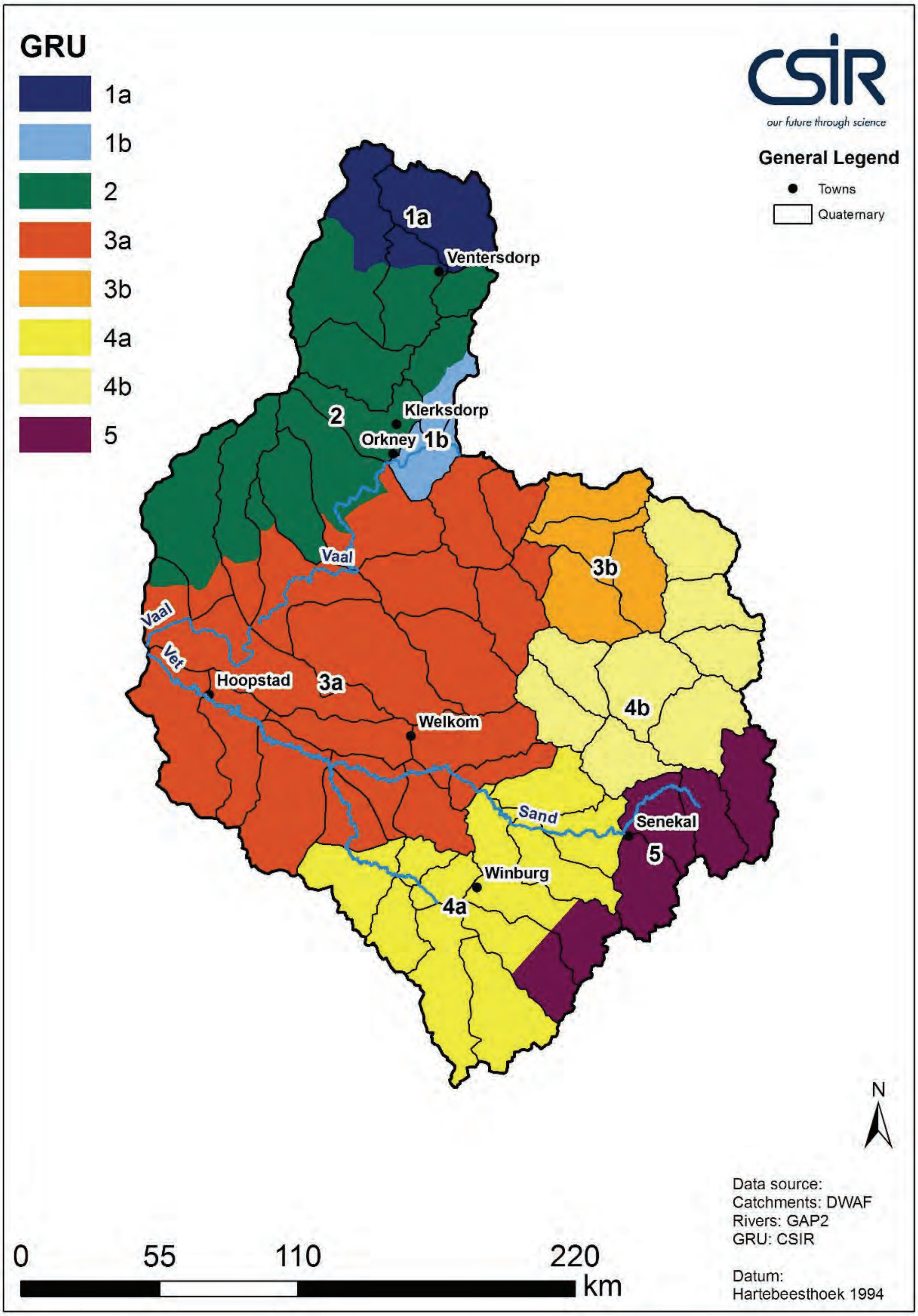

Figure 6-2. Final definition of groundwater resource units (GRUs) in the study area

6.2.4 GRU 4

GRU 4 comprises younger strata of the Karoo Supergroup represented by arenaceous rocks (sandstone) of the Beaufort Group. A further geologic characteristic of this GRU is the extensive occurrence of dolerite intrusions. These take the form of subhorizontal sills that have invaded the comparatively flat-lying (horizontally bedded) sandstone along pre-existing planes of weakness.

6.2.4.1 GRU 4a

GRU 4a encompasses the south-western portion of GRU 4 that receives a MAP of <550 mm, and which occupies a landscape that is generally located below a surface elevation of ~2000 m amsl. The more rural nature of the environment in this GRU is reflected in the ~70% of surface area that supports natural unimproved grassland as the principal land use type, followed by commercial dryland agriculture comprising ~22% (**Table 7-1**). Groundwater occurs in intergranular-and-fractured (type *d*) aquifers supporting borehole yields in the *2* (0.5-2 L/s) and *3* (2-5 L/s) yield class ranges.

6.2.4.2 GRU 4b

GRU 4b encompasses the north-eastern portion of GRU 4 that receives a MAP of >550 mm, and which occupies a landscape that is generally located above a surface elevation of ~2000 m amsl. Similar to GRU 4a, the more rural nature of the environment in this GRU is reflected in the ~69% of surface area that supports natural unimproved grassland as the principal land use type, followed by commercial dryland agriculture representing ~26% of the land use type in the area (**Table 7-1**). Groundwater occurs in intergranular-and-fractured (type *d*) aquifers supporting borehole yields in the *2* (0.5-2 L/s) and *3* (2-5 L/s) yield class ranges.

6.2.5 GRU 5

This GRU is underlain by the youngest strata in the WMA, and includes the arenaceous rocks of the Elliot, Molteno and Clarens formations and the basaltic lava of the Drakensberg Formation. The area experiences the highest MAP in the WMA with an upper limit of 700 mm, and also supports the highest terrain elevations that reach ~2200 m amsl along the surface water divide (with the Orange River) that forms the south-eastern boundary of the WMA. Land use type in the GRU is dominated by unimproved natural grassland (~65%), followed by cultivated commercial dryland farming (~32%) (**Table 7-1**). The hydrogeological environment represents a moderately productive resource that comprises mainly intergranular-and-fractured (type *d*) aquifers supporting borehole yields in the range 0.5-2 and 2-5 L/s (yield classes *3* and *4* respectively) as described in **Table 2-5**. The town of Paul Roux located ~30 km east of Senekal meets its current water requirement of 0.5 Mm^3/a from five boreholes (WRP, 2011c).

6.3 Synopsis

In summary, it is evident that ~77% of the Middle Vaal WMA is underlain by Karoo Supergroup strata that represent a fractured and intergranular groundwater environment. The remainder is underlain by much older Vaalian (Transvaal Supergroup) Era strata in the extent of 6% associated with carbonate strata (dolomite) of the Malmani Subgroup, and Randian (Witwatersrand and Ventersdorp supergroups) Era strata in the extent of 17% associated with quartzitic and intrusive strata.

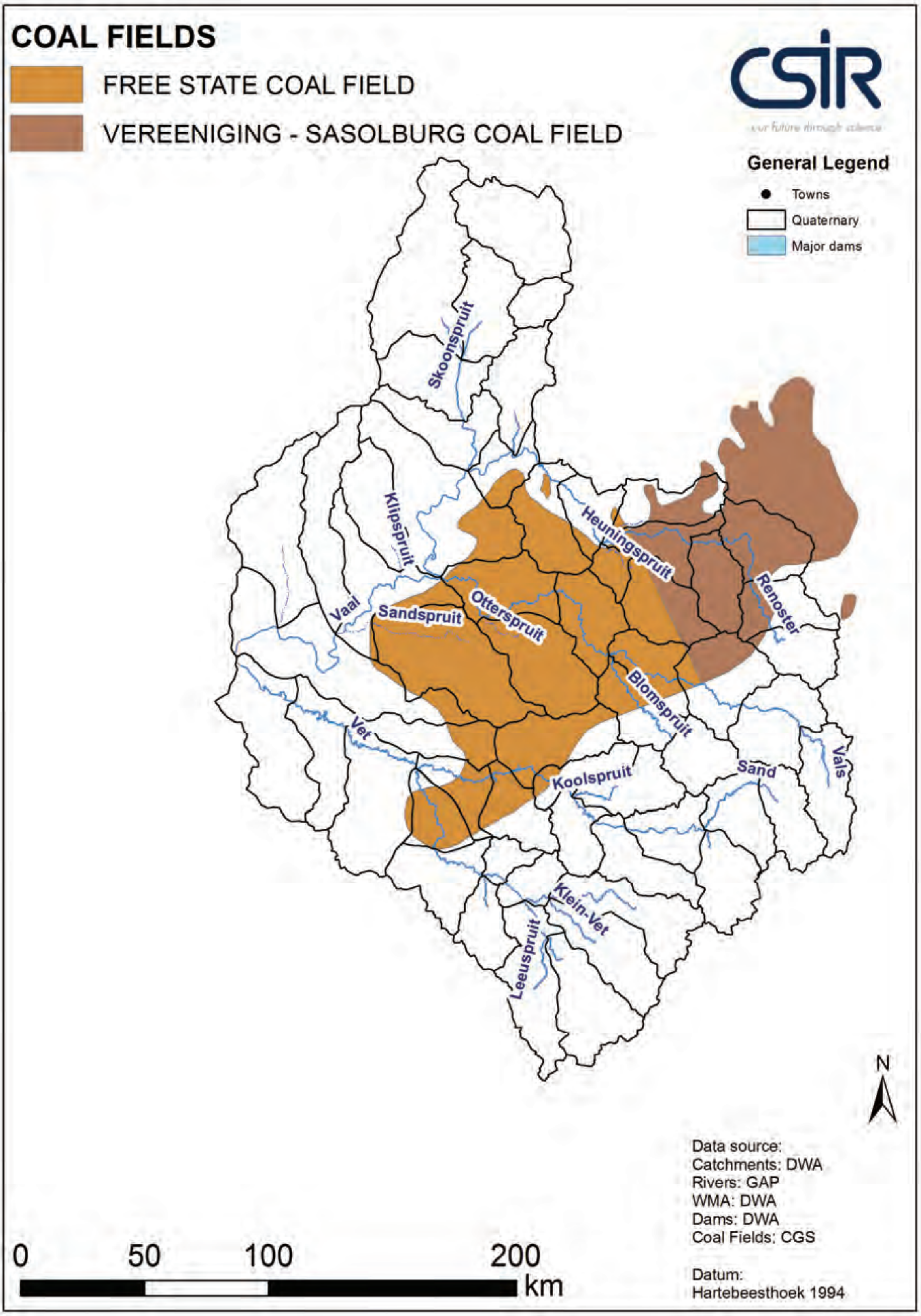

Figure 6-3. Geographic distribution of coal fields in the Middle Vaal WMA

7 DEGREE OF IMPACT AND PRESENT STATUS OF GROUNDWATER RESOURCES

7.1 National Land Cover Data

National land cover maps for South Africa together with hazard ratings with respect to pollution have been used together with groundwater chemistry and groundwater level data to evaluate the degree to which certain areas with a particular type of land cover have been impacted from a groundwater quality and quantity perspective, respectively.

The land use (**Table 7-1**) is made up of forest plantations (mixed spp); bare rock and soil (natural, erosion dongas and gullies); cultivated, temporary, subsistence, dryland and irrigated agriculture; urban/built-up (residential, mixed, hostels, informal township, informal squatter camp, smallholdings); grassland; and commercial, mercantile, industrial (heavy and light transport) and mines and quarries (underground and surface-based mining).

Table 7-1. Dominant land use (%) as per the National Land Cover (NLC) classification in the Middle Vaal WMA

Land Use	Groundwater Resource Unit							
	1a	1b	2	3a	3b	4a	4b	5
Thicket, Bushland, Bush Clumps, High Fynbos	1.93	4.27	3.88	1.10	1.74	1.76	0.71	0.28
Unimproved (natural) Grassland	74.42	66.08	63.02	41.80	53.48	70.38	69.42	64.62
Improved Grassland	0.00	0.23	0.39	0.07	0.00	0.01	0.04	0.01
Forest Plantations (Eucalyptus spp)	0.00	0.32	0.03	0.08	0.02	0.13	0.02	0.17
Waterbodies	0.23	0.73	0.24	1.12	0.45	0.54	0.55	0.13
Wetlands	0.74	1.04	0.90	4.36	1.95	1.35	0.62	0.59
Degraded Unimproved (natural) Grassland	0.00	3.56	0.72	0.34	0.05	0.93	0.13	0.38
Cultivated, temporary, commercial, irrigated	3.76	1.08	0.54	3.17	0.95	1.81	0.56	0.21
Cultivated, temporary, commercial, dryland	18.37	15.76	28.71	46.70	39.93	21.84	26.24	31.90
Urban / Built-up (residential, formal suburbs)	0.00	0.52	0.32	0.22	0.05	0.04	0.31	0.14
Urban / Built-up (residential, formal township	0.43	0.13	0.13	0.16	0.07	0.04	0.12	0.11
Mines & Quarries (mine tailings, waste dumps)	0.00	3.62	0.03	0.35	0.01	0.00	0.00	0.00

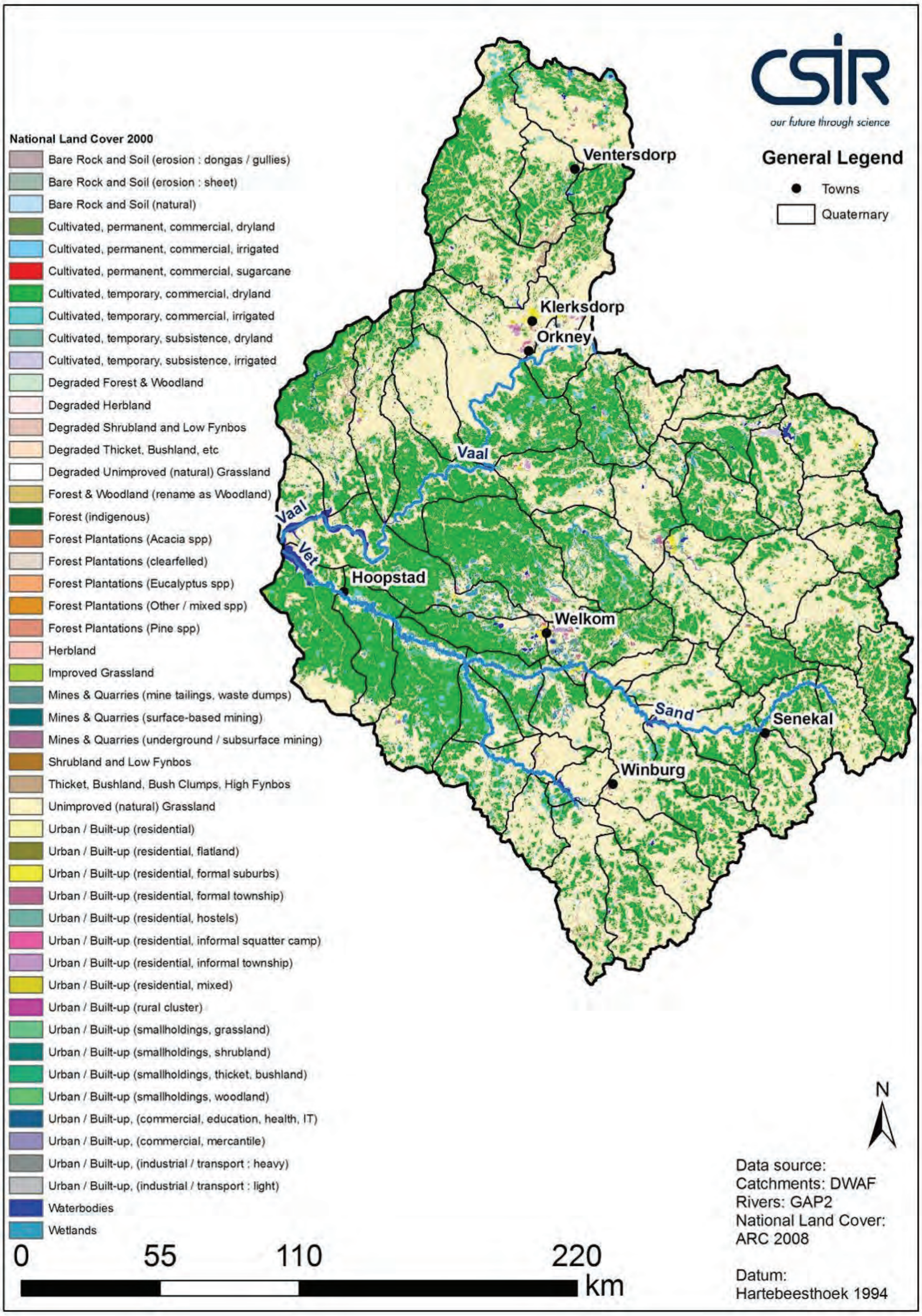

Figure 7-1. National Landcover 2000 for the Middle Vaal WMA (Van den Berg et al., 2008)

7.2 Groundwater Chemistry Trends

All chemistry data for the Middle Vaal WMA was entered into a data base and analysed for trends using AQUACHEM data management software. Each GRU was grouped separately and data further analysed per GRU. Classification of land cover and geology was taken into account. Due to a lack of data, only boreholes with the longest time series were selected for further analyses and indications of trends within the particular GRU, geological unit and land cover type. Period as well as number of records per boreholes in the various GRUs varied. Indicator variables selected were TDS and pH, which provide a general idea of chemistry for the particular area or unit. The plots accompanying the tables show the overall trend for the time record over which the data was collected. A GRU can thus be assessed in terms of water quality and one could comment on whether general water quality improved or deteriorated over time for a specific GRU.

7.2.1 GRU 1a

Only contains a single record hence no time series plot and assessment is possible.

7.2.2 GRU 1b

This GRU contains 29 records, for which most of the samples where more than one was collected, were collected in the same year.

7.2.3 GRU 2

This GRU contains 293 records for chemistry with 170 monitoring points. Of these only eight have time series chemistry data.

BH number	No. of Records	Period	Geology	Land Cover
1000000560	27	2002-2005	Malmani Subgroup	Unimproved natural grasslands
1000000570	38	2002-2007	Rietgat Formation	Unimproved natural grasslands
183311	11	2001-2007	Monte Christo Formation	Unimproved natural grasslands
184662	12	2001-2007	Monte Christo Formation	Unimproved natural grasslands
184686	10	2001-2007	Eccles Formation	Thicket, Bushland
184692	9	2001-2006	Monte Christo Formation	Urban/ built up
184748	8	2001-2006	Eccles Formation	Unimproved natural grasslands
90035	12	1997-2007	Hospital Hill Formation	Cultivated temporary commercial dryland

It was decided to consider the national land cover classification as the over-riding factor with respect to impact on water resources. Hence, boreholes were selected according to land cover with geology as a secondary parameter. The boreholes selected as representative for this GRU include borehole 1000000560 situated in the Malmani Subgroup and within an area containing unimproved natural grasslands, borehole 184692 in the Monte Christo Formation and with national land cover class urban /built up, and borehole 90035 in the Hospital Hill Formation within the cultivated temporary commercial dryland land cover class.

Encompassing ~63% of GRU 2, areas associated with unimproved grasslands (**Figure 7-3**) suggest no adverse impact on groundwater chemistry based on a decreasing trend in TDS concentration (R^2 = 0.68) and a slight increase in pH (R^2 = 0.29) over the 4 years for which data are available.

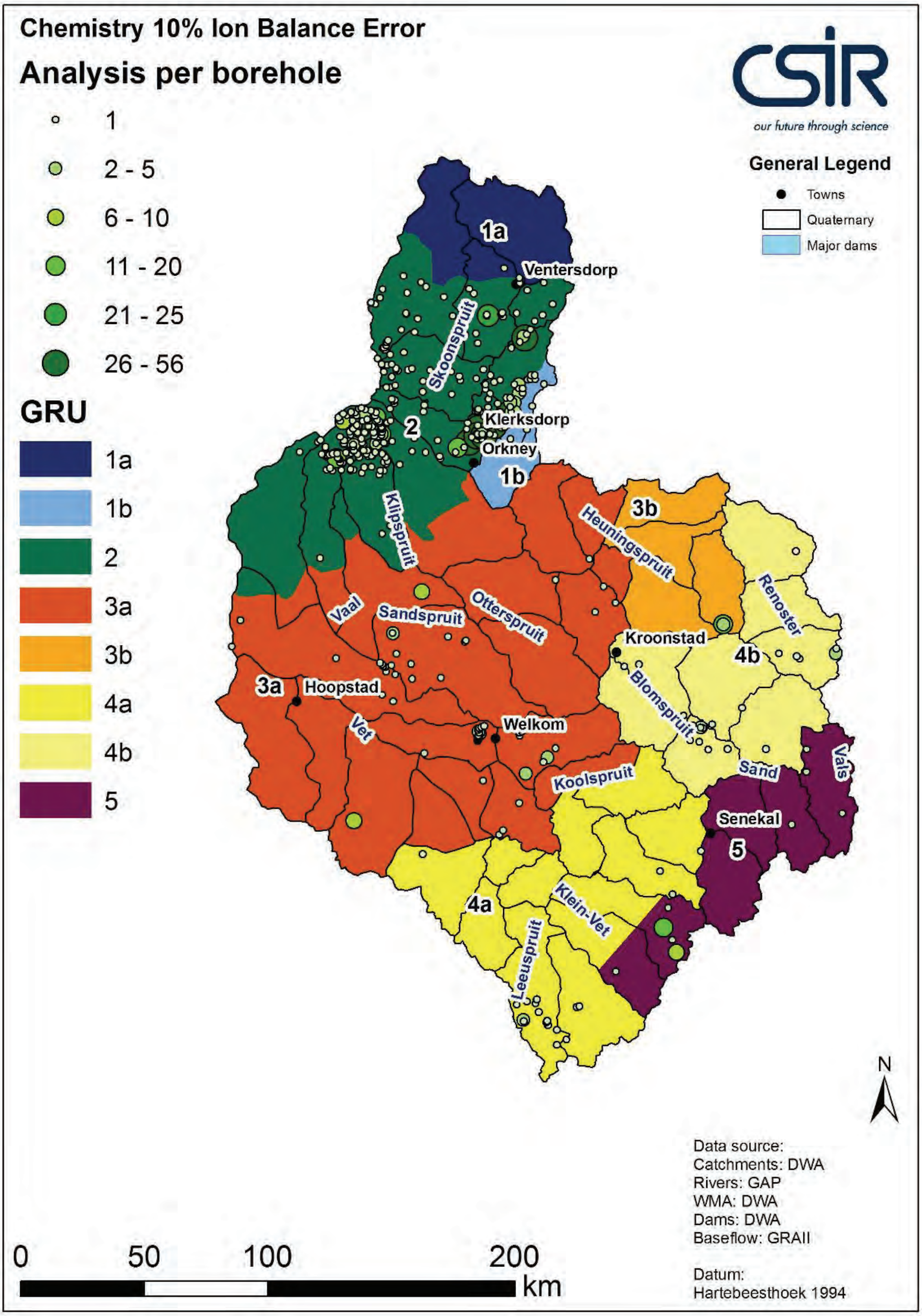

Figure 7-2. Map of the GRUs showing the sampling locations with an ion balance error <10% and the number of samples per station

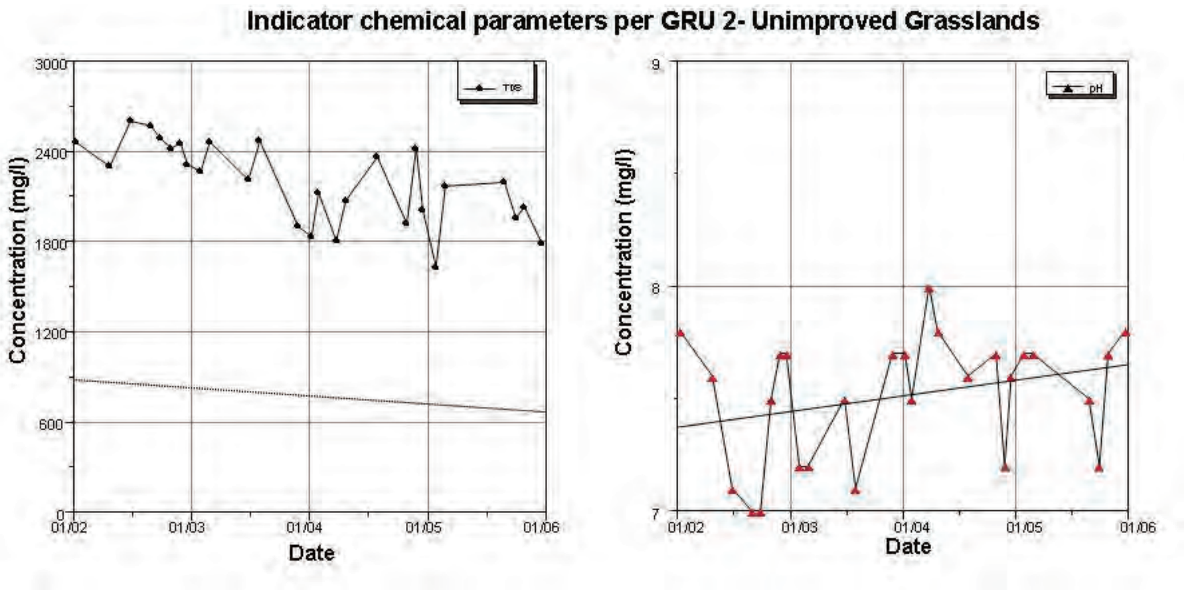

Figure 7-3. *Trend of TDS and pH for unimproved grassland areas in GRU 2*

The groundwater chemistry associated with built-up areas in GRU 2 (**Figure 7-4**) similarly indicates no discernible impact in respect of TDS concentration (R^2 = 0.38) and pH (R^2 = 0.02) in the period 2001-2007. The elevated TDS value in **Figure 7-4** is disregarded as being anomalous.

