GROUNDWATER RESERVE DETERMINATION FOR THE UPPER 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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The publication of this report emanates from a project titled *Groundwater Reserve Determination for the Vaal River Management Area* (WRC Project No. K8/969).

This report forms part of a series of two reports. The other report is *Groundwater Reserve Determination for the Middle Vaal River Management Area* (WRC Report No. KV 313/13).

EXECUTIVE SUMMARY

The Upper Vaal Water Management Area (WMA) encompassing ~55 500 km^2 in the central-northeastern portion of the country, occupies a sensitive position within the Vaal River System mainly because its location in the headwaters of this catchment coincides with significant mining activity in the region, and urban and industrial development on the Witwatersrand that represents the economic and industrial heartland of South Africa. The pressure from urban, industrial and mining development is arguably felt the greatest in this WMA in terms of both water supply and adverse impacts on the water resource environment. 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 nine groundwater resource units (GRUs) in the WMA. Three of these comprise two subdivisions 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 is only definable for GRUs 5a, 5b, 6b and 9. Apart from largely neutral slopes, negative slopes are in greater evidence than positive slopes. This is particularly true for GRUs 5b and 6b, both of which host extensive active and defunct mining activity in the form of gold (mainly GRU 5b) and coal (mainly GRU 6b). The pattern and trend of groundwater chemistry in the long-term indicates that discernible impacts are manifested in Tertiary catchments C21, C22 and C23 that host both active and defunct mining activities associated primarily with gold. In these instances, a trend from a $CaMg\text{-}HCO_3$ type to a $Ca\text{-}SO_4$ type groundwater is evident. The manifestation of mining impacts in the Highveld and Ermelo coalfields located primarily in Tertiary catchment C11 (the so-called Ekangala grasslands of Mpumalanga Province) is not readily determined on the basis of available information. 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 Witwatersrand goldfields and Mpumalanga coalfields, 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 42% of the catchment, a category BC over 44% of the catchment, and a category D

over the remaining 14%. The category D portion of the catchment comprises those GRUs that host the mining activity in the Witwatersrand Goldfield and Vereeniging-Sasolburg Coalfield (GRU 5b and 6b), together with a highly urbanised and industrialised area extending into GRU 6a.

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 ~744 Mm^3/a (~39% of the estimated total mean annual groundwater recharge of 1916 Mm^3). This value is 2.5 times the 299 Mm^3/a suggested in the National Water Resource Strategy (DWAF, 2004) be allocated to the ecological Reserve. The basic human needs component of the Reserve amounts to ~24 Mm^3/a (~1.3% of the estimated total mean annual groundwater recharge). The total volume of groundwater recommended for allocation to the Reserve therefore amounts to ~768 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 ~93% 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 7% 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. Eleven (~12%) of the 91 quaternary catchments in the study area exhibit this characteristic.

The estimated total annual groundwater use amounts to ~84 Mm^3. After the requirements of the Reserve (~768 Mm^3/a) and this volume are met, ~1063 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 ~532 Mm^3 is available for additional allocation annually.

The observation that ~93% 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 (~14%) 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 ~86% (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 ~744 Mm^3/a groundwater contribution to baseflow in the WMA.

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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)

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	mean 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
UVWMA	Upper Vaal Water Management Area
Na	sodium
NGA	National Groundwater Archive
NGDB	National Groundwater Data Base
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) unit was appointed by the Department of Water Affairs (DWA) to carry out a groundwater Reserve determination study of the Upper Vaal Water Management Area (WMA). The study was commissioned by the Chief Directorate: Resource Directed Measures (CD:RDM). 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 Upper 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 needs to meet 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 Upper 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 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 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 Upper Vaal have been 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 this project.

1.4 Project Implementation

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

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 triggered the second phase 2 of the project.

1.4.2 Phase 2 : Study Implementation

This phase was carried out with the following tasks:

Task 1 Preparation and Re-assessment of ToR

The Inception Report highlighted the large number of forums and other I&AP groupings in the Upper Vaal WMA. The literature survey documented in the Inception Report also revealed severe uncertainty regarding the situation of groundwater rebound in the dewatered karst aquifers of the Far West Rand basin (Carletonville Goldfield) and the East Rand basin, as well as on the groundwater environment in the Central and West Rand basins. These environments represent severely disturbed groundwater regimes, for which an intermediate level groundwater Reserve determination study would have difficulty in reconciling ecological requirements and the setting of mutually acceptable resource quality objectives. It was proposed, therefore, that the project addresses these circumstances with due consideration for the uncertainties and complexities involved, and which would necessarily be reflected in qualified confidence levels of GRDM assessment. These circumstances also applied to aspects such as the radioactive properties of mine water (DWAF, 1999a) that would eventually discharge to the surface and might have implications for human health in the impacted areas.

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 primarily 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 focussed field surveys and approaches to organisations such as mines and industries for localised data. The task facilitated a conceptual understanding of the groundwater environment that informed the subsequent tasks within the framework of a GRDM assessment, viz. 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 3-tiered delineation of groundwater resource units (GRUs) in the study area. This approach drilled down from a 1st tier primary level based on quaternary basins as the basic building block of a GRDM assessment, through a 2nd tier secondary level based on the identification and recognition of aquifer type and groundwater regimes, to a tertiary level defined by land-use and non-spatially explicit geoscientific knowledge of the area. Both physical and functional criteria were considered in the delineation in order to provide adequate protection for the groundwater component of the Reserve. 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 as 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, informs 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. This will be carried out in consultation with key stakeholders and other specialists, such as ecologists and hydrologists.

Task 7 Compile a Monitoring Programme for GRUs

This task closes Phase 2 of the study, and will draw on the understanding of the groundwater resources gained from the study results to develop a multifunctional groundwater monitoring programme for the Upper 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. Information sources are also available with processed data and assessments of groundwater recharge and use, etc. (Groundwater Resource Assessment, GRA2). 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 Pitman 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 Upper Vaal Water Management Area (UVWMA) occupies a central position in the north-eastern part of South Africa, as shown in **Figure 2-1**. It straddles four provincial boundaries, namely those of the Free State Province in the south-east, Mpumalanga Province in the east, Gauteng Province in the north, and Northwest Province in the far north-west and west (DWA, 2003). The major towns in the study area include Harrismith in the south, Ermelo and Standerton in the east, southern Johannesburg, Vereeniging and Vanderbijlpark in the north, as well as Carletonville and Potchefstroom in the north-west (DWA, 2004). The WMA is surrounded by several other WMAs. These are the Crocodile (West) and Marico, the Olifants, the Inkomati, the Usutu to Mhlatuze, the Thukela, the Upper Orange and the Middle Vaal WMAs (DWA, 2003). Encompassing an area of about 55 565 km^2 (DWA, 2004), the catchment supports 3 major dams, namely Vaal Dam, Grootdraai Dam and Sterkfontein Dam.

2.1.2 Physiography and Climate

The Upper Vaal WMA slopes gently from an elevation of ~1800 m above mean sea level (amsl) in the east to ~1450 m in the west in the vicinity of the Vaal Barrage. Steeper areas are found in the headwaters of the Wilge River tributary in the south-east.

Mean daily temperatures vary between 16˚C in the west to 12˚C in the east. Maximum daily temperatures are experienced in January and minimum temperatures in July. Seasonal rainfall occurs during the summer months from October to April, with peak rainfall usually in January and February in the form of convective thunderstorms. Due to the influence of altitude, frost and light snow commonly occur in winter (DWA, 2004). The rainfall varies considerably over the WMA, as shown in **Figure 2-2**. The mean annual precipitation varies from 1000 mm in the east to about 500 mm in the west with an average of ~700 mm for the entire WMA (DWA, 2004). Potential evaporation varies (class A-pan) from ~1600 mm in the east to 2200 mm in the west, with the highest monthly evaporation usually measured in January (180 to 260 mm) and the lowest in June (80 to 110 mm).

2.1.3 Vegetation and Soils

The vegetation is dominated by the “pure grassveld” veld type over most of the WMA. The vegetation in the upper Wilge River subcatchment is of a “temperate and transitional forest and shrub” type, whilst that of the Mooi River catchment is of a “false grassveld” type (DWA, 2004). Vegetation types are discussed in more detail in **section 4**. Generally the soil depths within the WMA are moderate to deep within an undulating relief. Three main soil types occur, namely a sandy loam in the upper reaches of the Vaal and Wilge River subcatchments, a clay loam in the Klip and Suikerbosrand river catchments, and clay in the middle and lower Wilge and Vaal river catchments upstream of Vaal Dam (DWA, 2004).

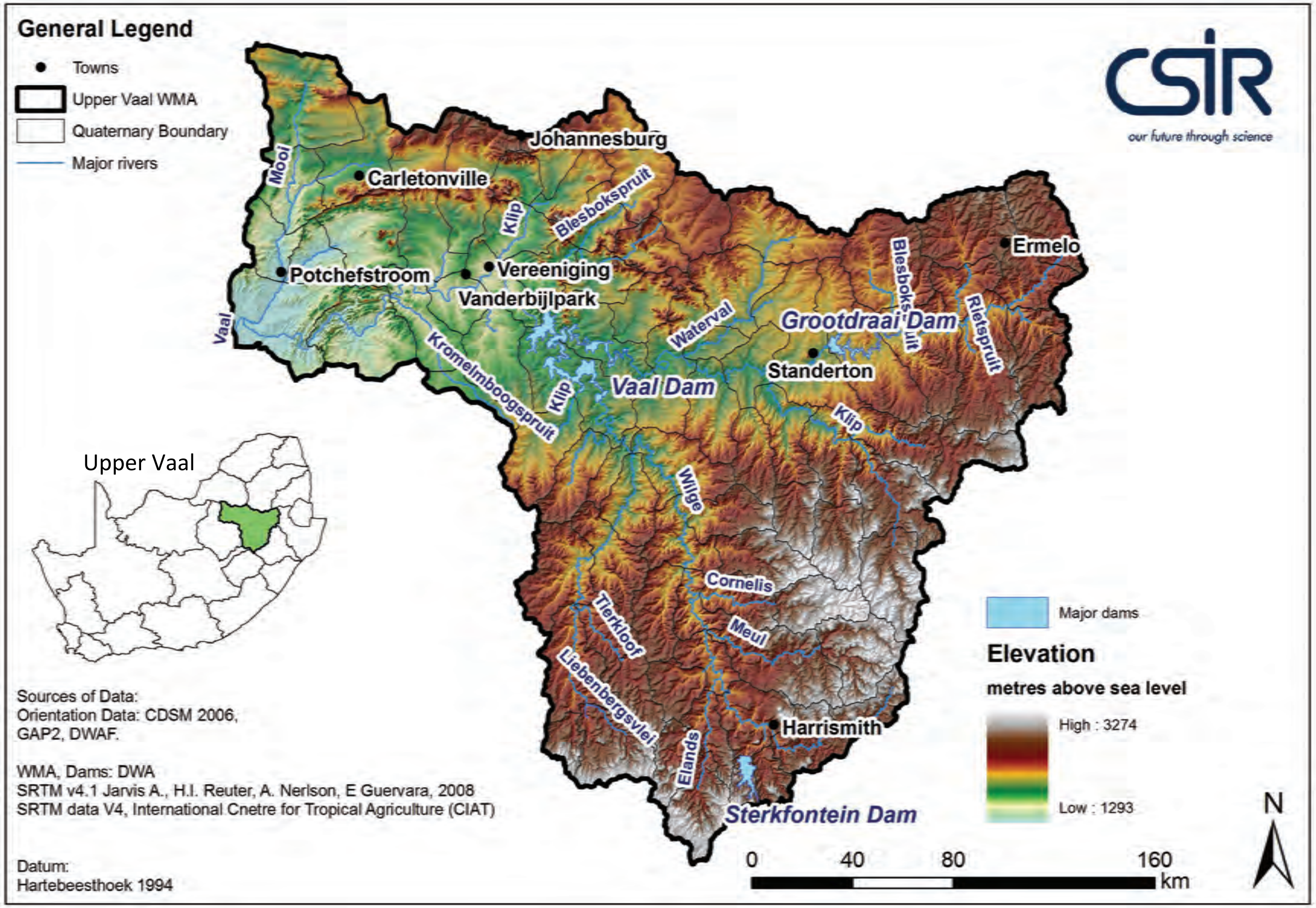

Figure 2-1. Location map of the Upper Vaal WMA showing quaternary catchments, major rivers, towns and dams

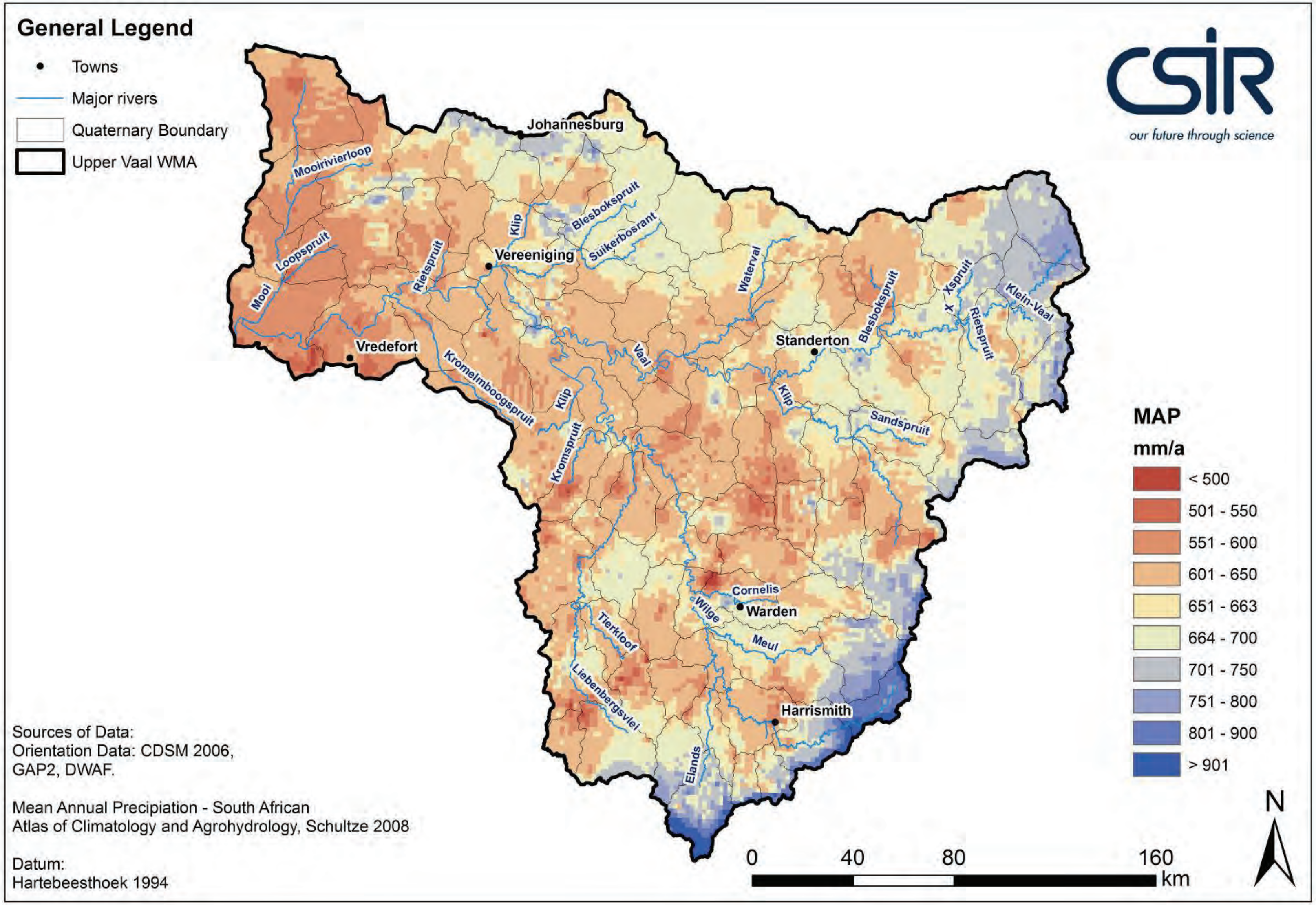

Figure 2-2. Distribution of mean annual precipitation across the Upper Vaal WMA.

2.1.4 Human Activity

The study area is the most densely populated WMA in South Africa (DWA, 2003b). The area downstream of the Vaal Dam is residence to >80% of the population of the WMA, of which 97% live in an urban setting. Although the city of Johannesburg is only partially situated in the Upper Vaal WMA, it has developed into the largest metropolitan area in South Africa, and is widely regarded as the economic hub of the country. The north-western parts of the WMA are characterised by dense urban, industrial and mining areas, whilst the eastern and south-eastern parts are characterised by agricultural activities such as the dryland cultivation of maize, wheat, etc. (DWA, 2003b). According to the DWA (2003b), nearly 20% of the Gross Domestic Product (GDP) of South Africa originates from the Upper Vaal WMA. In 1997, the largest economic sectors in the water management area, in terms of GDP, were (DWA, 2003b):

- Manufacturing 31.6%
- Trade 16.6%
- Financial services 12.9%
- Mining 10.8%

The manufacturing sector in the study area shows strong linkages with primary sector activities such as mining and agriculture (DWA, 2003b). In the northern Free State and southern Mpumalanga, manufacturing is mainly focussed on petro-chemical products related to the coal resources in the region, where the SASOL fuel-from-coal plants at Sasolburg and Secunda are of specific importance (DWA, 2003b). In the southern Gauteng region, the most dominant manufacturing activities relate to base-metal industries (e.g. Arcelor Mittal Steel) and the manufacturing of chemical, plastic and pharmaceutical products (e.g. AECI) (DWA, 2003b).

2.1.5 Geology

A wide variety of rock types occur in the study area, as summarised in **Table 2-1** and **Figure 2-3**. The geology is dominated by four major lithostratigraphical units. These are the Witwatersrand Supergroup, the Ventersdorp Supergroup, the Transvaal Supergroup and the Karoo Supergroup. The Witwatersrand, Ventersdorp and Transvaal Supergroups occur mainly in the north-west, together with older (>3600 Ma) Swazian strata represented by the Halfway House Granite Suite. Strata of the Karoo Supergroup dominate the eastern and southern parts of the study area.

The oldest Witwatersrand Supergroup consists of Randian Era (3100 to 2650 Ma) sedimentary rocks, mainly in the form of shale, quartzite and conglomerate, essentially deposited in a fluvial environment (DWA, 2008). These are shown in dark green in **Figure 2-3** and occur in the north-west of the WMA. The Witwatersrand Supergroup is subdivided into a lower West Rand Group consisting mainly of argillaceous rocks, and an upper Central Rand Group consisting almost entirely of quartzite and conglomerate (DWA, 2008). The Witwatersrand Basin is over 100 km wide and stretches over an area from Evander (east of Johannesburg) to south of Welkom in the Free State Province (southern boundary of basin) (**Figure 2-4**). The northern boundary of the basin extends from Krugersdorp (west of Johannesburg) to beyond Klerksdorp. The Witwatersrand Supergroup has not undergone any orogenic (mountain-building) deformation, but has been exposed to low grade metamorphism (CGS, 1986a). The succession of arenaceous and argillaceous sediments has been exposed to tilting, which resulted in erosion in the marginal areas of the main basin with local unconformities.