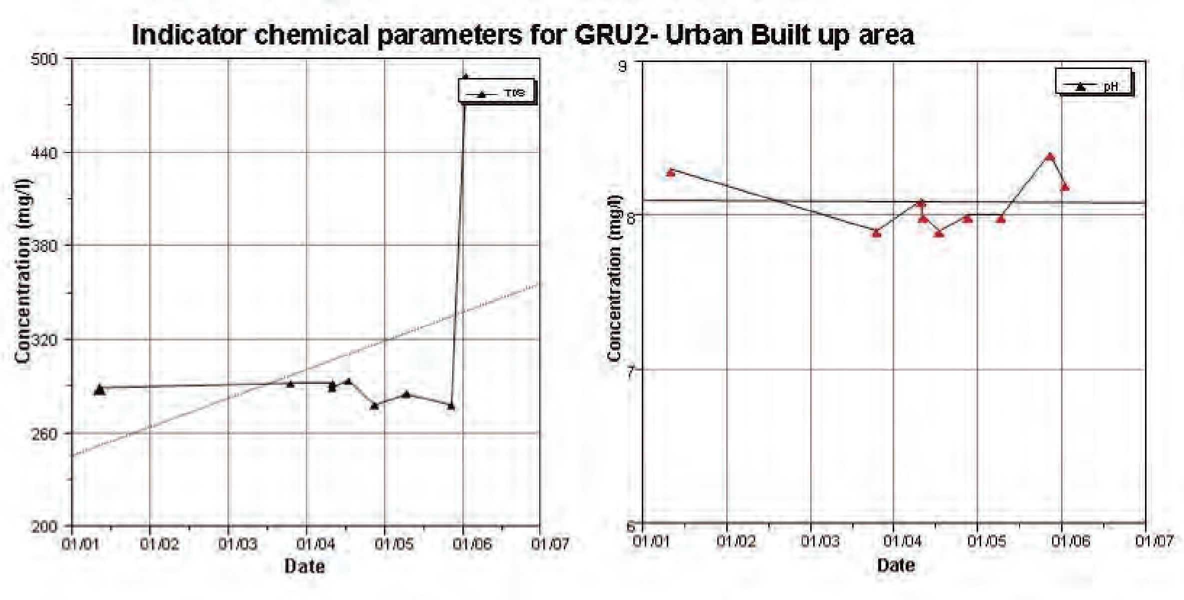

Figure 7-4. *Trend of TDS and pH for urban built up areas in GRU 2*

The groundwater chemistry associated with cultivated temporary commercial dryland in GRU 2 (**Figure 7-5**) also indicates no discernible impact in respect of TDS (R^2 = 0.15) and pH (R^2 = 0.51) in the period 1997-2007. This land cover extends over ~29% of GRU 2.

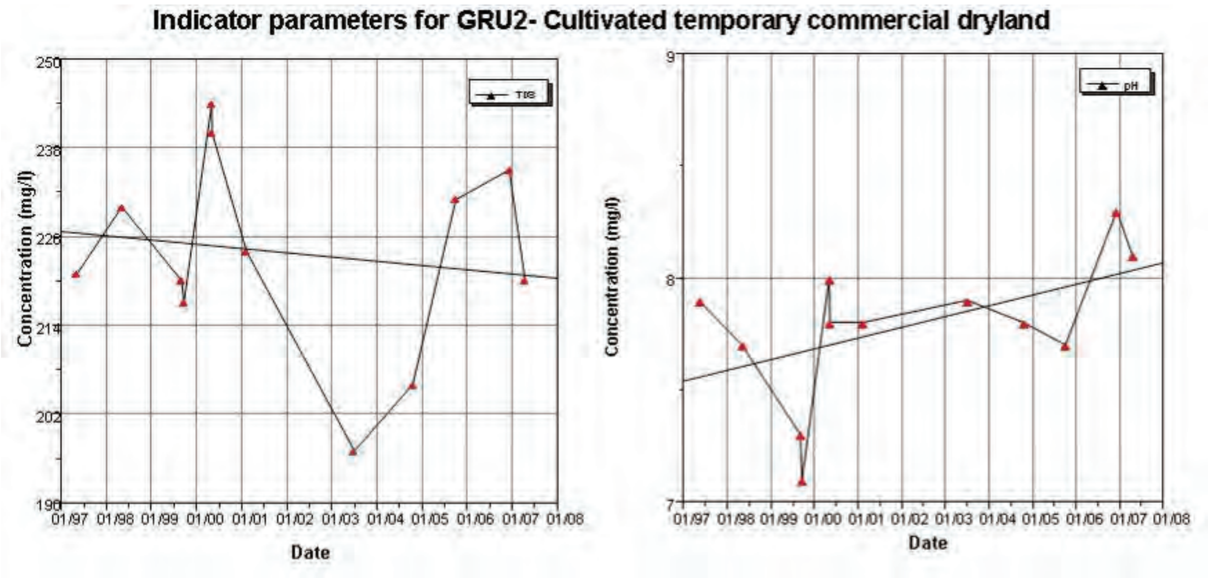

Figure 7-5. Trend of TDS and pH for cultivated temporary commercial dryland areas in GRU 2

7.2.4 GRU 3a

Station 182740, located in unimproved grassland that spans ~42% of this GRU, indicates a TDS of ~1200 mg/L and a slight decline in pH in the period 2000-2004.

BH number	No. of records	Period	Geology	Land Cover
182740	7	2000-2004	Karoo Dolerite	Unimproved grasslands

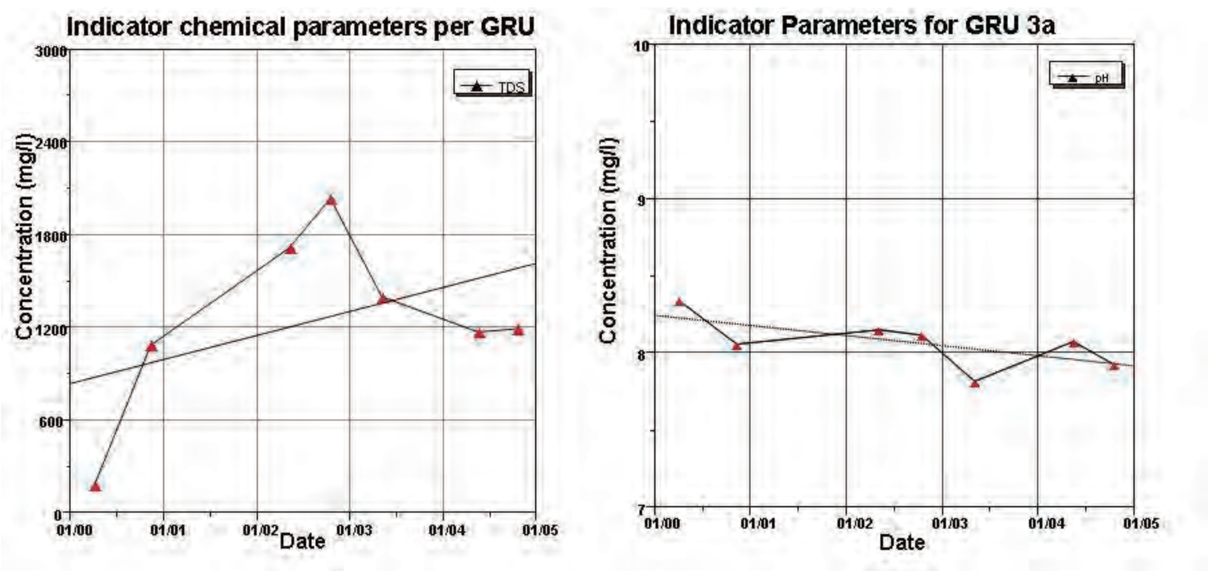

Figure 7-6. Trend of TDS and pH for unimproved grassland areas in GRU 3a

7.2.5 GRU 3b

Station 184430, located in unimproved grassland that spans ~53% of GRU 3b, indicates a gradually increasing TDS concentration (R^2 = 0.54) and a relatively constant pH in the period 2001-2007.

BH number	No. of records	Period	Geology	Land Cover
184430	10	2001-2007	Normandien Formation	Unimproved grasslands

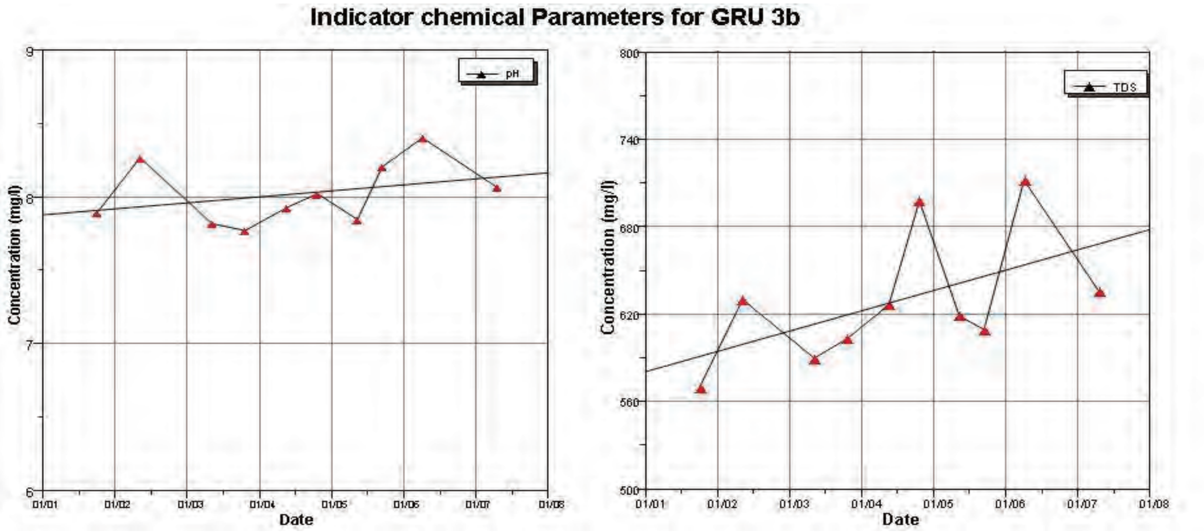

Figure 7-7. Trend of TDS and pH for GRU 3b under unimproved grasslands

7.2.6 GRU 4

None of the 18 groundwater chemistry monitoring stations in GRU 4a supports a time series data set.

Similarly none of the 18 monitoring stations in GRU 4b, with a combined data set of 20 analyses, provides the opportunity to assess groundwater chemistry trends in this GRU.

7.2.7 GRU 5

Varying landcover and geology warranted the plotting of TDS and pH for both boreholes in this GRU that had time series data.

BH number	No. of records	Period	Geology	Land Cover
184204	5	2001-2003	Alluvium	Unimproved grasslands
90114	9	1995-1999	Tarkastad Subgroup	Wetlands

The area under unimproved grasslands shows a marginal increase in TDS concentration (R^2 = 0.32) , while the pH trend exhibits a consistent decrease (R^2 = -0.58) in the period of record.

A positive slope of the regression line (R^2 = 0.81) indicates a significant increase in TDS concentration over the 5 year record for the area under wetlands, this agrees with the results of pivot table analysis using chemistry and land cover data. A slight decrease in the pH level (R^2 = -0.32) occurs over the same period of record.

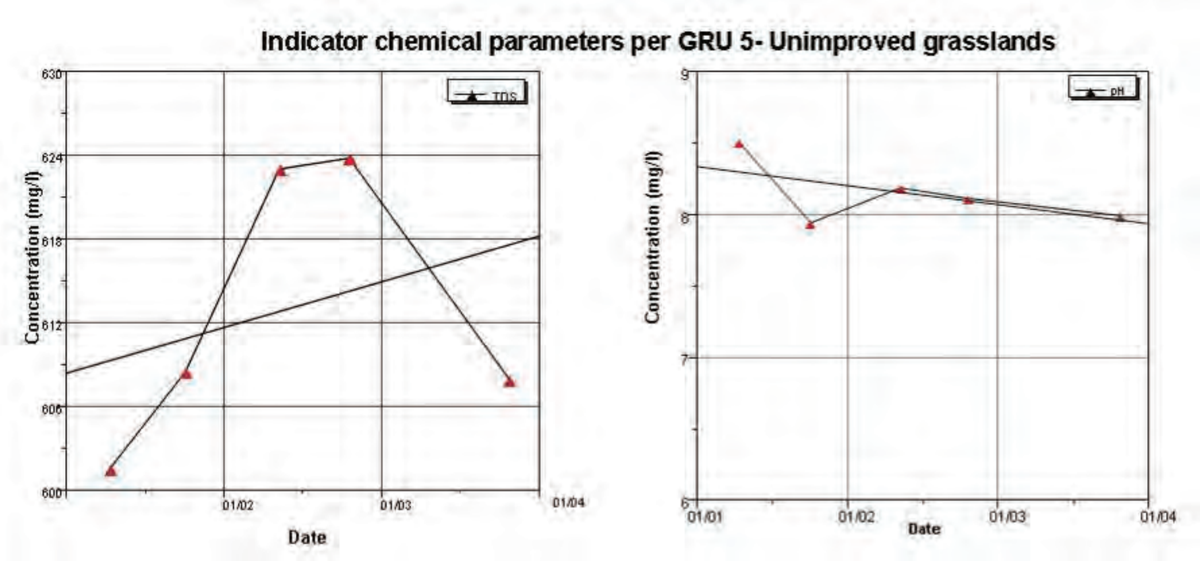

Figure 7-8. Trend of TDS and pH for unimproved grassland areas in GRU 5

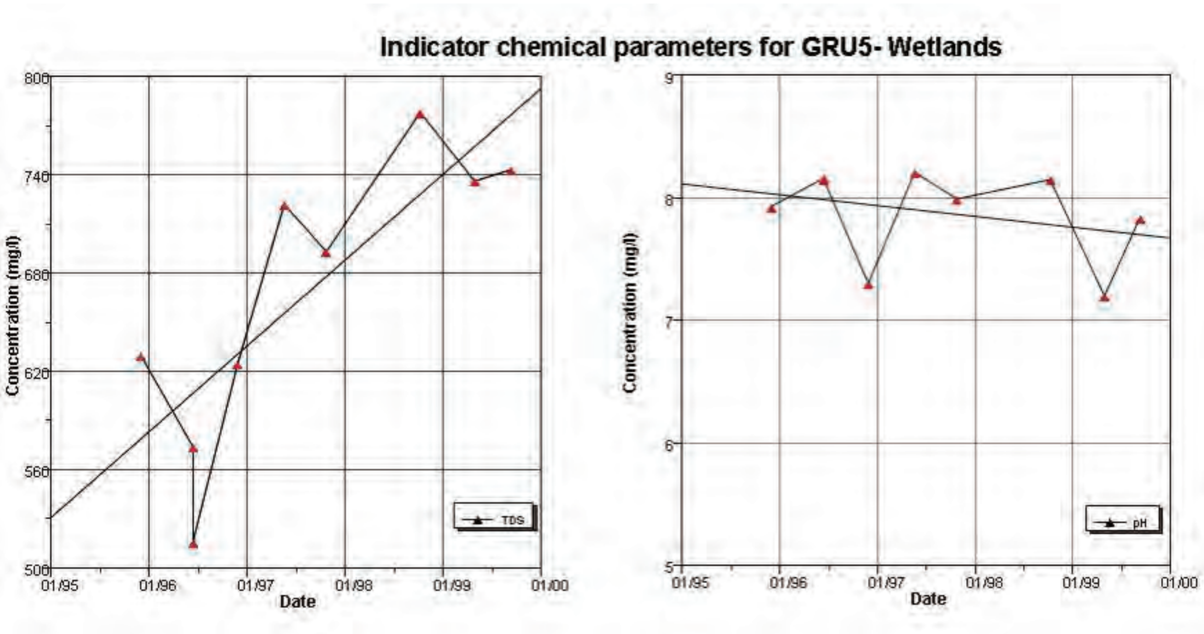

Figure 7-9. Trend of TDS and pH for wetland areas in GRU 5

7.3 Microbiological Quality

There are 976 boreholes listed in the DWA microbiological monitoring database. None of these, however, have any data for the study area. It would appear that more focus is placed on the active sampling of surface water and other pathways linked to this source, e.g. wastewater treatment works, pipelines, etc.

Additional sampling was proposed for *E. Coli* and Total Coliforms for the Middle Vaal area. Selected sites were close to rural villages in the study area. Sampling of six sources (**Table 7-2**) was undertaken on 05 March 2010 to obtain an indication of bacteriological water quality for the area.

The selected sites were located in close proximity to sources of potential pollution that might threaten local groundwater resources. The tap/pump was allowed to run for two minutes before sampling. Only taps at the wellhead were sampled where possible. In instances where no immediately proximal access was available, the closest tap was sampled. The sampling container cap was fitted immediately and tightened well. No preservatives were added to the sample. The tightly closed and properly labelled sample bottle was placed immediately in a cooler box with ice. The cooler box was kept out of direct sunlight. All samples were taken in duplicate for the purposes of testing the accuracy and precision of the laboratory method. The samples were delivered to the Rand Water laboratory on the same day of sampling for analysis.

7.3.1 Khutsong

The immediate surroundings of this location is natural unimproved grasslands, while other land uses include an informal rural settlement with some farming of cattle and maize. The sampled borehole is in constant use as a water supply borehole to the community. The field variable values and microbiological analysis results are presented in **Table 7-2**. These indicate a comparatively elevated salinity of ~138 mS/m and an unacceptably high total coliform concentration of 236 counts/100 mL. It is possible that these values together indicate a measure of impact on the ambient groundwater quality at this location. It is therefore imperative that the quality of this groundwater source be monitored frequently.

7.3.2 Goedgevonden

The immediate surroundings of this location are similar to those of Khutsong (**section 7.3.2**). The sampled borehole is similarly in constant use as a water supply borehole to the community. The field variable values and microbiological analysis results are presented in **Table 7-2**. The comparatively elevated salinity of ~153 mS/m is considered to be natural under circumstances where the bacteriological quality is acceptable. Nevertheless, the strategic water supply function of the borehole dictates that the quality of this groundwater source be monitored frequently.

7.3.3 Welgevonden

The immediate surroundings of this location and use of the borehole are similar to those of Khutsong (**section 7.3.2**) and Goedgevonden (**section 7.3.2**). The sample was collected at a tap ~50 m from the borehole. The field variable values and microbiological analysis results are presented in **Table 7-2**. The comparatively elevated salinity of ~168 mS/m is again considered to be natural under circumstances where the bacteriological quality is acceptable (**Table 7-2**). Nevertheless, the strategic water supply function of the borehole dictates that the quality of this groundwater source be monitored frequently.

7.3.4 Blinkwater

The site supports a low density informal settlement and farming community with cattle and maize farming being practised. Other land uses in the area include natural grasslands. The sample was collected from a windpump ~3 m above ground level. The field variable values and microbiological analysis results are presented in **Table 7-2**. The results do not give rise to undue concern for the bacteriological quality of the water, even though the total coliform count of 20 per 100 mL exceeds the SANS (2011a) guideline of 5 per 100 mL.

7.3.5 Stilfontein

The location is a farm with some farm buildings and a cattle pen adjacent to the site. Surrounding land use activities include mining, informal settlements and cattle farming. The sample was collected 200 m away from a pipe connected to the borehole. The field variable values and microbiological analysis results are presented in **Table 7-2**. The results do not give rise to concern for the bacteriological quality of the water.

7.3.6 Parys

This location is a guest house which is entirely dependent on the groundwater sourced from the local borehole. The surrounding land use activities include farming and natural grasslands. The sample was collected from a tap connected to the borehole. The field variable values and microbiological analysis results are presented in **Table 7-2**. Again the results do not give rise to concern for the bacteriological quality of the water. In fact, the very low salinity suggests that the groundwater might have an aggressive character due to poor buffering associated with a lack of alkalinity.

Table 7-2. Results of microbiological analyses

Sample Location	Sample Date	Field Variable Value			*E. Coli*(1) (count/100 mL)	Total Coliform(2) (count/100 mL)
		pH	EC (mS/m)	Temp. (°C)		
Parys	05/03/2010	7.0	5.9	22.2	0	2
Blinkwater	05/03/2010	7.2	19.8	20.6	0	20
Stilfontein	05/03/2010	7.6	19.4	25.2	0	5
Welgevonden	05/03/2010	7.2	167.5	22.4	0	1
Khutsong	05/03/2010	7.5	138.3	19.8	0	236
Goedgevonden	05/03/2010	7.3	152.9	20.5	0	1

(1) Standard limit =0 (SANS, 2011a)
(2) Standard limit =≤10 (SANS, 2011a)

7.3.7 Discussion

The bacteriological quality of groundwater is dependent on site-specific land use activities, and it is therefore problematic to gauge this hydrochemical property for an extensive area on the basis of only a few analyses. Nevertheless, the nil *E. coli* values returned for each of the six sampling sites is an encouraging indication that bacteriological contamination from faecal pollution is not evident at these localities.

7.4 Hydrochemical Characterisation per Tertiary Catchment

The data set was grouped according to the catchment area in which it was located. This was analysed with respect to minimum, mean and maximum concentrations of chemical water quality variables for a specific catchment (**Table 7-3**). Trilinear Piper diagrams were constructed to identify the dominant groundwater type(s) per Tertiary catchment and to examine the extent to which these may differ for the respective catchments. Data were separated according to date to evaluate whether earlier (pre-1985) and more recent (post-1990 or, where available, post-2000) data indicate any significant difference or change in water type. This was done to ascertain whether any impacts from known land use activities in the catchment areas could be observed in the water compositions.

Table 7-3. Salient statistical data for selected groundwater chemistry variables per tertiary catchment

Tertiary Catchment	**Chemistry Variable**						**Statistical Parameter**
	N	**pH(1)**	**EC(2) (mS/m)**	**SO_4(3) (mg/L)**	**NO_3(4) (mg N/L)**	**F(5) (mg/L)**	
C24	919	**2.0**	8.4	<4	0.02	0.05	Minimum
		7.8	86.5	226.4	5.9	0.16	Mean
		11.0	**840**	**3070.4**	**58.1**	**9.4**	Maximum
C25	25	6.9	21.4	<4	0.02	0.05	Minimum
		8.3	**175.8**	136.1	2.4	1.4	Mean
		11.3	**1162**	**903.9**	**20.3**	**4.5**	Maximum
C41	31	7.2	24.2	4.4	0.02	0.2	Minimum
		8.1	72.3	24.8	5.1	0.45	Mean
		8.5	107	47	**22.9**	1.1	Maximum
C42	25	7.2	33	<4	0.02	0.05	Minimum
		8.0	103.5	67.3	8.3	0.66	Mean
		8.9	**280**	209.4	**67.8**	**2.5**	Maximum
C43	16	7.0	23.6	11.7	0.2	0.1	Minimum
		7.9	124.9	127.4	3.4	0.32	Mean
		8.4	**311**	314.8	**16.5**	0.49	Maximum
C60	22	7.0	7.7	<4	0.02	0.12	Minimum
		8.0	89	101.6	4.7	0.59	Mean
		8.5	**309**	**790**	**22.7**	**2.3**	Maximum
C70	17	7.4	50	14.5	0.1	0.16	Minimum
		8.0	83.9	59.1	7.0	0.76	Mean
		8.6	**195**	103.1	**54.8**	**1.8**	Maximum

(1) SANS (2011a) Standard limit =≥5 to ≤9.7
(2) SANS (2011a) Standard limit =≤170
(3) SANS (2011a) Standard limit =≤500
(4) SANS (2011a) Standard limit =≤11
(5) SANS (2011a) Standard limit =≤1.5

It is evident from **Table 7-3** that the maximum values generally far exceed the mean values of the respective variables. This is particularly true in catchments C24 and C25 where land use is dominated by cultivated agriculture and mining activities. The latter is the most likely source of the lowest pH value of 2 observed in catchment C24. It is therefore not surprising that catchments C24 and C25 attract the greatest concern for the impact on groundwater chemistry. The remainder of the study area, including catchments C42 and C43 that host a portion of the Free State Gold Field, reflects a significantly lower risk in this regard.

7.4.1 Catchment C24

An inspection of **Figure 7-10** indicates the existence of earlier (pre-1980) data only for three quaternary catchments (excluding C24A) which are represented in the more recent (post-2000) data set. The dominance of a Ca-HCO_3 chemical composition over time in these catchments is evident, suggesting little if any change (impact) from land use activities on the ambient groundwater chemistry. The recognition of an additional CaMg-SO_4 groundwater type in catchments C24A and C24B in the post-2000 data set reflects the impact of mining activities centred on the Klerksdorp (KOSH area) Gold Field. This is highlighted as a result of the attention more recently afforded acid mine drainage, prompting the significantly greater focus placed on monitoring the extent and impact of this threat on water resources.