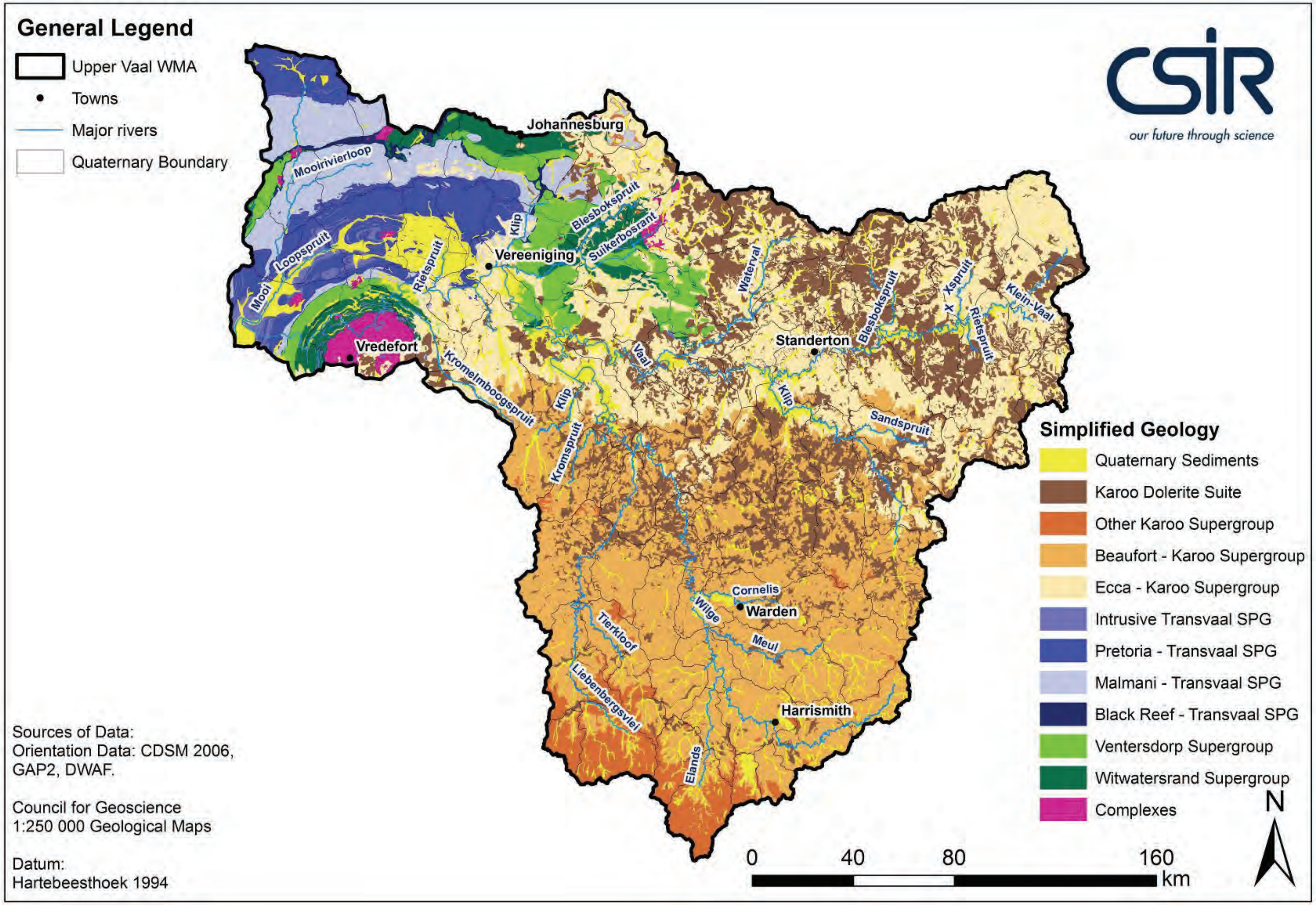

Figure 2-3. Simplified geological map of the Upper Vaal WMA (after CGS 1:250 000)

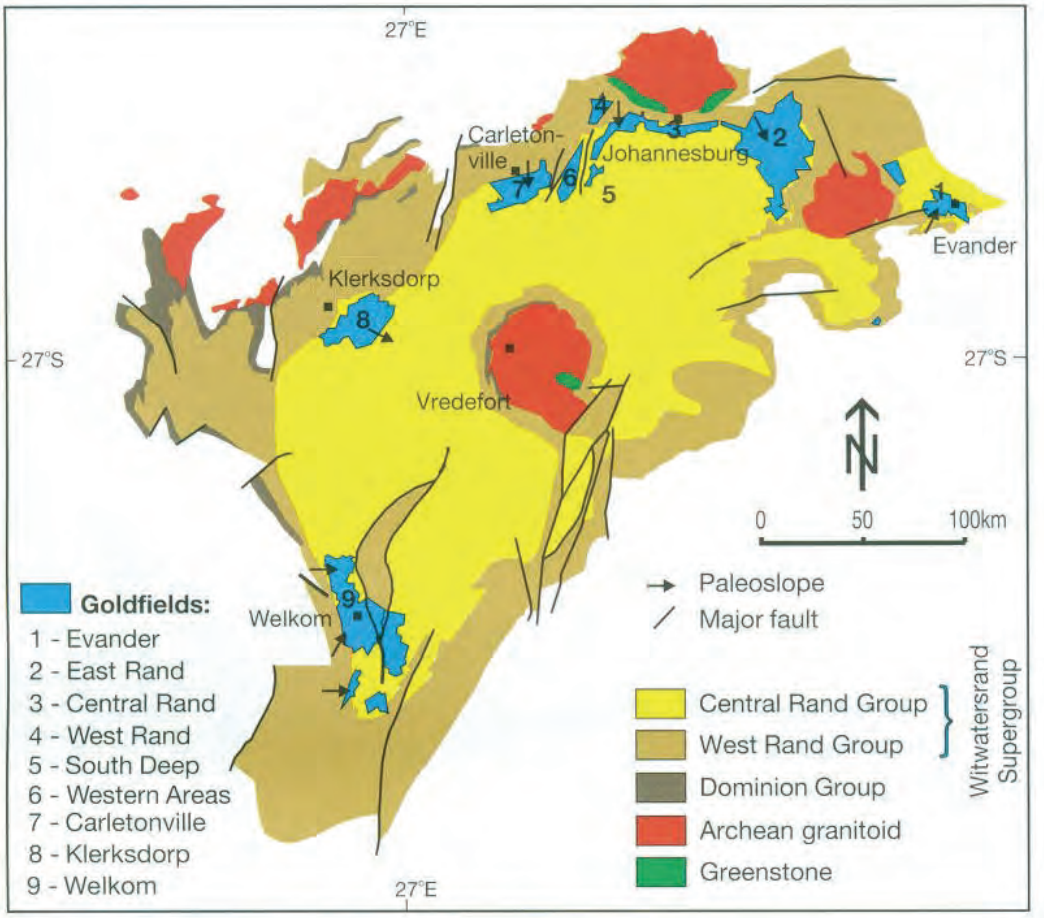

Figure 2-4. Location of the Witwatersrand Basin
(sourced at http://www.min.tu-clausthal.de/www/lager/Exc2005/bilder/klein/sa003.htm)

The Witwatersrand Supergroup, particularly the Central Rand Group, hosts the economic gold deposits (reefs) that have been extensively mined throughout the Witwatersrand Basin (DWA, 2008).

The Ventersdorp Supergroup comprises late Randian Era sedimentary and volcanic rocks subdivided into the older Klipriviersberg Group (mainly andesitic lavas) and the younger Platberg Group (quartzite, conglomerate, lava, quartz porphyry, andesite, chert and tuff) (CGS, 1986a). The topmost Allanridge Formation of the Platberg Group consists of andesitic lava, which marks the top of the Ventersdorp Supergroup. The Ventersdorp Supergroup outcrops in the vicinity of Orkney and also forms part of the western rim of the Vredefort Dome (DWA, 2003). The Ventersdorp Basin partially overlaps the Witwatersrand Basin. In the Free State Goldfield area, the Ventersdorp Supergroup occurs beneath the Karoo Supergroup sediments, and overlies the Witwatersrand Supergroup (DWA, 2003).

The Transvaal Supergroup (Vaalian Era) comprises (from oldest to youngest) the Chuniespoort Group, the Pretoria Group and the Rooiberg Group. These strata build the Transvaal Basin, the base of which is represented by the Black Reef Formation comprising mainly quartzite with lenses of grit and conglomerate (CGS, 1986b). The overlying Chuniespoort Group consists mainly of carbonate rocks in the form of dolomite, limestone and intercalated chert beds (CGS, 1986a). The Pretoria Group comprises of shale, quartzite, siltstone, conglomerate, andesitic lava and diabase (DWA, 2003). The diabase and basic sills that have intruded the Pretoria Group strata are designated the post-Transvaal diabase (CGS, 1986b). The Rooiberg Group does not occur in the study area.

Several igneous intrusions represent the Mokolian Era (2050 to 1000 Ma) (CGS, 1986). These are represented by the Kaffirskraal Complex (basic and ultrabasic rocks), the Losberg Complex (harzburgite, norite, quartz norite, quartz gabbro, granophyre), the Roodekraal Complex (diorite, albitite), the Rietfontein Complex (olivine gabbro, wehrite, alkali granite), the Baviaanskranz Complex (alkali granite) and the Schurwedraai Complex (alkali granite) (CGS, 1986a). These complexes occur scattered over the north-western portion of the WMA, where they have intruded the overlying rocks of the Witwatersrand, Ventersdorp and Transvaal supergroups (CGS, 1986).

The Karoo Supergroup sediments deposited during the Palaeozoic (354 to 250 Ma) and Mesozoic (250 to 144 Ma) eras, dominate the south-eastern two-thirds of the study area. Since the Karoo Basin deepens from north-east to south-west, the oldest stratigraphic units represented by the Dwyka Group (tillite) at the base and the overlying Ecca Group strata (sandstone, mudstone, siltstone, shale and coal) define the northern and north-eastern margins. Younger sedimentary strata (mudstone and sandstone) of the Beaufort Group build the south-central portion of the study area, and increasingly younger rocks of the Molteno, Elliot and Clarens Formations the rising terrain to the south-east. Extensive intrusions of dolerite in the form of subvertical dykes and subhorizontal sills occur within the Karoo Supergroup strata (CGS, 1992). The sills are typically recognised as forming the cap rock along mountain and hill tops.

Tertiary and Quaternary sand deposits associated with terrestrial sedimentation, are represented by aeolian sands, calcrete, colluvium, floodplain sediments and alluvium. These sandy deposits are generally very thin (only a few metres in thickness, except for some sand dunes that can be up to 20 m high) and localised (DWA, 2003). **Figure 2-5** and **Figure 2-6** represent typical cross-sections through the hydrogeologica settings in the southern and northern portions of the study area, respectively.

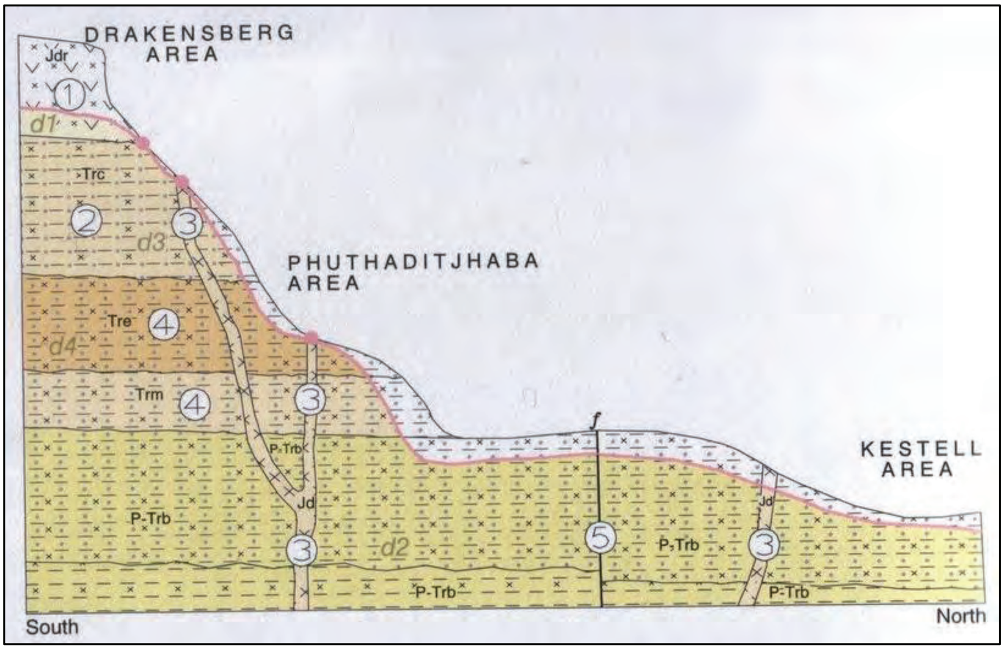

Figure 2-5. Geological cross-section of the southern part of the study area (after DWA, 2003)

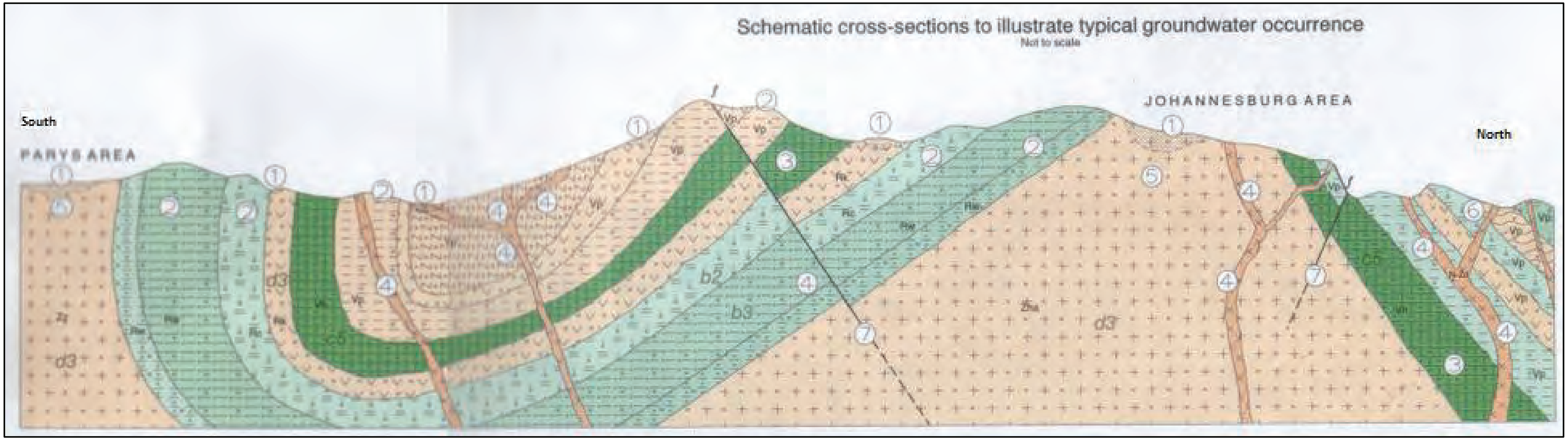

Figure 2-6. Geological cross-section of the northern part of the study area (after DWA, 2000)

Table 2-1. Summary of the lithostratigraphy of the Upper 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		
Sandstone	Clarens Formation				
Mudstone & subordinate sandstone	Elliot Formation				
Sandstone, mudstone & shale	Molteno Formation			(~250 Ma)	
Mudstone & sandstone	Driekoppen & Verkykerskop Formation	Beaufort Group		(~250 Ma)	Palaeozoic
Mudstone & subordinate sandstone	Normandien & Estcourt Formation				
Shale & subordinate sandstone	Volksrust Formation	Ecca Group			
Sandstone, shale & coal beds	Vryheid Formation				
Shale	Pietermaritzburg Formation				
Diamictite & shale		Dwyka Group		(~354 Ma)	
Alkali granite	Schurwedraai	Intrusive Complexes		(~1000 Ma)	Mokolian
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			(~2050 Ma)	
Quartzite	Magaliesberg Formation	Pretoria Group	Transvaal Supergroup	(~2050 Ma)	Vaalian
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			
Chert-poor dolomite	Monte Christo Formation				
Chert-rich dolomite	Lyttelton Formation				
Chert-poor dolomite	Oaktree Formation				
Quartzite, conglomerate	Black Reef Formation			(~2650 Ma)	
Andesite	Alanridge Formation	Platberg Group	Ventersdorp Supergroup	(~2650 Ma)	Randian
Conglomerate, sandstone	Bothaville Formation				
Andesite	Rietgat Formation				
Quartz porphyry	Makwassie Formation				
Conglomerate, calcareous shale	Kameeldoorns Formation				
Andesite, tuff		Klipriviersberg Group		(~2780 Ma)	
Arenaceous, rudaceous rocks		Central Rand Group	Witwatersrand Supergroup	(~2780 Ma)	
Quartzite, reddish ferruginous magnetic shale		West Rand Group			
Quartzite, conglomerate, shale, interbedded lava		Dominium Group		(~3100 Ma)	
Granite, gneiss	Halfway House Granite Suite	Intrusive Complex		Swazian (>3100 Ma)	

2.2 Overview of Surface Water Resources

The surface water hydrology of the Upper Vaal WMA is dominated by the Vaal River that flows from east to west. The Wilge River draining the south-eastern portion of the study area is the largest tributary of the Vaal. The DWA (2003) subdivided the Upper Vaal WMA into three subareas based on practical 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:

- **Wilge** subarea includes the catchment of the Wilge River to its confluence with the Vaal River.
- **Upstream of Vaal Dam** subarea includes the catchment upstream of the Vaal Dam, but excludes the Wilge River catchment.
- **Downstream of Vaal Dam** subarea includes the portion of the Vaal River between the Vaal Dam and the confluence of the Mooi River and Vaal River.

The Vaal River upstream of Vaal Dam contributes the largest portion (46%) of surface water flow in the WMA (DWA, 2003b). The Wilge River and the Liebenbergsvlei River together contribute about 36%, with the remaining 18% provided by the tributaries downstream of Vaal Dam (DWA, 2003b). No natural lakes occur in the study area, but important wetlands occur along the Klip River, as well as several marshes elsewhere in the WMA (DWA, 2003b). Whereas the hardening of the landscape in urban areas has resulted in relatively large increases in surface water runoff to stormwater systems, the infestation of drainages by alien vegetation has led to reduced runoff in water courses (DWA, 2003b). The numerous farm dams constructed upstream of the Vaal Dam have reduced inflow of surface water to the dam (DWA, 2003b).

The natural surface water resources of the WMA have been well developed through the construction of several large dams, and only limited potential for further development remains. According to DWA (2003b), the main storage dams are:

- Grootdraai Dam on the Vaal River upstream of Vaal Dam.
- Sterkfontein Dam and Fika Patso Dam in the Wilge River catchment, and Saulspoort Dam on the Liebenbergsvlei River in the Wilge subarea. Sterkfontein Dam is one of the largest dams in the country, and serves as a holding dam for water transferred from the Thukela WMA to the Vaal River System.
- The Vaal Barrage as well as the Klerkskraal Dam, Boskop Dam and Klipdrif Dam in the subarea downstream of Vaal Dam.

A list of the major dams in the WMA is provided in **Table 2-2** together with salient supporting information. The drainage network that defines the Upper Vaal WMA at a quaternary level is shown in **Figure 2-7**.

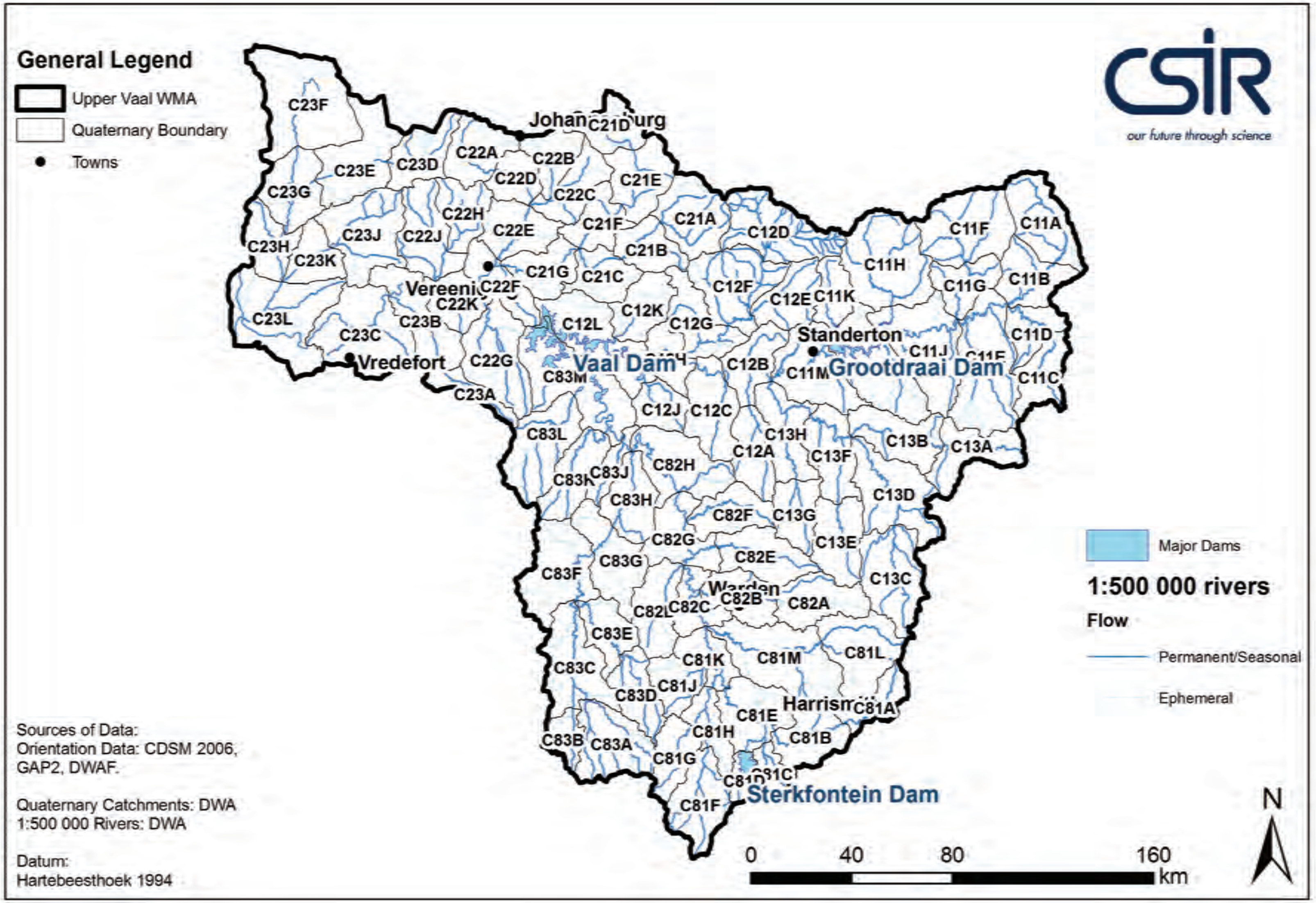

Figure 2-7. Rivers and major dams in the Upper Vaal WMA

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

Dam	Quaternary Catchment	River	Year Completed	Purpose	Natural MAR (Mm^3/a)	Full Supply Capacity (Mm^3/a)
Boskop	C23G	Mooi	1959	Irrigation	73.5	21
Douglas	C11F	Klein-Kafferspruit	1930	Domestic	58.9	2
Fika-Patso	C81F			Domestic	81.4	28
Grootdraai	C11L	Vaal	1978	Domestic	529.1	356
Klerkskraal	C23F	Mooi	1969	Irrigation	37.7	8
Klipdrif	C23J	Loop Spruit	1918	Irrigation	21.1	13
Saulspoort	C83A	Liebenbergsvlei	1969	Domestic	28.5	16
Sterkfontein	C81D	Nuwejaar Spruit	1977	Domestic	18.1	2617
Vaal	C22F	Vaal	1938	Domestic	1977	2610
Vaal Barrage	C22K	Vaal	1914	Domestic	2234	55
Vrede	C13G	Spruitsonderdrif	1951	Domestic	18.7	1
Water	C81F			Domestic	81.4	4

Large quantities of water are transferred into the Upper Vaal WMA from the Usutu to Mhlatuze WMA and the Thukela WMA as well as from the Senqu (Orange) River in Lesotho, to augment the local resources. The water transferred from the latter water management areas is generally of good quality and reduces the salinity and turbidity of water in Vaal Dam (DWA, 2003b). However, there are also water transfers out of the Upper Vaal WMA to the Crocodile (West) and Marico WMA, as well as to the Olifants WMA and through releases along the Vaal River to the Middle Vaal and Lower Vaal WMAs (DWA, 2003b). Several options for the possible further development of surface water resources have been investigated, with a dam on the Klip River to augment supplies to users from Grootdraai Dam regarded as the only feasible option (DWA, 2003b).

2.3 Overview of Groundwater Resources

2.3.1 Hydrostratigraphy

The geographic distribution of borehole yields as per the hydrogeological map ‘classification’ presented in **Table 2-3** is shown in **Figure 2-8**. 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.

Table 2-3. Explanation to Figure 2-8

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

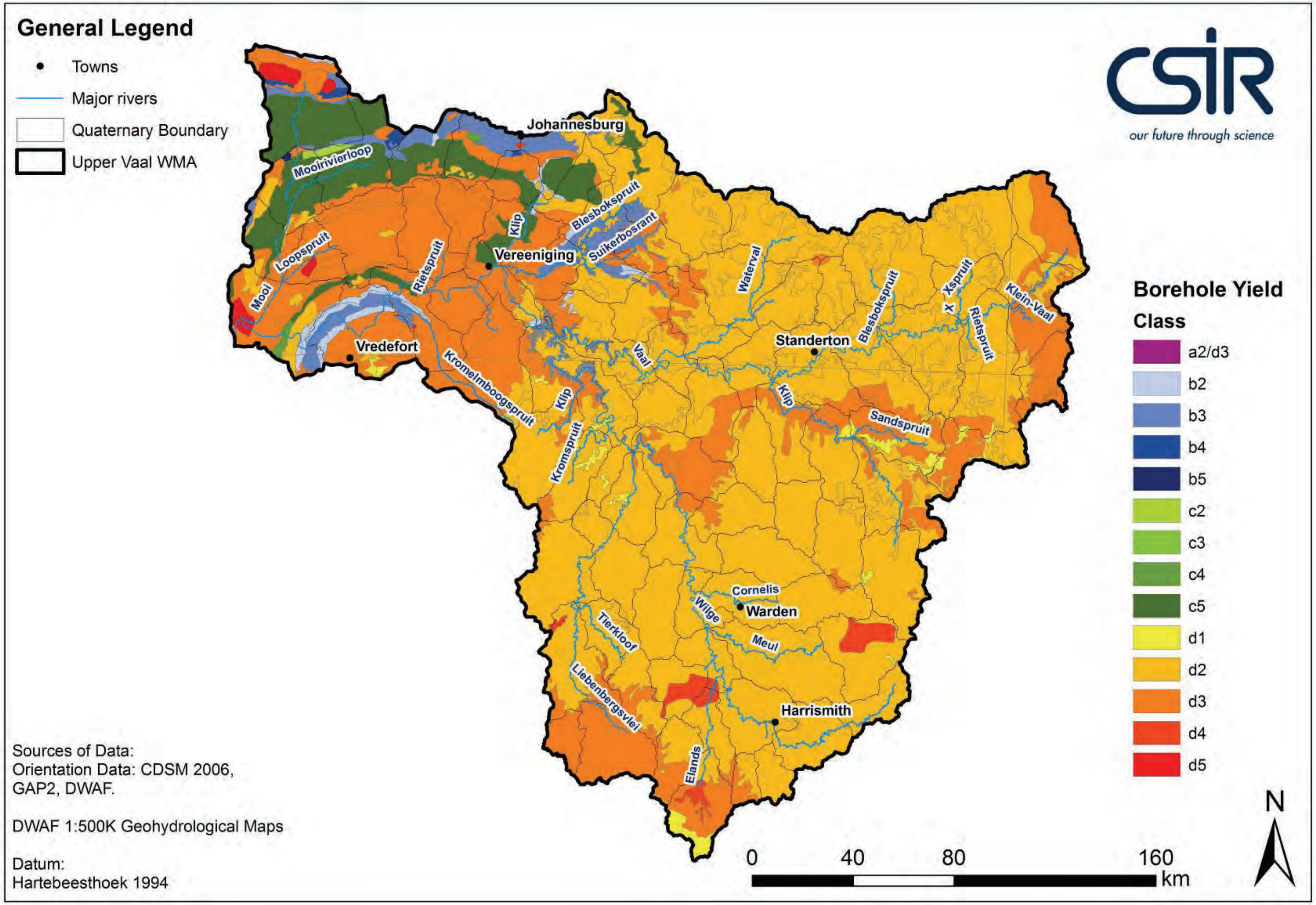

Figure 2-8. Distribution of borehole yields per quaternary catchment in the Upper Vaal WMA (after DWA 1:500 000 geohydrological map series)

The older strata associated with the Witwatersrand, the Ventersdorp and the Transvaal Supergroup occurring in the north-western portion of the WMA represent mainly a fractured aquifer. Typical borehole yields vary greatly, with the DWA (2000) reporting median borehole yield values in the range 0.5-2 L/s for the West Rand Group and Central Group within the Witwatersrand Supergroup. The groundwater quality associated with these strata is classed as good on the basis of mean electrical conductivity (EC) values of ~37 and ~29 mS/m, respectively. Within the Ventersdorp Supergroup, the Kameeldoorns and Bothaville Formations are identified as the main water-bearing strata intersected through drilling, supporting median borehole yield values in the ranges 0.5-2.0 L/s and 2.0-5.0 L/s respectively. Mean respective EC values of 48 and 30 mS/m indicate the generally good quality of this groundwater.

Similarly, the Black Reef Formation, the Daspoort Formation and the Magaliesberg Formation of the Transvaal Supergroup have extensively been explored through drilling, and share a median borehole yield value in the range 0.-5-2.0 L/s and a mean EC value in the range 26 to 48 mS/m. The andesitic lavas of the Ventersdorp Supergroup are generally regarded as an aquitard since they have widely spaced joint sets and are massive (DWA, 2008). Slightly elevated borehole yields may be associated with these strata along major joints, faults and structural lineaments, but borehole yields in this environment rarely exceed 2 L/s (DWA, 2008). 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 (DWA, 2008).

The carbonate rocks of the Chuniespoort Group of the Transvaal Supergroup in the north-western portion of the study area constitute a significant and important karst aquifer (DWA, 2000). The occurrence of groundwater in karst is associated with the presence of dissolution openings that occur due to the solubility of calcium carbonate minerals with slightly acidic infiltrating rain water and groundwater. These dissolution openings occur along discontinuities such as joints, faults, and bedding planes, and may also produce open cavities and caves. The DWA (2000) reports a median borehole yield value for Chuniespoort Group strata of >5.0 L/s.

Several high yielding springs are associated with the Chuniespoort Group (DWA, 2000). The most notable of these is the Gerhard Minnebron Eye with a long-term mean discharge of ~60 ML/d, or 21.9 Mm^3/a (Winde and Stoch, 2009). An unfortunate legacy of gold mining in the Far West Rand is the drying up of springs such as the Oberholzer Eye (55 ML/d) and Bank Eye (50 ML/d) in 1959 due to intentional dewatering of, amongst others, the Oberholzer and Bank compartments.

Intentional dewatering of a karst aquifer such as for mining purposes, or over-abstraction for irrigated agriculture, may result in the formation of sinkholes and surface subsidence. Nevertheless, this resource has been extensively developed for irrigation, domestic, mining and municipal/industrial water supply purposes (DWA, 2000). For example, the Boskop-Turffontein Compartment downstream of the dewatered Oberholzer, Bank, Venterspost and Gemsbokfontein compartments of the Carletonville Goldfield, contributes significantly to the drinking water supply of Potchefstroom and surrounding communities (Winde and Stoch, 2010). Although the average EC value of 63 mS/m reported by DWA (2000) for a sample population of 223 analyses suggests that this groundwater is generally of good quality, the standard deviation and coefficient of variation values associated with elements such as sulphate, chloride and nitrate indicate the negative impact from poorer water sources or land use practices on the karst groundwater. For example, the DWAFs long-term water quality monitoring record of the Gerhard Minnebron Eye indicates a continuously deteriorating water quality over the past some 35 years (Winde and Stoch, 2010), and may well be an indicator of long-term groundwater pollution caused by upstream gold mining (DWAF, 2005).

As indicated in **Table 2-1**, the Chuniespoort Group is subdivided into a succession of chert-poor and chert-rich assemblages at the Formation level. Whereas the chert-poor assemblages weather evenly to produce a relatively low storage potential stratum, the chert-rich assemblages weather preferentially to produce a much more productive aquifer that generally favours the large-scale development of the resource (DWA, 2008). The karst environment is often intruded by dykes and sills that compartmentalise the aquifer into smaller units, as is the case in the Natalspruit Basin and along the upper Klip River Valley area of the East Rand (DWA, 2008), and along the Wonderfontein Spruit of the West Rand and Far West Rand areas in the Carletonville Goldfield.

The greater part (~75%) of the Upper Vaal WMA is underlain by Karoo Supergroup strata that represent a fractured and intergranular aquifer. Such aquifers are characterised by a dual porosity, one component of which is associated with the porosity of the sedimentary rock mass itself, and the other with the porosity associated with fractures, fissures, joints and bedding planes that intersect the rock mass. Whereas the median borehole yield associated with the fractured and intergranular aquifer of the Ecca Group sediments that dominate the north-eastern portion of the study area falls in the range 0.1-0.5 L/s, that associated with the Beaufort Group sediments further south and west falls in the range 0.5-5.0 L/s. Although the basement intrusive rocks as well as the intrusives of the Witwatersrand, Ventersdorp and Transvaal supergroups similarly support a fractured and intergranular aquifer in the north-western portion, the median borehole yield seldom exceeds 0.5 L/s.

Intergranular type aquifers are generally poorly represented in the WMA, and are limited to the alluvial deposits that occur in and along most of the river systems. The alluvial aquifers are generally limited to only a few metres in thickness, and vary in width from a few tens of metres to >100 m along major rivers (DWA, 2003). These aquifers are generally not seen as a major groundwater resource, and have not been extensively explored for their water supply potential (DWA, 2003).

2.3.2 Groundwater Recharge

Groundwater recharge is reported as being highly variable across the WMA (DWA, 2005), amounting to between 10 and 20 mm/a over the central parts, and gradually increasing in a north-westerly and easterly direction to between 40 and 60 mm/a (**Figure 2-9**). A maximum value of >200 mm/a is observed along the southern margin of the study area marking the border with Lesotho (**Figure 2-9**) where rainfall is highest (>800 mm). Even under these conditions, however, a recharge that is equivalent to ~25% of the MAP must be considered extraordinarily high, especially for geologic strata that comprise Beaufort Group sediments (mudstone and sandstone).

In the extreme north-western portion of the study area, surface water flow in the Mooi River originates as springflow from the Schoonspruit Eye draining the dolomitic aquifer of the Mooirivier Compartment (DWA, 2004; Maré et al., undated). Increased abstraction from these aquifers and associated lowering of the water table may result in a decrease in surface water flow in the Mooi River.

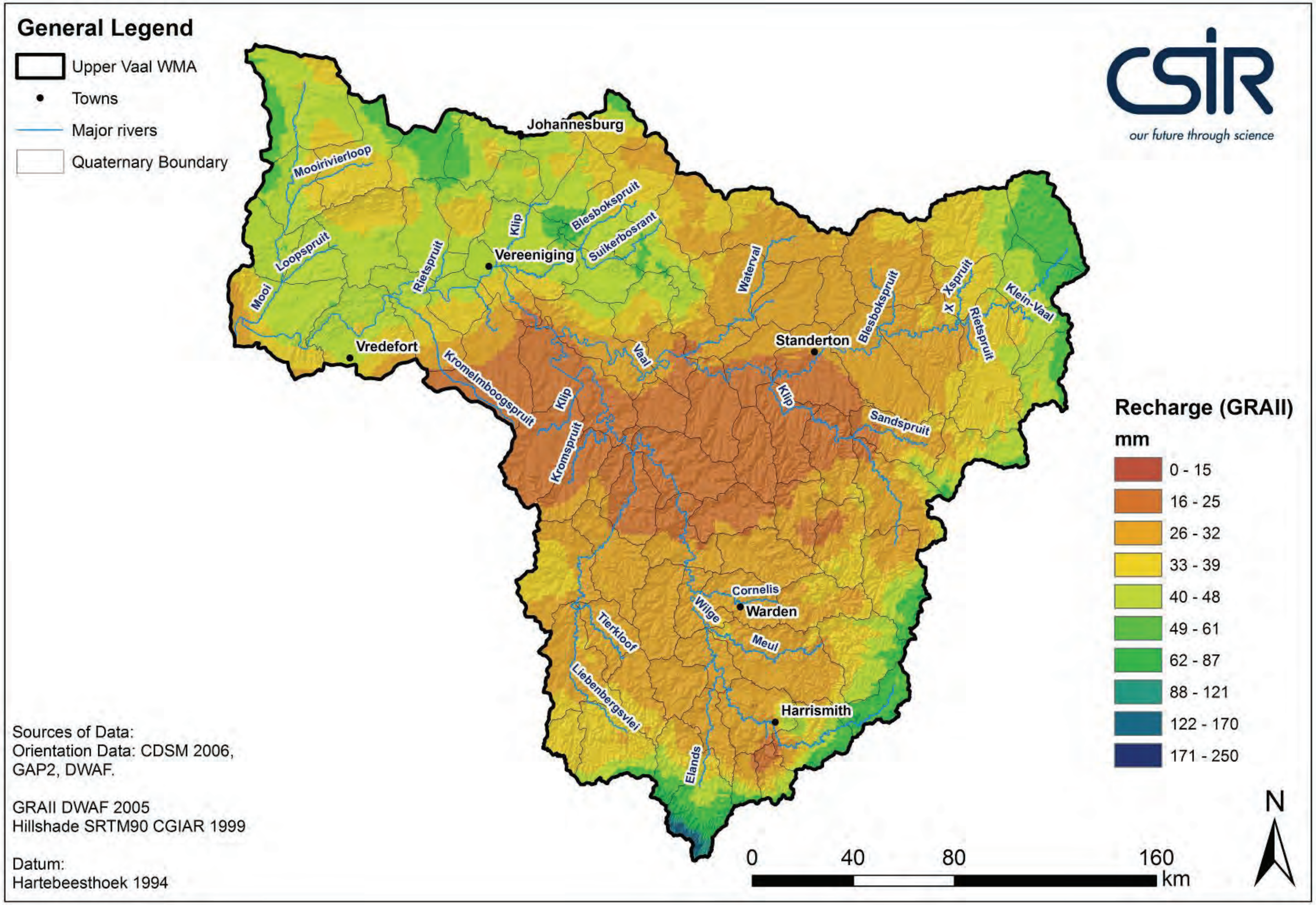

Figure 2-9. Distribution of estimated recharge (mm/a) per quaternary catchment (after DWAF, 2005 GRAII)

2.3.3 Groundwater Use

As already mentioned, groundwater in the dolomitic aquifer in the north-western parts of the Upper Vaal WMA is currently used for urban, irrigation, mining and industrial purposes. Intentional dewatering of the dolomitic aquifers in the Carletonville Goldfield traversed by the Wonderfontein Spruit has resulted in the formation of well over 1000 sinkholes in the past some 50 years (Swart et al., 2003b).

In the east and south of the WMA, the Karoo Supergroup sediments have been explored mainly for rural domestic water supplies and stock watering purposes. Although the source-specific volumes of water abstracted from the Karoo aquifers are low, the total combined abstraction testifies to the strategic importance of these resources.

The DWA (2005) reports the estimates of total groundwater use per quaternary catchment, subdivided into quantities per economic sector, given in **Table 2-4**. These estimates are expressed as a percentage of the estimated recharge per quaternary catchment in **Figure 2-11**, to obtain an indication of the relative sustainability and geographic distribution of groundwater use in the study area. This exercise identifies only two quaternary catchments, namely C23E (mining use ~33.9 Mm^3/a) in the north-west and C83F (industrial use ~11 Mm^3/a) along the south-western margin, as exceeding values of 25%. For much of the study area, estimated groundwater use amounts to <5% of the estimated recharge from rainfall.

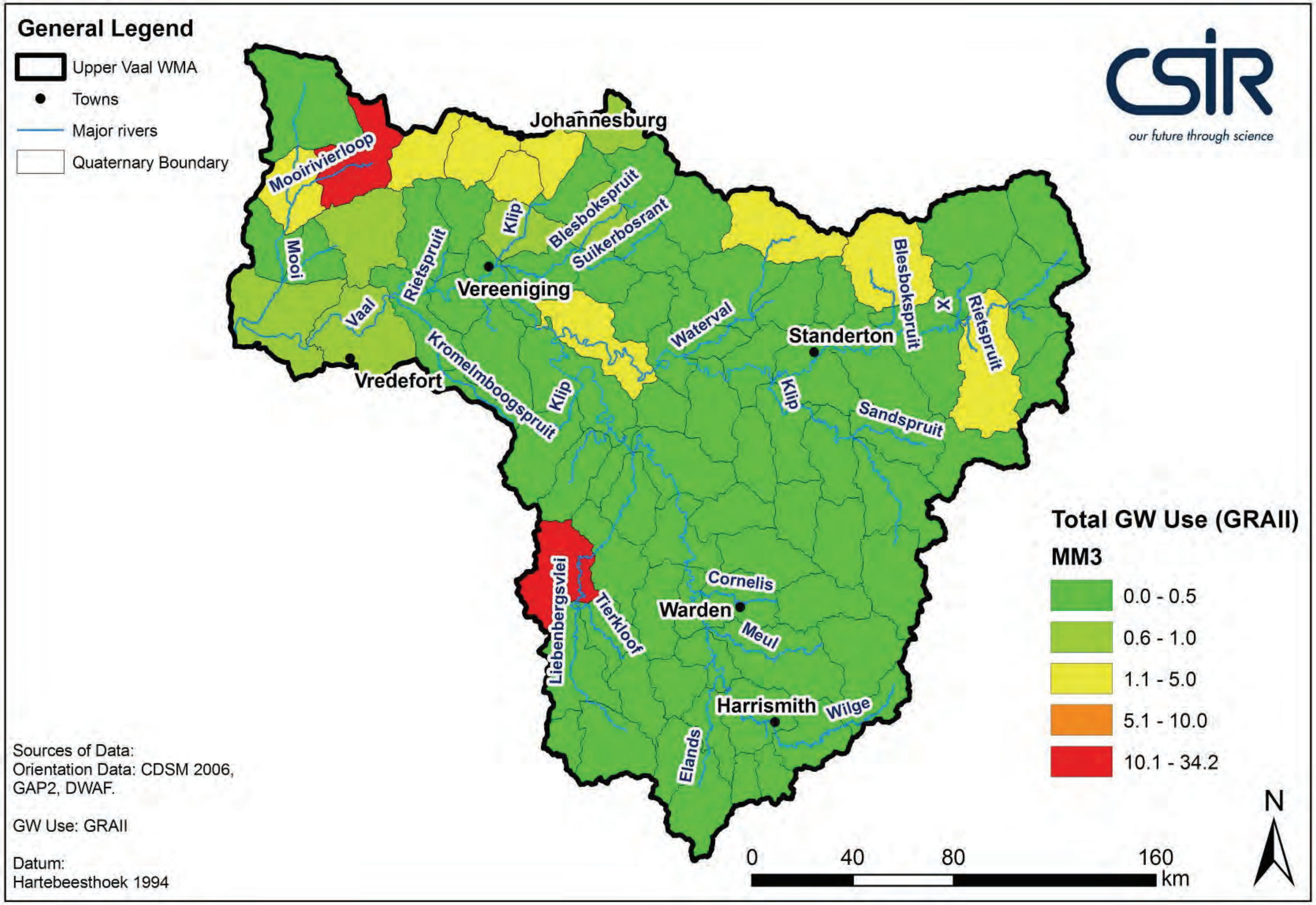

Figure 2-10. Distribution of estimated total groundwater use per quaternary catchment in Mm^3/a (after DWAF, 2005 GRAII)

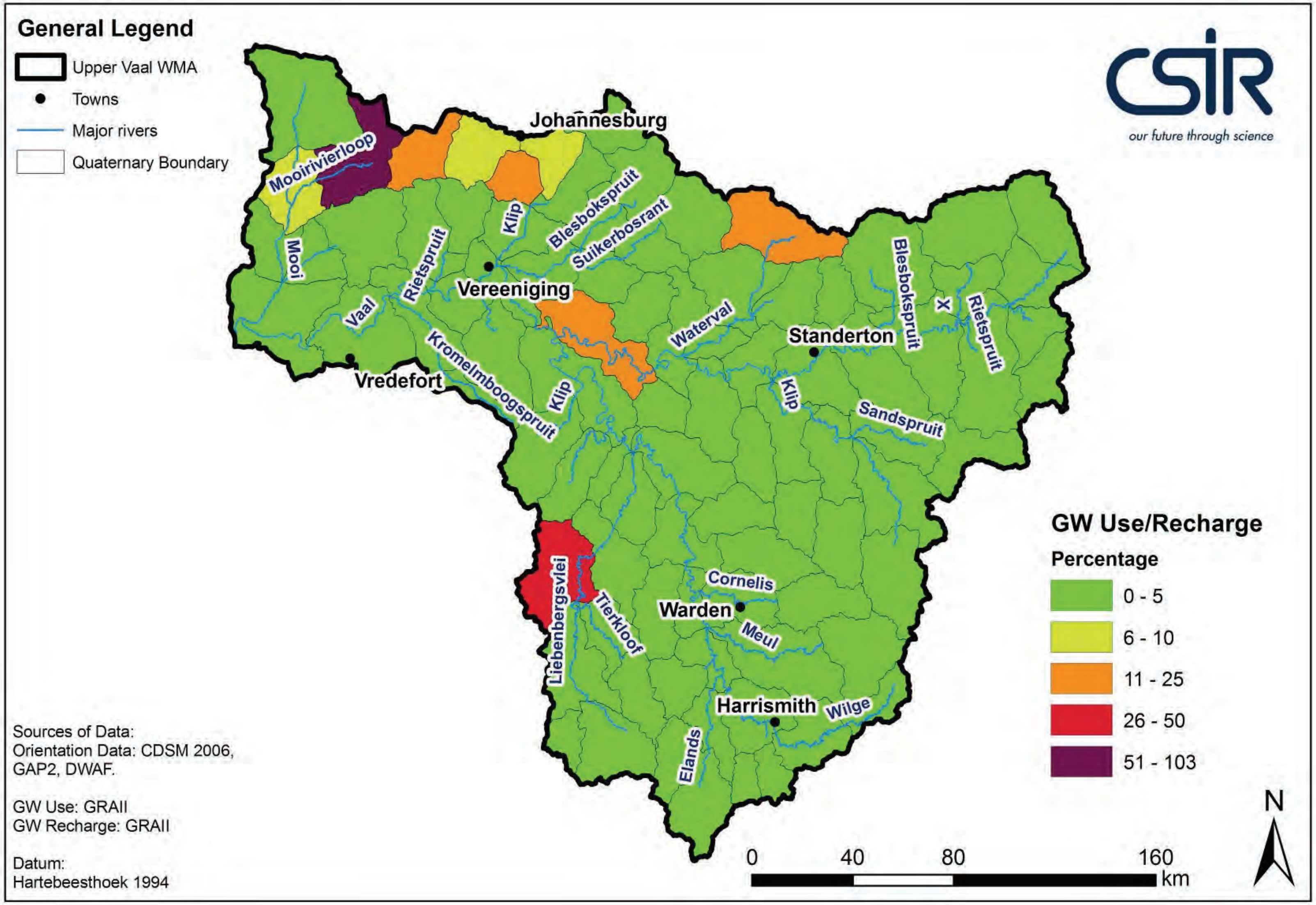

Figure 2-11. Distribution of estimated groundwater use as a percentage of recharge per quaternary catchment