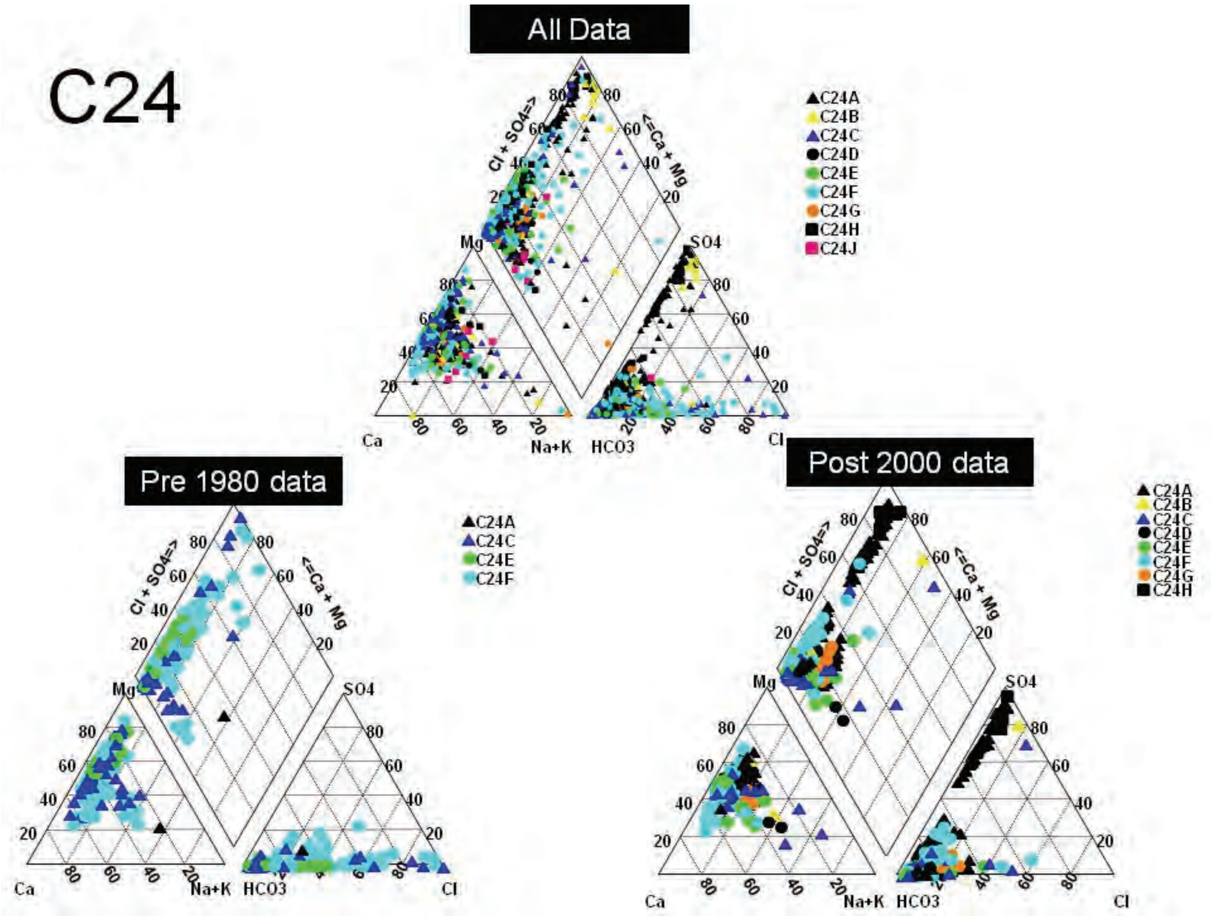

Figure 7-10. Trilinear diagram of groundwater chemistry associated with Tertiary catchment C24

7.4.2 Catchment C25

Figure 7-11 indicates the mutual existence of pre-1980 and post-2000 data for only two quaternary catchments. These reveal the earlier occurrence of both a Ca-HCO_3 and a CaMg-SO_4 type groundwater. The latter is not evident in the post-2000 data set, which is characterised by both a Na-HCO_3 and a Na-Cl type groundwater especially in catchment C25B. The reason for this apparent change in ambient groundwater chemistry is not clear, although the extensive cultivated agriculture practised in this catchment might be manifesting itself as a gradual soil salinisation impact that is transported into typically shallow groundwater resources. It is shown in section 7.5.3.1 (**Table 7-8**) that although the median depth to groundwater level in quaternary catchment C25B is ~26 m bs, this groundwater parameter typically occupies a shallower depth in the range 7-16 m bs within the C2 Secondary catchment portion of GRU 3a.

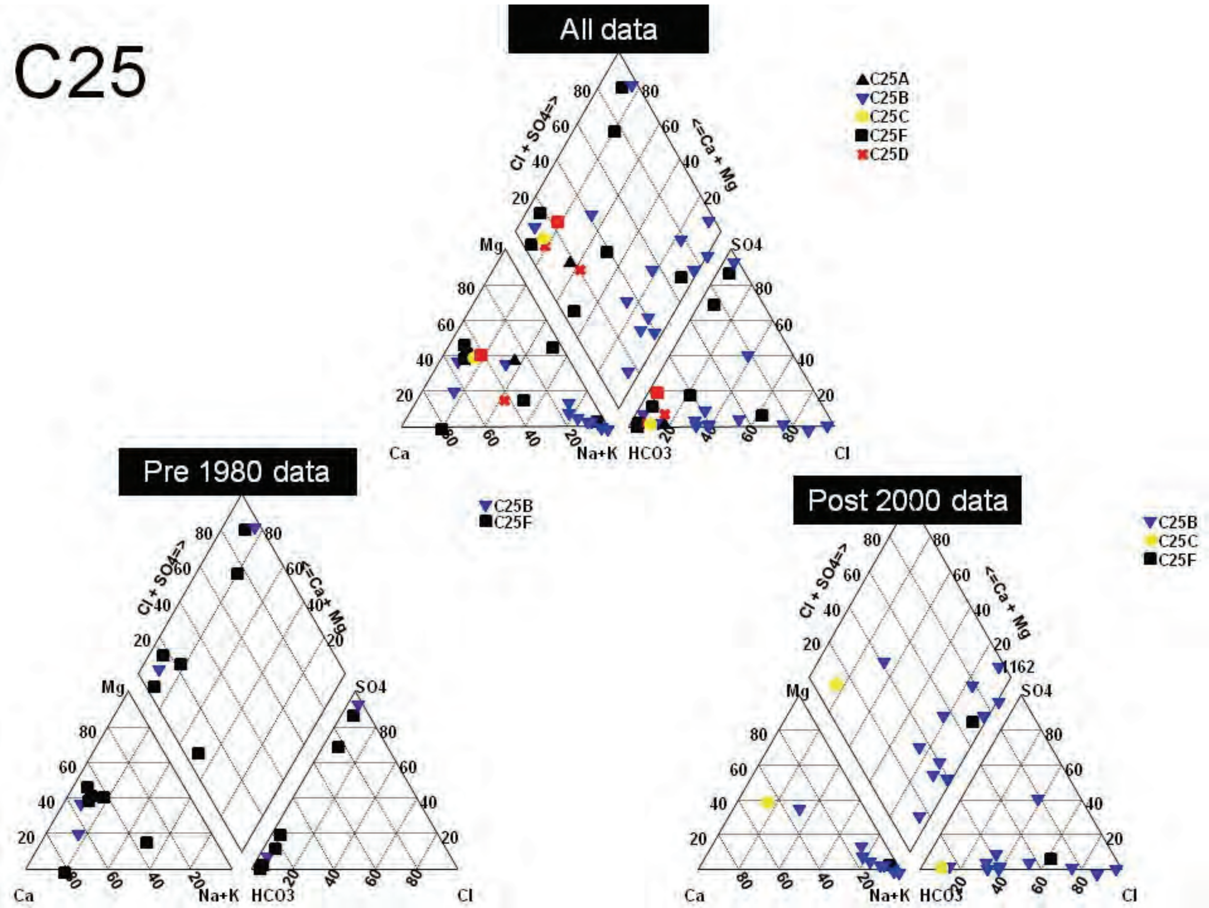

Figure 7-11. Trilinear diagram of groundwater chemistry associated with Tertiary catchment C25

7.4.3 Catchment C41

This catchment is characterised by a dearth of early (pre-1985) and more recent (post-2000) groundwater chemistry data (**Figure 7-12**), the bulk of the information being associated with the period in between. The extremely limited early and recent data do not indicate a change in the Na-HCO_3 character of the groundwater over time.

7.4.4 Catchment C42

Catchment C42 is similarly characterised by a dearth of early (pre-1980) and more recent (post-1990) groundwater chemistry data (**Figure 7-13**). It is also evident that the early and recent data sets do not have a quaternary catchment in common, which precludes an assessment of possible changes in ambient groundwater chemistry over time. The significant variation in chemical composition that characterises the full set of data associated with quaternary catchment C42J encompassing the area to the west of Welkom supports the futility of an attempt at such assessment.

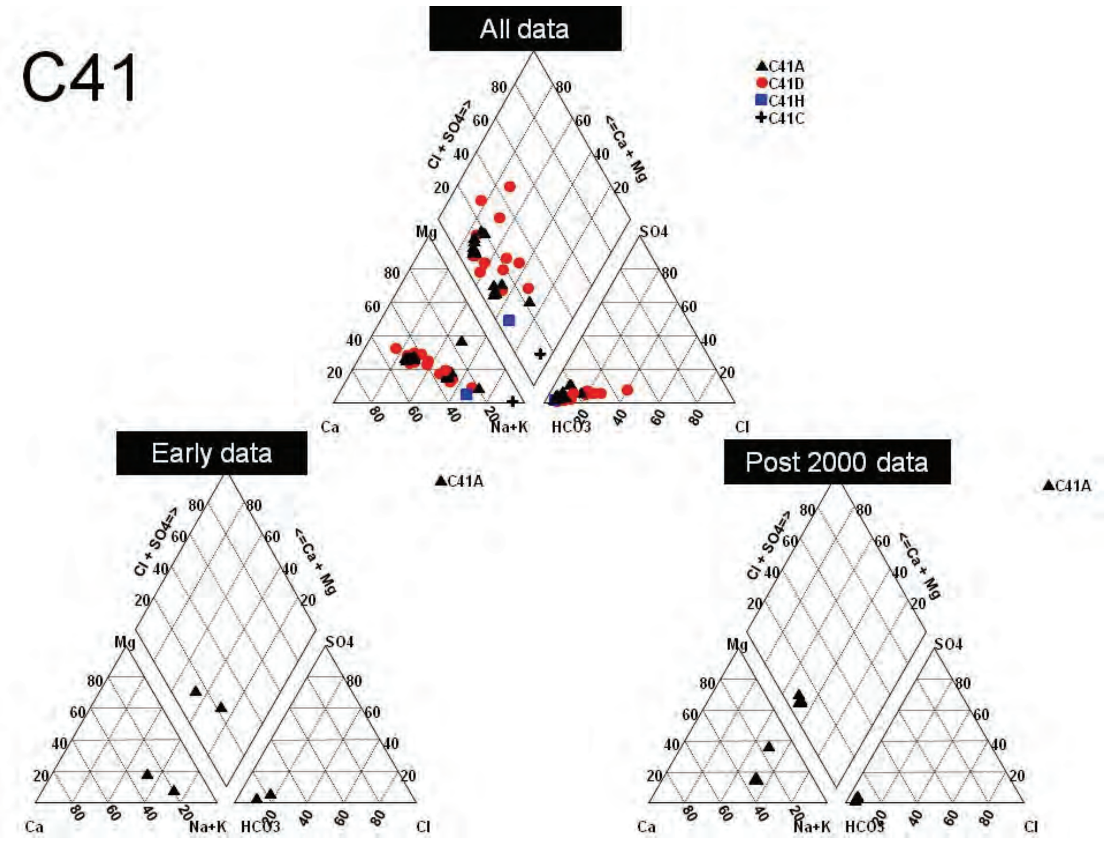

Figure 7-12. Trilinear diagram of groundwater chemistry associated with Tertiary catchment C41

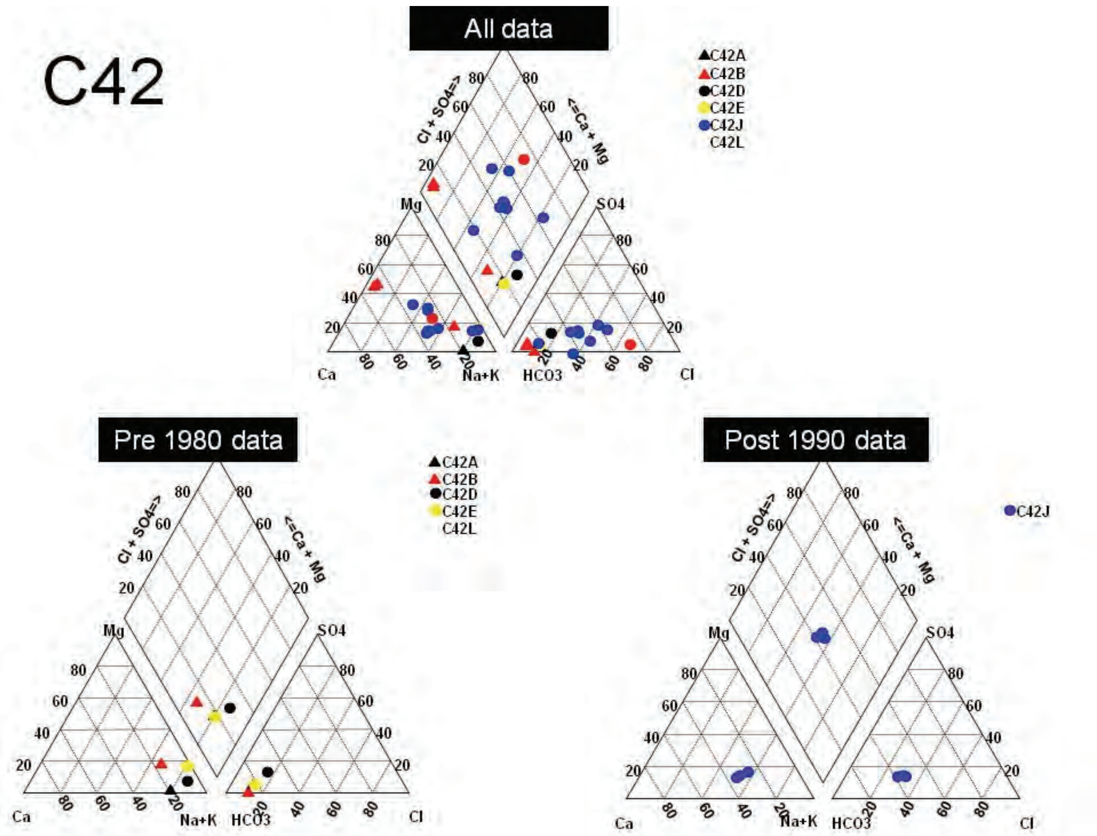

Figure 7-13. Trilinear diagram of groundwater chemistry associated with Tertiary catchment C42

7.4.5 Catchment C43

Figure 7-14 indicates the disparity between pre-1986 and post-2000 data for Tertiary catchment C43. The quaternary catchments C43A and C43B in GRU 3a span the middle reaches of the Vet River to the west and south-west of Welkom. There is no cause to infer any relationship between the observed earlier Ca-HCO_3 character of the groundwater in C43B with the more recent Ca-Cl character of the groundwater in C43A.

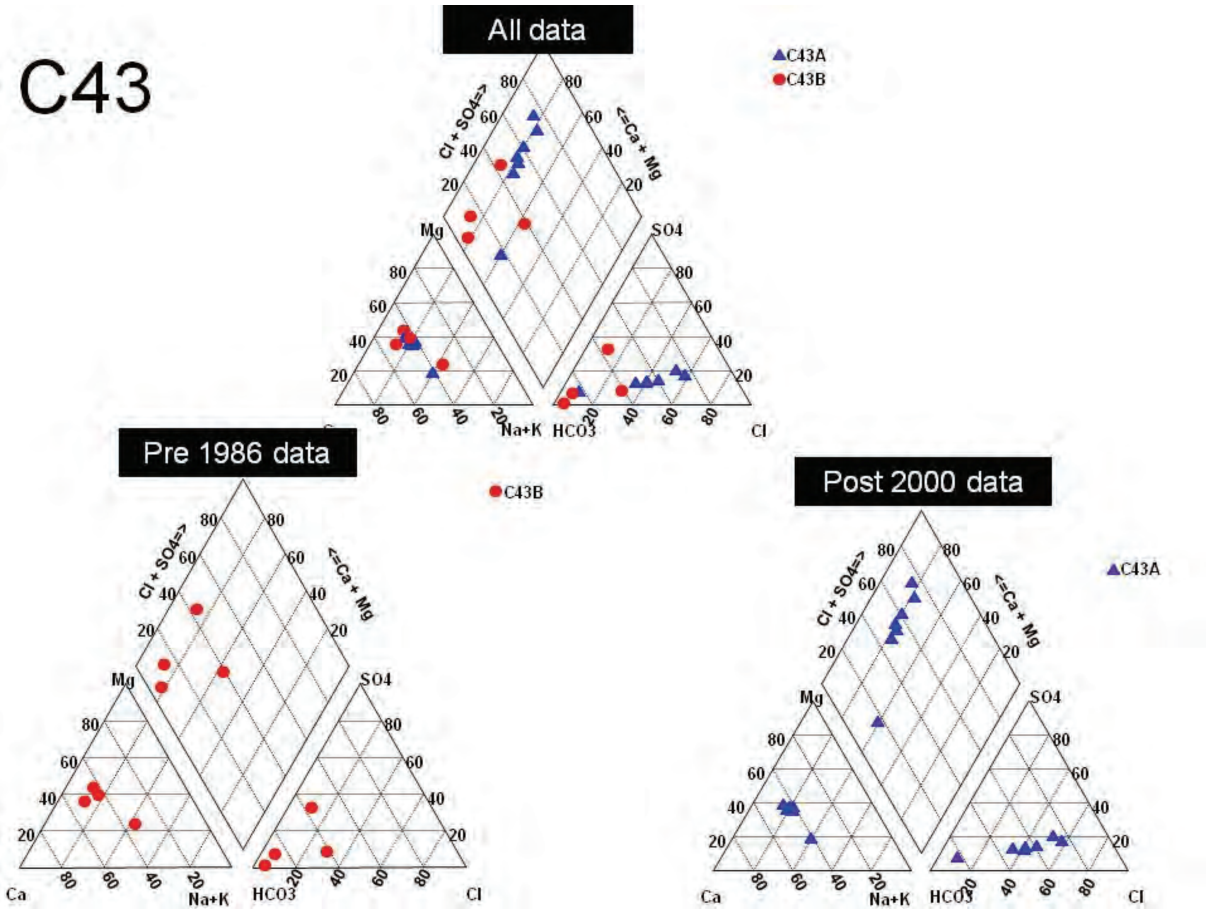

Figure 7-14. Trilinear diagram of groundwater chemistry associated with Tertiary catchment C43

7.4.6 Catchment C60

The data sets presented in **Figure 7-15** do not provide a means to compare early and more recent groundwater chemistry associated with this catchment. The diagrams do, however, serve the purpose of illustrating the general dominance of a NaMg-HCO_3 type groundwater chemistry that characterises this catchment.

7.4.7 Catchment C70

As in the case of catchment C60, the data sets presented in **Figure 7-16** do not provide a means to compare early and more recent groundwater chemistry associated with this catchment. Nevertheless, the diagrams similarly illustrate the general dominance of a Na-HCO_3 type groundwater chemistry that characterises this catchment.

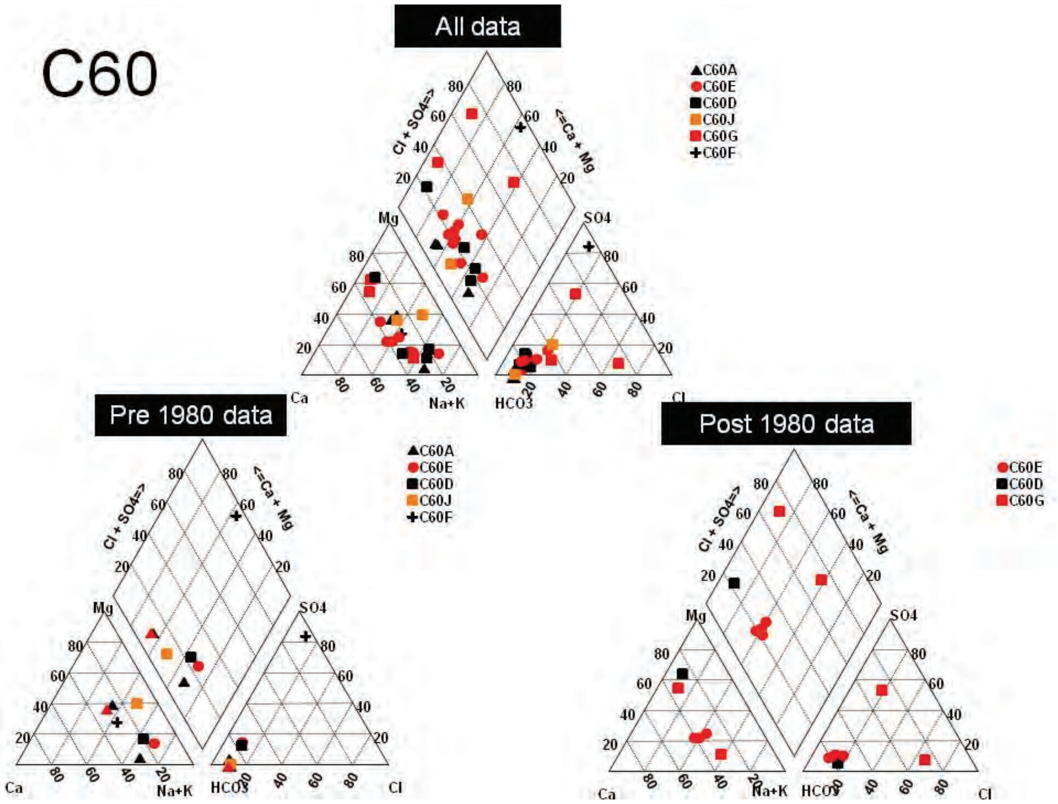

Figure 7-15. Trilinear diagram of groundwater chemistry associated with Tertiary catchment C60

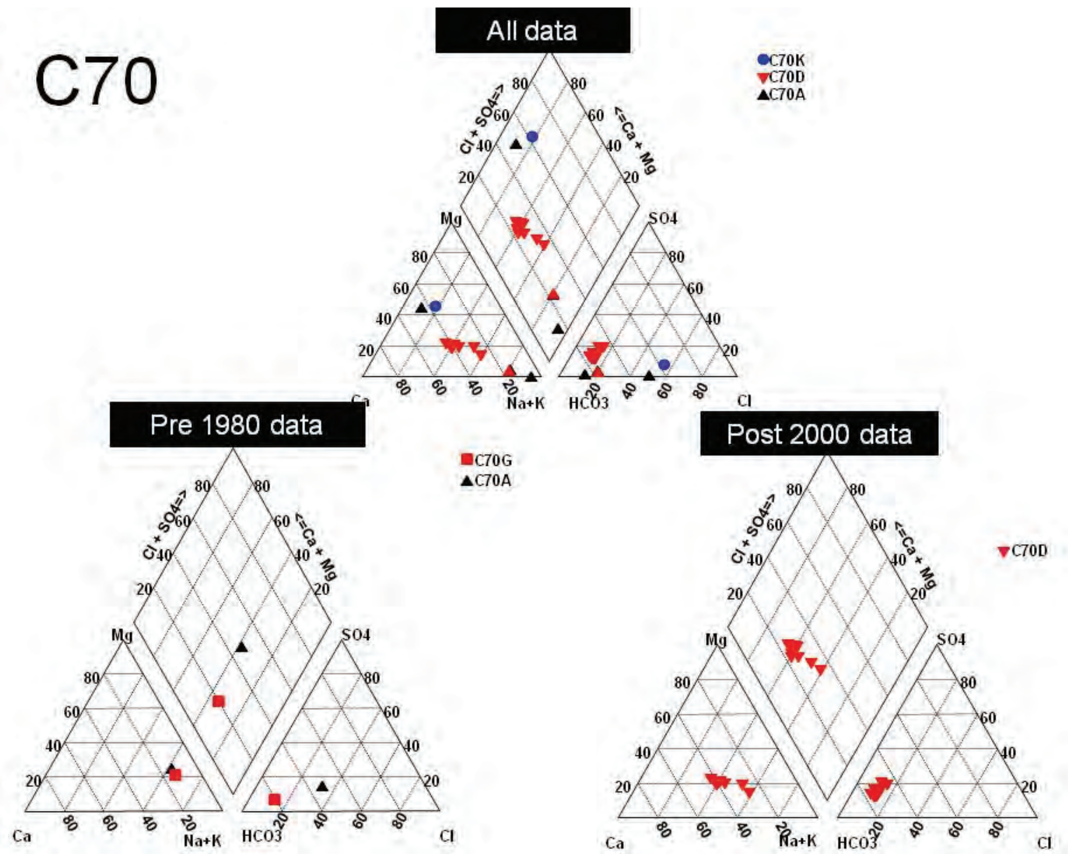

Figure 7-16. Trilinear diagram of groundwater chemistry associated with Tertiary catchment C70

7.5 Groundwater Level Evaluation

Groundwater level data were obtained from the DWAs National Groundwater Database (NGDB) for all the enumerated boreholes located in the study area. Due to the size of the data set, it was decided to only analyse stations supporting >100 records and which spanned a measurement period of >10 years. A summary of this data set is presented in **Table 7-4**, and reveals a comparative dearth of long-term records for all except GRUs 1a and 1b. The distribution of these stations is shown in **Figure 7-18**, which confirms the bias of hydrogeologic monitoring in favour of karst terrains. These records were interrogated to identify possible impacts, mainly anthropogenic, on the groundwater level in the study area. The data are presented per GRU in **Appendix A**. A synthesis of groundwater level data statistics for each GRU is presented in **Figure 7-17**.

Table 7-4. Summary of available long-term groundwater water level data per GRU

GRU	Number of Stations	Number of Stations with >100 records
1a	884	20
1b	220	61
2	3354	2
3a	163	0
3b	16	0
4a	30	0
4b	287	5
5	72	0
Total	5026	88

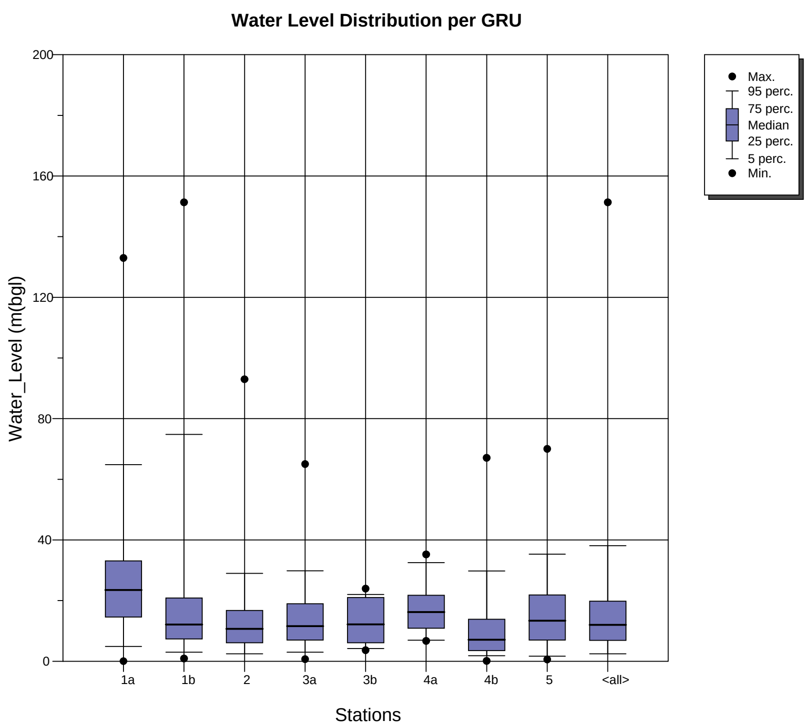

Figure 7-17. Groundwater level statistics per GRU based on mean water level reading per station for the complete record

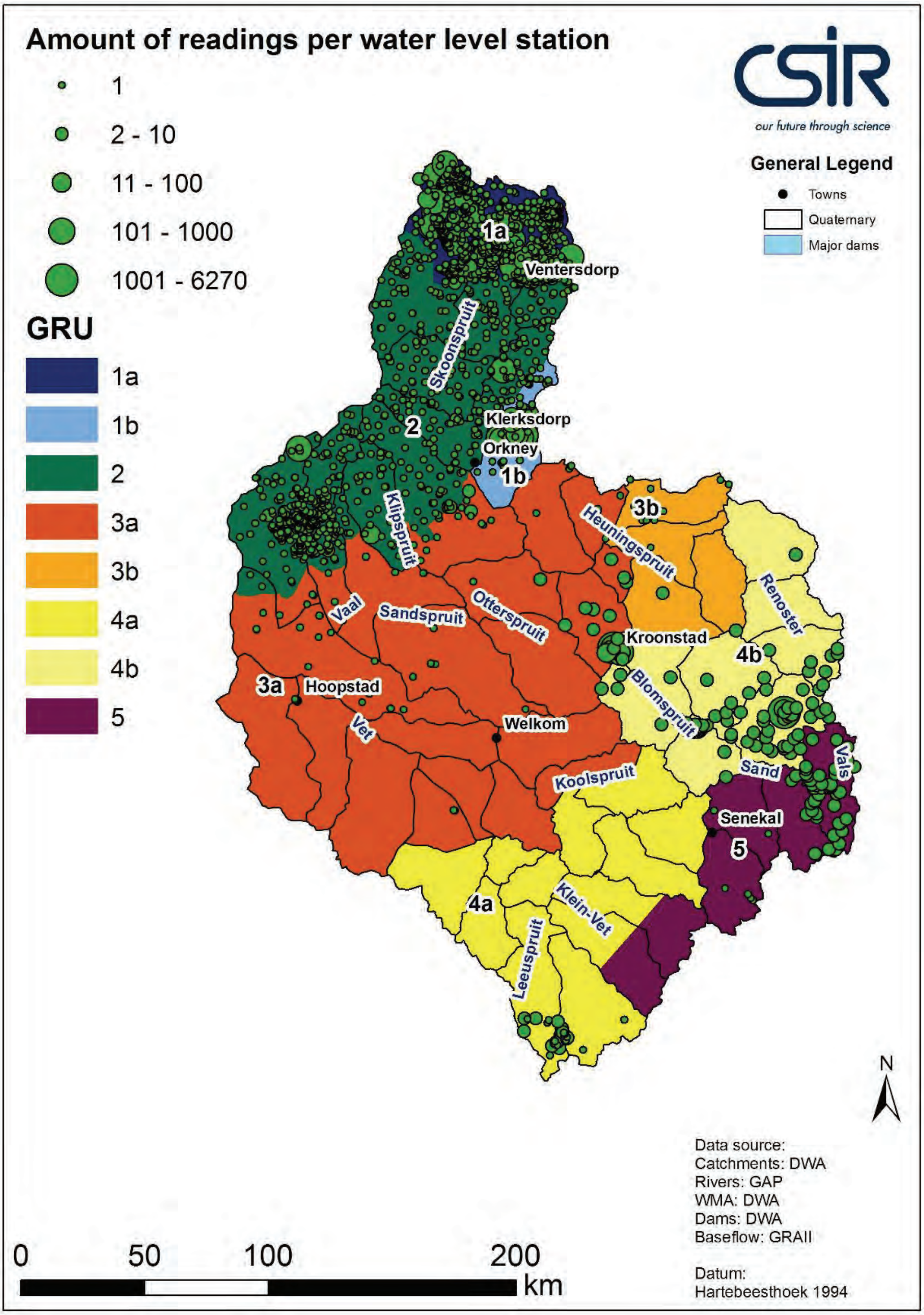

Figure 7-18. Distribution and volume of groundwater level data in the study area

The information presented in **Figure 7-17** indicates a relatively shallow mean depth (<15 m) to groundwater level in all GRUs except GRU 1a (~25 m). This is associated with the karst environment that forms this GRU, and confirms the common observation that the water table in a dolomitic aquifer does not follow the Bayesian relationship to land surface that characterises this hydrogeologic parameter in other groundwater environments.

7.5.1 GRU 1

7.5.1.1 GRU 1a

Summary statistics for groundwater level data associated with GRU 1a per quaternary catchment are presented in **Table 7-5**. A graphical illustration of this information is shown in **Figure 7-19** which confirms the earlier observation that the occurrence of relatively deep groundwater levels in GRU 1a is particularly prevalent in quaternary catchment C24C, which fully encompasses dolomitic strata.

Table 7-5. Summary statistics for groundwater level data associated with GRU 1a per quaternary catchment

Quaternary	N	Minimum	Median	95%ile	Maximum	Range
C24C	521	0.55	26.1	69.6	133	132.5
C24E	106	1.6	18.1	37.8	44.4	42.9
C24F	257	0.03	21.3	42.3	70.1	70.1

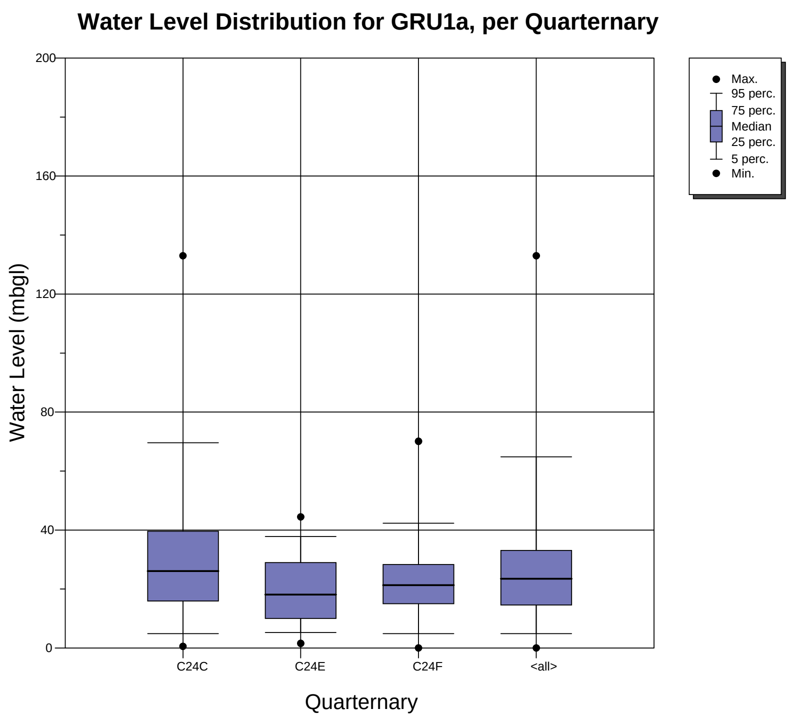

Figure 7-19. Groundwater level statistics for GRU 1a per quaternary catchment

Station 2626BB00165 in GRU 1a reflects a long-term decline in groundwater rest level amounting to ~9 m in the period 1990-2005 (**Figure 7-20**). The substantial high-frequency fluctuation evident in the record since 1994 reveals the impact of abstraction on the groundwater level at this location. The declining water table trend, however, highlights the sensitivity of karst resources to over-exploitation and, therefore, the need for monitoring of these resources.

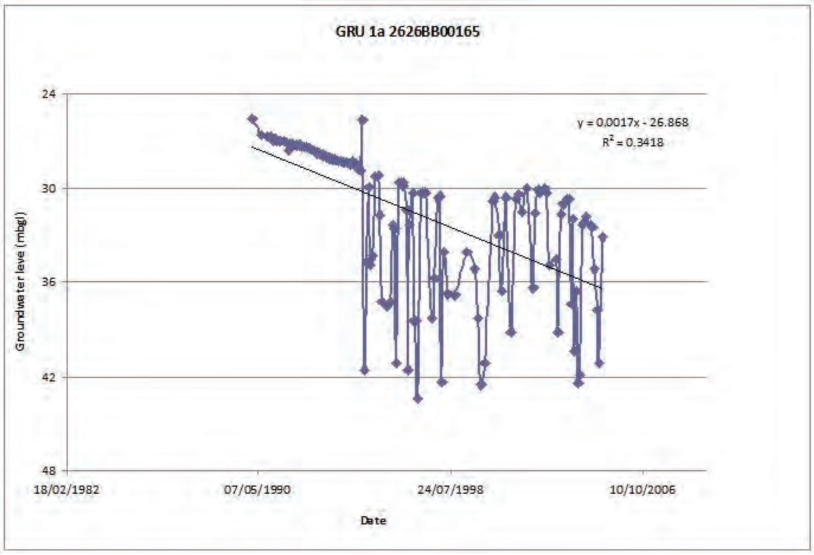

Figure 7-20. Groundwater level pattern and trend for a long-term monitoring station in GRU 1a

7.5.1.2 GRU 1b

Summary statistics for groundwater level data associated with GRU 1b per quaternary catchment are presented in **Table 7-6**. A graphical illustration of this information (**Figure 7-21**) reveals the close similarity in the metrics that describe this hydrogeologic parameter in the two quaternary basins.

Table 7-6. Summary statistics for groundwater level data associated with GRU 1b per quaternary catchment

Quaternary	N	Min	Median	95%ile	Max	Range
C24A	190	1.2	12.2	69.1	151	150.1
C24B	30	0.9	11.7	61.7	100	99.1

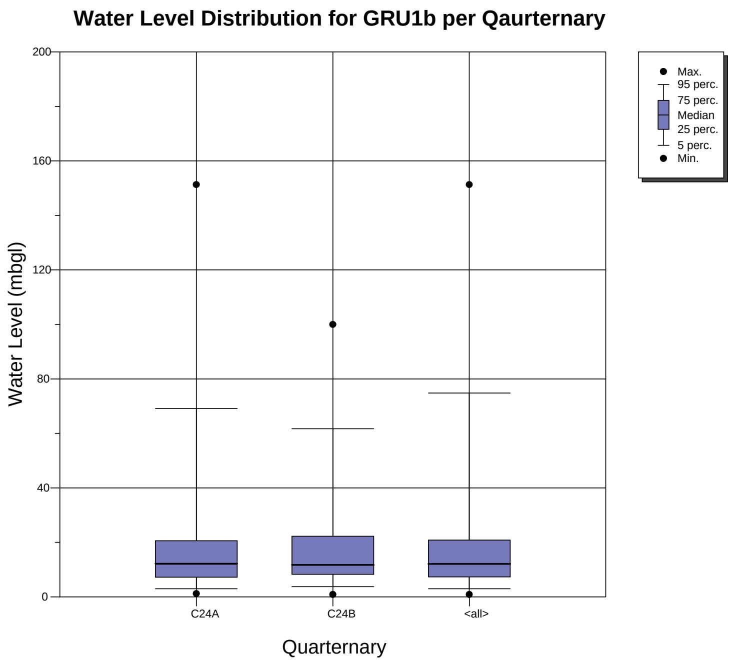

Figure 7-21. Groundwater level statistics for GRU 1b per quaternary catchment

Station 2626DD00244 in GRU 1b (**Figure 7-22**) exhibits a rising trend in the period 1966-1998. Superimposed on this trend, however, is a medium-term fluctuation with an amplitude of ~5 m. It is tenuous to attribute the rise in water table to rewatering in a mining environment such as that which characterises GRU 1b.

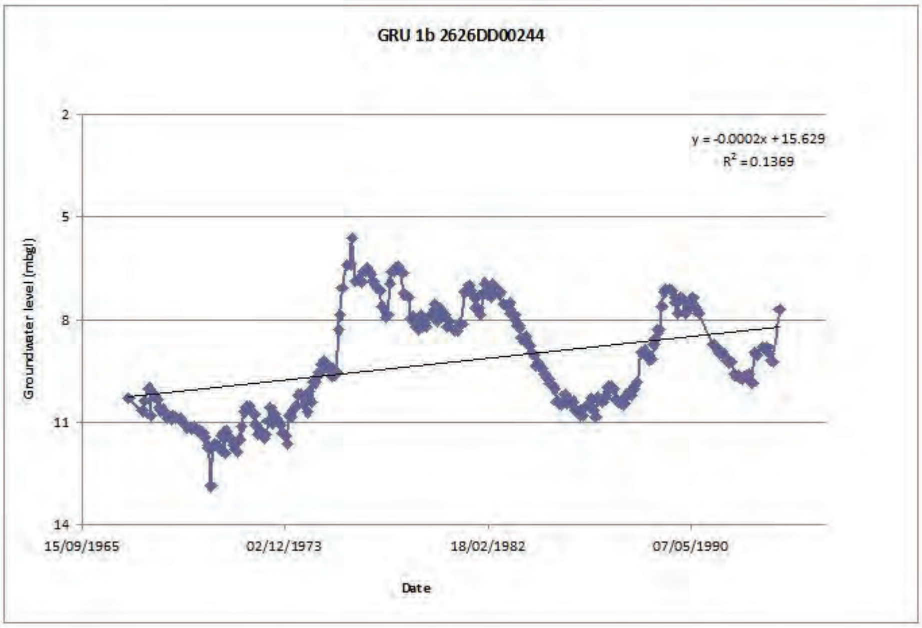

Figure 7-22. Groundwater level pattern and trend for a station in GRU 1b

7.5.2 GRU 2

GRU 2 encompasses 12 quaternary catchments of which one (C25F) has insufficient groundwater level data for statistical analysis (**Table 7-7**). A graphical illustration of this information is shown in **Figure 7-23**, which indicates that relatively similar water table conditions prevail across all of the quaternary catchments.

Table 7-7. Summary statistics for groundwater level data associated with GRU 2 per quaternary catchment

Quaternary	N	Min	25%ile	Median	Mean	75%ile	95%ile	Max	Range
C25A	332	0.61	6.1	9.8	11.4	15.2	25.8	54.6	54
C24A	191	0.01	7.2	12	13.2	18	30.2	60	60
C24D	131	0.61	7.2	11.8	13.5	18.7	29	44.2	43.6
C24E	258	0.3	4.9	9	10.8	13.7	27.7	39.6	39.3
C24F	199	1	5.5	9.1	11.1	15	25.1	90	89
C24G	586	0.01	7	12.2	15	21.3	32.2	63.2	63.1
C24J	409	0.91	7.3	10.7	12.2	15.2	24.4	93	92.1
C25C	74	1.4	6.6	10.7	11.7	14	23.4	30.5	29.1
C25D	493	0.08	6.1	9.5	11.2	14.6	24.8	48.8	48.7
C25E	358	0.08	6.1	11.3	12.3	17.2	27.4	57.9	57.8
C25F	2	3.7	N/A	N/A	5.2	N/A	N/A	6.7	3.1
C24H	321	0.23	7.3	11	12.9	16.8	29.3	84	83.8

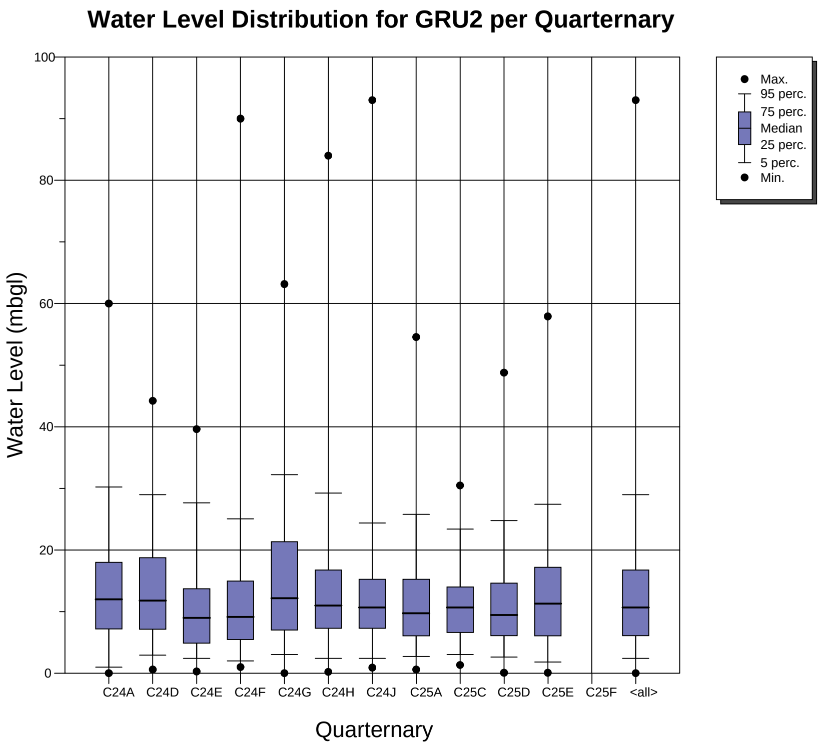

Figure 7-23. Groundwater level statistics for GRU 2 per quaternary catchment

Station 2625DD0001 in GRU 2 (**Figure 7-24**) exhibits a declining trend in the period 1976-2005. Superimposed on this trend is a medium-term fluctuation with an amplitude of ~18 m. Of considerable concern, however, is the overall drop in water level of ~43 m in the period of record. The location of this station in an area underlain by volcanic strata (lava) of the Klipriviersberg Group (**Appendix A**) provides a possible explanation for this trend, since the productivity of these strata as an aquifer are known to be highly variable in terms of both the quantity and sustainability of borehole yields.

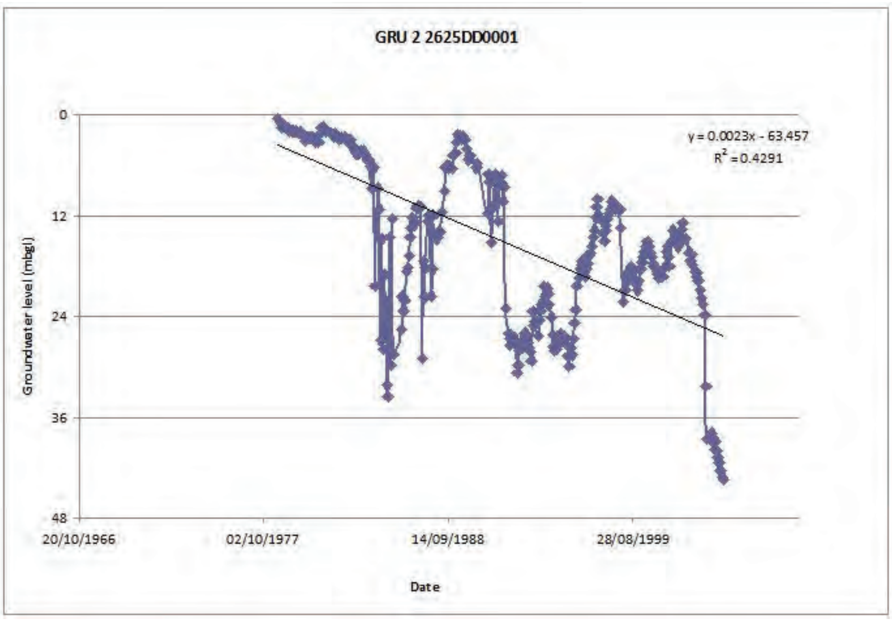

Figure 7-24. Groundwater level pattern and trend for a station in GRU 2

7.5.3 GRU 3

7.5.3.1 GRU 3a

This GRU encompasses 13 quaternary catchments of which three have insufficient groundwater level data for statistical analysis (**Table 7-8**). A graphical illustration of this information is shown in **Figure 7-25**, which indicates quite a wide variation of water table conditions between the various quaternary catchments represented in this GRU. This is possibly due to the considerable geographic extent encompassed by this GRU (**Figure 7-18**).

Table 7-8. Summary statistics for groundwater level data associated with GRU 3a per quaternary catchment

Quaternary	N	Min	25%ile	Median	Mean	75%ile	95%ile	Max	Range
C60J	2	8	N/A	N/A	14	N/A	N/A	20	12
C43D	2	9.1	N/A	N/A	10.2	N/A	N/A	11.3	2.2
C60G	8	4	5.5	11.8	13.3	19.3	26.5	30	26
C70H	3	10	15.5	21	20.3	25.5	29.1	30	20
C70J	11	2	6.7	10.7	11.2	15.5	20	22	20
C24J	38	0.91	3.1	7	10.5	12.9	29.8	40	39.1
C25B	8	6	18.8	25.6	26.9	28.5	52.8	65	59
C25C	15	4.8	9.4	14.3	15.1	16.6	30.8	45.7	40.9
C25D	9	5.2	10.1	12.2	12.9	15.2	20.4	22.9	17.7
C25E	25	4.6	7	9.1	10.6	12.2	20.7	24.4	19.8
C25F	34	3.1	9.4	16.2	16.6	21.3	29.6	42.7	39.6
C41J	2	10	N/A	N/A	10	N/A	N/A	10	0
C70K	6	0.69	12.8	17.5	14.6	20	20	20	19.3

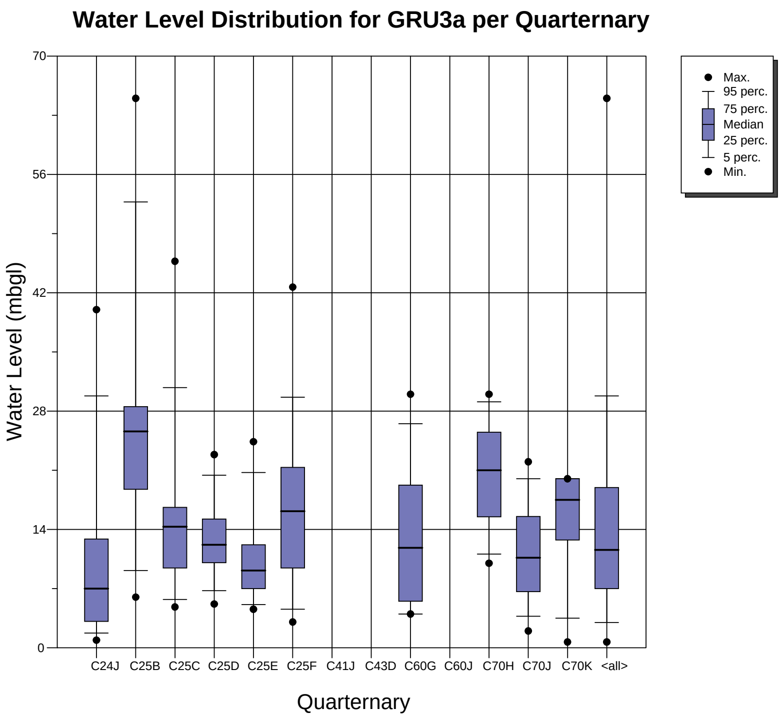

Figure 7-25. Groundwater level statistics for GRU 3a per quaternary catchment

7.5.3.2 GRU 3b

GRU 3b encompasses four quaternary catchments of which only one (C70E) supports a reasonable number of stations from which to draw tenuous conclusions regarding the water table characteristics (**Table 7-9**). A graphical illustration of this information is shown in **Figure 7-26**, from which it is difficult to infer much in regard to this hydrogeologic parameter in GRU 3b except that even maximum depths to the water table are comparatively shallow (<24 m).

Table 7-9. Summary statistics for groundwater level data associated with GRU 3b per quaternary catchment

Quaternary	N	Min	25%ile	Median	Mean	75%ile	95%ile	Max	Range
C70D	1	24	N/A	N/A	24	N/A	N/A	24	0
C70E	11	3.7	5.9	7.6	10.3	12.6	21	21	17.4
C70F	2	10.4	N/A	N/A	15.9	N/A	N/A	21.3	11
C70G	2	14.6	N/A	N/A	18	N/A	N/A	21.3	6.7

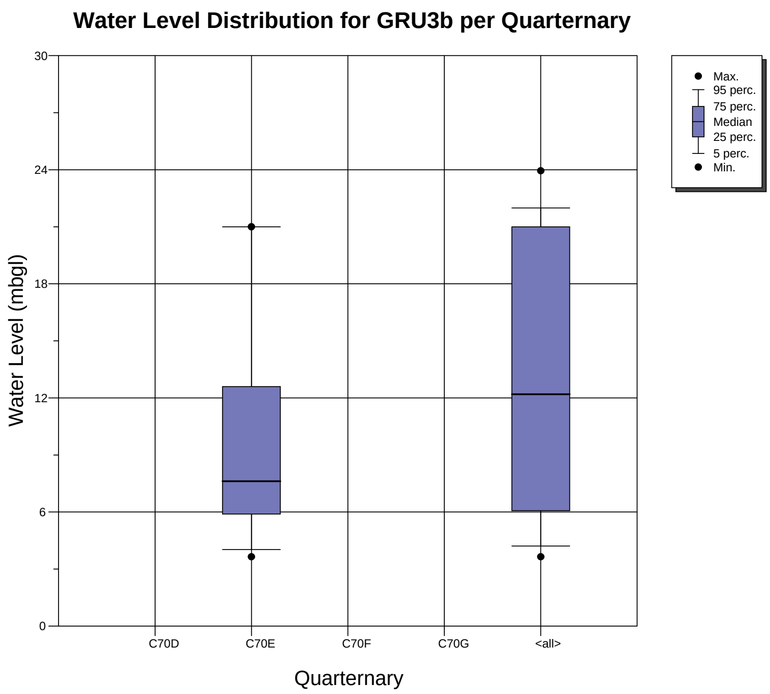

Figure 7-26. Groundwater level statistics for GRU 3b per quaternary catchment

7.5.4 GRU 4

7.5.4.1 GRU 4a

This GRU is characterised by a paucity of groundwater level information except in the two most southerly quaternary catchments C41C and C41D (**Figure 7-18**). In this part of the GRU, the median depth to groundwater level falls in the range 13-15 m bs, with a maximum depth to water level in the order of 32 m bs.