Table 2-4. Summary of groundwater use in the Upper Vaal WMA (DWA, 2005) (values in Mm^3/a)

Quaternary Catchment	Total	Rural	Municipal	Agriculture		Mining	Industry	Aquatic
				Irrig.	Livestock			
C23F	0.2736	0.019	0	0	0.2546	0	0	0
C21D	0.8413	0	0.2614	0	0.0012	0.0384	0.207	0.3333
C23E	34.2309	0	0	0	0.2839	33.945	0.002	0
C23D	4.9254	0	0	0	0.1254	4.8	0	0
C22A	1.4034	0	0	0	0.0394	1.2	0.164	0
C22B	1.4629	0	1.2808	0	0.0041	0.009	0.169	0
C21E	0.22	0	0	0	0.154	0	0.066	0
C22C	0.0299	0	0	0	0.0289	0	0.001	0
C23G	2.3242	0	0	1.886	0.2875	0.0007	0.15	0
C22D	2.3405	0	0	1.7855	0.003	0	0.552	0
C11A	0	0	0	0	0	0	0	0
C21A	0.0585	0	0	0	0.0515	0	0.007	0
C11F	0.3857	0.037	0	0	0.3487	0	0	0
C21F	0.589	0	0.4266	0	0.1394	0	0.023	0
C22H	0.0662	0	0	0	0.0662	0	0	0
C22J	0.2402	0	0	0	0.2392	0	0.001	0
C12D	3.777	3.184	0	0	0.593	0	0	0
C23J	0.6314	0.008	0.119	0	0.5024	0	0.002	0
C22E	0.9108	0	0.3788	0	0	0	0.532	0
C11H	1.3823	0	0.0526	0	1.3297	0	0	0
C23H	0.2713	0.001	0	0	0.2663	0	0.004	0
C21B	0.226	0	0.1048	0	0.1182	0	0.003	0
C11B	0.0874	0.01	0	0	0.0774	0	0	0
C23K	0.2599	0.012	0	0	0.2439	0	0.004	0
C21G	0.0302	0	0	0	0.0142	0	0.016	0
C12F	0.3649	0	0	0	0.3649	0	0	0
C22F	0.0544	0	0	0	0.0464	0	0.008	0
C11G	0.2219	0	0	0	0.2139	0	0.008	0
C21C	0.1311	0	0	0	0.1311	0	0	0
C11K	0.3058	0.053	0	0	0.2348	0	0.018	0
C12E	0.2556	0.003	0	0	0.2526	0	0	0
C12G	0.2003	0	0	0	0.2003	0	0	0
C23B	0.4006	0.009	0	0	0.3796	0	0.012	0
C12K	0.0928	0.001	0	0	0.0888	0	0.003	0
C23L	0.729	0.004	0	0	0.685	0	0.04	0
C22K	0.34	0.113	0.0005	0.0027	0.2198	0	0.004	0
C11E	1.2575	0.747	0	0	0.5105	0	0	0
C11J	0.4774	0.001	0	0	0.4734	0	0.003	0
C23C	0.597	0.016	0	0.0146	0.5534	0	0.013	0
C11D	0.1734	0	0	0	0.1734	0	0	0
C12L	3.7728	0	0	0	0.1958	0	3.577	0
C11L	0.4884	0.019	0	0	0.4694	0	0	0
C22G	0.4663	0	0	0	0.4663	0	0	0
C11C	0.135	0	0	0	0.135	0	0	0
C11M	0.4291	0.019	0	0	0.4041	0	0.006	0
C12B	0.1264	0.003	0	0	0.1234	0	0	0
C12H	0.0807	0	0	0	0.0807	0	0	0
C83M	0.3943	0	0	0	0.3943	0	0	0
C12C	0.1651	0	0	0	0.1651	0	0	0

Quaternary Catchment	Total	Rural	Municipal	Agriculture		Mining	Industry	Aquatic
				Irrig.	Livestock			
C23A	0.1197	0	0	0	0.1197	0	0	0
C12J	0.1675	0	0	0	0.1675	0	0	0
C13H	0.0208	0	0	0	0.0208	0	0	0
C83L	0.0547	0	0	0	0.0547	0	0	0
C13F	0.0329	0	0	0	0.0329	0	0	0
C13B	0.274	0	0	0	0.274	0	0	0
C12A	0.0002	0	0	0	0.0002	0	0	0
C13A	0.2099	0	0	0	0.2099	0	0	0
C83J	0.1094	0	0	0	0.1074	0	0.002	0
C82H	0.1936	0	0	0	0.1936	0	0	0
C83K	0.2441	0	0	0	0.2441	0	0	0
C13D	0.11	0	0	0	0.11	0	0	0
C83H	0.2407	0	0	0	0.2277	0	0.013	0
C13G	0.0062	0	0	0	0.0062	0	0	0
C82F	0.0081	0	0	0	0.0081	0	0	0
C13E	0.0097	0	0	0	0.0097	0	0	0
C82G	0.0919	0	0	0	0.0919	0	0	0
C83G	0.2086	0	0	0	0.2086	0	0	0
C13C	0.0417	0	0	0	0.0417	0	0	0
C83F	11.2326	0	0	0	0.2826	0	10.95	0
C82E	0.0399	0	0	0	0.0399	0	0	0
C82D	0.1602	0	0	0	0.1602	0	0	0
C82C	0.0693	0	0	0	0.0693	0	0	0
C82B	0.0706	0	0	0	0.0706	0	0	0
C82A	0.0788	0	0	0	0.0788	0	0	0
C83E	0.1058	0	0	0	0.1058	0	0	0
C81L	0.1111	0	0	0	0.1111	0	0	0
C83C	0.0964	0	0	0	0.0964	0	0	0
C81M	0.16	0	0	0	0.156	0	0.004	0
C81K	0.0521	0	0	0	0.0521	0	0	0
C83D	0.0491	0	0	0	0.0491	0	0	0
C81A	0.0506	0	0	0	0.0506	0	0	0
C81J	0.0558	0	0	0	0.0558	0	0	0
C81E	0.0977	0	0	0	0.0917	0	0.006	0
C81H	0.0352	0	0	0	0.0352	0	0	0
C81B	0.0815	0	0	0	0.0815	0	0	0
C83A	0.0738	0	0	0	0.0738	0	0	0
C83B	0.0255	0	0	0	0.0235	0	0.002	0
C81G	0.0925	0	0.0647	0	0.0278	0	0	0
C81C	0.032	0	0	0	0.032	0	0	0
C81F	0.349	0.349	0	0	0	0	0	0
C81D	0.0265	0	0	0	0.0265	0	0	0

2.3.4 Basic Human Needs

Population data was sourced from the Geospatial Analysis Platform 2 (GAP2) developed by the CSIR. The population data was disseminated per mesozone (~50 km^2). The population density per mesozone is shown in **Figure 2-12**. The 2004 population data was obtained from the StatsSA census, extracted from the so-called Small Area Layer (SAL) and the sub-place population profiles. The data, summarised per quaternary catchment, is shown in **Table 2-5**.

Table 2-5. Population per quaternary catchment also showing the population below mean living level

Quaternary	Population	Population below MLL	Quaternary	Population	Population below MLL
C11A	3349	1955	C23B	4740	2152
C11B	3839	2142	C23C	68420	42653
C11C	1601	1277	C23D	314323	99677
C11D	1360	965	C23E	200758	64906
C11E	32108	23889	C23F	6508	2373
C11F	57969	31634	C23G	2805	1605
C11G	2452	1460	C23H	31654	8385
C11H	57676	33924	C23J	72082	25528
C11J	5014	3106	C23K	4469	1605
C11K	5775	2970	C23L	90530	40749
C11L	11156	6416	C81A	555	323
C11M	72511	38506	C81B	2513	1374
C12A	874	758	C81C	400	230
C12B	4067	2461	C81D	375	216
C12C	5020	4257	C81E	37764	21029
C12D	154155	53555	C81F	351881	236987
C12E	3429	1960	C81G	7113	3855
C12F	5514	3241	C81H	2113	1227
C12G	9719	6797	C81J	2589	1496
C12H	18975	16104	C81K	1339	793
C12J	749	627	C81L	1133	689
C12K	3955	2739	C81M	4978	2936
C12L	3180	2116	C82A	2077	1303
C13A	4890	2807	C82B	8047	4736
C13B	4283	2395	C82C	1564	978
C13C	7162	5970	C82D	2816	1849
C13D	2553	1742	C82E	2227	1725
C13E	1325	1130	C82F	954	827
C13F	2021	1525	C82G	1418	1086
C13G	18717	15885	C82H	1811	1537
C13H	2104	1688	C83A	6511	3635
C21A	12236	4853	C83B	3978	2141
C21B	27347	19019	C83C	72418	39056
C21C	13196	8820	C83D	3064	1761
C21D	528762	180660	C83E	2950	1918
C21E	234818	40363	C83F	3127	2266
C21F	160387	71170	C83G	22377	14040
C21G	6077	2339	C83H	6182	4173
C22A	1759369	517617	C83J	21996	18257
C22B	1109427	237009	C83K	1236	943
C22C	295024	96073	C83L	2889	2014
C22D	143102	30823	C83M	22249	9691
C22E	44976	13549			
C22F	246509	109440			
C22G	6741	2596			
C22H	693870	282162			
C22J	44748	14856			
C22K	166928	58152			
C23A	1462	1028			

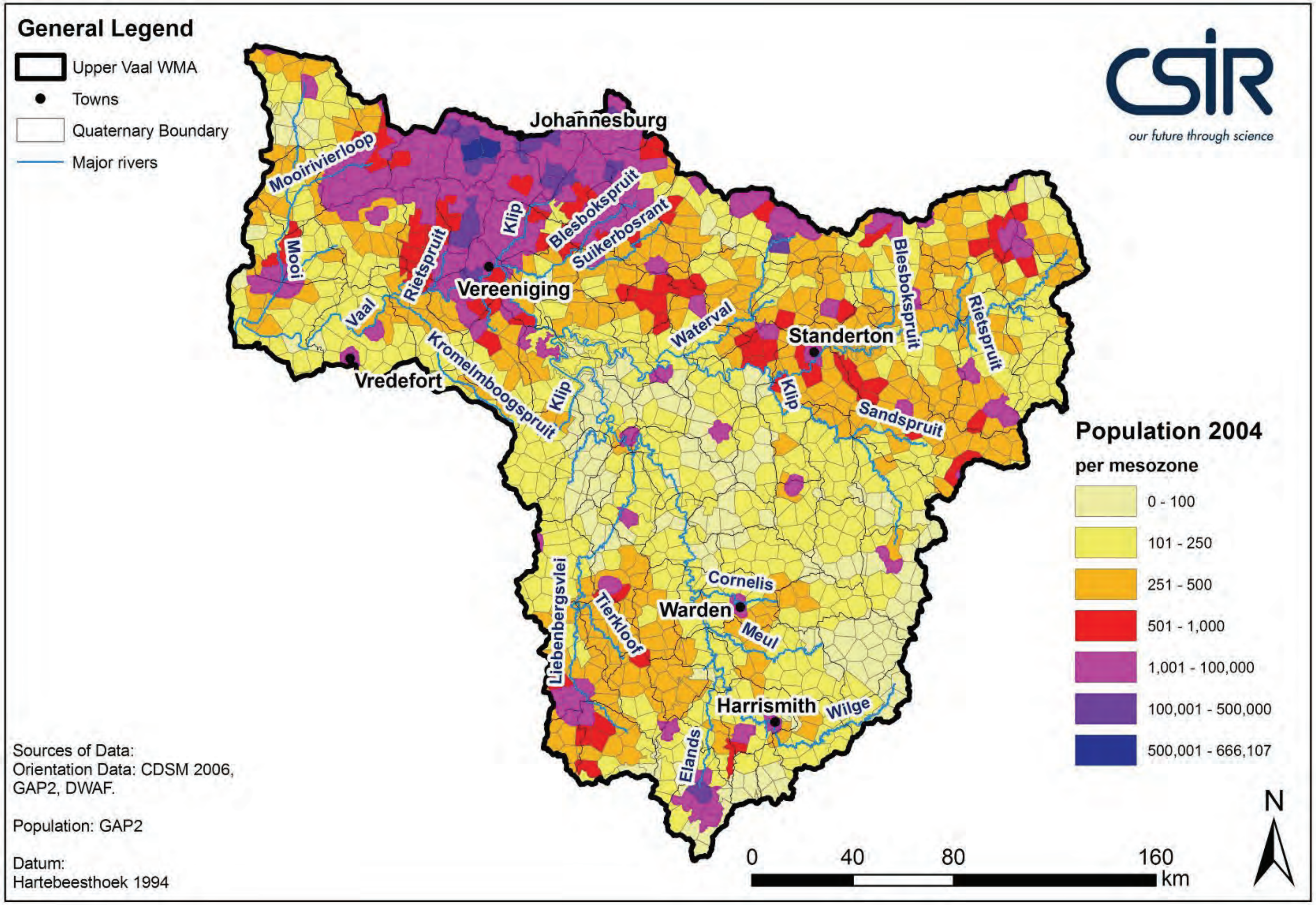

Figure 2-12. Distribution of population per mesozone overlain on the quaternary catchment mosaic

3 PRESENT STATUS OF GROUNDWATER

3.1 Water Level Data

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

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 Upper 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. Salient information that describes this exercise is provided in **Table 3-1** and a statistical evaluation of the results presented in **Figure 3-1**.

Table 3-1. Summary of water level data availability per geological unit and associated metadata

Geological Unit	Number of Stations	Number of values (total)	Stations with more than 100 values	Stations with only 1 value	Number of Quaternaries
Elliot Formation	4	4	0	4	3
Swazian	133	1759	5	126	5
Basement Complex	11	11	0	11	1
Beaufort Group	359	370	0	348	21
Black Reef Formation	167	999	1	156	12
Central Rand	226	230	0	222	14
Chuniespoort Group	1244	86513	180	906	19
Dominion Group	24	24	0	24	1
Dwyka Group	25	29	0	24	5
Ecca Group	2408	16899	45	2305	46
Intrusive strata	139	252	1	138	10
Platberg Group	39	166	1	38	3
Quaternary Deposits	579	7735	10	556	45
Roodekraal Complex	4	4	0	4	1
Steynskraal Complex	2	2	0	2	1
West Rand Group	185	318	1	181	13
Witwatersrand Supergroup	1	1	0	1	1

The information presented in **Figure 3-1** indicates that the minimum depth to water level varies marginally between the various lithologies, but is generally shallow and close to ground level. A 95%ile depth of about 100 m bgl is associated with the Chuniespoort Group, and a value of some 90 m bgl with the Ecca Group. All the other lithologies represented support a 95%ile value of <50 m bgl.

The median groundwater rest level depth is not significantly different for the Basement Complex, Beaufort Group, Central Rand Group, Dwyka Group, Ecca Group, Intrusive strata, Karoo Dolerite Suite and the Platberg Group lithologies. The Black Reef Formation, Chuniespoort Group, Dominion Group and Elliot Formation strata support a slightly greater median depth to ground water level. Further analysis of depth to groundwater rest level data per individual geological unit focussed on the statistical evaluation of this variable per quaternary catchment for each of the lithologies hosted.

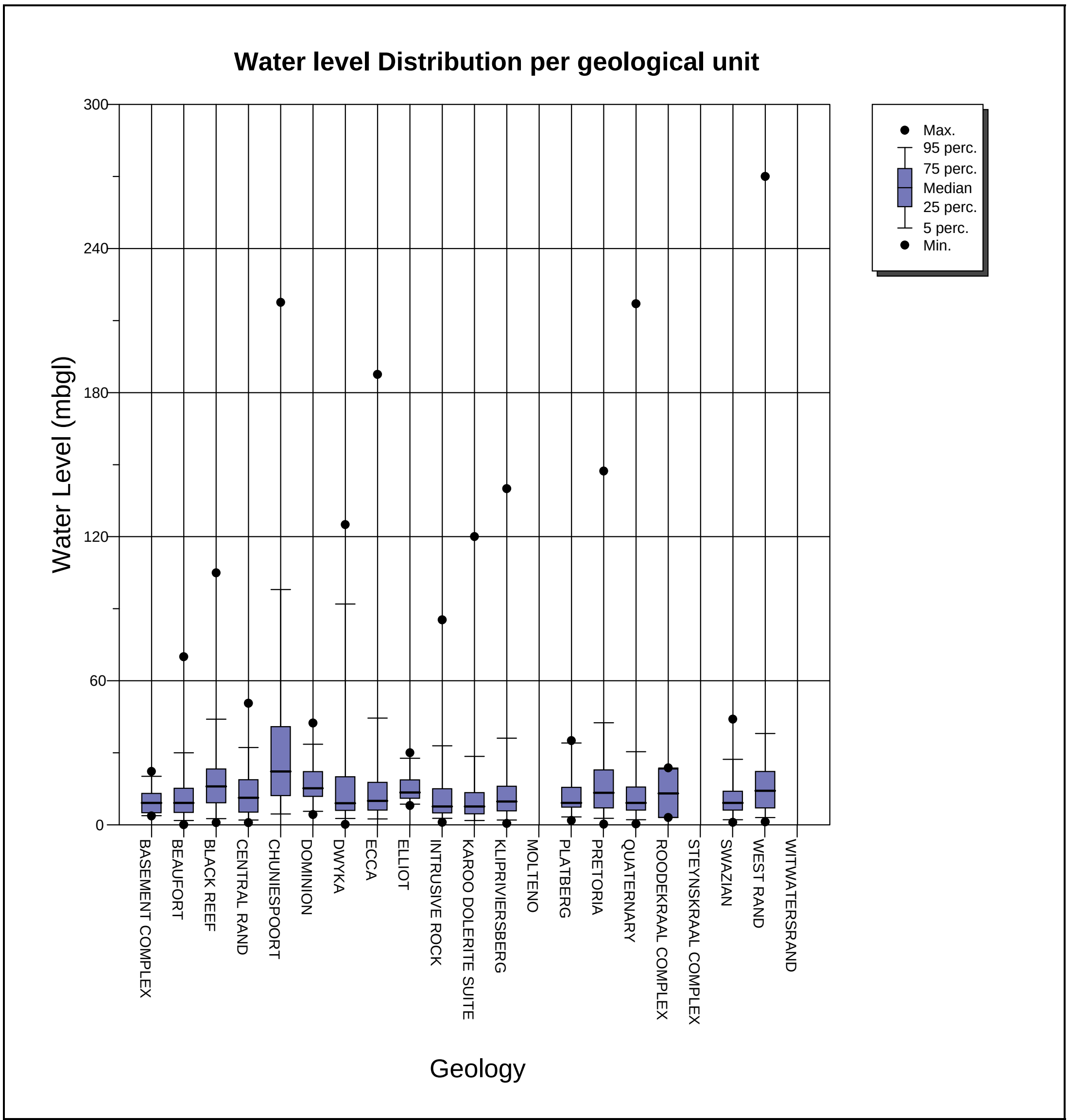

Figure 3-1. Statistical analysis of water level data per geological unit

The distribution of groundwater level data points in the study area is shown in **Figure 3-2**. Also indicated in this figure are those stations for which more than one water level value is available. It is noticeable that the latter are primarily concentrated in the north-western portion of the study area. These circumstances reflect the importance assigned to the karst groundwater resources that underlie much of this portion of the study area, and which also explains the greater density of measurement points in this quadrant.

3.1.2 Geological Unit Assessment

3.1.2.1 Swazian Strata

A total of 133 geosites with water level data provide 1759 water level records for this geological unit. Five of the geosites support in excess of 100 records, and 126 stations provide only a single record. The Swazian strata occurs in the five quaternary catchments identified in **Figure 3-3**, in each of which it is characterised by the reported water rest level statistical values.

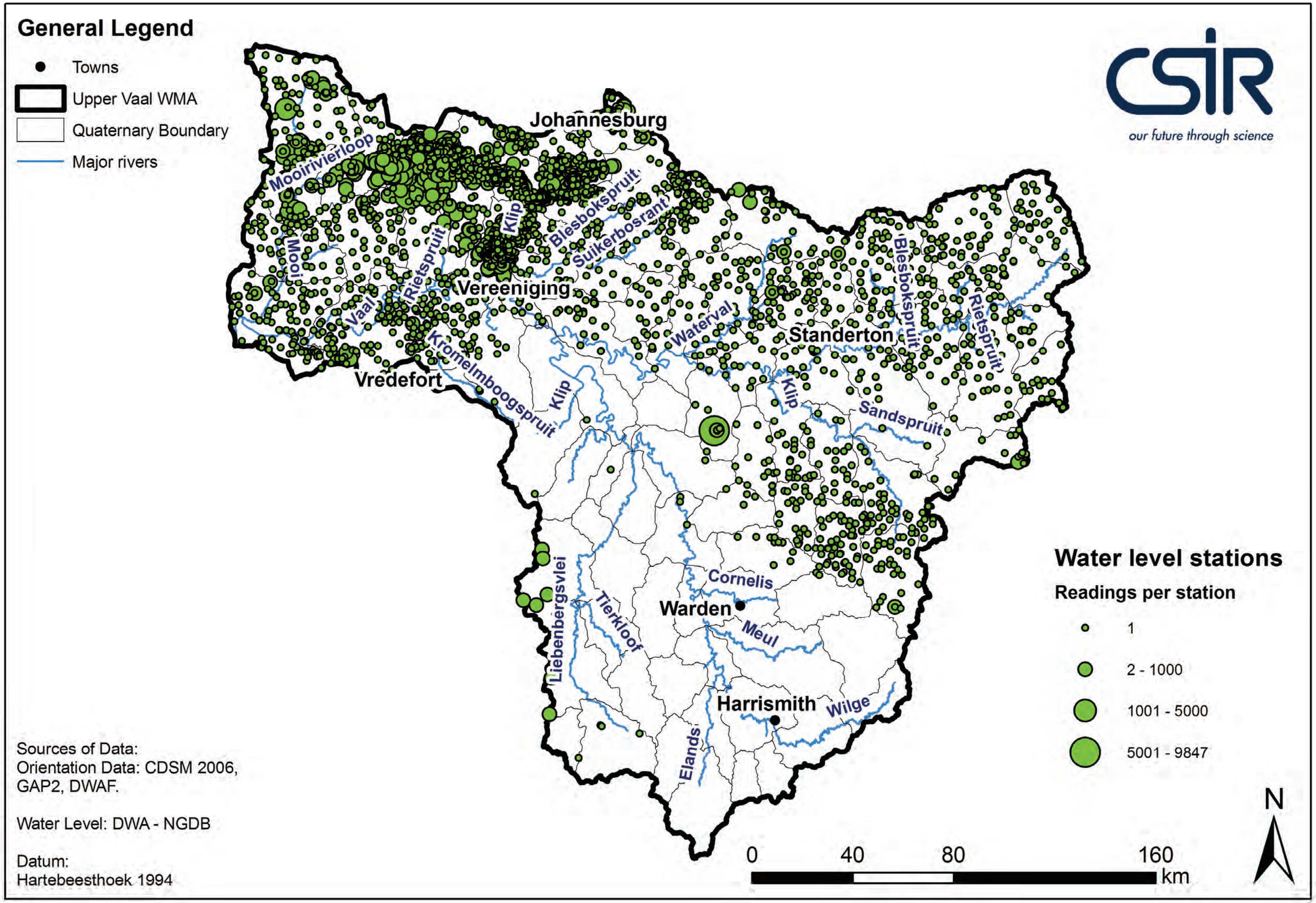

Figure 3-2. Distribution of groundwater level data points in the study area

Whereas quaternary catchments C21B and C23C reflect a similar pattern of groundwater rest level statistical values, catchment C21A is distinguished by a shallower median and 95%ile value, and catchment C23G by a significantly greater median variance in 25%ile and 75%ile values.

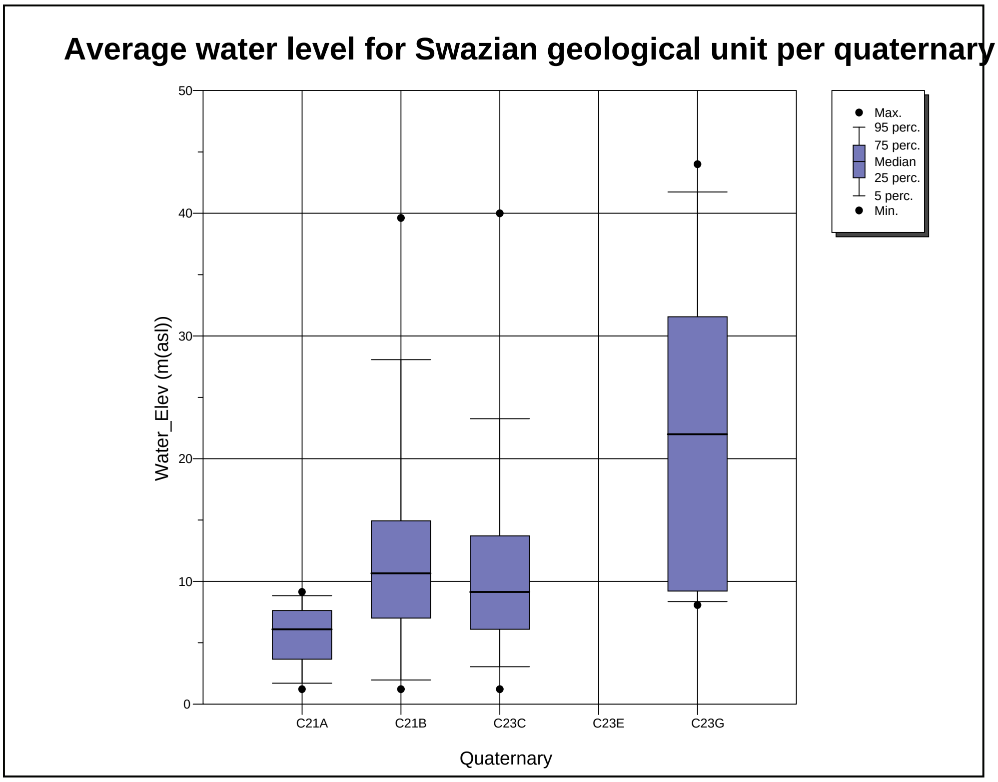

Figure 3-3. Statistical analysis of water level data for boreholes penetrating Swazian strata per quaternary catchment

3.1.2.2 Basement Complex

The Basement Complex strata water level data set intersects a single quaternary catchment (C23C), in which 11 geosites each provide a single value. **Figure 3-4** indicates that this lithology is characterised by a comparatively shallow depth to groundwater rest level, with a median value of 9 m bgl and a 75%ile value of only some 20 m bgl. The 'once-off' data precludes an assessment of temporal groundwater rest level behaviour associated with this lithology.

3.1.2.3 Beaufort Group

Although the sedimentary strata of the Beaufort Group reflect 370 water rest level values, 348 of these represent a single value associated with a geosite, the remaining 22 values being distributed equally between a further 11 geosites. These circumstances again preclude a temporal assessment of water level response patterns, restricting the interrogation of these data to the outcome presented in **Figure 3-5**. Quaternary catchments without a box-and-whisker plot support fewer than seven water level records. **Figure 3-5** shows that the majority of catchments support a median depth to groundwater rest level in the range 8-16 m bgl. Notable exceptions are catchments C82A (greatest median value of ~24 m bgl) and C83F (shallowest median value of ~4 m bgl). The greatest variance between 1st (25%ile) and 3rd (75%ile) quartile values is associated with catchment C82E, and the least variance with catchment C83F.

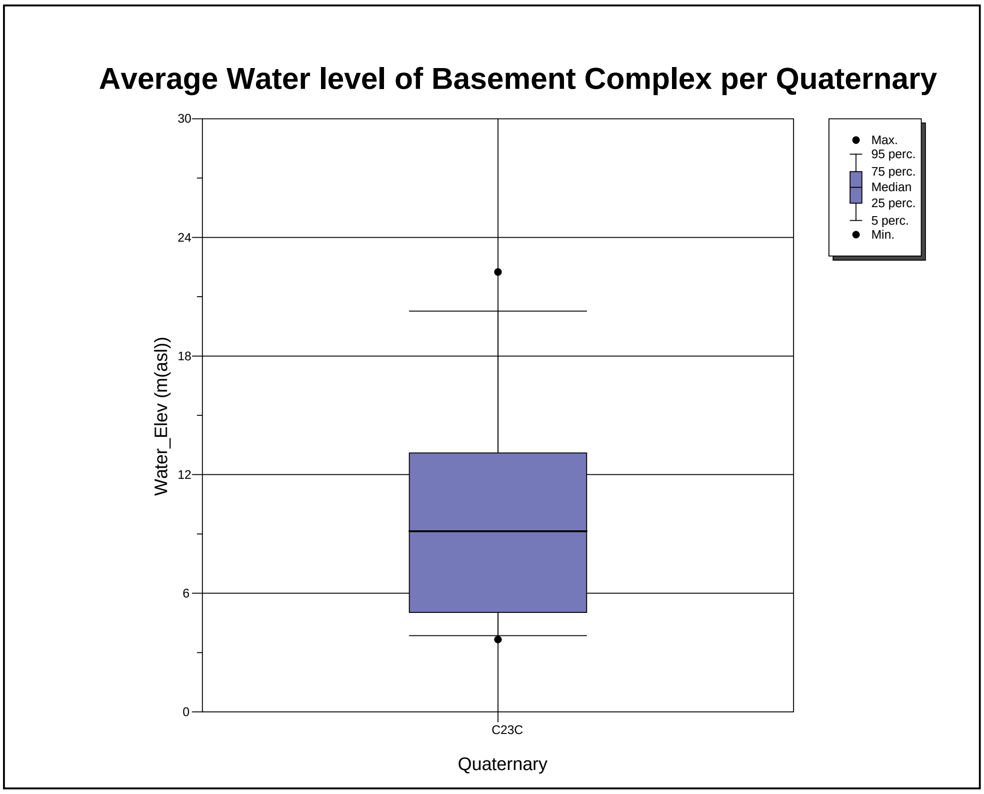

Figure 3-4. Statistical analysis of water level data for boreholes penetrating Basement Complex strata per quaternary catchment

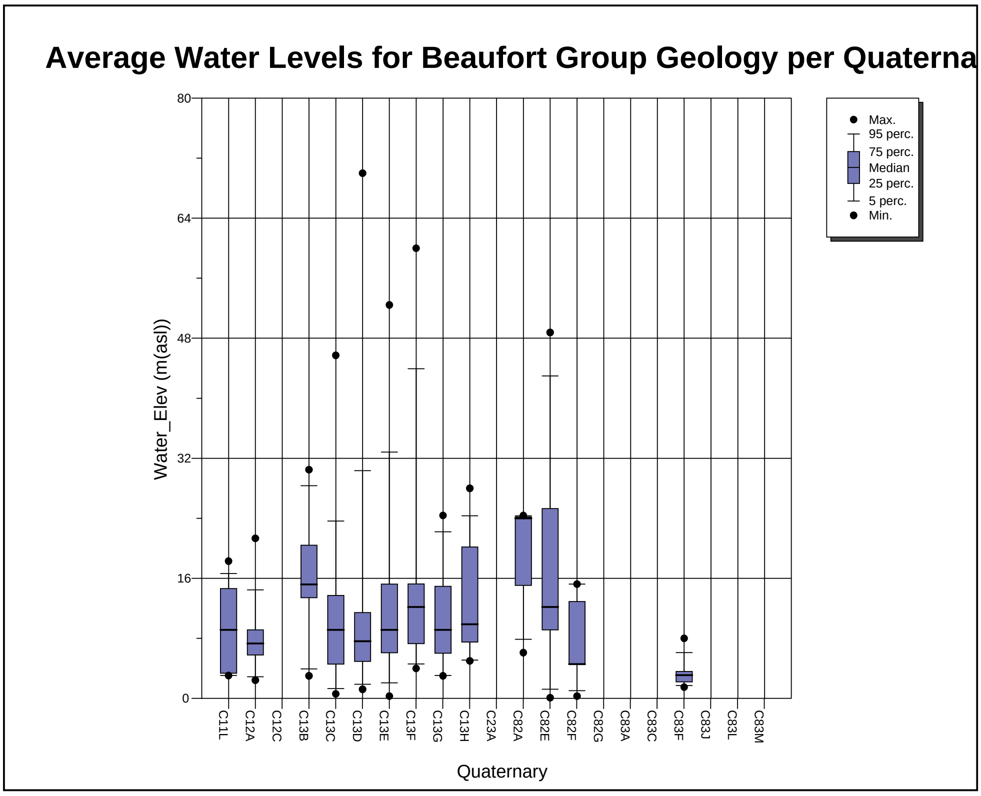

Figure 3-5. Statistical analysis of water level data for boreholes penetrating Beaufort Group strata per quaternary catchment

3.1.2.4 Black Reef Formation

The 167 geosites providing 999 water level values for this lithology include only one station with >100 readings, whilst 156 geosites provide only one reading. The remaining 10 geosites provide between 2 and 99 readings. Although strata of this geological unit are found in 12 quaternary catchments (**Figure 3-6**) in the study area, not all of these support sufficient data to evaluate statistically.

It is evident from **Figure 3-6** that the median depth to groundwater rest level associated with Black Reef Formation strata occurs in the range 10-25 m bgl across all of the quaternary catchments represented. The more extreme water rest level depths represented by 95%ile values of ~90 m bgl are associated with catchments C23D, C23E and C23G. These catchments are all located in the north-western portion of the study area where the historical impact of gold mining activities, in particular intentional dewatering of overlying dolomitic aquifers, has previously been discussed. Bear in mind that the Black Reef Formation lies at the base of the Chuniespoort Group that hosts the dolomitic strata.

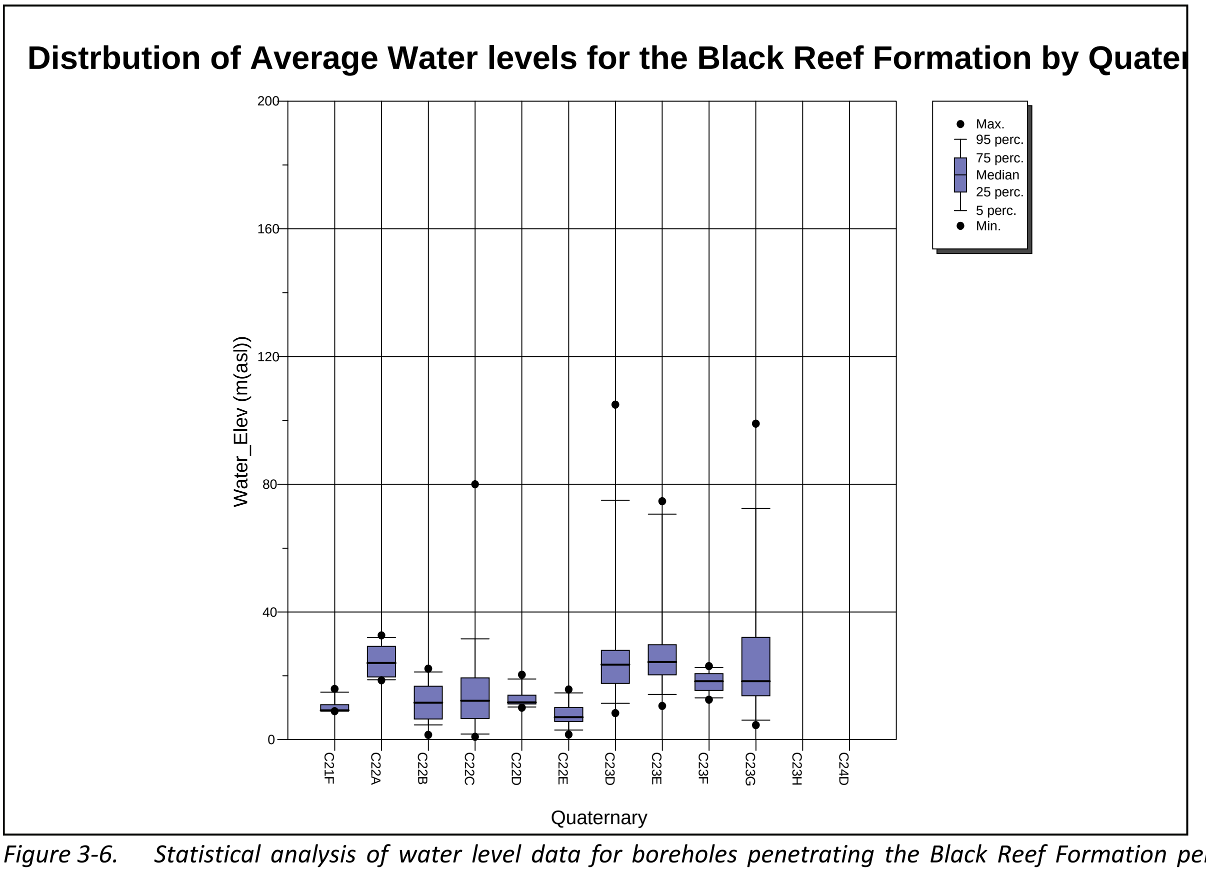

Figure 3-6. Statistical analysis of water level data for boreholes penetrating the Black Reef Formation per quaternary catchment

3.1.2.5 Central Rand Group

Lithologies associated with this group occur in 14 quaternary catchments of the WMA, and provide 226 geosites together producing a total of 230 water rest level values. These circumstances indicate that no time series water level data exist for this geological unit.

Figure 3-7 indicates a median depth to groundwater rest level that varies in the comparatively narrow range of 12 ±3 m bgl in 9 of the catchments. Despite this ostensible homogeneity, the wide variance in 1st and 3rd quartile values associated with these strata in seven catchments reflects the heterogeneous reality that characterises this groundwater resource. Even so, the maximum depth to water rest level in the record amounts to only ~50 m bgl.

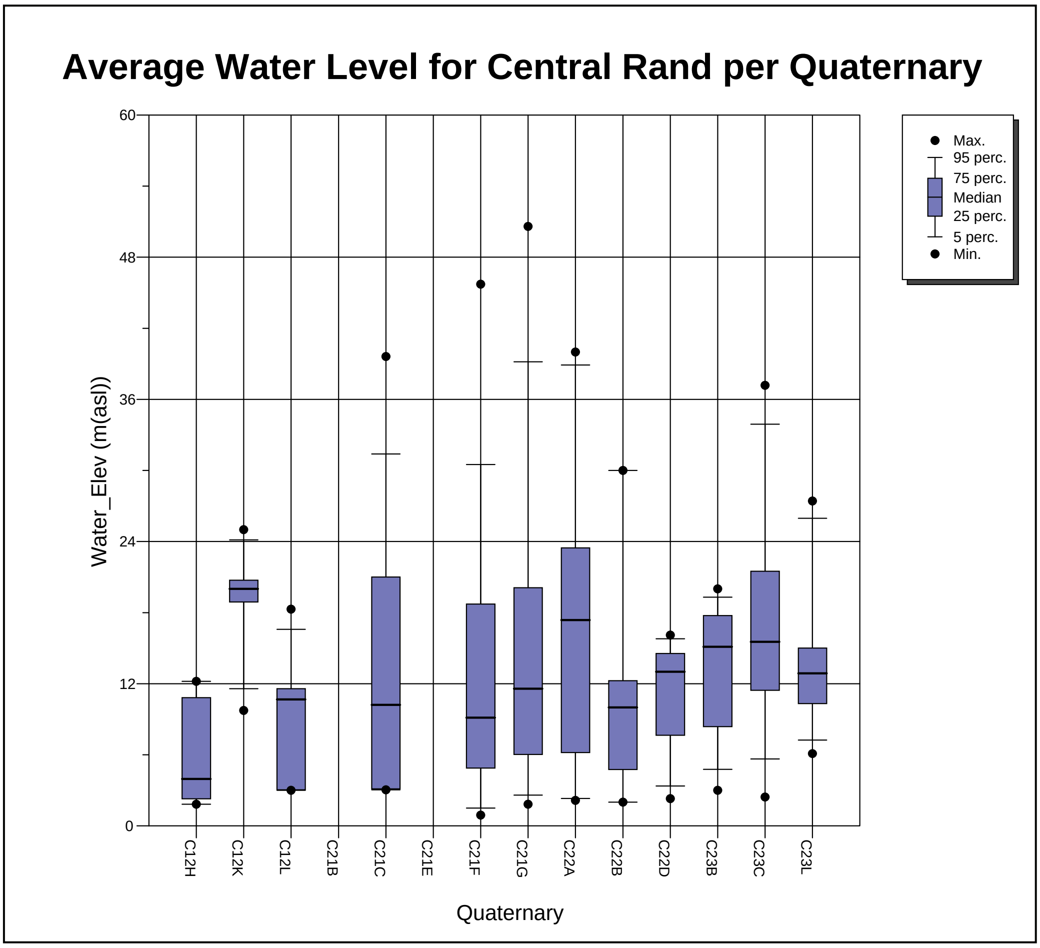

Figure 3-7. Statistical analysis of water level data for boreholes penetrating the Central Rand Group per quaternary catchment

3.1.2.6 Chuniespoort Group

The 1244 geosites that provide a total of 86 513 depth to water level values far surpasses in number those associated with any other geological unit represented in the study area. The further observations that 109 of these geosites provide a long-term record in excess of 100 values each, and that these strata occur within 19 quaternary catchments in the WMA, testify to the singular hydrogeological importance attached to the dolomitic strata in the WMA. As might be expected of a groundwater resource in which groundwater rest levels seldom replicate the surface topography of their geomorphological environment, the median depth to water rest level value occupies a relatively wide range between 10 and 50 m bgl (**Figure 3-8**). A similar large variance is exhibited in the 1st and 3rd quartile, the 5 and 95%ile and the maximum and minimum values. Unsurprisingly, the greatest of these variances are again associated with the quaternary catchments that define the gold mining areas in the north-western portion of the study area.

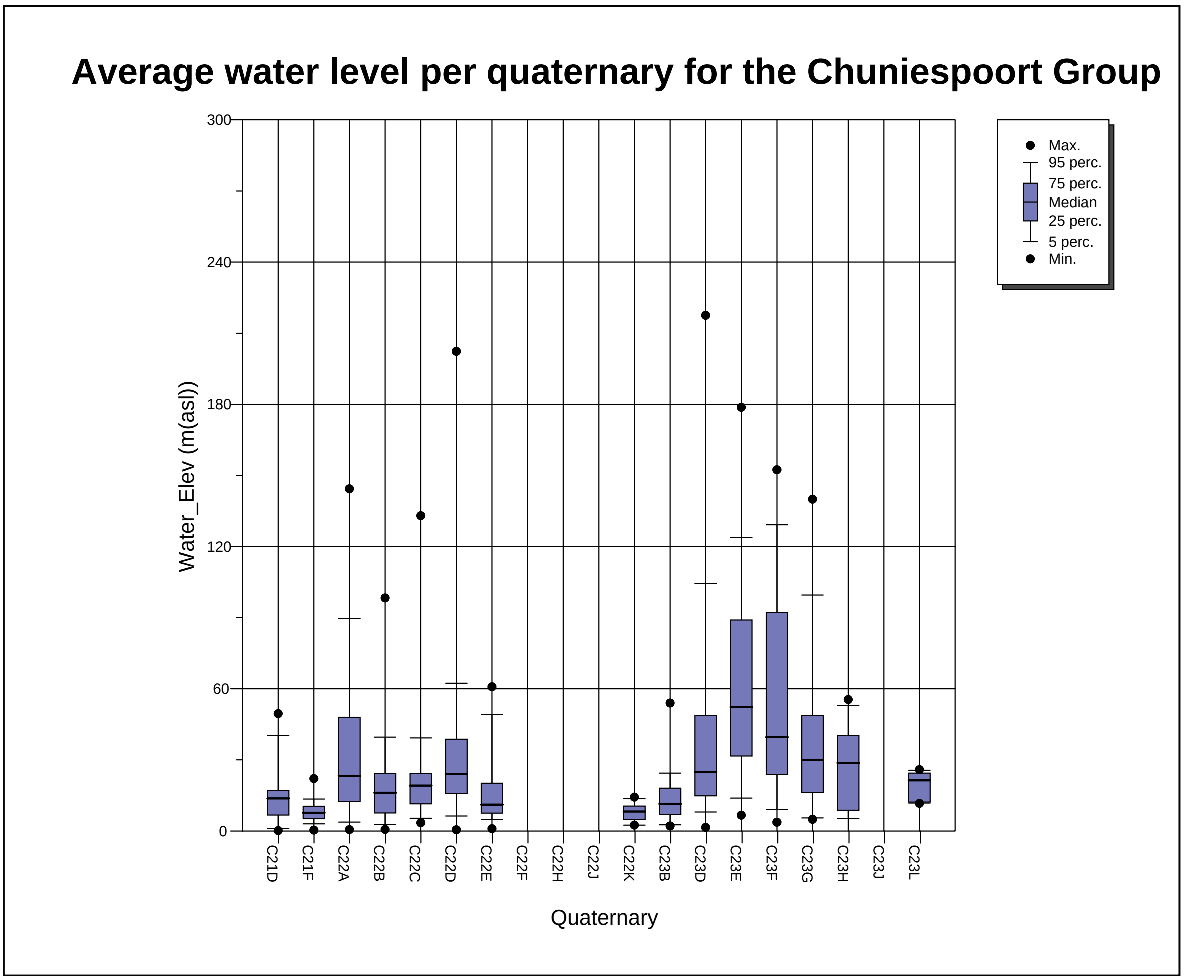

Figure 3-8. Statistical analysis of water level data for the Chuniespoort Group per quaternary catchment

3.1.2.7 *Dominion Group*

The Dominion Group is represented by 24 geosites each providing a single depth to water rest level value. Further, it is also represented in only one quaternary catchment, namely C23C (**Figure 3-9**). An analysis of the available data indicates a comparatively shallow median depth to groundwater rest level of some 15 m bgl. The 95%ile value of little more than 30 m bgl suggests a relatively small variance in the magnitude of this variable in this geological unit.