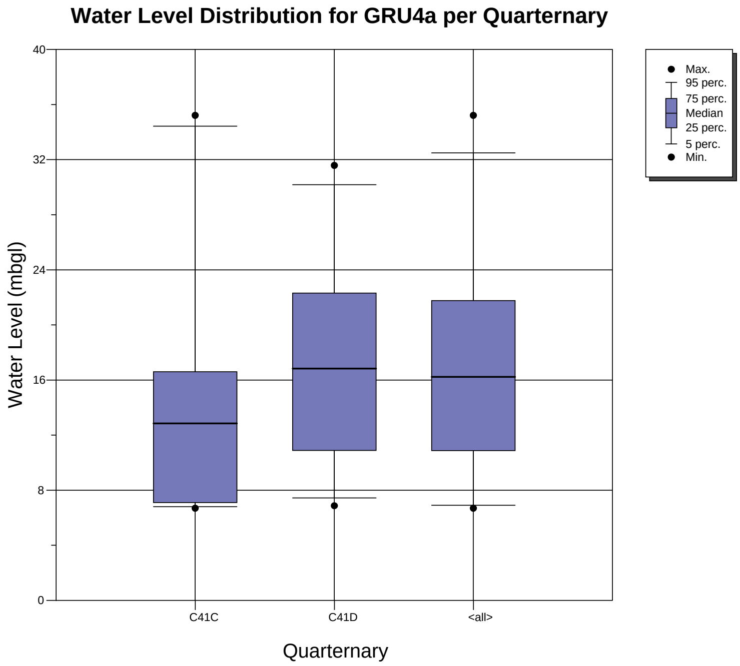

Figure 7-27. Groundwater level statistics for GRU 4a per quaternary catchment

7.5.4.2 GRU 4b

This GRU encompasses the seven quaternary catchments listed in **Table 7-10**. The data presented in this table indicate median depths to groundwater level in the range 5-20 m bs. It is notable, however, that the greatest water level depths (refer the 95%ile and maximum values in **Table 7-10**) occur in quaternary catchments C60D and C60F around Kroonstad.

Table 7-10. Summary statistics for groundwater level data associated with GRU 4b per quaternary catchment

Quaternary	N	Min	25%ile	Median	Mean	75%ile	95%ile	Max	Range
C60B	114	0.1	4.5	7.3	9.6	12.1	25	45.7	45.6
C60C	13	4	10	12.5	15.7	22	27.8	32	28
C60D	36	2.6	11.3	15.2	17.7	18.7	36.5	67.1	64.5
C60E	86	0.1	2.2	3.1	6	7.8	17.4	30.5	30.4
C60F	12	4.9	8.3	20.1	20.1	24.6	43.1	60	55.1
C70A	25	1.5	2.4	6	7.4	10.4	18.5	30	28.5
C70C	1	15	N/A	N/A	15	N/A	N/A	15	0

7.5.5 GRU 5

This GRU encompasses the four quaternary catchments listed in **Table 7-11**. As is also evident from **Figure 7-18**, most of the water level data are associated with quaternary C60A. The comparatively shallow mean (and median) depth to groundwater rest level (~15 m bs) associated with quaternary catchments C42A, C42B and C60A is in keeping with that for most of the other GRUs. The limited data set for catchment C42C militates against attributing too much significance to the substantially greater value associated with this catchment.

Table 7-11. Summary statistics for groundwater level data associated with GRU 5 per quaternary catchment

Tertiary Catchment	Statistical Parameter								
	N	Min	25%ile	Median	Mean	75%ile	95%ile	Max	Range
C42A	10	1.8	3.9	11	13.2	16.6	32.9	36.9	35.1
C42B	3	13	16	19	17.3	19.5	19.9	20	7
C42C	4	25	27.3	33	40.3	46	65.2	70	45
C60A	55	0.6	7	13	14.8	20.5	31	60	59.4

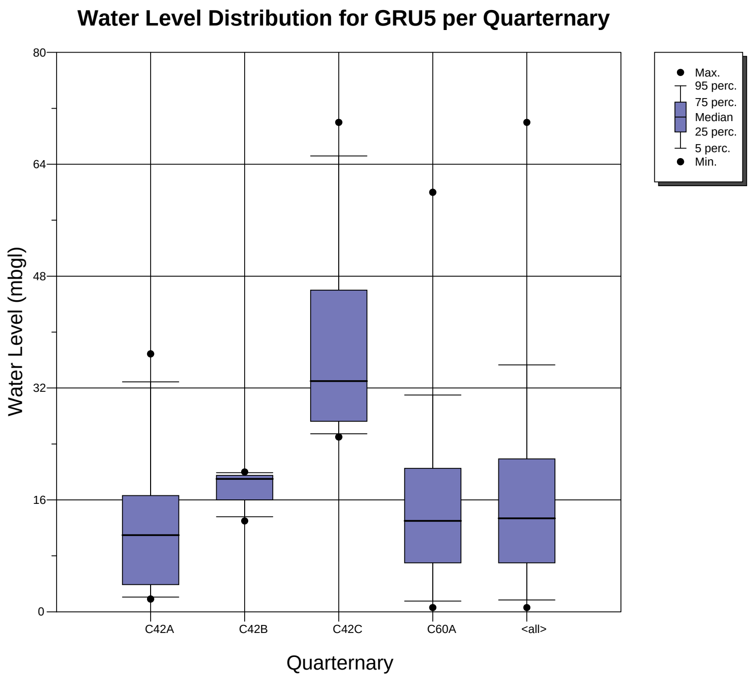

Figure 7-28. Groundwater level statistics for GRU 5 per quaternary catchment

7.5.6 Groundwater Level Trend Analysis

An analysis of groundwater level trends in the study area was carried out on the data obtained from the DWAs NGA. The analysis targeted those stations (totalling 88 in number out of a population of 5026 stations) for which >100 values over a period of >10 years were available. The analytical results are presented in **Appendix A**. The trend analysis entailed determining the slope (positive = rising or negative = falling) of each data set, reporting the variability in terms of the R^2 function. Additional statistical parameters reported in **Appendix A** are the minimum, maximum, mean and standard deviation values. To distinguish between natural and anthropogenic impacts on groundwater levels, long-term monthly rainfall records were requested from the South African Weather Services (SAWS). The data for all stations located in the study area (**Table 7-12**) exhibited a temporal scale from approximately 1980-2009. Statistical results for the data are presented in **Table 7-12**.

7.5.6.1 GRU 1a

In GRU 1a (**Table 7-4**) 20 sites were identified which exhibited a data record with a length >10 years and >100 values. The dominant outcrop lithology and land cover in the areas where boreholes are located are the Malmani Subgroup (Chuniespoort Group) dolomite and unimproved/natural grasslands respectively. Groundwater levels were observed to vary between 3.18-73.03 m bs. The overall trends of the groundwater level hydrographs were evident to be negligible. The slopes of the hydrographs ranged between -0.0052 and 0.0009 (**Figure 7-29**), with an average of -0.0002. R^2 values were generally below 0.8 indicating that the data set exhibits variability, i.e. a constant increasing or decreasing trend was not maintained. Only one rainfall station was identified within this GRU (**Table 7-12**). The data represents a positive slope (2.6218), which is indicative of an overall increase in annual rainfall amounts. One monitoring station in this GRU is interpreted to be impacted, i.e. 2627AA00107. It is however located in an area where land use is dominated by natural grassland, which suggests that this impact is not a result of anthropogenic activities. Groundwater use as a percentage of recharge varies between 2.1-50% in GRU 1a. In general, a comparison between the general groundwater hydrograph and rainfall trends within this GRU indicates that groundwater levels show no to minimal impacts from anthropogenic activities within this GRU. The general positive slopes of the groundwater level hydrographs are interpreted to be a result of increasing annual rainfall.

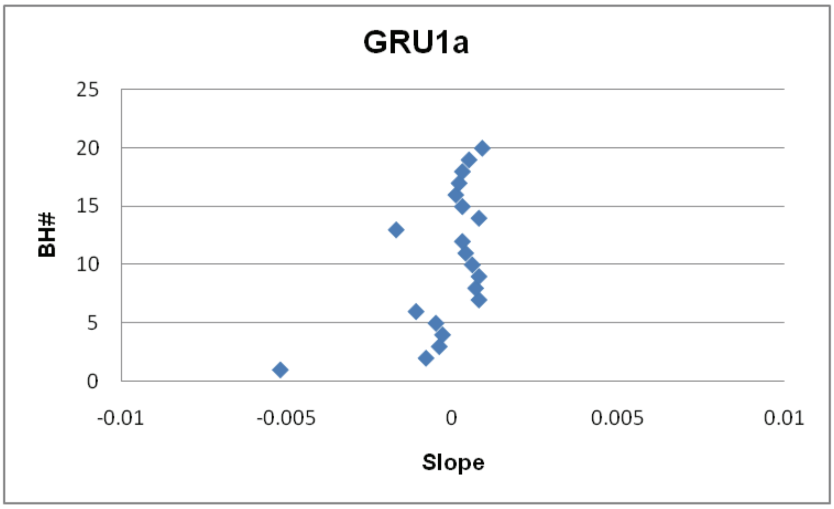

Figure 7-29. Distribution of groundwater level slope associated with long-term monitoring stations in GRU 1a

7.5.6.2 GRU 1b

In GRU 1b (**Table 7-3**) 61 sites were identified which exhibited a data record with a length >10 years and >100 values. The dominant outcrop lithology in areas where boreholes are sited is the Malmani Subgroup (Chuniespoort Group) dolomite. In addition to unimproved/natural grasslands, boreholes are also sited in areas where mines and quarries are located. Groundwater levels were observed to vary between 0.65-218.85 m bs. The overall trends of the groundwater level hydrographs were observed to be positive. The slopes of the hydrographs ranged between -0.0130 and 0.0107 (**Figure 7-30**), with an average of 0.0002. Certain monitoring points did however exhibit a slope of less than -0.005. These points are located in areas dominated by natural grassland, which suggests that the impact is not from anthropogenic activities. Groundwater use as a percentage of recharge varies between 0-1.5% in GRU 1b. R^2 values were generally below 0.8 indicating that the data set exhibits variability, i.e. a constant increasing or decreasing trend was not maintained. Only one rainfall station was identified within this GRU (**Table 7-12**). The data represents a positive slope (8.6292), which is indicative of an overall increase in annual rainfall amounts. A comparison between the general groundwater level hydrograph and rainfall trends within this GRU indicates that increasing groundwater levels are a result of increased rainfall.

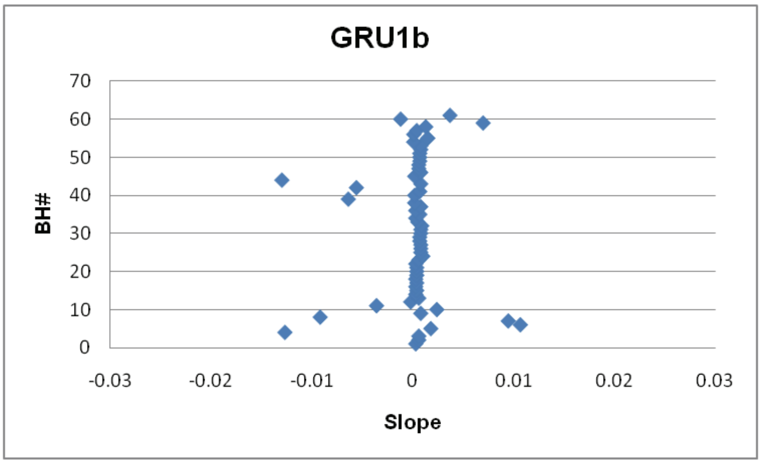

Figure 7-30. Distribution of groundwater level slope associated with long-term monitoring stations in GRU 1b

7.5.6.3 GRU 2

In GRU 2 (**Table 7-4**) 2 sites were identified which exhibited a data record with a length >10 years and >100 values. The outcrop lithologies at these sites are the Hospital Hill Formation and Klipriviersberg Group. Land cover is dominated by cultivated, temporary, commercial and dryland agriculture. Groundwater levels were observed to vary between 0.53-43.50 m bs (Klipriviersberg Group) and 9.23-22.16 m bs (Hospital Hill Formation). The overall trends of the groundwater level hydrographs observed at these sites were both increasing and decreasing, with slopes of 0.0024 (Hospital Hill Formation) and -0.0023 (Klipriviersberg Group). R^2 values were generally below 0.8 indicating that the data set exhibits variability, i.e. a constant increasing or decreasing trend was not maintained. Four rainfall stations were identified within this GRU (**Table 7-12**), which exhibited large variability in terms of slope. The slope of long-term rainfall records were observed to vary between 10.4885 and -24.744, with an average of -2.2257. The data therefore indicates both an overall increase and decrease in annual rainfall. Although this variability is also observed with groundwater levels this large spatial variability in rainfall is interpreted to be a result of heterogeneity in rainfall distribution. Insufficient groundwater level data, however, does not allow for any conclusion regarding natural or anthropogenic impacts on groundwater levels in this GRU. Groundwater use as a percentage of recharge varies between 1.1-10% in GRU 2.

7.5.6.4 GRU 4b

In GRU 4b (**Table 7-4**) 5 sites were identified which exhibited a data record with a length >10 years and >100 values. The dominant outcrop lithology in areas where boreholes are sited is the Adelaide Subgroup. Land cover is dominated by unimproved/natural grassland. Groundwater levels were observed to vary between 0.06-46.43 m bs. The overall trends of the groundwater level hydrographs were observed to be relatively flat. However, it was observed to show an increasing trend at times. The slopes of the hydrographs ranged between -0.0002 and 0.0083 (**Figure 7-31**), with an average of 0.0033. R^2 values were generally below 0.8 indicating that the data set exhibits variability, i.e. a constant increasing or decreasing trend was not maintained. Three rainfall stations were identified within this GRU (**Table 7-12**). The data exhibits variable slopes, i.e. ranging between -12.06 and 1.3490. The limited groundwater level data within this GRU indicates that the groundwater levels are rising, which is most likely a result of increased rainfall. The data also suggests that there is no to limited influence from anthropogenic activities on groundwater levels. Groundwater use as a percentage of recharge varies between 1.1-10% in GRU 4b.

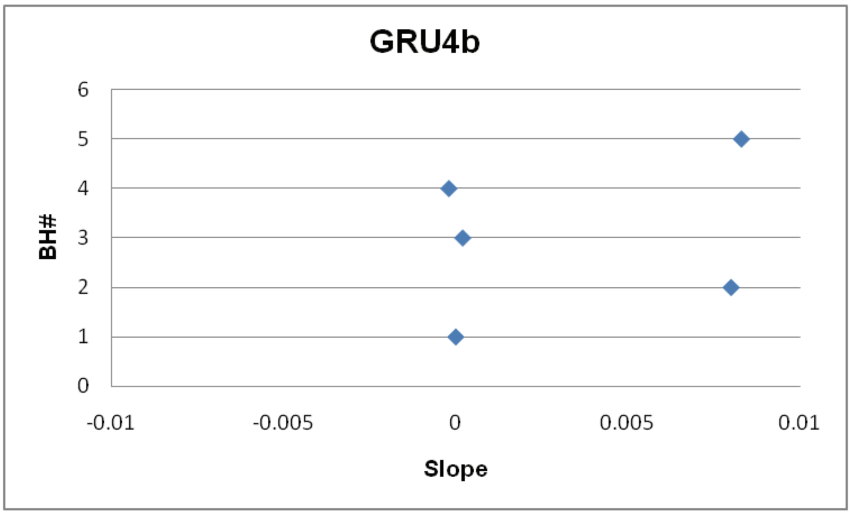

Figure 7-31. Distribution of groundwater level slope associated with long-term monitoring stations in GRU 4b

7.5.6.5 Exclusions

No dated records exhibiting a record length >10 years and comprising >100 measurements were identified in GRU 3a, GRU 3b, GRU 4a and GRU 5.

Table 7-12. Rainfall statistics for the Middle Vaal WMA per GRU

GRU	Station Name	Station Number	Slope	P-Value	R^2
1a	Lichtenburg Manana	0472455 7	2.6218	0.4002	0.0254
1b	Stilfontein	0436410 8	8.6292	0.1204	0.1163
2	Klerksdorp Beatrix	0436495 5	-1.8225	0.7121	0.0053
	Ventersdorp	0473559A3	10.4885	0.3732	0.0727
	Ottosdal – Police Station	0434888 3	7.1757	0.0166	0.1883
	Ottosdal	0435019 5	-24.7444	0.0285	0.3658
3a	Wesselsbron – Municipality	0363651 8	-5.24	0.24	0.05
4a	Excelsior Police Station	0295116A6	-56.6300	0.2234	0.4385
	Tweespruit	0263041 6	-5.04	0.25	0.05
4b	Lindley – Municipality	0366743 1	1.3490	0.6822	0.0061
	Heilbron Prison	0402827 8	0.9015	0.7966	0.0024
	Kroonstad	0365398 8	-12.06	0.21	0.10
5	Vadersgift	0331318 7	-4.57	0.94	0.0017
	Smalfontein	0296517A7	2.88	0.51	0.02

8 RESOURCE DIRECTED MEASURES

Resource directed measures (RDM) are first given effect in the form of a suitably motivated and succinctly described present ecological state for the groundwater resources in each GRU. This exercise informs the preliminary classification of groundwater resources in the study area. RDM is next given effect in the preliminary determination of the groundwater quantity and quality Reserve. The RDM framework is completed with the setting of preliminary groundwater resource quality objectives (RQOs) in regard to both groundwater quantity and quality. These are of a descriptive rather than a semi-quantitative nature. It is acknowledged that this does not facilitate their practical application, implementation and subsequent compliance monitoring.

The preliminary classification embodied in RDM is characterised by distinctive terminology such as category (e.g. present status category and desired status category) and class (e.g. water resource class and management class) that warrants explanation. The hierarchical nature and inter-relationship of these components is illustrated in **Table 8-1**.

Table 8-1. Description of the hierarchical classification terminology for various GRDM component class/category descriptors

<table>
<tr><th colspan="2">Present Status Category</th><th>Water Resource Class</th><th colspan="2">Desired Status Category</th><th>Management Class</th></tr>
<tr><td rowspan="2">A</td><td rowspan="2">Unmodified; approximates natural conditions</td><td>Natural</td><td rowspan="2">A</td><td rowspan="2">Highly sensitive systems, negligible risk allowed</td><td>Excellent</td></tr>
<tr><td rowspan="3">Good</td><td rowspan="3">Good</td></tr>
<tr><td>B</td><td>Largely natural; few localised modifications, no negative impacts apparent</td><td>B</td><td>Sensitive systems, small risk allowed</td></tr>
<tr><td rowspan="2">C</td><td rowspan="2">Moderately modified; moderate changes apparent</td><td rowspan="2">C</td><td rowspan="2">Moderately sensitive systems, moderate risk allowed</td></tr>
<tr><td rowspan="2">Fair</td><td rowspan="2">Fair</td></tr>
<tr><td>D</td><td>Largely modified; widespread loss of natural functioning</td><td>D</td><td>Resilient systems, large risk allowed</td></tr>
<tr><td>E</td><td>Seriously modified; loss of natural functioning extensive</td><td rowspan="2">Poor</td><td rowspan="2" colspan="2">Not allowed</td><td rowspan="2">Not allowed</td></tr>
<tr><td>F</td><td>Critically modified; complete modification with near-complete loss of natural functioning</td></tr>
</table>

8.1 Preliminary Groundwater Present Ecological State

The present status category is informed by the extent to which the current groundwater environment has been modified from the reference groundwater environment. This, in turn, is informed by factors such as the impact of groundwater usage on the sustainable utilisation of groundwater resources and acceptability of associated environmental risks (e.g. reduction of baseflow and spring discharge, land subsidence and sinkhole development, etc.), and the impact of land uses on existing groundwater quality and potential or expected groundwater contamination. It is considered that the material presented in the preceding sections of this report provides a sufficient body of hydrogeologic information with which to establish the present status category, and hence also the class of groundwater resources in the study area.

8.1.1 GRU 1a

8.1.1.1 Groundwater Quantity

The 20 long-term water level records that describe the temporal behaviour of groundwater rest levels in this GRU indicate a general overall trend that can be described as neutral with a slight bias toward a negative (declining) slope. However, since land use in this GRU is dominated by unimproved (natural) grassland (~74% of the area), it is reasonable to expect that groundwater rest levels have not been impacted upon to the extent that the present status differs significantly from the reference conditions. The ~4% of land cover that comprises irrigated agriculture based on local dolomitic groundwater resources might account for the slight negative bias observed in overall groundwater level trend.

8.1.1.2 Groundwater Quality

The more recent (post-2000) occurrence of groundwater with a Na-Cl and a Na-SO_4 composition in the largely dolomitic quaternary catchment C24C suggests a measure of impact from sources of non-carbonate water. Likely sources are agriculture for the Na-Cl groundwater, and sewage effluent for the Na-SO_4 groundwater. Whilst these observations remain necessarily broad, their occurrence is reason for caution regarding the continued generally good to excellent quality of groundwater in this GRU.

8.1.1.3 Discussion

The hydrogeological environment of GRU 1a is assessed as being slightly to moderately modified from its natural status, and is therefore assigned a present ecological state (PES) category of BC. This is based mainly on the ~22% of GRU area that supports cultivated temporary commercial dryland (~18%) and irrigated (~4%) agriculture. The potential for irrigated agriculture to expand on the basis of available plentiful karst groundwater resources is an ever-present concern that warrants careful observation and monitoring.

8.1.2 GRU 1b

8.1.2.1 Groundwater Quantity

The 61 stations in this GRU that support a hydrograph length >10 years and comprises >100 values (**Table 7-4**) reveal a mainly neutral trend with an equal bias toward negative (declining) and positive (rising) slopes. Although comprising ~70% land use characterised by unimproved (natural) grassland (~66%) and thicket/bushland/bush clumps (~4%), mining activities account for a significant ~4% of land cover in GRU 1b. Under these circumstances, an impact on groundwater levels might be expected in both a positive context (as reflected in rising groundwater levels) and a negative context (as reflected in declining groundwater levels).

8.1.2.2 Groundwater Quality

The association of this GRU with impacts related to mining activity in the Klerksdorp (KOSH area) Gold Field is clearly manifested in the Ca-SO_4 composition of more recent (post-2000) groundwater chemistry sourced in quaternary catchment C24A and the south-eastern portion of catchment C24H. These circumstances, illustrated in **Figure 7-10**, suggest that the groundwater quality component is significantly changed from its reference condition.

8.1.2.3 Discussion

The hydrogeological environment of GRU 1b is assessed as being moderately to significantly modified from its natural status, and is therefore assigned a present ecological state (PES) category of D. This is based on the observed negative impact on groundwater quality from mining activity, and the comparatively large urban area (~0.7%) associated mainly with the towns of Orkney and Klerksdorp.

8.1.3 GRU 2

8.1.3.1 Groundwater Quantity

The groundwater level response in this GRU is not readily assessed because of a dearth of water level monitoring data. Under circumstances where ~92% of the land cover comprises unimproved natural grassland (~63%) and cultivated temporary dryland agriculture (~29%) which have little impact on groundwater levels, it is unlikely that the present potentiometric conditions vary significantly from the historical reference conditions.

8.1.3.2 Groundwater Quality

The hydrochemical data for groundwater associated with this GRU indicates little change between the earlier (pre-1980) and the more recent (post-2000) chemical composition. This suggests that the present groundwater quality is little changed from the reference condition, a situation that might be ascribed to the dominant land cover (~92%) represented by unimproved natural grassland (~63%) and cultivated temporary dryland agriculture (29%) as described in **section 8.1.3.1**. These land uses have little impact on groundwater quality.

8.1.3.3 Discussion

The hydrogeological environment of GRU 2 is assessed as being slightly modified from its natural status, and is therefore assigned a present ecological state (PES) category of B. This situation is also unlikely to change under circumstances where the geologic environment is not conducive to excessive groundwater resource development. The very small proportion of groundwater use to recharge (<10%) in this GRU lends support to this observation.

8.1.4 GRU 3a

8.1.4.1 Groundwater Quantity

The groundwater level response in GRU 3a is not readily assessed because of a dearth of water level monitoring data (**section 7.5.6.5**). Under circumstances where ~89% of the land cover comprises unimproved natural grassland (~42%) and cultivated temporary dryland agriculture (~47%) which have little impact on groundwater levels, it is unlikely that the present potentiometric conditions vary significantly from the historical reference conditions. The significant land cover represented by wetlands (~4%) suggests a close association with the groundwater environment. Although extremely tenuous because of the paucity of data, this finds support in the relatively shallow depth (<7 m bs) of 5%ile and minimum water level values (**Figure 7-25**). It is therefore considered unlikely that the present potentiometric conditions vary significantly from the historical reference conditions.

8.1.4.2 Groundwater Quality

The hydrochemical data for groundwater associated with GRU 3a is insufficient to assess any change between earlier (pre-1980) and more recent (post-2000) chemical composition in this GRU. The occurrence of both a Ca-HCO_3 and a Na-HCO_3 composition across the GRU is juxtaposed with a Ca-Cl and Na-Cl type groundwater associated with certain quaternary catchments, notably C43A and C60G. These observations further obfuscate an assessment of groundwater quality in this GRU. Nevertheless, it is considered that the present groundwater quality is little changed from the reference condition on the basis that the dominant land cover is represented by unimproved natural grassland and cultivated temporary dryland agriculture as described in **section 8.1.4.1**.

8.1.4.3 Discussion

The hydrogeological environment of GRU 3a is assessed as being slightly to moderately modified from its natural status, and is therefore assigned a present ecological state (PES) category of BC. This recognises the large proportion of the GRU area that supports cultivated temporary dryland agriculture. This situation is also unlikely to change under circumstances where the geologic environment is not conducive to excessive groundwater resource development. The very small proportion of groundwater use to recharge (typically <3%) in this GRU supports this observation.

8.1.5 GRU 3b

8.1.5.1 Groundwater Quantity

The groundwater level response in GRU 3b is not readily assessed because of a paucity of water level monitoring data (**section 7.5.6.5**). Under circumstances where ~93% of the land cover comprises unimproved natural grassland (~53%) and cultivated temporary dryland agriculture (~40%) which have little impact on groundwater levels, it is unlikely that the present potentiometric conditions vary significantly from the historical reference conditions. As in GRU 3a, land cover represented by wetlands (~2%) suggests a close association with the groundwater environment. Although even more tenuous in this instance than GRU 3a because of the paucity of data, the relatively shallow depth (<7 m bs) of median depth to water level values (**Table 7-9** and **Figure 7-26**) supports this observation. It is therefore considered unlikely that the present potentiometric conditions vary significantly from the historical reference conditions in this GRU.