3.1.2.8 Dwyka Group

Similar to the Dominion Group, the Dwyka Group is represented by 25 geosites providing 29 water level records distributed over five quaternary catchments (**Figure 3-10**). Only three of the latter have sufficient data for statistical evaluation. The similar median depth to groundwater rest level of ~10 m bgl is not matched by the disparate variances in the inter-quartile and the 5 to 95%ile ranges that reach a maximum in quaternary catchment C22C.

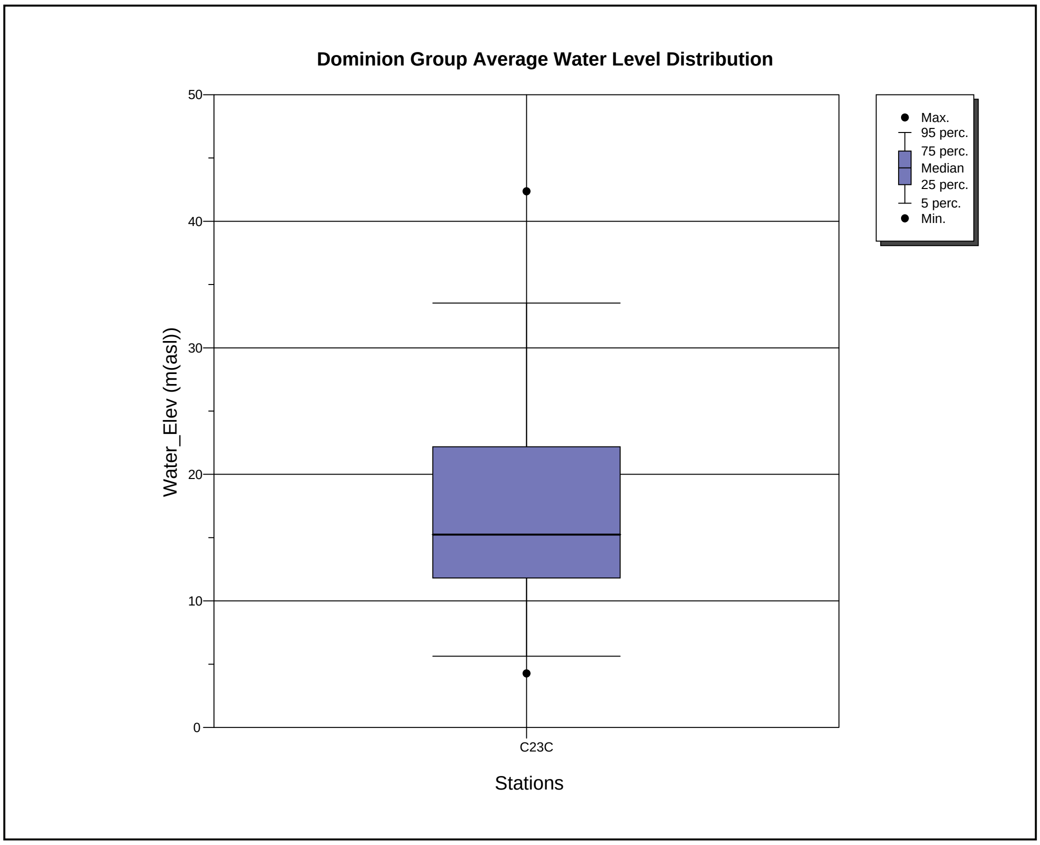

Figure 3-9. Statistical analysis of water level data for the Dominion Group per quaternary catchment

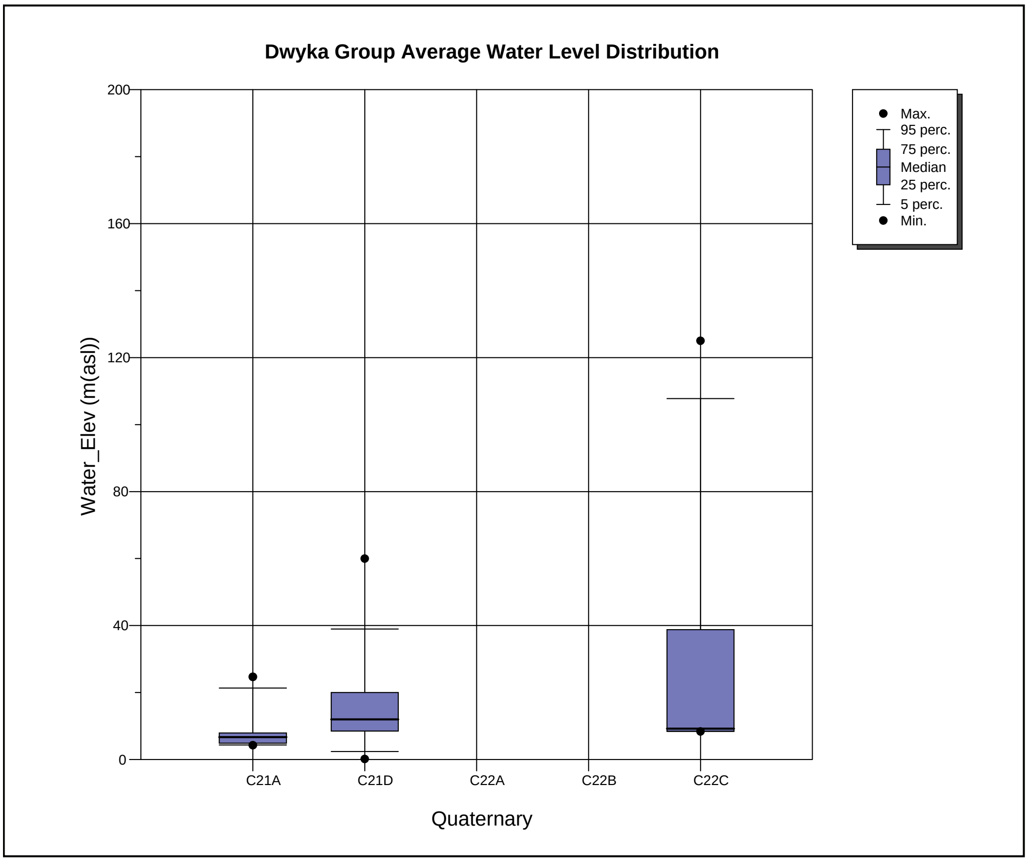

Figure 3-10. Statistical analysis of water level data for the Dwyka Group per quaternary catchment

3.1.2.9 Ecca Group

The Ecca Group supports 2408 geosites providing a total of 16 899 water level values. A total of 49 geosites provide a record length that comprises more than 100 values. The Ecca Group is represented in 46 quaternary catchments across the WMA, which reflects the widespread occurrence of the sedimentary strata associated with this subdivision of the Karoo Supergroup in the study area. **Figure 3-11** reveals the substantial uniformity in median groundwater rest level depth of ≤20 m bgl that characterises the great majority of quaternary catchments. Exceptions in this regard are the catchments C22A, C23D and, most notably, C23E. The latter not only supports a median water rest level value of ~100 m bgl, but is also characterised by a comparatively small variance between the more extreme statistical values.

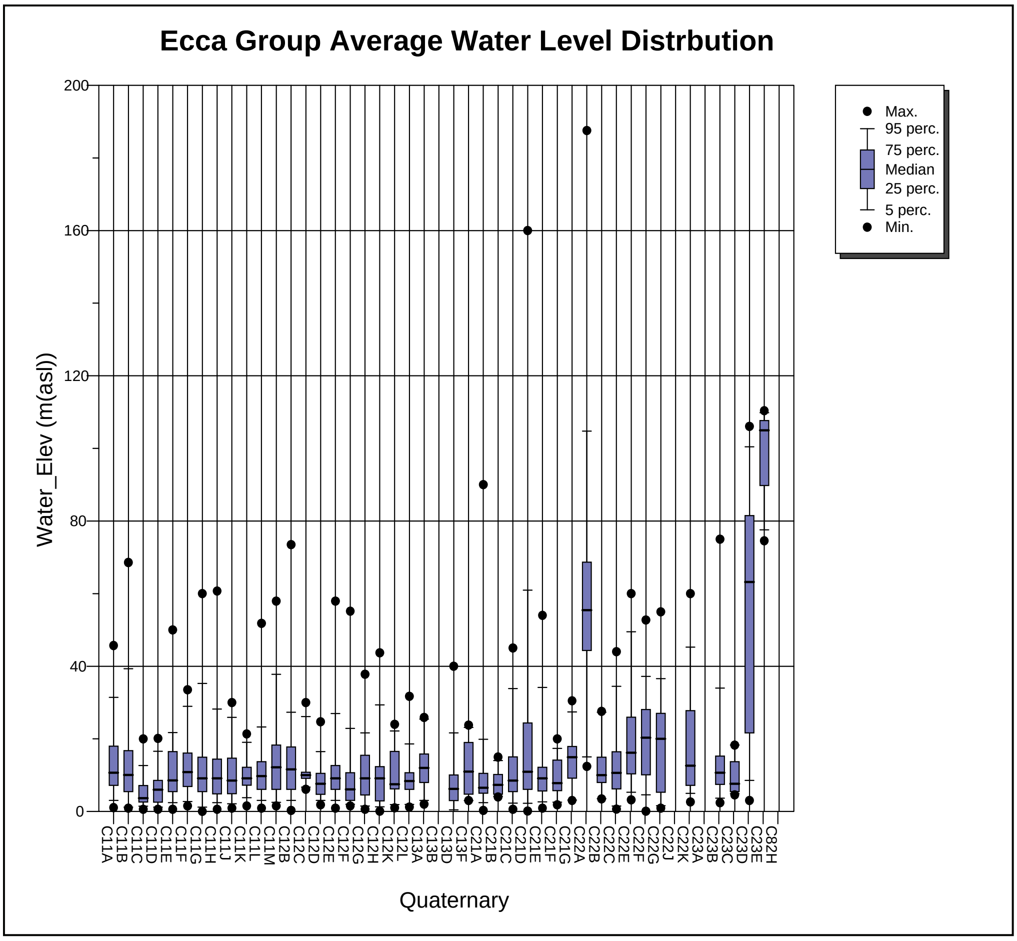

Figure 3-11. Statistical analysis of water level data for the Ecca Group per quaternary catchment

3.1.2.10 Intrusive Strata

The 139 geosites that intersect Intrusive strata across 10 quaternary catchments in the study area include only 1 station that provides more than 100 values. The median depth to groundwater rest level of <18 m bgl that characterises this variable in 5 of the catchments is exceeded in catchment C23C with a value of ~30 m bgl (**Figure 3-12**). The typically low variance reflected in the more extreme statistical values is not evident in catchment C23L.

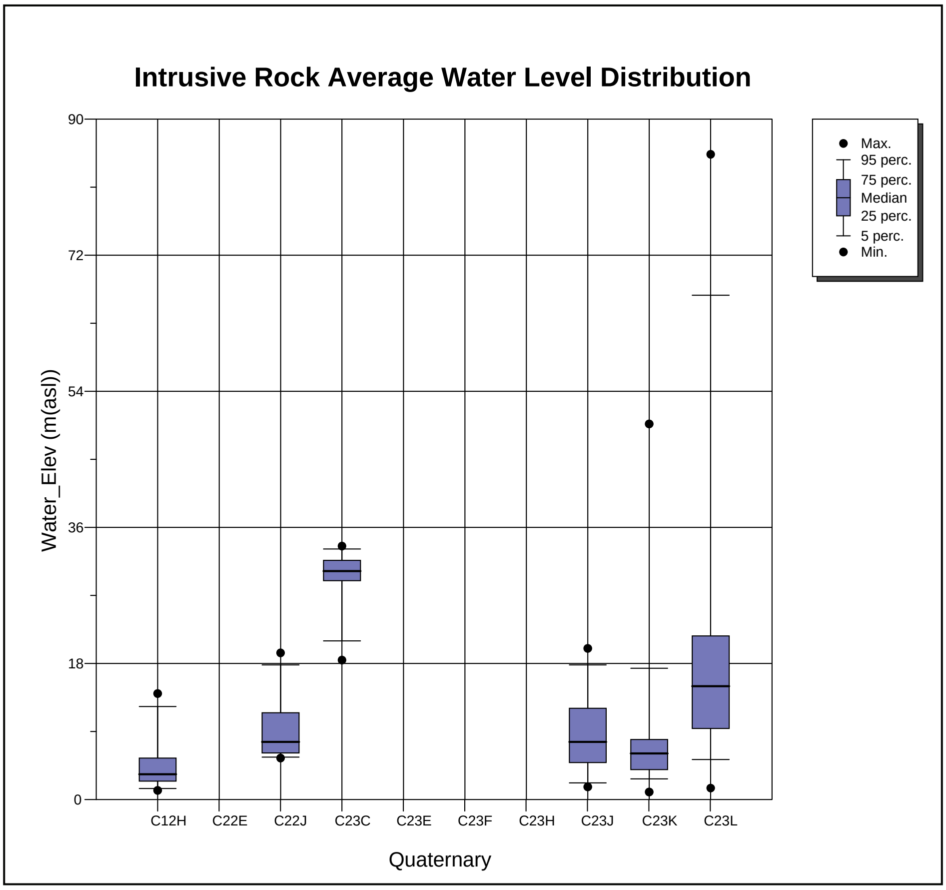

Figure 3-12. Statistical analysis of water level data for Intrusive strata per quaternary catchment

3.1.2.11 Platberg Group

This geological unit is represented by only 39 geosites for which water level data are available, 38 of which provide single values and one represents a record length in excess of 100 values. Although the Platberg Group occurs in three quaternary catchments in the study area, sufficient data for a statistical assessment is only available for one catchment, namely C23G (**Figure 3-13**). The median value of ~10 m bgl indicates a comparatively shallow depth to groundwater rest level.

3.1.2.12 Quaternary Deposits

Of the 579 geosites that intersect Quaternary sediments in the study area, 10 provide a record length that exceeds 100 water level values. The substantial length of these records is reflected in the 7735 values that comprise the water level data set despite the fact that 556 geosites provide only a single value. The widespread occurrence of Quaternary strata in the study area is reflected in its occurrence in 45 catchments.

Since this lithology relates primarily to more recent surface deposits, the value of 60 m bgl that defines the greatest depth to groundwater rest level in all but three of the quaternary catchments is not surprising. Against this background, the abnormally large values of >120 m bgl (**Figure 3-14**) are not readily explained.

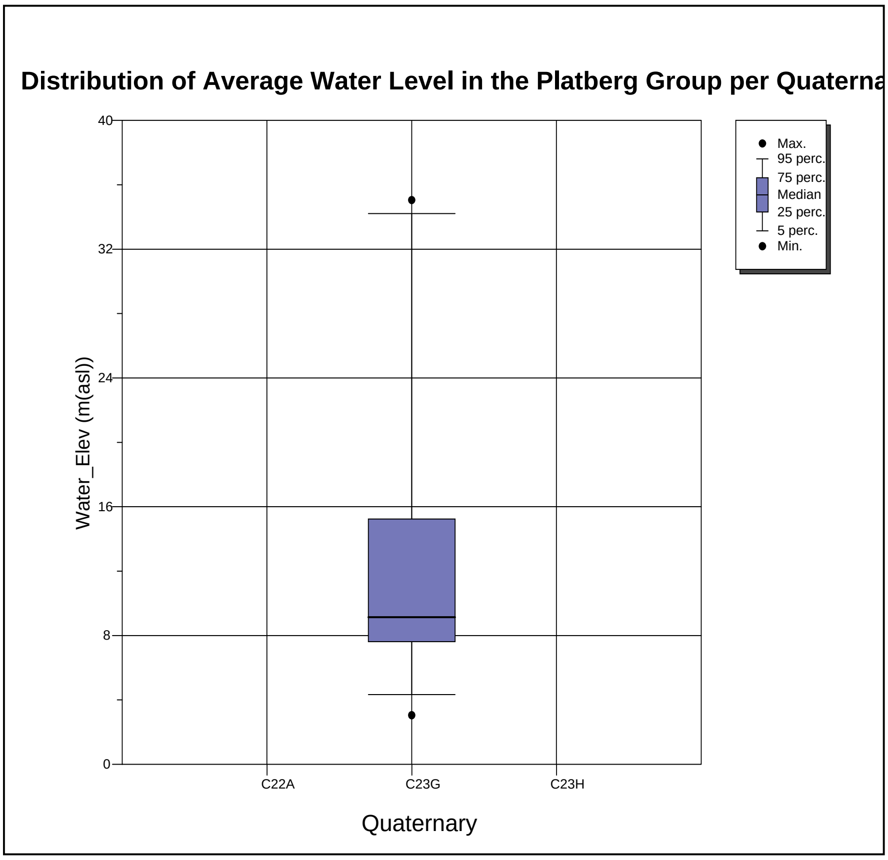

Figure 3-13. Statistical analysis of water level data for the Platberg Group per quaternary catchment.

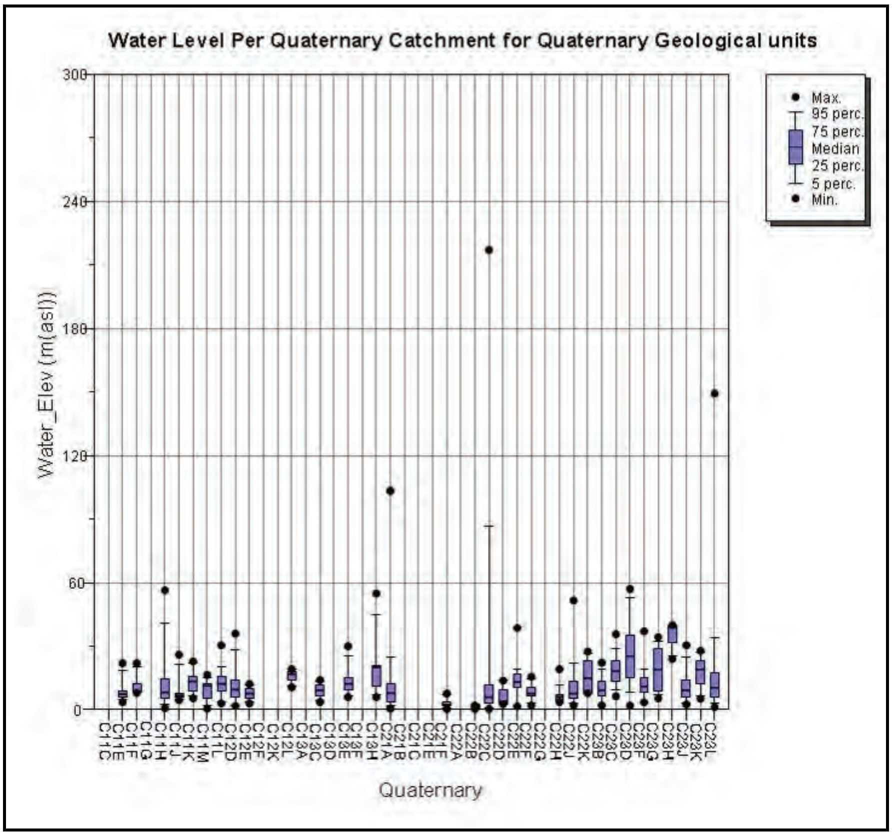

Figure 3-14. Statistical analysis of water level data for Quaternary strata per quaternary catchment

3.1.2.13 West Rand Group

Outcropping in 13 quaternary catchments in the study area, water levels in West Rand Group strata are recorded for 185 geosites providing 318 values. Only one geosite exhibits a long-term record that comprises more than 100 measurements.

Although the median groundwater rest level depth varies significantly between catchments from ~5 m bgl to ~35 m bgl (**Figure 3-15**), the variance between more extreme values is only large in two catchments, namely C23D and C23L. The greater median depths and variances are again associated with the north-western portion of the WMA where gold mining activities represent the dominant land use.

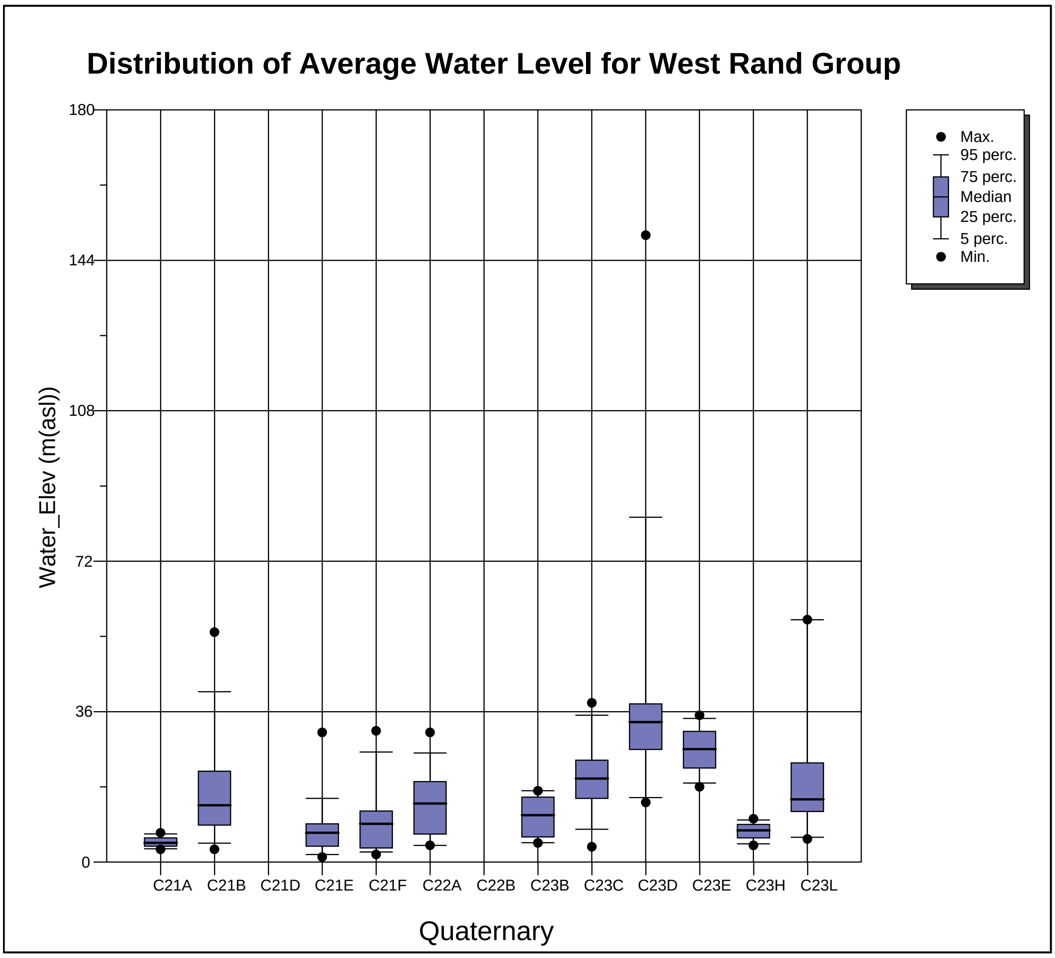

Figure 3-15. Statistical analysis of water level data for the West Rand Group per quaternary catchment

3.1.2.14 Other Geological Units

The paucity of water level data for the other geological units represented in the WMA precludes a rigorous evaluation of this variable. For example, the Roodekraal Complex is represented by four geosites all located in catchment C23L and each providing a single value. The Steynskraal Complex is represented by only two geosites with one sampling event each.

3.2 Hydrochemical Data

3.2.1 Sources of Data

Chemical data were sourced from the Department of Water Affairs as the principal custodian of water resource 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 hydrogeological 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 of Data

The Upper Vaal WMA is served by 1324 geosites providing groundwater quality data amounting to 5221 chemical analyses spanning the period 1970 to 2007. The distribution of these stations is shown in **Figure 3-17**, together with an indication of the number of analyses associated with each station. It is evident from **Figure 3-16** that only nine of the monitoring stations support a data set that exceeds 100 analyses. These are all located in the north-western portion of the study area (**Figure 3-17**).

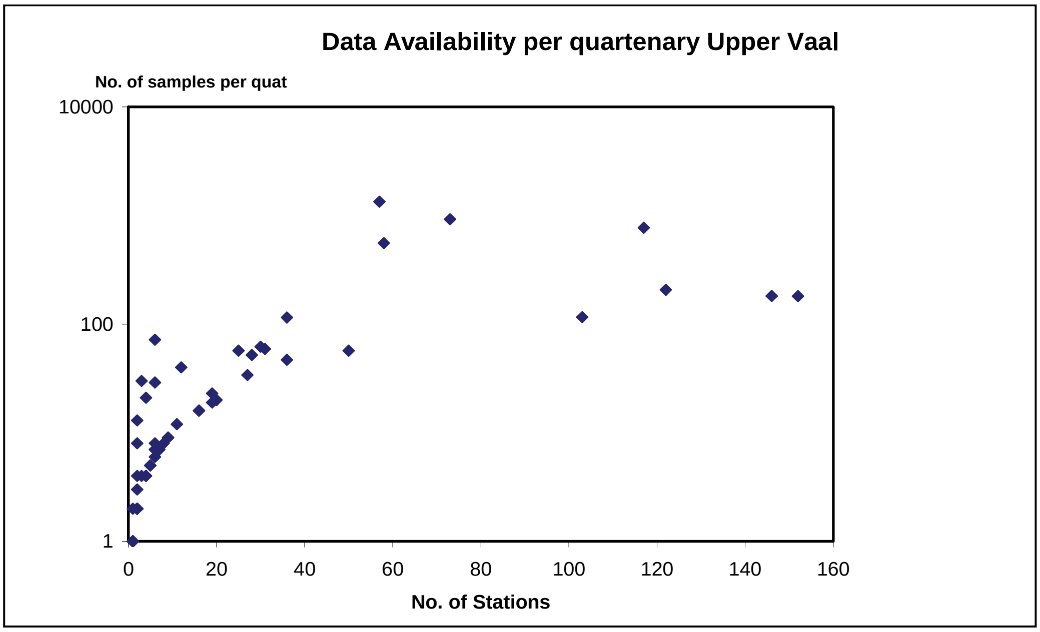

Figure 3-16. Plot of number of stations versus number of analyses per station for each quaternary catchment in the Upper Vaal WMA

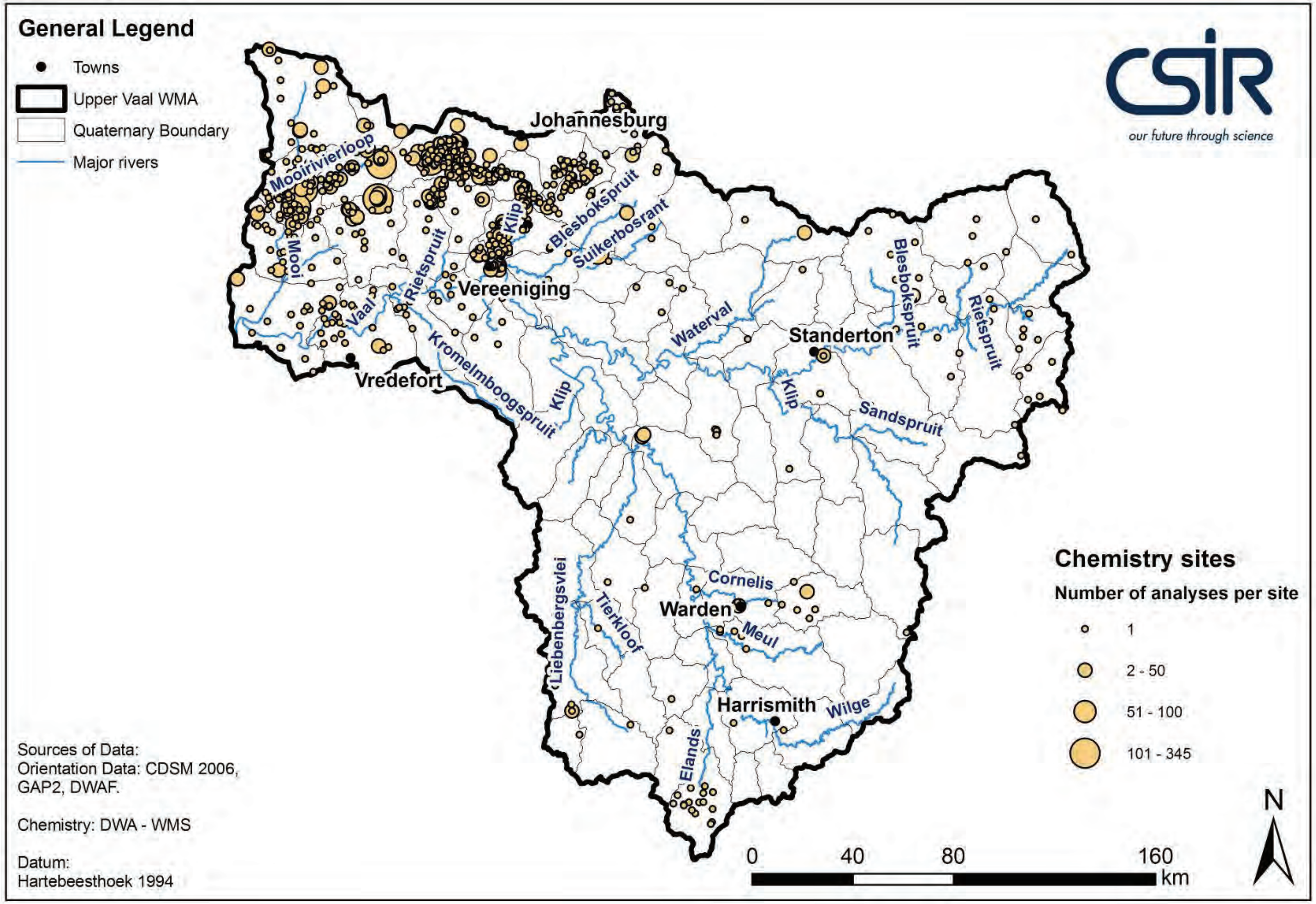

Figure 3-17. Distribution of groundwater quality sampling stations in the Upper Vaal WMA

3.2.3 Data Quality Assessment

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). However, considering the many uncertainties and margin for error during sampling, preserving, storing, transporting and actual analysis, the time lags involved throughout these steps as well as the amount of data potentially discardable due to strict application of this 'rule', an error balance of ≤10% was accepted for this study. Despite this relaxation, only 23.6% (1232) of the analyses were found acceptable, the rest either exceeding the 10% cut-off or being incomplete (in terms of major ions reported) for this calculation. This result is illustrated in **Figure 3-18**. As a consequence, a number of quaternary catchments have necessarily been excluded from the groundwater quality assessment component of this study.

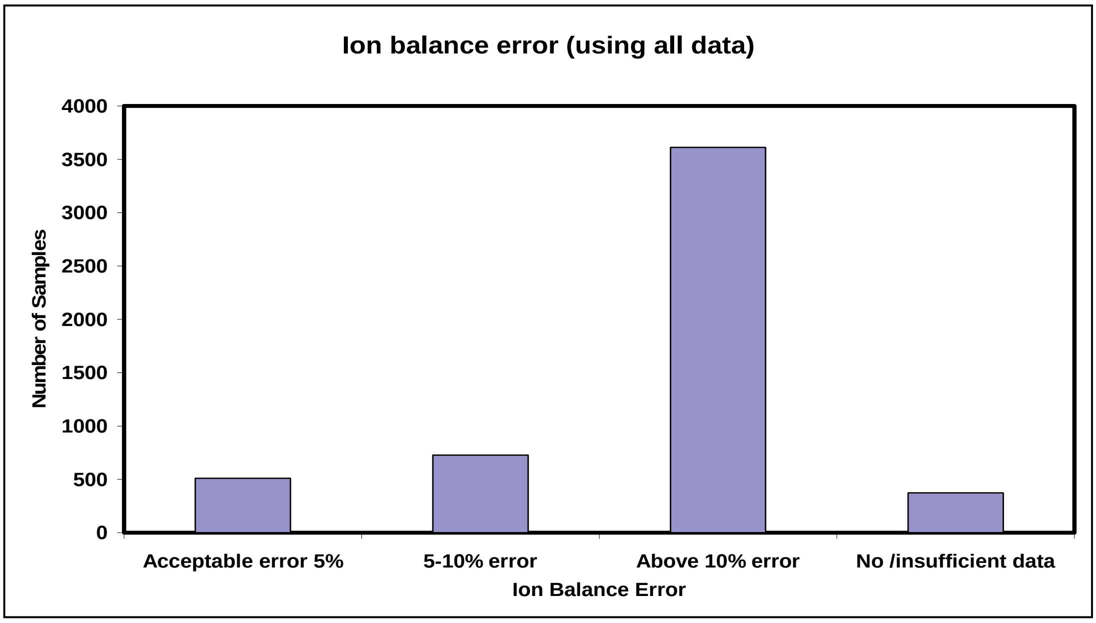

Figure 3-18. Ion balance error distribution for the Upper Vaal WMA hydrochemistry data set

3.2.4 Temporal Distribution of the Data

Figure 3-19 shows the distribution of hydrochemical data according to the date sampled. The assessment applies to the full data set, and not the subset considered acceptable in terms of the ion balance error. The assessment reveals the very 'productive' period from 1980 to 2000, when more than 80% of the analyses on record were generated. The implication is that the earlier and later records, which represent the 'reference' and 'current' conditions respectively, are data-poor.

A summary description of the outcome of the data verification exercise is presented in **Table 3-2**.

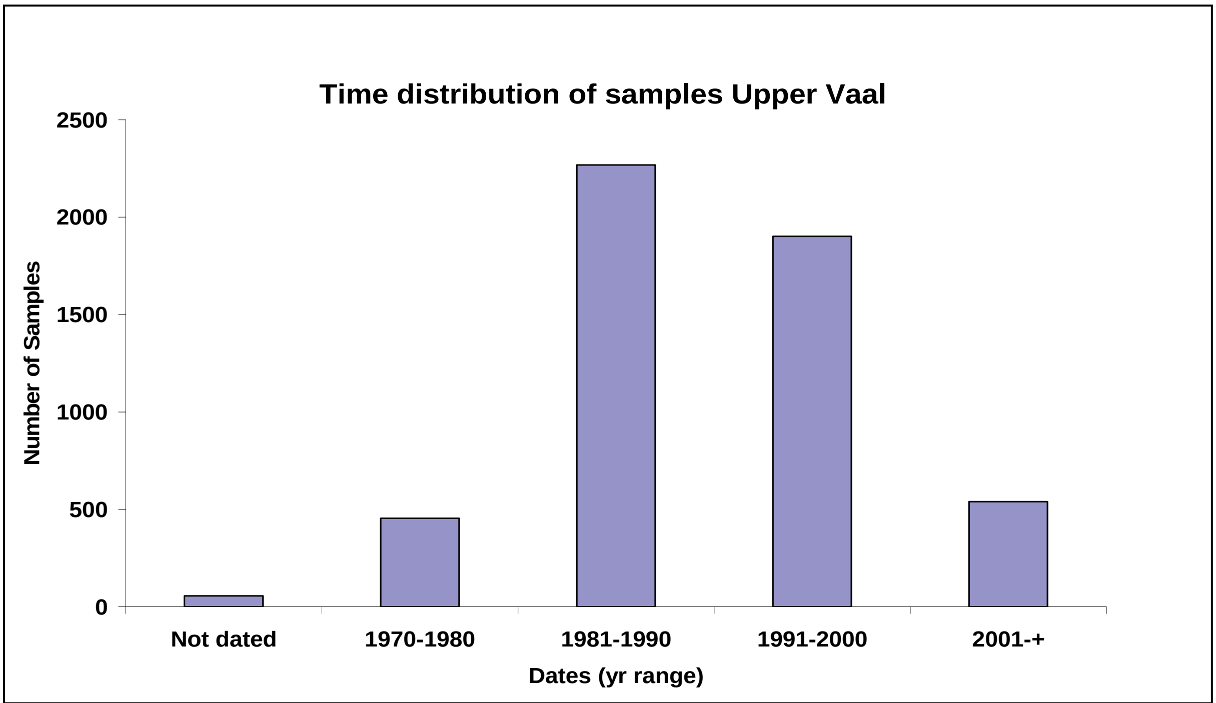

Figure 3-19. Temporal distribution of analyses to evaluate data availability for reference and current conditions

Table 3-2. Summary of hydrochemical data screening exercise outcome, ≥10% 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
C11	10	41	64	1.56	6	58
C12	5	16	40	2.50	7	33
C13	3	3	3	1.00	1	2
C21	6	42	127	3.02	17	109
C22	10	348	532	1.53	140	392
C23	9	333	2412	7.24	529	1883
C81	6	27	27	1.00	27	0
C82	5	13	37	2.85	11	26
C83	6	10	30	3.00	7	23

3.2.5 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 3-3** 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 rock composition to age of water to level of impact of surrounding activities in the area.

Table 3-3. Mean concentrations of hydrochemical variables per geological unit in the study area

Geological Unit	No. of Stations	No. of Analyses	Mean Variable Concentration										
			pH	EC (mS/m)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	Cl (mg/L)	SO_4 (mg/L)	T.Alk. (mg/L)	F (mg/L)	NO_3 (mg/L)
Black Reef Formation	15	16	7.5	31	22	17	13	2.4	16	24	86	0.065	4.5
Boshoek Formation	4	4	8.1	40	26	82	18	0.6	15	4	168	0.218	2.2
Daspoort Formation	5	5	7.6	55	49	32	21	1.6	23	21	233	0.182	3.4
Dwyka Group	4	4	7.6	26	16	9	23	2.3	10	8	100.4	0.293	0.4
Ecca Group	104	171	7.7	84	62	30	51	4.4	59	85	212	0.403	2.4
Malmani Subgroup	349	2084	7.7	69	62	36	30	2.7	26	161	151	0.149	2.4
Monte Christo Formation	5	43	7.9	44	48	28	4	1.0	4	6.1	231	0.131	1.1
Normandlen Formation	18	32	8.0	57	44	15	56	2.9	44	54	172	0.820	0.8
Tarkastad Subgroup	7	7	7.8	47	21	12	74	3.1	30	22	182	0.870	3.9
Molteno Formation	5	5	7.0	33	26	9	35	2.1	11	9	150	0.696	0.9
Elliot Formation	11	11	7.4	30	27	7	26	1.5	4	3	134	0.282	1.8
Klipriviersberg Group	30	106	7.7	84	73	42	42	3.3	56	118	186	0.860	15.4
Silverton Formation	9	27	8.4	74	52	41	38	2.3	43	70	239	0.283	2.6
Strubenkop Formation	3	10	8.1	37	22	13	32	1.8	34	11	108	1.000	2.7
Timeball Hill Formation	38	298	7.3	62	52	20	46	2.9	51	145	68	0.213	5.8
Central Rand Group	5	5	7.3	33	22	16	14	7.6	20	35	97	0.210	1.8
Rietgat Formation	6	7	7.3	33	22	18	16	1.9	7	4	135	0.069	4.8
Klapperkop Member	10	57	9.0	83.7	70	13	42	9.9	52	82	146	0.400	8.7
Karoo Dolerite	38	69	7.9	74	58	37	38	1.8	46	85	209	0.280	4.8
Hekpoort Formation	30	61	8.1	62	57	34	17	1.5	27	66	194	0.167	6.5
Basement Complex	5	29	7.9	81	43	28	52	4.5	24	17	272	0.433	4.6
West Rand Group	17	23	7.6	51	21	17	20	1.9	13	9	124	0.477	4.1
Minimum			7.0	26	16	7	4	0.6	4	3	68	0.065	0.4
Mean			7.8	54	41	59	32	2.9	28	47	164	0.386	3.9
Median			7.7	53	43	19	31	2.3	25	23	160	0.283	3.1
Maximum			9.0	84	73	823	74	9.9	59	161	272	1.000	15.4
Standard Deviation			0.4	20	18	171	17	2.1	18	48	55	0.283	3.3
Coefficient of Variation (%)			6	37	45	291	53	74	63	102	34	73	84
Total	718	3074											

3.2.5.1 Quaternary Sediments

The alluvial deposits that represent the majority of these 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 started much earlier than groundwater quality monitoring programmes. Nevertheless, the pre-1984 (**Figure 3-20**) data reveal a distribution that favours a CaMgNa-HCO_3 chemical composition, whereas the post-1986 data set clearly shows a tighter grouping in the Ca-HCO_3 quadrant with a few anomalous analyses exhibiting a Cl-dominated anionic composition indicative of contamination.

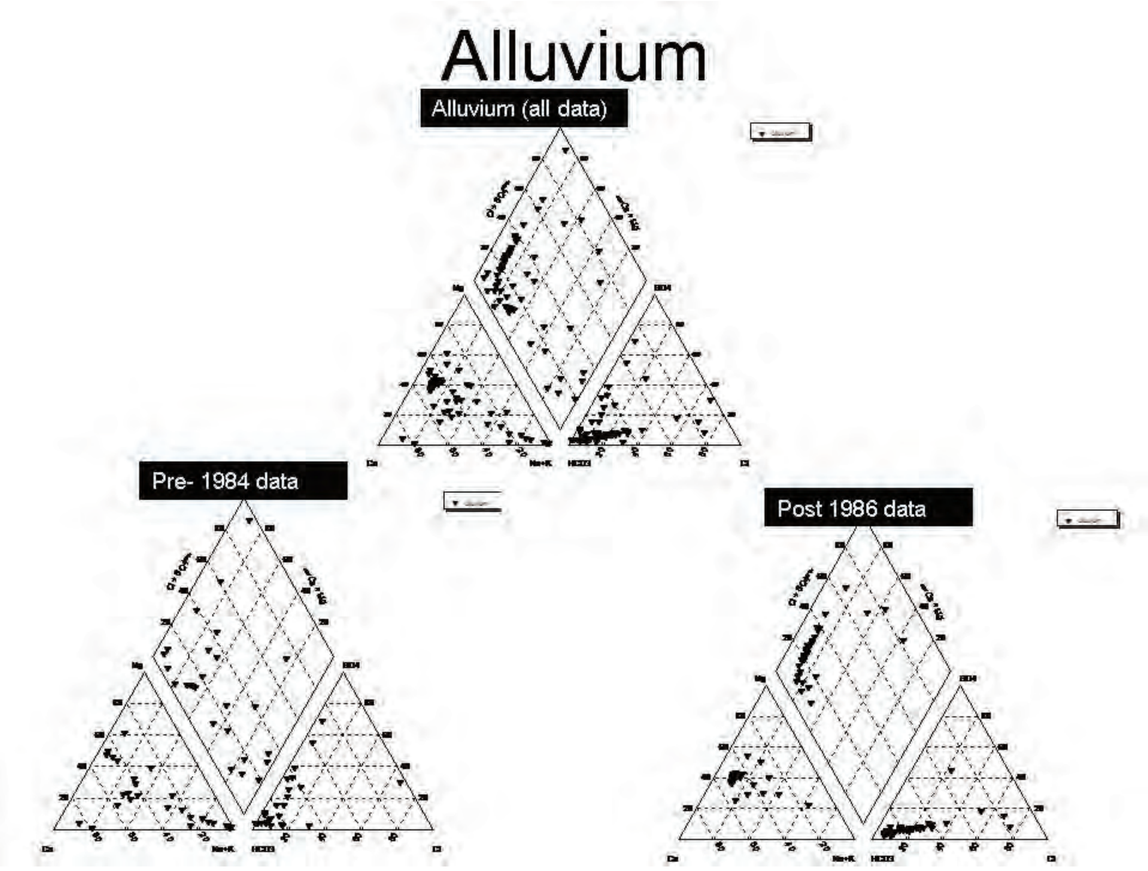

Figure 3-20. Trilinear diagram of alluvial groundwater hydrochemistry

3.2.5.2 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, along the southern margin of the study area where a combination of steep topography and near-horizontal bedding facilitate the grouping of these strata into a single undifferentiated unit for mapping purposes. Both the earlier (pre-1995) and later (post-2000) data sets (**Figure 3-21**) show a clustering of analyses in the Ca-HCO_3 quadrant which is much 'tighter' in the later set. The earlier data set, however, also indicates a number of analyses that have Na as the dominant cation which, in one instance, is paired with Cl to yield a Na-Cl type groundwater.