8.1.5.2 Groundwater Quality

The hydrochemical data for groundwater associated with GRU 3b is insufficient to assess any change between earlier (pre-1980) and more recent (post-2000) chemical composition in this GRU. The occurrence of a CaNa-HCO_3 composition across the GRU is in keeping with that observed in regard to GRU 3a, and it is considered that the present groundwater quality is little changed from the reference condition for similar reasons as put forward in regard to GRU 3a (**section 8.1.4.2**).

8.1.5.3 Discussion

The hydrogeological environment of GRU 3b is assessed as being slightly to moderately modified from its natural status, and is therefore assigned a present ecological state (PES) category of BC. This recognises the substantial proportion of the GRU area that supports cultivated temporary dryland agriculture. This situation is also unlikely to change under circumstances where the geologic environment is not conducive to excessive groundwater resource development. The very small proportion of groundwater use to recharge (typically <2%) in this GRU supports observation.

8.1.6 GRU 4a

8.1.6.1 Groundwater Quantity

The groundwater level response in GRU 4a is not readily assessed because of a paucity of water level monitoring data (**section 7.5.6.5**). Under circumstances where ~92% of the land cover comprises unimproved natural grassland (~70%) and cultivated temporary dryland agriculture (~22%) which have little impact on groundwater levels, it is unlikely that the present potentiometric conditions vary significantly from the historical reference conditions.

8.1.6.2 Groundwater Quality

The hydrochemical data for groundwater associated with this GRU reflects a continuum between a Ca-HCO_3 and a Na-HCO_3 type groundwater for the entire >30-year period of record. There is no indication of a change in composition between earlier and more recent quality, nor any indication of anthropogenic impact such as might be reflected by an anion bias toward SO_4 or Cl. It is considered, therefore, that the present groundwater quality is little changed from the reference condition on the basis that the dominant land cover is represented by unimproved natural grassland and cultivated temporary dryland agriculture as described in **section 8.1.6.1**.

8.1.6.3 Discussion

The hydrogeological environment of GRU 4a is assessed as being slightly modified from its natural status, and is therefore assigned a present ecological state (PES) category of B. This recognises the substantial proportion of the GRU area that supports unimproved natural grassland. This situation is also unlikely to change under circumstances where the geologic environment is not conducive to excessive groundwater resource development. The very small proportion of groundwater use to recharge (typically <5%) in this GRU lends support to this observation.

8.1.7 GRU 4b

8.1.7.1 Groundwater Quantity

The 5 long-term water level records that describe the temporal behaviour of groundwater rest levels in this GRU indicate a general overall trend that can be described as neutral with a slight bias toward a positive (rising) slope. However, since land use in this GRU is dominated by unimproved (natural) grassland (~69% of the area), and a further ~26% comprises cultivated dryland agriculture, it is reasonable to expect that groundwater rest levels have not been impacted upon to the extent that the present status differs significantly from the reference conditions. This situation is unlikely to change under circumstances where the geologic environment is not conducive to excessive groundwater resource development, as finds support in the typically <3% proportion of groundwater use to recharge in this GRU.

8.1.7.2 Groundwater Quality

The more recent (post-2000) occurrence of groundwater with a Na-HCO_3 composition is similar to that reflected in the entire period of hydrochemical record, which suggests that that the present groundwater quality is little changed from the reference condition. This situation is unlikely to change where the current dominant land cover/use itself is unlikely to change significantly.

8.1.7.3 Discussion

The hydrogeological environment of GRU 4b is assessed as being slightly modified from its natural status, and is therefore assigned a present ecological state (PES) category of B. As indicated in **sections 8.1.6.1** and **8.1.6.2**, this situation is also unlikely to change in the foreseeable future.

8.1.8 GRU 5

8.1.8.1 Groundwater Quantity

The groundwater level response in GRU 5 is not readily assessed because of a paucity of water level monitoring data (**section 7.5.6.5**). Under circumstances where ~96% of the land cover comprises unimproved natural grassland (~65%) and cultivated temporary dryland agriculture (~32%) which have little impact on groundwater levels, it is unlikely that the present potentiometric conditions vary significantly from the historical reference conditions. This might be expected under circumstances where the geologic environment is not conducive to excessive groundwater resource development, as finds support in the typically <2% proportion of groundwater use to recharge.

8.1.8.2 Groundwater Quality

The occurrence of groundwater with a Na-HCO_3 composition is reflected throughout the entire period of hydrochemical record for this GRU. This again indicates that the present groundwater quality is little changed from the reference condition, which might be expected under circumstances where the current dominant type of land cover/use has not changed significantly.

8.1.8.3 Discussion

The hydrogeological environment of GRU 5 is assessed as being slightly modified from its natural status, and is therefore assigned a present ecological state (PES) category of B. As indicated in **sections 8.1.8.1** and **8.1.8.2**, this situation is also unlikely to change in the foreseeable future.

8.1.9 Synthesis of Groundwater PES Assessment

The outcome of the present ecological state assessment for each GRU in the study area is summarised in **Table 8-2**. As illustrated in **Figure 8-1**, this indicates that ~52% of the study area supports a B category PES, ~46% a BC category PES, and only ~2% a D category PES.

Table 8-2. Synthesis of proposed present ecological state (PES) per GRU for the Middle Vaal WMA

Groundwater Resource Unit	Present Ecological State		Proportion of Study Area (%)
	Category	Description	
1a	BC	Slightly to moderately modified	4.6
1b	D	Significantly modified	1.7
2	B	Slightly modified	17.2
3a	BC	Slightly to moderately modified	36.1
3b	BC	Slightly to moderately modified	5.4
4a	B	Slightly modified	15.4
4b	B	Slightly modified	11.8
5	B	Slightly modified	7.9

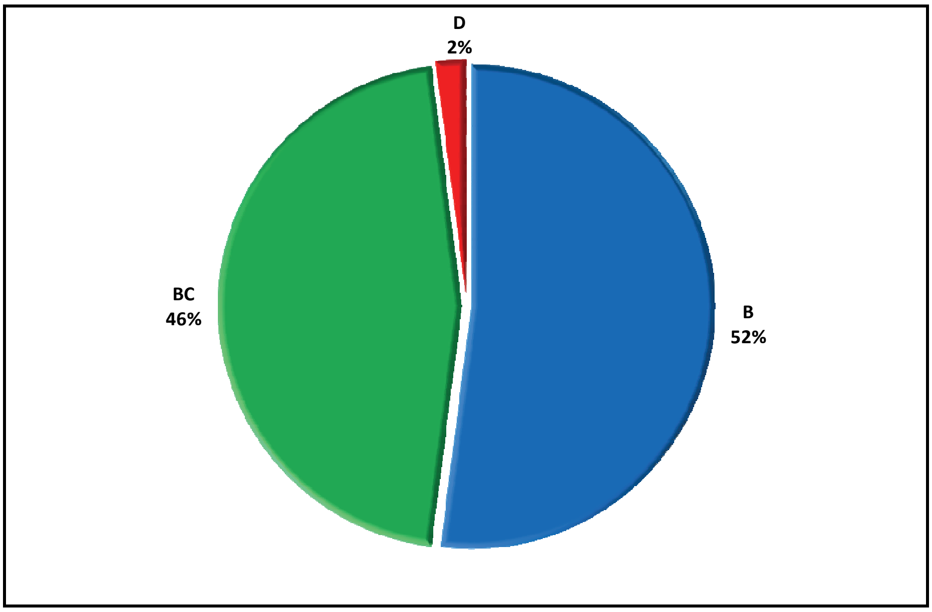

Figure 8-1. Percentage of study area categorised by present groundwater ecological status category

8.1.10 Surface Water Present Ecological State

8.1.10.1 Assessment Method

The present ecological state (PES) for rivers in the Middle Vaal WMA derives from the recently completed NFEPA project (Nel et al., 2009). The PES ranges from category A to F. Regional workshops were held throughout South Africa with aquatic (river) scientists and experienced practioner's during 1989-1999. The categories are obtained from expert assessments of modifications of six attributes from natural condition, i.e. flow, inundation, water quality, stream bed condition, introduced stream biota, riparian and stream bank condition. This is informed by existing data and information where possible. Intact rivers are considered to be in an "AB" category, moderately modified in a “C” category, and largely modified in “D-F” category. DWAs Present Ecological State (PES) (Kleynhans, 2000) was used as the base GIS layer for the quaternary catchment mainstem rivers.

The river condition was modelled for all other 1:500 000 tributaries (i.e. rivers that nest within quaternary catchments), using GIS which was based on the national land cover mosaic (NLC 2000) with transformed waterbodies GIS layer. This was achieved by using the percentage natural land cover within 100 m, 500 m and the sub-quaternary catchments (smaller planning units delineated using digital elevation models) and the percentage erosion within 500 m of the tributary. Tributaries remained intact if the minimum value for the percentage natural land cover was ≥75% and the erosion percentage was ≤5% within the 500 m buffer of a river segment (Nel et al., 2009). Exclusions to these criteria form the “Z” (not intact) category. The base layer was updated during 2009 with existing data and assessments from experts around the country during the NFEPA project.

8.1.10.2 Synthesis of Surface Water PES Assessment

Comprehensive EWR studies were limited to the Upper Vaal and only data from NFEPA was used for the PES determination of the Middle Vaal WMA. **Figure 8-2** shows the PES condition assigned to mainstems and tributaries in the study area.

An inspection of **Figure 8-2** indicates that very few drainages have been assigned to an AB category. Further, that these occur mainly in GRUs 3b, 4a and 4b. Except for the Z category (not intact) tributaries, the majority of drainages are assigned to the moderately modified C category. The main drainage in the study area, the Vaal River, is assigned a largely modified D category, as are sections of the middle reaches of the Vet River around Welkom in the Free State Gold Field.

8.1.10.3 Comparison of Surface Water / Groundwater PES

The surface water PES assessment illustrated in **Figure 8-2** finds agreement with the groundwater PES assessments per GRU described in **section** 8 (**Table 8-2** and **Figure 8-1**). The groundwater PES assessment identifies four of the GRUs as exhibiting a category B (slightly modified) present ecological state, and a further three GRUs as exhibiting a category BC (slightly to moderately modified) PES. Only GRU 1b, which encompasses the Klerksdorp (KOSH area) Gold Field traversed by the Vaal River, represents a category D (largely modified) PES groundwater environment in the study area.

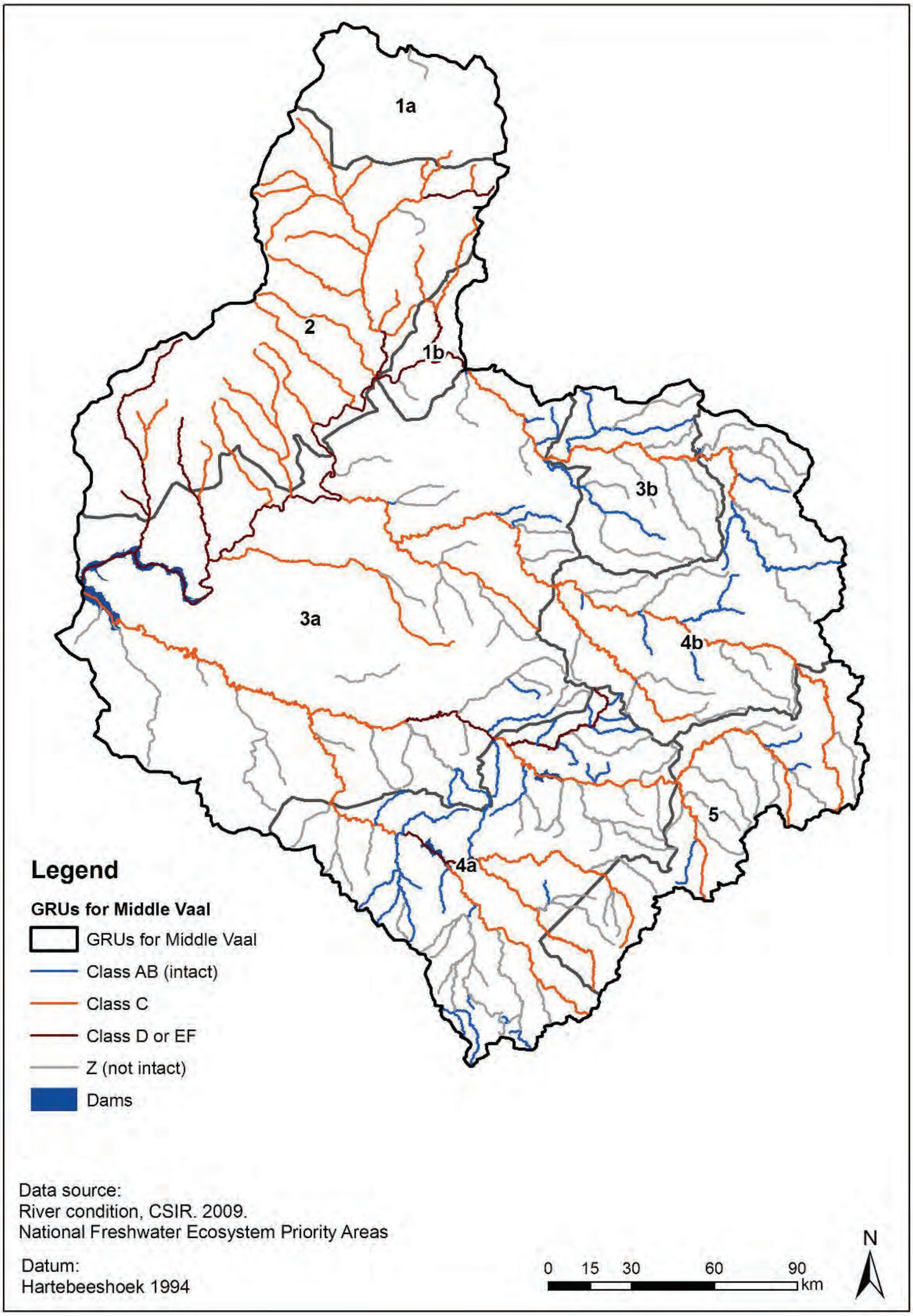

Figure 8-2. Present ecological state (PES) of rivers in the Middle Vaal WMA (from Nel et al., 2009)

8.2 Preliminary Groundwater Reserve Determination

8.2.1 Approach

The derivation of resource directed measures also requires that the Reserve be determined. Such determination is of a preliminary nature under circumstances where a final Reserve requires consultation with stakeholders in the form of public participation. Sections 14(1)(b) and 17(1) of the National Water Act (Act no. 36 of 1998) prescribe the setting of groundwater quantity and quality components of the Reserve for ecological and basic human needs purposes.

The intermediate level of Reserve determination is considered adequate to meet the short-term objective of the study, viz. provide the groundwater environment with appropriate (albeit provisional) protection against potentially negative impacts in the interim, under circumstances where there currently is no protection whatsoever. In meeting this objective, the study also informs the following principles and medium- to long-term objectives.

- Foster sustainable development, i.e. be sufficiently strict to protect the groundwater environment without imposing unduly onerous and economically prohibitive restrictions on future development.
- Promote the management of groundwater resources against the background of water use licensing.
- Form the basis for the development of a catchment management plan (CMP).
- Facilitate the implementation of integrated water resource management (IWRM).

8.2.2 Groundwater Quantity

The specialist groundwater report included as Appendix C with the DWAFs ISP document (DWAF, 2004a) reports estimated baseflow values per quaternary catchment. Analysis of this information returns the data presented in **Table 8-3**. The analysis in regard to sub-areas C2 and C4, however, is flawed under circumstances where the specialist groundwater report (DWAF, 2004a) fails to include the baseflow associated with tertiary catchment C25 in sub-area C2, and C41 and C43 in sub-area C4. This might account (at least partly) for the higher percentages of available groundwater relative to baseflow evident in **Table 8-3**.

Table 8-3. Synthesis of estimated baseflow and available groundwater (after DWAF, 2004b)

Sub-area	Area		Baseflow		Baseflow per km^2 (mm/a)*	Available Groundwater	
	km^2	%	Mm^3/a	%		(Mm^3/a)	% of Baseflow
C6/C7 (Rhenoster/Vals)	14522.5	27.6	43	43.4	3.0	12	27.9
C4 (Sand/Vet)	19148.7	36.4	27	27.3	1.4	17	63.0
C2 (Middle Vaal)	18879.5	35.9	29	29.3	1.5	25	86.2
Total *Mean*	52551	100	99	100	*1.9*	54	*59.0*

* Mm^3/a/km^2

An analysis for the Middle Vaal WMA based on the GRUs identified in this study (**section** 6) returns the summarised results presented in **Table 8-4**. The information derives from the data for each quaternary catchment and its aggregation to GRU level as presented in **Appendix C**, and which forms the basis for the following discussion.

The total mean groundwater recharge amounts to 501 Mm^3/a for the Middle Vaal WMA. This represents ~55% of the total mean annual runoff of ~913 Mm^3 reported in WR2005 (Middleton and Bailey, 2011) for this WMA. Total annual groundwater use amounts to ~11% (~54 Mm^3) of the total mean annual groundwater recharge. The groundwater component of baseflow accounts for a further ~40% (202 Mm^3) of the total mean annual groundwater recharge. This value is notably greater than the ~89 Mm^3 represented by the sum of the baseflow values reported in **Table 5-1**, and the ~99 Mm^3 reported in **Table 8-3**. It is also almost twice the 109 Mm^3/a suggested in the National Water Resource Strategy (DWAF, 2004c) be allocated to the ecological Reserve. The basic human needs requirement amounts to only ~2% (8.6 Mm^3) of the total mean annual groundwater recharge.

The groundwater "loss" components listed above together account for ~53% (~264 Mm^3) of the total mean annual groundwater recharge. This theoretically leaves ~237 Mm^3/a of groundwater in storage, not all of which is available for allocation to water users because of limitations imposed by accessibility for abstraction. It is considered reasonable to accept that not more than 50% of the remaining groundwater in storage is accessible and therefore available for allocation. This amounts to not more than ~119 Mm^3/a, which represents ~24% on average (within the range 9-34%) of the total mean annual groundwater recharge (**Table 8-4**). Against this background, it must be noted that WR2005 (Middleton and Bailey, 2011) reports a utilisable groundwater exploitation potential (UGEP) for the Middle Vaal WMA of 398 Mm^3/a. This is more than three times greater than the value arrived at by this study.

Table 8-4. Summary of the quantity component of the preliminary groundwater Reserve for the MVWMA

Preliminary Groundwater Reserve Quantity Component Parameter		**Groundwater Resource Unit**								**Total**
		1a	**1b**	**2**	**3a**	**3b**	**4a**	**4b**	**5**	***Mean***
Recharge	Area (km^2)	2408.9	880.9	9061.5	18958.6	2833.1	8084.9	6194.8	4128.7	52 551
	Mean annual precipitation (mm)	574.7	571.8	549.7	520.3	580.6	550.7	591.0	611.3	*568.8*
	Mean groundwater recharge (% MAP)	10.1	6.0	2.0	0.9	1.4	0.7	1.1	1.6	*3.0*
	Mean groundwater recharge (Mm^3/a)	146.5	30.2	99.4	89.8	23.7	30.9	39.9	40.4	501.0
Use	Groundwater use (Mm^3/a)	23.7	5.4	7.1	8.6	1.3	3.7	3.2	1.1	54.1
Reserve	Groundwater component of baseflow (Mm^3/a)	27.5	6.8	45.6	43.1	14.9	18.3	28.1	26.6	201.5
	Population at minimum living level	51 483	33 363	156 481	247 763	19 932	182 085	138 878	55 369	885 354
	Basic human needs Reserve (Mm^3/a)	0.47	0.30	1.63	2.26	0.18	2.00	1.27	0.51	8.6
	Total Reserve (Mm^3/a)	28.0	7.1	47.2	45.4	15.1	20.3	29.4	27.1	210.1
Allocation	Allocable groundwater (Mm^3/a)	59.0	10.3	22.6	16.9	3.7	3.8	3.7	5.7	122.2
	Allocable groundwater (% of Reserve)	210.7	145.0	47.9	37.2	24.5	18.7	12.6	21.0	*58.2*
	Allocable groundwater (% of recharge)	40.3	34.1	22.7	18.8	15.6	12.3	9.3	14.1	*24.4*

The aggregation of the groundwater Reserve quantities to the GRU level as represented in **Table 8-4** masks those quaternary catchments that exhibit small allocable groundwater quantities. This indicates that the quaternary catchment is at risk of exhibiting a groundwater deficit. For practical purposes, quaternary catchments exhibiting allocable volumes <5% of the mean annual groundwater recharge of the host GRU are identified as being at risk of deficit. This is invariably associated with a groundwater component of baseflow that closely approaches or even exceeds the mean annual groundwater recharge. Although this improbable situation reflects the use of different data sets (e.g. GRAII and WR90) in the derivation of the groundwater quantity Reserve and allocable volume of groundwater, it nevertheless identifies a cautionary situation. Quaternary catchments in this category are identified by the shaded rows in **Appendix C**, and indicate that 13 (~19%) of the 67 quaternary catchments in the study area exhibit this characteristic.

8.2.3 Groundwater Quality

The quality component of the groundwater Reserve has been determined for each of the GRUs on the basis of a comparison between the individual ion concentrations associated with the recent groundwater chemistry and the various ion limits that define a Class 1 drinking water (SANS, 2011a; 2011b). The outcome of this determination, based on the information presented in **Table 3-4** as reference, is presented in **Table 8-5**. The veracity of the results is given credence by the electrical balance values which are all within the ±5% error margin for acceptability. Nevertheless, reservations regarding the relevance of some of the outcomes exist. These are discussed as follows.

Table 8-5. Preliminary determination of the groundwater quality component of the Reserve for the study area

Chemistry Variable	**Groundwater Resource Unit**								
	1a	**1b**	**2**	**3a**	**3b**	**4a**	**4b**	**5**	**SANS (2011a)[1]**
pH	8.1	7.7	7.6	8.0	8.0	8.1		8.5	5.0-9.7
	5.0-9.7	5.0-9.7	5.0-9.7	5.0-9.7	5.0-9.7	5.0-9.7		5.0-9.7	
EC (mS/m)	49.1	**181.0**	60.2	**386.2**	128.4	75.0		41.0	<150
	54.0	**199.1**	66.3	**424.8**	141.2	82.5		45.1	
Ca (mg/L)	43.9	199.8	52.2	**179.5**	73.1	56.7		14.0	<150
	48.3	219.8	57.4	**197.5**	80.4	62.4		15.4	
Mg (mg/L)	31.2	**117.9**	31.9	**135.8**	42.0	23.5		2.7	<70
	34.3	**129.7**	35.1	**149.4**	46.1	25.9		3.0	
Na + K (mg/L)	7.6	61.0	24.7	**534.2**	161.4	78.6		96.7	<200
	8.3	67.1	27.2	**587.6**	177.6	86.5		106.4	
Cl (mg/L)	23.0	49.4	29.1	**1012.0**	**225.0**	31.0		15.5	<200
	25.3	54.3	32.0	**1113.2**	**247.5**	34.1		17.1	
SO_4 (mg/L)	9.1	**775.8**	90.5	**441.9**	86.2	55.6		12.3	<400
	10.0	**853.4**	99.6	**486.1**	94.8	61.2		13.5	
T. Alk. (mg $CaCO_3$/L)	191.2	239.6	149.1	207.6	290.5	288.8		211.0	n.s.
	210.3	263.6	164.0	228.4	319.6	317.7		232.1	
NO_3 (mg N/L)	5.4	3.0	8.4	8.3	4.2	3.8		0.5	<11
	5.9	3.3	9.2	9.1	4.6	4.1		0.6	
Electrical balance (%)	–0.1	3.2	4.3	1.6	0.0	1.9		2.1	≤5%
Chemical character	CaMg-HCO_3	Ca-SO_4	CaMg-HCO_3	Mg-Cl	Ca-Cl	Ca-HCO_3		Ca-HCO_3	—
Count (n)	326	195	309	2	35	54		2	—

(1) Standard health-related limit for consumption of 2 L/d over 70 years by a 60 kg person

Notes: Unshaded rows denote reference groundwater quality (chemistry) used to derive shaded rows

Shaded rows denote proposed groundwater quality component of the Reserve

Bold text denotes exceedance of SANS (2011a) limit as defined above

The dolomitic groundwater resources that characterise GRUs 1a and 1b are necessarily dealt with as homogeneous hydrogeologic units even though they are most probably physically represented by compartments that exhibit different groundwater chemistry signatures. Despite this generalisation, the poorer reference water chemistry associated with GRU 1b compared with GRU 1a (**Table 8-5**) reflects the association of the former with an impacted mining environment characterised by a Ca-SO_4 groundwater chemical composition. It is reasonable to presume, however, that the majority of the analyses considered for GRU 1b derive from sources where the likelihood of mining-related impact is greater, providing a bias toward an associated water chemistry at the expense of non-impacted karst groundwater resources in this GRU. Under these circumstances, it is recommended that the proposed groundwater quality Reserve for GRU 1b be applied in those instances where a mining impact is likely, and that the proposed groundwater quality Reserve for GRU 1a be applied elsewhere in GRU 1b.

Of greater concern, however, is the exceedance of the SANS (2011a) limits for most of the variables (both the reference and proposed groundwater quality Reserve values) associated with GRU 3a. This is attributed to the situation where the source reference data comprise single analyses obtained from two boreholes (**Table 8-5**). This is clearly not representative for GRU 3a as a whole, which is primarily underlain by Ecca Group sediments. It is therefore considered appropriate that the significantly larger data set available for the equivalent GRU 4 in the neighbouring Upper Vaal WMA be employed to arrive at a more realistic proposed groundwater quality Reserve for the Ecca Group sediments in the Middle Vaal WMA, especially in those instances where a paucity of data raises doubt over the veracity of the information presented in **Table 8-5**. The comparison is made in **Table 8-6**, and clearly reveals the better quality reflected by the 175 analyses for GRU 4 in the Upper Vaal WMA compared to the Middle Vaal WMA.

Table 8-6. Comparison of the proposed groundwater quality component of the Reserve for Ecca Group sediments between the Middle Vaal and the Upper Vaal WMAs

Chemistry Variable	**Middle Vaal WMA[1]**		**Upper Vaal WMA**	**SANS (2011a)[2]**
	GRU 3a	**GRU 3b**	**GRU 4**	
pH	8.0	8.0	7.7	5.0-9.7
	5.0-9.7	5.0-9.7	5.0-9.7	
EC (mS/m)	**386.2**	128.4	55	<150
	424.8	141.2	60.5	
Ca (mg/L)	**179.5**	73.1	39.0	<150
	197.5	80.4	42.9	
Mg (mg/L)	**135.8**	42.0	19.5	<70
	149.4	46.1	21.5	
Na + K (mg/L)	**534.2**	161.4	39.0	<200
	587.6	177.6	42.9	
Cl (mg/L)	**1012.0**	**225.0**	34.5	<200
	1113.2	**247.5**	38.0	
SO_4 (mg/L)	**441.9**	86.2	46.7	<500
	486.1	94.8	51.4	
T. Alk. (mg $CaCO_3$/L)	207.6	290.5	156.2	n.s.
	228.4	319.6	171.8	
NO_3 (mg N/L)	8.3	4.2	1.4	<11
	9.1	4.6	1.5	
Electrical balance (%)	1.6	0.0	1.9	≤5%
Chemical character	Mg-Cl	Ca-Cl	Ca-HCO3	—
Count (n)	2	35	175	—

(1) From **Table 8-5**
(2) Standard health-related limit for consumption of 2 L/d over 70 years by a 60 kg person
Notes: Unshaded rows denote reference groundwater quality (chemistry) used to derive shaded rows
Shaded rows denote proposed groundwater quality component of the Reserve
Bold text denotes exceedance of SANS (2011a) standard health-related limit as defined above

The comparison in **Table 8-6** also shows the difference in variable values between GRU 3b in the MVWMA and GRU 4 in the UVWMA. Although not as marked as in the case of GRU 3a, the differences are still considered sufficiently significant (especially in regard to sulphate) to raise a caution for the relevance of the listed values. In both instances, the respective Mg-Cl (GRU 3a) and Ca-Cl (GRU 3b) compositions of the groundwater are at variance with the Ca-HCO_3 composition that characterises the groundwater of GRU 4 in the Upper Vaal WMA.

In light of the above, it is recommended that the proposed groundwater quality component of the Reserve set for the UVWMAs GRU 4 be applied also to GRUs 3a and 3b of the MVWMA, at least in those areas where anthropogenic impacts are associated with agriculture, or largely natural conditions prevail.

8.3 Proposed Desired Status Category and Management Class

The comparatively low impact on groundwater resources associated with the mainly dryland agriculture practiced in the study area indicates that the proposed management class for the hydrogeologic environment might replicate the present ecological state of this environment. The PES categorisation per GRU shown in **Table 8-2** provides the framework for the setting of the proposed desired status category and management class as per **Table 8-7**.

Table 8-7. Proposed desired status category and management class per GRU for the Middle Vaal WMA

Groundwater Resource Unit	Preliminary Water Resource Class	Proposed Desired Status Category	Proposed Management Class	Proportion of Study Area (%)
1a	Fair	C	Fair	4.6
1b	Fair	C	Fair	1.7
2	Good	B	Good	17.2
3a	Fair	C	Fair	36.1
3b	Fair	C	Fair	5.4
4a	Good	B	Good	15.4
4b	Good	B	Good	11.8
5	Good	B	Good	7.9

It is evident from **Table 8-7** that the proposed desired status categories and management classes conform to the respective preliminary water resource classes associated with the GRUs. No proposed desired status category or management class is higher (better) than the preliminary water resource class. This supports the ostensible resilience of the groundwater environment to anthropogenic impacts without imposing unduly onerous obligations on the authority/authorities responsible for its implementation, maintenance and management.

Table 8-7 shows that four of the eight GRUs are classified as "Good". These GRUs together represent ~52% of the study area. The remaining GRUs are classified as "Fair". Two of the latter are associated with the karst aquifers in the study area. These circumstances indicate that the groundwater resources in the study area have not yet experienced excessive modification despite their occurrence within a modified surface environment. Nevertheless, a caution must be expressed in regard to GRU 1b which is assigned a present ecological state of D (**Table 8-2**) mainly because of the impact from mining activity in this GRU in conjunction with its dolomitic character. Degeneration of this GRU to a "Poor" class is possible if water resources management efforts in this GRU do not address the potential mine water impact.

The resilience of the groundwater environment to anthropogenic impacts is considerable yet finite. It is therefore required that a monitoring programme and management plan be implemented that is based on a well-informed set of resource quality objectives (RQOs). Although the National Water Resource Strategy (DWA, 2011) describes a situation where "………. *procedures for determining RQOs are still under development* ……" and "……. *implementation has not yet occurred*", a discussion of relevant issues in this regard is presented in **section 8.4**.

8.4 Preliminary Groundwater Resource Quality Objectives

8.4.1 Background

The derivation of resource directed measures requires finally that resource quality objectives (RQOs) be set for the water resource being assessed. As in the case of the groundwater Reserve, the GRDM assessment provides only preliminary RQOs in the absence of stakeholder consultation via a public participation process.

The aim of RQOs as stated in the National Water Act (Act 36 of 1998) is "……… *to establish clear goals relating to the quality of the relevant water resources. In determining resource quality objectives, a balance must be sought between the need to protect and sustain water resources on the one hand, and the need to develop and use them on the other.*" The DWAF (1999b) "manual" identifies RQOs as "…….. *a numerical or descriptive statement of the conditions which should be met in the receiving water resource, in terms of resource quality, in order to ensure that the water resource is protected.*"

Colvin et al. (2003) list a number of hydrogeologic variables that might be used as potential RQOs, including water levels and hydraulic gradients, storage volumes and sustainable yield, aquifer characteristics such as storativity and recharge, and phenomena such as sinkholes and caves. The information presented in this report must provide the material with which to set at least semi-quantitative and quasi-numerical RQOs for the various groundwater resource units identified in the Middle Vaal WMA. The steps to setting a suite of resource quality objectives (RQOs) to protect a significant groundwater resource are identified by Colvin et al. (2003) as follows:

- broadly characterise the groundwater resource;
- define the aquifer attributes which support or limit the recognised uses;
- define the risk to uses with respect to hazards present in the catchment and aquifer vulnerability;
- select key measurable indicators which relate to the resource itself or land-use impacts;
- quantify the reference conditions, present status, sustainability threshold and variability of these resource indicators;
- outline the management actions that may be necessary to ensure different levels of modification/protection are maintained; and
- set RQO values for the key measurable indicators.

8.4.2 Discussion of Conceptual RQOs

8.4.2.1 Groundwater Quantity

It has been stated in **section 6.3** that ~77% of the Middle Vaal WMA is underlain by Karoo Supergroup strata that represent a fractured and intergranular groundwater environment. The remainder is underlain by much older Vaalian (Transvaal Supergroup) and Randian (Witwatersrand and Ventersdorp supergroups) Era strata, of which ~6% is associated with carbonate strata (dolomite) of the Malmani Subgroup. This distinction is important under circumstances where the mode of groundwater occurrence in a karst environment (aquifer) differs significantly from that in a fractured and intergranular environment. The main difference is the degree to which the potentiometric surface follows the topographic surface in a fractured and intergranular hydrosystem, compared to the poor correlation between these two surfaces in a karst hydrosystem.

The observation that ~94% of the study area represents a fractured and intergranular aquifer suggests that comparatively simple and uniform RQOs can be applied in regard to groundwater levels across almost the entire WMA. Only the relatively small area of karst hydrosystem needs to be approached differently.

A further aspect relevant to the setting of RQOs for groundwater quantity is the relatively small proportion (~2%) of the study area that reflects a significantly modified category “D” present ecological state (**Table 8-2**) and proposed desired status category and management class (**Table 8-7**). This implies that the remaining ~98% representing a slightly to moderately modified PES and good to fair proposed desired status category and management class requires a “closer to natural” set of RQOs in order to protect the ecological Reserve. In the context of groundwater quantity, this will secure the surface water / groundwater interaction that supports the bulk of the ~202 Mm^3/a groundwater contribution to baseflow in the WMA (**Table 8-4**).

8.4.2.2 Groundwater Quality

Preliminary RQOs for the groundwater quality component in the Upper Vaal WMA are simply set in accordance with the preliminary determination of this component in regard to the Reserve (**Table 8-5** and **Table 8-6**). This approach encompasses the different GRUs identified in the study area.

Because the Reserve supports only the ecological and basic human needs components, its focus is jointly directed at the potable (domestic) use of water and that of aquatic ecosystems. It has been shown in **section 2.3.3** (**Table 2-6**), however, that the principal anthropogenic groundwater use in the study area relates to irrigation farming. The quality of water for this use is defined in Volume 4 of the South African Water Quality Guidelines (SAWQG) published by the DWAF (1996). It is therefore appropriate to also recognise the quality of groundwater for irrigation purposes. This is attempted in **Table 8-8**, which shows that irrigation use sets a more sensitive (stringent) threshold value (limit) in regard to electrical conductivity than either domestic (potable) use or that required for aquatic ecosystems.

Table 8-8. Comparison of RQO values with water quality parameter limits for appropriate water uses

Parameter Unit	Domestic Use	Irrigation	Aquatic Ecosystems	Critical Value	Max. RQO Value
Total coliforms #/100mL	10	Not specified	Not specified	10	10
E. coli #/mL	1	1 (Faecal Coliforms)	Not specified	1	1
Algae (Blue-green units)	Not specified	Not specified	Not specified	6 (<2000 *Mycrosystis* cells)	6 (<2000 *Mycrosystis* cells)
pH ($-\log_{10}[H^+]$)	5.0 — 9.5	6.5 — 8.4	No more than 0.5 pH unit or 5% variation on background		
Electrical conductivity mS/m	150	40	Not specified	40	As per
Sulphate mg SO_4/L	400	Not specified	Not specified	400	As per
Total hardness mg $CaCO_3$/L	300	Not specified	Not specified	300	300
Total dissolved solids mg/L	450	260	No more than 15% change from normal cycle and no change in amplitude and frequency of cycles	260	260
Total suspended solids mg/L	Not specified	50	<10% increase in background		
Ammonia mg N/L	Not specified	5 (Inorganic nitrogen as N)	≤0.007 (as unionized ammonia)		
Nitrate mg N/L	10		Not specified	10	As per
Chloride mg Cl/L	200	100	Not specified	100	As per
Fluoride mg F /L F	1	2	≤0.75	≤0.75	≤0.75
Phosphate mg PO_4/L	Not specified	Not specified	0.005	0.005	0.005
Calcium mg Ca /L	150	Not specified	Not specified	150	As per
Magnesium mg Mg /L	100	Not specified	Not specified	100	As per
Sodium mg/L Na	200	70	Not specified	70	As per
Potassium mg K/L	50	Not specified	Not specified	50	As per
Aluminium mg Al/L	Not specified	5	@ pH <6.5: ≤0.005 @ pH >6.5: ≤0.01	5	5
Arsenic mg As/L	0.05	0.1	≤0.01	0.05	0.05
Boron mg B/L	Not specified	0.5	Not specified	0.5	0.5
Cadmium mg Cd/L	0.005	0.01	0.00015 to 0.0004 depending on hardness and fish type	0.005	0.005
Chromium mg Cr/L	Not specified	0.1 (as Cr VI)	VI: ≤0.007 III: ≤0.012	0.1	0.1
Cobalt mg Co/L	Not specified	0.05	Not specified	0.05	0.05
Copper mg Cu/L	1.3	0.2	0.0003-0.0014 depending on hardness	0.2	0.2
Iron mg Fe/L	1	5	≤10 % variation on background dissolved Fe	1	1
Mercury mg Hg/L	Not specified	Not specified	≤0.00004	0.001	0.001
Manganese mg Mn/L	0.4	0.02	0.18	0.02	0.02
Molybdenum mg Mo/L	Not specified	0.01	Not specified	0.01	0.01
Nickel mg Ni/L	Not specified	0.2	Not specified	0.2	0.2
Lead mg Pb/L	Not specified	0.2	0.0002-0.0012 depending on hardness	0.1	0.1
Selenium mg Se/L	Not specified	0.02	≤0.002	0.02	0.02
Zinc mg Zn/L	20	1	≤0.002	1	1

9 CONCLUSIONS

The outcome of the GRDM study in regard to the Middle Vaal WMA indicates the following.

- That the Middle Vaal WMA is readily subdivided into eight groundwater resource units (GRUs) that to a substantial degree integrates the aggregated footprint of quaternary catchments (as basic hydrologic assessment unit) with lithology (as basic hydrogeologic assessment unit).

- That ~52% of the WMA (representing four GRUs) supports a B category (slightly modified) present ecological state, ~46 (representing three GRUs) supports a BC category (slightly to moderately modified) PES, and ~2% (representing one GRU) supports a D category (significantly modified) PES.

- That total mean annual groundwater recharge amounts to ~501 Mm^3.

- That the groundwater contribution to baseflow accounts for ~202 Mm^3/a (~40%) of the total mean annual groundwater recharge.

- That total annual groundwater use accounts for ~54 Mm^3 (~11%) of the total mean annual groundwater recharge.

- That the amount of allocable groundwater amounts to ~122 Mm^3/a; this is only ~30% of the utilisable groundwater exploitation potential of 398 Mm^3/a obtained in WR2005.

- That 13 (~19%) of the 67 quaternary catchments reflect cautionary circumstances indicative of experiencing unacceptable groundwater "stress"; eleven of these catchments are associated with the Karoo Supergroup strata that underlie the central portion of the WMA, and remaining two with the older Randian strata that underlie the north-western portion of the WMA.

- That comparatively simple and uniform RQOs can be applied in regard to groundwater levels across the ~94% of the WMA representing a fractured and intergranular aquifer in which the potentiometric surface typically reflects the topographic surface, and the nature of surface water / groundwater interaction therefore generally represents a reasonably simple gaining hydrologic environment (losing hydrogeologic environment). The remaining 6% of the catchment that comprises carbonate strata (dolomite), portions of which are severely compromised by gold mining activity, represents the much more complicated exception to these circumstances.

- That the relatively small proportion (~2%) of the study area that reflects a significantly modified category "D" present ecological state, proposed desired status category and management class implies that the remaining ~98% (representing a slightly to moderately modified PES and good to fair proposed desired status category and management class) requires a "closer to natural" set of RQOs in order to protect the ecological Reserve. In the context of groundwater quantity, this will secure the surface water / groundwater interaction that supports the bulk of the ~202 Mm^3/a groundwater contribution to baseflow in the WMA.

It is concluded that the GRDM assessment of the Middle Vaal WMA has advanced the understanding of the groundwater resources environment in this area despite the challenges posed by a paucity of regionally extensive hydrogeologic data and information. This challenge is not readily resolved within an environment where severe competition for available funds necessarily results in those aspects such as groundwater resource monitoring that do not return gains in the short-term, suffering a measure of "relaxation" or neglect. Concerns in this regard are reflected in section 6.5.6 of the draft National Water Resource Strategy (DWA, 2011).

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APPENDIX A.GROUNDWATER LEVELS

GRU 1a

Site ID	Outcrop Lithology	Land Cover	Maximum Value (m bs)	Maximum Date	Minimum Value (m bs)	Minimum Date	Average (m bs)	Standard Deviation	R^2	Slope
2627AA00107	Malmani Subgroup	Unimproved (natural) grassland	52.77	23/06/1969	32.49	07/08/1963	42.93	6.24	0.87	-0.0052
2526CD00001	Malmani Subgroup	Cultivated, temporary, commercial, irrigated	27.07	29/11/1995	21.09	25/09/1986	23.37	1.25	0.67	-0.0008
2526DC00027	Quaternary surface deposits	Unimproved (natural) grassland	20.41	29/12/1995	14.35	09/04/1997	18.05	1.24	0.30	-0.0004
2526DC00028	Quaternary soil cover	Unimproved (natural) grassland	24.33	27/11/1995	17.50	03/09/1990	20.30	1.12	0.13	-0.0003
2526DC00029	Malmani Subgroup	Forest Plantations (Other / mixed spp.)	18.75	28/12/1995	13.50	28/08/1990 20/02/1991	16.27	1.28	0.35	-0.0005
2626AB00002	Quaternary soil cover	Unimproved (natural) grassland	23.58	04/11/1999	12.13	07/03/1996	19.26	2.78	0.38	-0.0011
2626AB00051	Malmani Subgroup	Unimproved (natural) grassland	31.88	22/03/1995	18.32	02/07/2002	24.23	3.00	0.17	0.0008
2626AB00052	Malmani Subgroup	Unimproved (natural) grassland	18.79	28/12/1995	7.71	29/01/2002	14.51	2.05	0.26	0.0007
2626AB00053	Quaternary soil cover	Cultivated, temporary, commercial, dryland	45.40	30/01/1996	36.82	25/09/2003	42.53	1.58	0.18	0.0008
2626AB00054	Malmani Subgroup	Unimproved (natural) grassland	42.38	28/12/1995	35.33	02/07/2002	39.24	1.65	0.31	0.0006
2626BA00099	Malmani Subgroup	Cultivated, temporary, commercial, dryland	30.50	28/12/1995	24.97	06/08/2002	27.57	1.16	0.25	0.0004
2626BA00100	Malmani Subgroup	Unimproved (natural) grassland	21.14	14/10/1994	15.00	13/12/1989	18.29	1.19	0.17	0.0003

2626BB00165	Malmani Subgroup	Unimproved (natural) grassland	43.44	22/02/1997	25.60	24/01/1990	31.63	4.56	0.34	-0.0017
2626BB00166	Malmani Subgroup	Unimproved (natural) grassland	73.03	28/12/1995	7.62	02/12/2004	70.01	5.46	0.05	0.0008
2626BB00167	Malmani Subgroup	Unimproved (natural) grassland	32.19	28/01/1997	20.30	28/01/2003	29.19	1.21	0.16	0.0003
2626BB00168	Malmani Subgroup	Unimproved (natural) grassland	5.97	31/12/1996	3.18	19/08/2003	4.08	0.47	0.19	0.0001
2626BB00169	Malmani Subgroup	Unimproved (natural) grassland	28.76	21/07/2004	22.47	16/10/2002	24.00	0.95	0.13	0.0002
2626BB00170	Malmani Subgroup	Unimproved (natural) grassland	30.00	15/12/1989	24.36	25/01/2005	26.08	0.75	0.32	0.0003
2626BB00171	Malmani Subgroup	Unimproved (natural) grassland	38.37	28/12/1995	23.93	03/02/1994	30.27	1.67	0.21	0.0005
2626BD00141	Malmani Subgroup	Unimproved (natural) grassland	22.62	28/12/1995	15.64	02/07/2002	19.03	1.85	0.54	0.0009

GRU 1b

Site ID	Outcrop Lithology	Land Cover	Maximum Value (m bs)	Maximum Date	Minimum Value (m bs)	Minimum Date	Average (m bs)	Standard Deviation	R^2	Slope
2626DD00227	Malmani Subgroup	Unimproved (natural) grassland	21.10	30/11/1970	13.46	28/02/1977	16.92	1.86	0.17	0.0003
2626DD00228	Malmani Subgroup	Unimproved (natural) grassland	17.98	07/06/1971	9.65	30/06/1990	12.74	2.29	0.41	0.0006
2626DD00223	Malmani Subgroup	Unimproved (natural) grassland	45.14	31/10/1970	24.53	30/08/1981	38.39	4.28	0.19	0.0006
2626DD00246	Malmani Subgroup	Unimproved (natural) grassland	213.72	31/10/1987	62.85	30/11/1981	151.34	48.13	0.51	-0.0127
2626DD00267	Malmani Subgroup	Unimproved (natural) grassland	15.10	30/11/1970	5.36	28/02/1977	11.33	2.66	0.55	0.0018
2626DD00268	Malmani Subgroup	Unimproved (natural) grassland	74.20	30/11/1970	24.72	31/07/1978	50.34	17.75	0.76	0.0107
2626DD00269	Malmani Subgroup	Unimproved (natural) grassland	78.26	30/11/1970	17.87	30/06/1978	49.58	19.18	0.67	0.0095
2626DC00100	Malmani Subgroup	Unimproved (natural) grassland	187.95	31/01/1985	42.90	30/06/1974	100.00	51.27	0.24	-0.0092
2626DD00210	Malmani Subgroup	Mines & quarries (underground / subsurface mining)	17.52	30/11/1970	7.36	31/07/1989	11.24	2.92	0.54	0.0008
2626DD00212	Malmani Subgroup	Unimproved (natural) grassland	58.04	30/11/1970	30.67	31/05/1988	45.70	8.59	0.64	0.0024
2626DD00213	Malmani Subgroup	Unimproved (natural) grassland	113.52	31/10/1989	45.14	31/07/1967	74.77	18.43	0.27	-0.0036
2626DD00214	Ecca Group	Unimproved (natural) grassland	32.17	31/03/1986	17.32	31/05/1977	21.21	2.11	0.10	-0.0002
2626DD00215	Malmani Subgroup	Unimproved (natural) grassland	11.40	30/11/1970	3.00	30/11/1981	6.21	2.11	0.53	0.0006

2626DD00216	Malmani Subgroup	Urban / Built-up (residential, hostels)	15.40	30/11/1970	9.21	01/06/1982	11.80	1.42	0.37	0.0003
2626DD00217	Malmani Subgroup	Urban / Built-up (residential, hostels)	14.70	30/11/1970	8.01	01/06/1982	10.79	1.56	0.39	0.0004
2626DD00218	Malmani Subgroup	Unimproved (natural) grassland	13.24	31/01/1972	7.50	30/11/1981	10.23	1.51	0.37	0.0003
2626DD00219	Malmani Subgroup	Urban / Built-up (residential, hostels)	14.23	31/01/1972	5.08	30/04/1978	10.43	1.87	0.38	0.0004
2626DD00220	Malmani Subgroup	Unimproved (natural) grassland	12.07	30/11/1970	3.78	28/02/1989	7.06	1.55	0.29	0.0003
2626DD00221	Malmani Subgroup	Unimproved (natural) grassland	12.83	30/11/1970	5.69	28/02/1982	8.37	1.77	0.42	0.0004
2626DD00222	Malmani Subgroup	Unimproved (natural) grassland	11.60	30/11/1970	5.23	29/04/1982	7.52	1.56	0.45	0.0004
2626DD00225	Malmani Subgroup	Forest Plantations (Eucalyptus spp)	15.41	30/11/1970	6.25	28/02/1989	11.04	2.19	0.25	0.0004
2626DD00226	Malmani Subgroup	Unimproved (natural) grassland	22.10	31/12/1970	14.34	30/01/1977	17.88	1.89	0.16	0.0003
2626DD00229	Malmani Subgroup	Unimproved (natural) grassland	13.75	31/01/1972	4.09	08/05/1981	8.50	2.72	0.41	0.0006
2626DD00230	Malmani Subgroup	Unimproved (natural) grassland	24.34	30/11/1970	6.71	29/04/1982	15.01	4.89	0.30	0.0010
2626DD00231	Ecca Group	Urban / Built-up (residential, formal suburbs)	30.33	30/11/1970	15.06	30/11/1981	22.33	3.89	0.32	0.0008
2626DD00232	Ecca Group	Urban / Built-up (residential, formal suburbs)	28.20	30/11/1970	13.08	29/04/1982	20.16	3.91	0.32	0.0008
2626DD00233	Malmani Subgroup	Urban / Built-up (residential, formal suburbs)	25.50	31/10/1970	8.85	29/04/1982	15.60	4.53	0.22	0.0008
2626DD00234	Malmani Subgroup	Mines & quarries (underground /	13.20	30/11/1970	3.35	30/04/1989	7.03	2.78	0.50	0.0007

		subsurface mining)								
2626DD00235	Malmani Subgroup	Mines & quarries (underground / subsurface mining)	13.00	30/11/1970	3.70	11/12/1981	7.29	2.47	0.54	0.0007
2626DD00236	Malmani Subgroup	Mines & quarries (underground / subsurface mining)	16.80	30/11/1970	6.17	15/11/1979	10.61	2.95	0.55	0.0008
2626DD00237	Malmani Subgroup	Mines & quarries (underground / subsurface mining)	21.40	30/11/1970	11.27	31/03/1982	15.18	2.89	0.51	0.0008
2626DD00238	Ecca Group	Unimproved (natural) grassland	23.41	30/11/1970	12.00	31/07/1990	17.45	2.97	0.54	0.0009
2626DD00239	Malmani Subgroup	Unimproved (natural) grassland	12.01	30/11/1970	3.56	30/11/1981	6.86	2.20	0.43	0.0005
2626DD00240	Malmani Subgroup	Unimproved (natural) grassland	19.11	30/11/1970	11.58	28/02/1977	14.92	1.91	0.18	0.0003
2626DD00241	Ecca Group	Urban / Built-up (residential, mixed)	21.73	30/11/1970	8.50	08/05/1981	14.87	3.31	0.33	0.0007
2626DD00242	Malmani Subgroup	Unimproved (natural) grassland	16.52	30/11/1970	6.25	31/05/1976	11.04	2.05	0.17	0.0003
2626DD00243	Malmani Subgroup	Mines & quarries (underground / subsurface mining)	15.30	30/11/1970	4.54	31/07/1989	8.80	3.00	0.55	0.0008
2626DD00244	Malmani Subgroup	Unimproved (natural) grassland	12.87	30/11/1970	5.61	31/08/1976	9.25	1.56	0.14	0.0002
2626DD00245	Malmani Subgroup	Unimproved (natural) grassland	198.98	30/05/1985	37.32	30/04/1979	126.38	40.42	0.18	-0.0064
2626DD00247	Malmani Subgroup	Unimproved (natural) grassland	21.09	30/11/1970	14.66	31/07/1976	17.62	1.48	0.12	0.0002
2626DD00248	Malmani Subgroup	Thicket, Bushland, Bush Clumps, High Fynbos	14.65	30/11/1970	2.16	31/12/1981	5.83	2.90	0.43	0.0007

2626DD00249	Malmani Subgroup	Unimproved (natural) grassland	130.65	30/04/1986	16.07	31/05/1976	81.38	32.30	0.21	-0.0056
2626DD00250	Malmani Subgroup	Unimproved (natural) grassland	26.13	30/11/1970	15.13	31/03/1991	19.86	2.96	0.54	0.0008
2626DD00251	Malmani Subgroup	Unimproved (natural) grassland	218.85	31/01/1989	38.18	28/02/1977	117.81	55.98	0.47	-0.0130
2626DD00252	Malmani Subgroup	Unimproved (natural) grassland	25.40	30/11/1970	16.46	31/03/1976	21.40	1.70	0.08	0.0002
2626DD00253	Ecca Group	Unimproved (natural) grassland	80.89	31/05/1974	45.90	29/02/1968	57.11	7.65	0.07	0.0008
2626DD00254	Malmani Subgroup	Mines & quarries (underground / subsurface mining)	12.53	30/11/1970	3.81	01/06/1982	7.20	2.27	0.49	0.0006
2626DD00255	Malmani Subgroup	Mines & quarries (underground / subsurface mining)	12.20	30/11/1970	3.89	31/03/1991	7.35	2.23	0.54	0.0006
2626DD00256	Malmani Subgroup	Mines & quarries (underground / subsurface mining)	13.21	30/11/1970	3.51	30/04/1991	7.13	2.47	0.54	0.0007
2626DD00257	Malmani Subgroup	Mines & quarries (underground / subsurface mining)	13.23	30/11/1970	3.77	30/06/1982	7.36	2.63	0.50	0.0007
2626DD00258	Malmani Subgroup	Mines & quarries (underground / subsurface mining)	14.30	31/03/1971	3.97	29/04/1982	7.55	2.59	0.50	0.0007
2626DD00259	Malmani Subgroup	Mines & quarries (underground / subsurface mining)	13.91	30/11/1971	4.85	30/04/1989	8.68	2.88	0.50	0.0008
2626DD00260	Malmani Subgroup	Mines & quarries (underground / subsurface mining)	14.80	30/11/1970	4.25	31/03/1989	8.54	2.90	0.54	0.0008
2626DD00265	Malmani Subgroup	Unimproved (natural) grassland	7.70	30/11/1970	1.52	31/05/1976	3.98	1.18	0.02	0.0001

2626DD00266	Malmani Subgroup	Unimproved (natural) grassland	16.33	30/11/1970	6.37	30/06/1982	10.75	3.15	0.72	0.0015
2626DD00271	Malmani Subgroup	Unimproved (natural) grassland	14.03	30/11/1970	6.91	11/12/1981	11.39	0.96	0.11	0.0001
2626DD00272	Malmani Subgroup	Unimproved (natural) grassland	119.50	30/06/1986	21.25	31/05/1976	76.49	28.22	0.00	0.0004
2626DD00273	Malmani Subgroup	Unimproved (natural) grassland	176.15	28/02/1985	26.94	31/05/1976	82.35	33.14	0.01	0.0013
2626DD00274	Malmani Subgroup	Unimproved (natural) grassland	112.10	30/11/1970	20.70	31/03/1976	76.17	25.10	0.24	0.0070
2626DD00275	Malmani Subgroup	Unimproved (natural) grassland	15.46	31/01/1984	0.65	28/02/1977	4.36	3.43	0.35	-0.0012
2626DD00276	Malmani Subgroup	Unimproved (natural) grassland	39.58	30/04/1969	6.33	31/03/1976	20.29	10.47	0.43	0.0037

GRU 2

Site ID	Outcrop Lithology	Land Cover	Maximum Value (m bs)	Maximum Date	Minimum Value (m bs)	Minimum Date	Average (m bs)	Standard Deviation	R^2	Slope
2626DB00045	Hospital Hill Formation	Cultivated, temporary, commercial, dryland	22.16	04/12/1970	9.23	23/02/1976	18.21	3.50	0.60	0.0024
2625DD00001	Klipriviers-berg Group	Cultivated, temporary, commercial, dryland	43.50	07/01/2005	0.53	20/07/1978	14.99	10.12	0.43	-0.0023

GRU 4b

Site ID	Outcrop Lithology	Land Cover	Maximum Value (m bs)	Maximum Date	Minimum Value (m bs)	Minimum Date	Average (m bs)	Standard Deviation	R^2	Slope
2727CA00097	Adelaide Subgroup	Unimproved (natural) Grassland	18.47	02/11/1966	15.04	20/04/1967	16.84	0.68	0	0
2727CA00087	Adelaide Subgroup	Unimproved (natural) Grassland	46.43	01/08/1966	9.04	09/09/1967	9.95	3.75	0.11	0.0080
2727CA00098	Adelaide Subgroup	Unimproved (natural) Grassland	14.60	29/12/1972	10.97	14/04/1972	11.73	0.49	0.05	0.0002
2727CA00101	Quaternar, alluvium	Improved Grassland	22.46	31/01/1973	13.97	28/09/1971	16.24	1.54	0.01	-0.0002
2727DD00072	Karoo dolerite	Unimproved (natural) Grassland	14.92	29/01/1973	0.06	15/05/1976	5.26	4.78	0.67	0.0083

APPENDIX B.BASEFLOW DATA

QUATERNARY CATCHMENT	AREA (km^2)	MAP (mm)	WRP2005 MAR (Mm^3)	BASEFLOW						MEAN BASEFLOW (excl. SCHULZE) (Mm^3/a)	STANDARD DEVIATION (excl. SHULZE) (Mm^3/a)	COEFFICIENT OF VARIATION (%)	COEFFICIENT OF VARIATION (excl. SCHULZE) (%)	HUGHES BASEFLOW (% of MAR)	GROUNDWATER CONTRIBUTION TO BASEFLOW (% of MAR)	GROUNDWATER CONTRIBUTION TO SAMI BASEFLOW (Mm^3/a)	VIRGIN CONDITIONS		MODIFIED CONDITIONS	
				WRP (Mm^3/a)	WRP BASEFLOW/MAR (%)	SCHULZE (Mm^3/a)	PITMAN (Mm^3/a)	HUGHES (Mm^3/a)	SAMI (Mm3/a)								BASSEFLOW (Mm^3/a)	GROUNDWATER CONTRIBUTION TO BASEFLOW (Mm^3/a)	BASSEFLOW (Mm^3/a)	GROUNDWATER CONTRIBUTION TO BASEFLOW (Mm^3/a)
C24A	839	584	32.13	3.26	10%	0.43	3.44	8.77	5.21	5.17	2.56	73	49	27	12%	3.94	6.21	4.69	5.83	4.31
C24B	530	562	19.71	2.32	12%	0.27	1.80	4.79	2.86	2.94	1.31	68	44	24	12%	2.28	5.40	4.30	2.58	1.48
C24C*	1350	587		14.3		5.84	21.20	22.36	21.74	19.90	3.76	41	19			21.55	16.11	15.97	5.33	5.19
C24D	364	584	10.97	0.72	7%	0.96	1.13	2.89	2.20	1.73	0.99	59	57	26	16%	1.70	6.05	4.68	5.66	4.29
C24E	925	560	14.63	0.88	6%	0.27	2.31	6.15	4.59	3.48	2.34	88	67	42	26%	3.75	4.96	4.05	2.44	1.53
C24F	2020	577	28.12	3.08	11%	0.59	5.86	14.79	11.07	8.70	5.24	82	60	53	32%	8.86	5.48	4.39	4.89	3.80
C24G	985	581	23.86	2.59	11%	0.29	2.86	7.39	5.56	4.60	2.29	74	50	31	19%	4.42	5.65	4.48	5.32	4.16
C24H	840	576	13.73	0.51	4%	0.00	0.00	0.00	0.99	0.38	0.48	148	127	0	5%	0.74	1.18	0.89	0.78	0.48
C24J	2110	552	10.54	0.73	7%	0.00	0.00	0.00	2.01	0.69	0.95	160	138	0	15%	1.62	0.95	0.77	0.82	0.63
C25A	864	542	3.36	0.63	19%	0.00	0.00	0.00	0.91	0.39	0.46	141	119	0	20%	0.67	1.06	0.77	0.89	0.60
C25B	1888	509	2.52	0.65	26%	0.00	0.00	0.00	1.51	0.54	0.72	154	132	0	47%	1.19	0.80	0.63	0.71	0.54
C25C	1210	522	4.14	0.01	0%	0.00	0.00	0.00	1.07	0.27	0.53	221	198	0	20%	0.83	0.89	0.68	0.72	0.51
C25D	1203	525	10.06	0.66	7%	0.00	0.00	0.00	1.09	0.44	0.53	144	122	0	8%	0.85	0.90	0.71	0.76	0.56

C25E	1537	510	3.89	0.63	16%	0.00	0.00	0.00	1.20	0.46	0.58	148	126	0	25%	0.98	0.78	0.64	0.53	0.39
C25F	2219	481	3.45	0	0%	0.00	0.00	0.00	1.33	0.33	0.66	224	200	0	33%	1.14	0.60	0.51	0.52	0.43
C41A	1078	598	37.32	2.3	6%	0.03	0.00	8.72	8.42	4.86	4.39	112	90	23	14%	5.24	7.81	4.86	7.27	4.32
C41B	1005	598	34.88	1.18	3%	0.02	0.00	8.10	7.82	4.28	4.28	122	100	23	14%	4.89	7.79	4.86	7.55	4.63
C41C	1095	595	37.13	1.11	3%	0.03	0.00	8.65	8.35	4.53	4.61	123	102	23	14%	5.28	7.62	4.82	7.46	4.66
C41D	1155	549	28.04	1.11	4%	0.00	0.00	6.48	6.67	3.56	3.51	120	98	23	17%	4.87	5.77	4.22	5.63	4.07
C41E	391	519	9.93	0.03	0%	0.00	0.00	1.38	1.54	0.74	0.84	135	113	14	13%	1.28	3.93	3.29	3.74	3.10
C41F	555	496	12.34	0.02	0%	0.00	0.00	1.62	1.90	0.89	1.02	136	115	13	13%	1.54	3.43	2.78	3.21	2.56
C41G	272	516	6.36	0.01	0%	0.00	0.00	0.73	0.75	0.37	0.42	135	114	11	10%	0.64	2.76	2.36	2.62	2.23
C41H	887	500	20.44	0.02	0%	0.00	0.00	2.81	2.73	1.39	1.59	136	115	14	11%	2.24	3.07	2.53	3.06	2.52
C41J	556	495	12.35	0.01	0%	0.00	0.00	1.61	1.65	0.82	0.94	136	115	13	11%	1.38	2.97	2.48	2.97	2.48
C42A	695	633	22.43	3.95	18%	1.15	3.96	9.28	7.97	6.29	2.75	63	44	41	27%	6.08	11.47	8.75	11.01	8.30
C42B	727	582	19.79	2.56	13%	1.03	3.27	7.29	6.28	4.85	2.29	64	47	37	26%	5.21	8.64	7.17	8.19	6.72
C42C	793	626	24.32	2.22	9%	1.25	4.36	10.14	8.71	6.36	3.70	74	58	42	28%	6.75	10.98	8.51	10.57	8.10
C42D	663	556	12.63	3.45	27%	0.84	2.59	5.58	4.84	4.11	1.35	54	33	44	33%	4.20	7.30	6.33	6.84	5.88
C42E	750	565	15.23	3.37	22%	0.98	3.15	6.69	5.83	4.76	1.77	57	37	44	33%	4.99	7.77	6.66	7.32	6.21
C42F	734	567	23.33	1.36	6%	0.94	3.16	7.61	6.18	4.58	2.84	77	62	33	21%	4.91	8.42	6.69	8.12	6.39
C42G	555	549	15.75	1.26	8%	0.66	2.11	5.15	4.16	3.17	1.80	72	57	33	22%	3.43	7.50	6.18	7.12	5.80
C42H	445	540	11.73	0.68	6%	0.49	1.60	3.79	3.12	2.30	1.41	76	62	32	22%	2.62	7.01	5.88	5.09	3.96
C42J	1014	530	25.04	0.02	0%	1.13	3.45	8.19	6.66	4.58	3.63	90	79	33	23%	5.69	6.57	5.61	6.17	5.21
C42K	668	521	15.51	0.71	5%	0.73	2.20	5.16	4.15	3.06	1.99	78	65	33	23%	3.59	6.21	5.37	5.01	4.18
C42L	511	506	11.73	0.67	6%	0.33	1.53	3.50	2.73	2.11	1.26	77	60	30	20%	2.33	5.35	4.57	5.22	4.44
C43A	1491	483	2.46	0	0%	0.00	0.00	0.00	0.38	0.10	0.19	224	200	0	15%	0.37	0.26	0.25	0.24	0.23
C43B	723	495	3.82	0	0%	0.00	0.00	0.00	0.21	0.05	0.11	224	200	0	5%	0.20	0.29	0.27	0.27	0.25
C43C	913	470	1.35	0	0%	0.00	0.00	0.00	0.21	0.05	0.10	224	200	0	15%	0.20	0.23	0.22	0.20	0.19
C43D	1476	465	2.45	0	0%	0.00	0.00	0.00	0.32	0.08	0.16	224	200	0	13%	0.31	0.22	0.21	0.19	0.19
C60A	860	625	35.23	2.58	7%	1.16	4.82	10.41	9.23	6.76	3.68	72	54	30	16%	5.74	10.74	6.67	10.56	6.49
C60B	1022	610	37.27	3.85	10%	1.30	5.11	10.94	9.81	7.43	3.47	66	47	29	17%	6.52	9.60	6.38	9.15	5.93
C60C	1048	571	28.63	3.57	12%	1.19	3.88	8.37	7.53	5.84	2.47	61	42	29	20%	5.69	7.19	5.43	6.83	5.07

C60D	645	550	16.66	2.1	13%	0.58	1.94	4.68	3.95	3.17	1.36	62	43	28	18%	3.05	6.12	4.73	5.88	4.49
C60E	664	557	16.07	2.13	13%	0.75	2.19	5.00	4.49	3.45	1.51	61	44	31	22%	3.50	6.77	5.27	5.92	4.42
C60F	659	556	17.87	2.14	12%	0.61	2.11	5.00	4.24	3.37	1.47	63	44	28	18%	3.23	6.43	4.90	6.12	4.59
C60G	782	537	18.53	2.15	12%	0.67	2.11	5.12	4.34	3.43	1.53	63	45	28	19%	3.45	5.54	4.42	3.78	2.65
C60H	1232	513	1.13	0	0%	0.00	0.00	0.00	0.26	0.07	0.13	224	200	0	23%	0.26	0.21	0.21	0.14	0.14
C60J	959	548	6.77	0	0%	0.00	0.00	0.00	0.28	0.07	0.14	224	200	0	4%	0.28	0.29	0.29	0.12	0.12
C70A	613	627	18.52	1.78	10%	0.63	3.43	7.04	6.28	4.64	2.46	73	53	38	25%	4.71	10.25	7.68	9.53	6.96
C70B	660	612	17.76	1.04	6%	0.63	3.43	6.77	5.97	4.30	2.60	78	60	38	26%	4.70	9.05	7.12	8.48	6.55
C70C	887	615	24.45	1.9	8%	0.84	4.61	8.97	7.95	5.86	3.23	74	55	37	26%	6.28	8.96	7.08	8.47	6.59
C70D	675	586	13.51	1.03	8%	0.43	2.77	5.68	5.00	3.62	2.13	78	59	42	31%	4.20	7.41	6.22	6.52	5.33
C70E	693	578	16.76	1.02	6%	0.41	2.70	6.49	5.50	3.93	2.51	83	64	39	25%	4.16	7.93	6.00	7.58	5.66
C70F	564	574	13.05	0.97	7%	0.33	2.20	5.22	4.38	3.19	1.95	81	61	40	26%	3.34	7.76	5.92	7.36	5.52
C70G	901	577	16.91	1.86	11%	0.56	3.51	7.62	6.59	4.90	2.67	75	55	45	32%	5.34	7.31	5.92	6.97	5.59
C70H	251	568	5.48	0.76	14%	0.14	0.90	2.16	1.83	1.41	0.69	71	49	39	26%	1.43	7.31	5.68	7.00	5.37
C70J	521	575	12.54	1.54	12%	0.29	2.03	4.67	3.96	3.05	1.50	72	49	37	24%	3.05	7.59	5.85	7.15	5.41
C70K	891	565	8.07	1.4	17%	0.66	3.12	7.42	6.24	4.55	2.77	79	61	92	61%	4.92	7.00	5.53	6.30	4.82

* "This entire quaternary catchment is an endoreic area and there is no natural surface runoff from this catchment. There is however outflow from the Schoonspruit Eye and the natural outflow from the eye is provided as SCHOONEYE.NAT"

APPENDIX C.QUANTITY COMPONENT OF THE GROUNDWATER RESERVE

GRU	Quaternary Catchment	Area (km^2)	Population	MAP (mm)	Recharge		Groundwater Use (Mm^3/a)	Groundwater Component of Baseflow (Mm^3/a)	Basic Human Needs (Mm^3/a)	Allocable Groundwater	
					(Mm^3/a)	% MAP				Total (Mm^3/a)	50% of Total
1a	C24C	1349.8	25 663	586.9	96.98	12.24	14.9	13.09	0.23	68.76	34.38
	C24E	249.8	13 889	560.0	14.47	10.35	2.03	5.88	0.13	6.44	3.22
	C24F	807.9	11 931	577.8	42.63	9.14	0.52	8.52	0.11	33.49	16.74
Total *Mean*		2407.5	51 483	*574.7*	154.09	*10.58*	17.45	27.48	0.47	101.11	50.55
1b	C24A	352.4	2 107	582.6	13.27	6.47	0.13		0.02	13.12	6.56
	C24B	529.6	31 256	561.0	16.31	5.49	5.1	3.55	0.29	7.37	3.69
Total *Mean*		881.9	33 363	*571.8*	30.19	*5.98*	5.23		0.31	20.50	10.25
2	C24A	486.6	2 910	582.6	5.33	1.88	0.17		0.03	5.14	2.57
	C24D	364.3	3 079	584.3	3.99	1.88	0.2	7.53	0.03	-3.77	-1.88
	C24E	675.3	37 550	560.0	7.40	1.96	5.48	4.29	0.34	-2.71	-1.36
	C24F	1211.9	17 896	577.1	13.28	1.90	0.78	5.11	0.16	7.23	3.61
	C24G	985.2	20 852	581.6	11.75	2.05	0.3	9.01	0.19	2.25	1.12
	C24H	839.8	5 225	574.9	10.81	2.24	1.4	3.64	0.05	5.72	2.86
	C24J	1096.9	9 050	550.9	17.51	2.90	0.42	5.36	0.08	11.64	5.82
	C25A	863.4	2 998	542.8	12.49	2.67	0.5	2.88	0.03	9.08	4.54
	C25C	133.1	550	523.0	1.92	2.76	0.09	0.70	0.05	1.08	0.54
	C25D	937.9	46 930	526.1	7.49	1.52	0.47	1.36	0.55	5.11	2.56
	C25E	1336.4	9 219	510.7	7.38	1.08	1.65	1.03	0.10	4.60	2.30
	C25F	133.1	222	481.9	0.60	0.94	0.04	0.19	0.03	0.34	0.17
Total *Mean*		9063.7	156 481	*549.7*	99.35	*1.98*	11.50	41.10	1.63	45.11	22.55
3a	C24J	1012.5	8 353	550.9	4.80	0.86	0.38	4.95	0.08	-0.61	-0.30
	C25B	1887.6	63 942	510.0	18.16	1.89	0.6	4.45	0.58	12.53	6.26
	C25C	1076.6	4 454	523.0	5.10	0.91	0.71	5.70	0.04	-1.35	-0.67
	C25D	264.5	13 237	526.1	1.25	0.90	0.13	0.38	0.12	0.62	0.31
	C25E	199.7	1 378	510.7	0.95	0.93	0.25	0.15	0.01	0.53	0.27
	C25F	2085.1	3 484	481.9	9.88	0.98	0.56	3.05	0.03	6.24	3.12

GRU	Quaternary Catchment	Area (km^2)	Population	MAP (mm)	Recharge (Mm^3/a)	Recharge % MAP	Groundwater Use (Mm^3/a)	Groundwater Component of Baseflow (Mm^3/a)	Basic Human Needs (Mm^3/a)	Allocable Groundwater Total (Mm^3/a)	Allocable Groundwater 50% of Total
	C41J	555.5	11 390	494.6	2.16	0.79	0.1	0.90	0.10	1.06	0.53
	C42H	445.0	41 319	541.1	0.53	0.22	1.1	0.53	0.38	-1.48	-0.74
	C42J	1013.9	12 391	530.8	1.99	0.37	0.4	1.29	0.11	0.18	0.09
	C42K	668.0	587	522.1	0.67	0.19	0.9	0.16	0.01	-0.39	-0.20
	C42L	510.8	1 182	505.2	0.96	0.37	0.1	0.70	0.01	0.15	0.07
	C43A	1490.7	26 707	482.2	3.37	0.47	0.3	1.98	0.24	0.84	0.42
	C43B	723.3	1 854	494.0	1.26	0.35	0.2	0.05	0.02	0.99	0.50
	C43C	912.5	9 364	469.0	3.17	0.74	0.3	1.04	0.09	1.74	0.87
	C43D	1475.4	24 645	464.0	3.95	0.58	0.4	0.58	0.22	2.75	1.38
	C60G	781.6	1 300	539.2	2.28	0.54	2.1	2.34	0.01	-2.17	-1.09
	C60H	1232.0	6 274	514.8	2.69	0.42	0.3	0.25	0.06	2.08	1.04
	C60J	958.9	6 169	550.6	10.02	1.90	0.8	3.84	0.06	5.33	2.66
	C70H	250.6	3 081	570.4	1.92	1.34	0.1	1.59	0.03	0.20	0.10
	C70J	520.6	3 602	577.3	6.45	2.14	0.2	3.99	0.03	2.23	1.11
	C70K	890.6	3 050	567.4	9.39	1.86	0.7	5.14	0.03	3.52	1.76
Total *Mean*		18955.5	247 763	*520.3*	89.82	*0.89*	10.63	43.06	2.26	33.87	16.94
3b	C70D	674.6	2 012	586.6	3.82	0.96	0.6	2.30	0.02	0.90	0.45
	C70E	692.8	13 034	580.4	7.67	1.91	0.2	4.67	0.12	2.68	1.34
	C70F	564.3	2 141	576.4	4.95	1.52	0.2	3.98	0.02	0.76	0.38
	C70G	901.2	2 745	579.1	7.15	1.37	0.3	3.91	0.03	2.91	1.45
Total *Mean*		2832.9	19 932	*580.6*	23.68	*1.44*	1.3	14.86	0.18	7.34	3.67
4a	C41A	538.9	27 068	598.2	3.76	1.17	0.55	1.33	0.49	1.39	0.69
	C41B	492.4	9 816	598.2	4.49	1.52	0.19	1.50	0.18	2.62	1.31
	C41C	1094.6	21 292	594.7	10.09	1.55	0.3	3.05	0.19	6.55	3.27
	C41D	1154.5	29 024	549.5	4.94	0.78	0.3	2.09	0.26	2.29	1.15
	C41E	391.3	2 629	519.0	0.62	0.30	0.1	2.75	0.02	-2.26	-1.13
	C41F	555.5	8 630	494.9	0.56	0.20	0.2	0.01	0.08	0.27	0.14
	C41G	271.8	130	516.8	0.29	0.21	0.1	0.24	0.00	-0.05	-0.02
	C41H	887.4	8 669	499.2	2.32	0.52	0.2	0.78	0.08	1.27	0.63
	C42D	662.5	21 992	555.5	1.71	0.46	0.3	2.45	0.20	-1.24	-0.62
	C42E	750.4	6 150	564.0	2.93	0.69	0.3	2.19	0.06	0.38	0.19

GRU	Quaternary Catchment	Area (km^2)	Population	MAP (mm)	Recharge (Mm^3/a)	Recharge % MAP	Groundwater Use (Mm^3/a)	Groundwater Component of Baseflow (Mm^3/a)	Basic Human Needs (Mm^3/a)	Allocable Groundwater Total (Mm^3/a)	Allocable Groundwater 50% of Total
	C42F	733.7	39 809	568.2	1.42	0.34	0.2	0.25	0.36	0.60	0.30
	C42G	555.0	6 876	550.4	0.82	0.27	0.2	1.64	0.06	-1.08	-0.54
Total		8087.8	182 085		30.85		2.94	18.27	2.00	7.63	3.82
Mean				*550.7*		*0.67*					
4b	C60B	1021.6	10 790	617.8	10.11	1.60	0.5	8.26	0.10	1.25	0.63
	C60C	1047.4	8 469	578.4	5.51	0.91	0.4	3.64	0.08	1.39	0.70
	C60D	644.7	2 567	552.7	2.53	0.71	0.2	0.85	0.02	1.46	0.73
	C60E	663.9	7 788	563.9	2.76	0.74	0.6	1.12	0.07	0.97	0.48
	C60F	659.1	96 217	558.2	1.94	0.53	0.2	1.29	0.88	-0.42	-0.21
	C70A	612.5	2 218	628.1	7.02	1.82	0.5	5.28	0.02	1.22	0.61
	C70B	659.7	6 715	612.6	4.74	1.17	0.4	3.53	0.06	0.75	0.38
	C70C	886.9	4 114	616.0	5.92	1.08	0.4	4.14	0.04	1.34	0.67
Total		6195.9	138878		39.89		3.20	28.12	1.27	7.30	3.65
Mean				*591.0*		*1.07*					
5	C41A	538.9	27 068	598.2	5.28	1.64	0.55	1.33	0.25	3.15	1.58
	C41B	512.4	10 217	598.2	5.02	1.64	0.21	1.56	0.09	3.16	1.58
	C42A	694.7	5 110	632.0	8.77	2.00	0.3	7.24	0.05	1.18	0.59
	C42B	726.5	1 903	581.0	5.10	1.21	0.3	4.06	0.02	0.73	0.36
	C42C	793.3	8 731	625.6	6.27	1.26	0.3	4.76	0.08	1.13	0.57
	C60A	859.4	2 340	632.8	10.01	1.84	0.2	7.68	0.02	2.11	1.06
Total		4125.2	55 369		40.42		1.86	26.62	0.51	11.43	5.72
Mean				*611.3*		*1.60*					