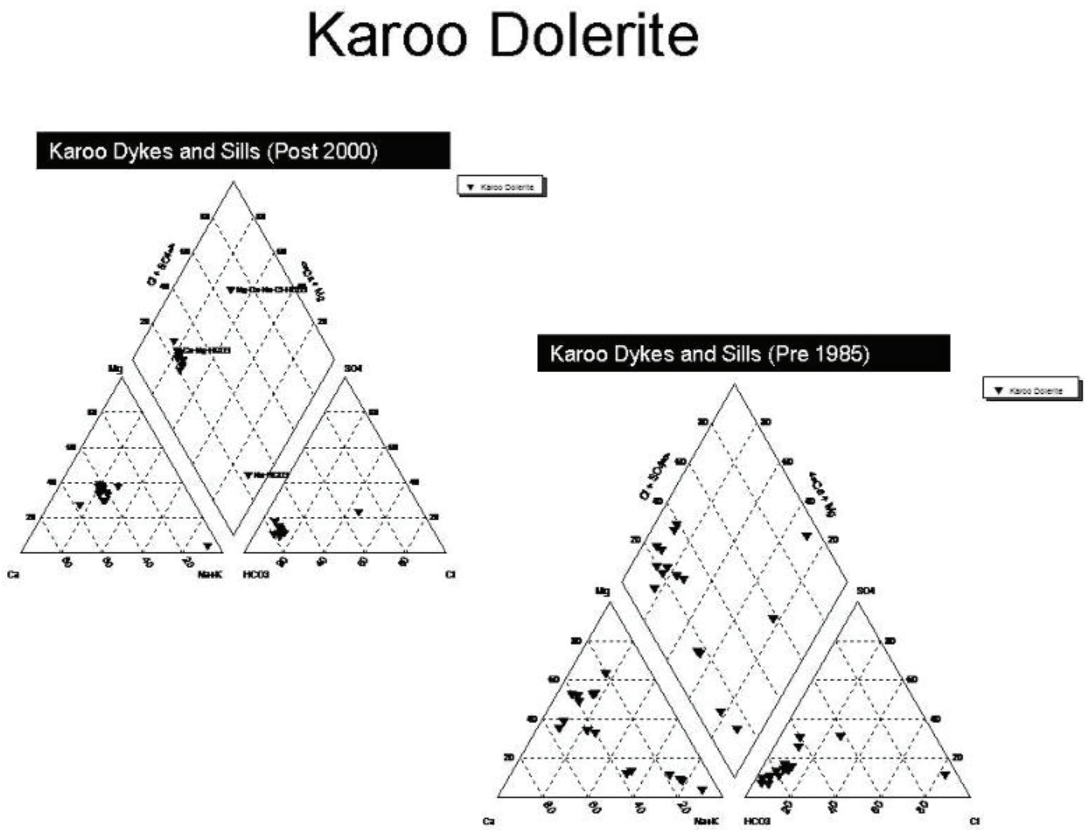

Figure 3-21. Trilinear diagram of groundwater sourced from undifferentiated Karoo strata

3.2.5.3 Clarens, Elliot and Molteno Formations

The data quality assessment process left the Clarens Formation with a single analysis (**Figure 3-22**) that reflects a $Na\text{-}HCO_3$ type groundwater. Under circumstances where Baran and Dziembowski (2003) provide no indication of the groundwater chemistry associated with this formation, it is clear that information in this regard is virtually non-existent. It is reasonable to presume, however, that groundwater produced from this formation will be no worse than that which characterises the older (underlying) Elliot and Molteno formations.

Available and acceptable hydrochemical data for the Elliot Formation pre-date 1985 (**Figure 3-23**), and reflect either a $Ca\text{-}HCO_3$ or a $Na\text{-}HCO_3$ groundwater chemistry which might be indicative of cation exchange.

The chemistry associated with groundwater from the Molteno Formation strata (**Figure 3-24**) exhibits a similar composition to that from the Elliot Formation. This observation lends support for the postulated similarity of hydrochemistry associated with the Clarens, Elliot and Molteno formations.

3.2.5.4 Beaufort Group

This unit is represented by analyses associated with the Normandien Formation and the Tarkastad Subgroup (**Figure 3-25**). Whereas the post-2000 data for the Normandien Formation exhibits a definitive $Ca\text{-}HCO_3$ composition, that of the whole data set reveals $Na\text{-}HCO_3$ type groundwater that also characterises the hydrochemistry of Tarkastad Subgroup groundwater.

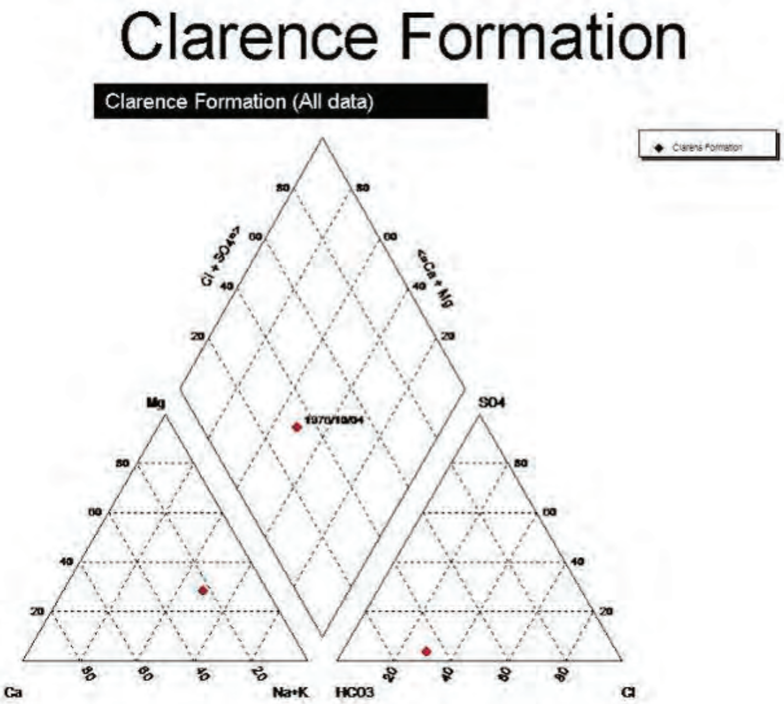

Figure 3-22. Trilinear diagram of groundwater sourced from Clarens Formation strata

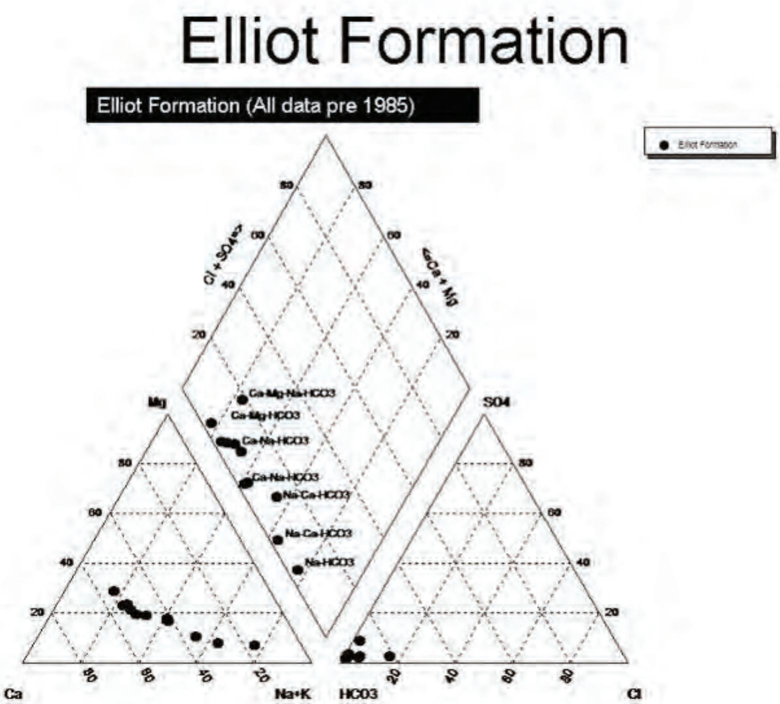

Figure 3-23. Trilinear diagram of groundwater sourced from Elliot Formation strata

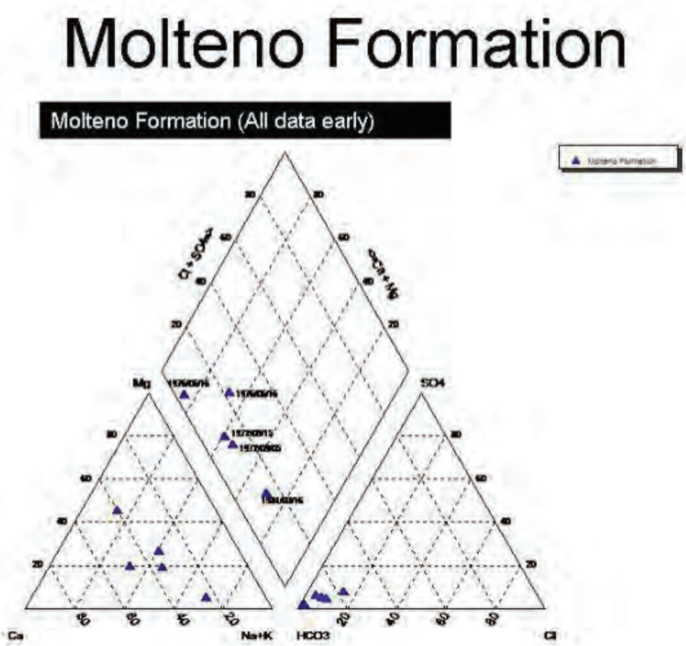

Figure 3-24. Trilinear diagram of groundwater sourced from Molteno Formation strata

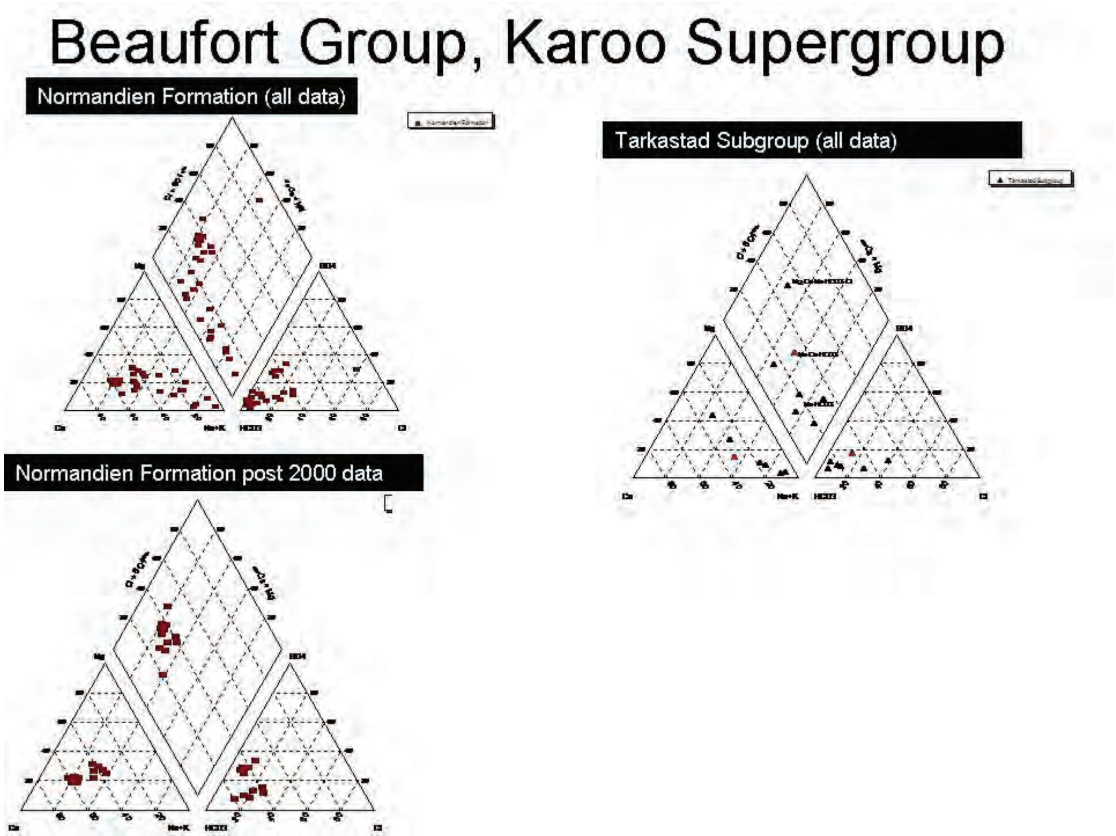

Figure 3-25. Trilinear diagram of groundwater sourced from Beaufort Group strata

3.2.5.5 Ecca Group

The chemistry of Ecca Group groundwater is represented by analyses associated with the Volksrust and Vryheid formations (**Figure 3-26**). The analyses reflect a range of compositions that include Ca-HCO_3, Na-HCO_3 and even a few Ca-SO_4 and Na-Cl type groundwaters. The latter are particularly evident in the recent data set, which indicates the manifestation of negative impacts from anthropogenic activities on the natural groundwater quality. This is especially relevant in regard to the coal-bearing Vryheid Formation that supports the coal mining industry in the study area.

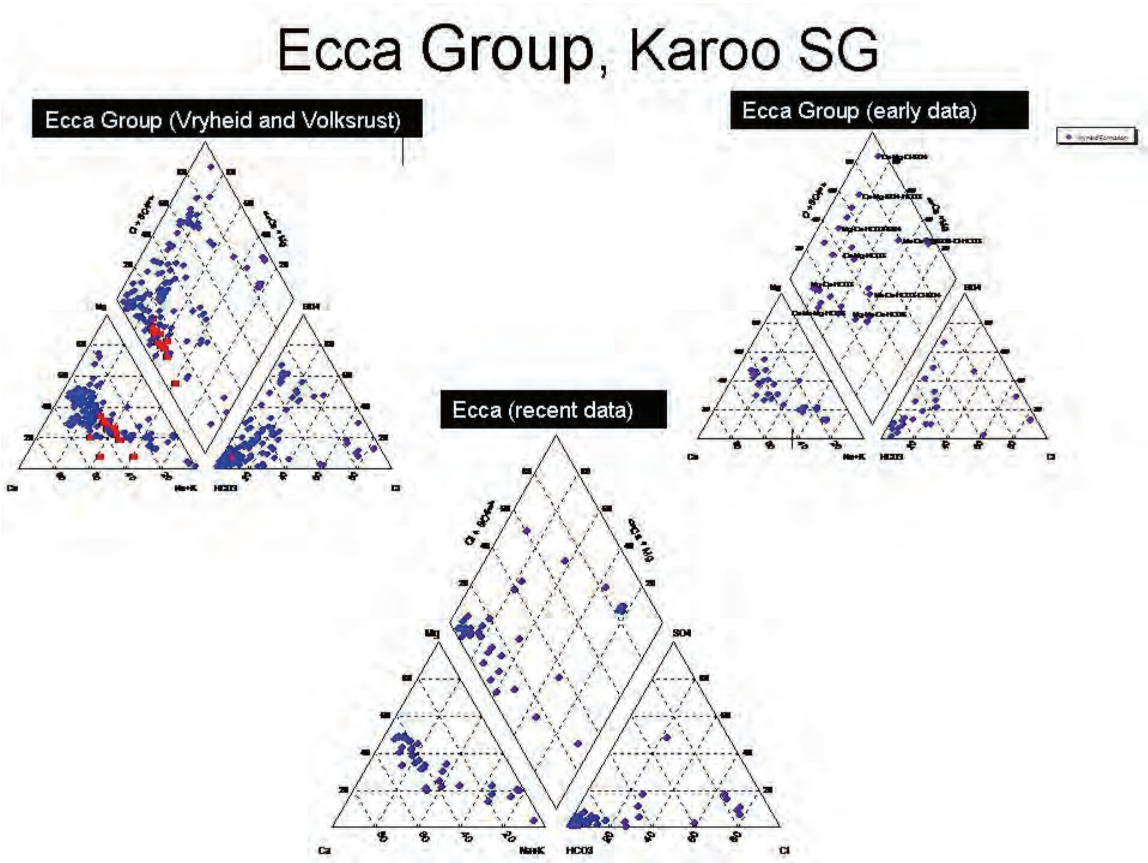

Figure 3-26. Trilinear diagram of groundwater sourced from Ecca Group strata

3.2.5.6 Dwyka Group

The hydrochemistry of this unit is represented by only four analyses (**Figure 3-27**). This is due mainly to the paucity of outcrop of this rock (tillite) in the study area. Three of the chemical analyses exhibit a CaMg-HCO_3 character, which is in keeping with that reported by Barnard (2000) based on 46 analyses. The fourth analysis reflects a Na-HCO_3 composition.

3.2.5.7 Pretoria Group

The groundwater composition associated with the various lithostratigraphic units that comprise the Pretoria Group is illustrated in **Figure 3-28** for the younger units, and in **Figure 3-29** for the older units. The Daspoort, Strubenkop and Boshoek formations reveal a relative paucity of data compared to the other units (**Figure 3-28**).

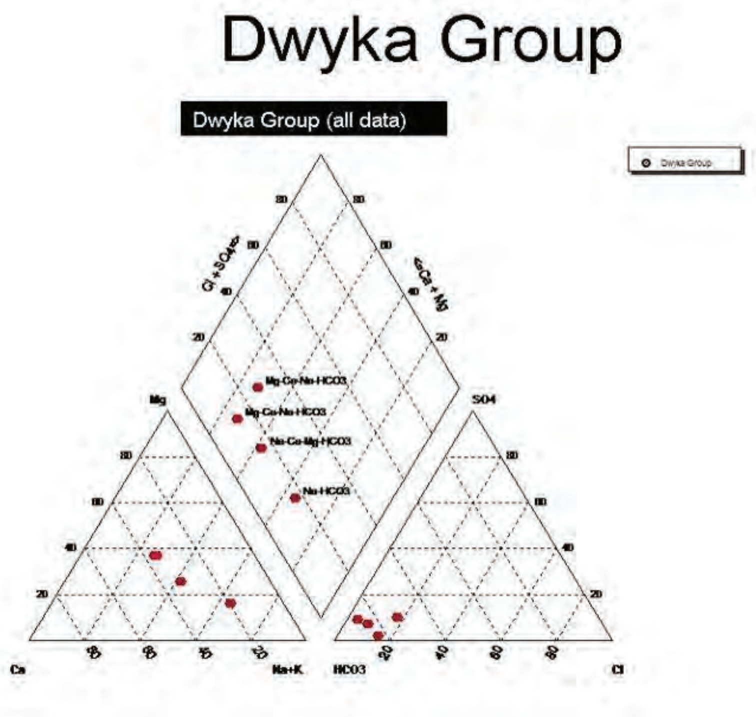

Figure 3-27. Trilinear diagram of groundwater sourced from Dwyka Group strata

The Mg-HCO_3 composition that characterises groundwater from the Pretoria Group strata is evident in all instances. The Hekpoort (**Figure 3-28**) and Timeball Hill (**Figure 3-29**) formations also indicate that SO_4 represents the dominant anion in some analyses. In regard to the latter formation, this is evident in both the pre-1985 and the post-2000 data sets (**Figure 3-29**). As might be expected, the composition of groundwater associated with the Klapperkop Quartzite Member within the Timeball Hill Formation to a large extent mimics that of its parent lithostratigraphic unit.

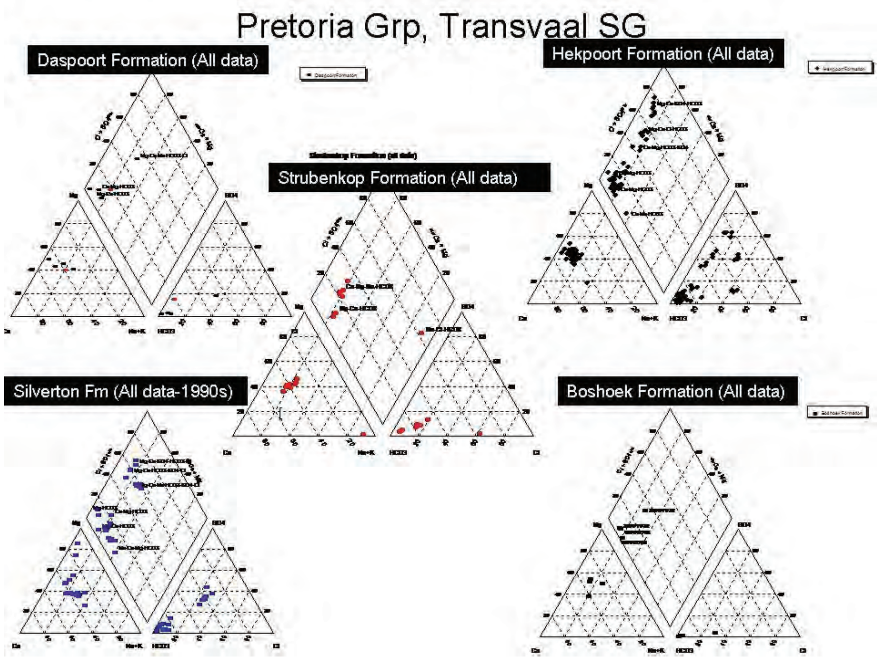

Figure 3-28. Trilinear diagram of groundwater sourced from the younger Pretoria Group strata

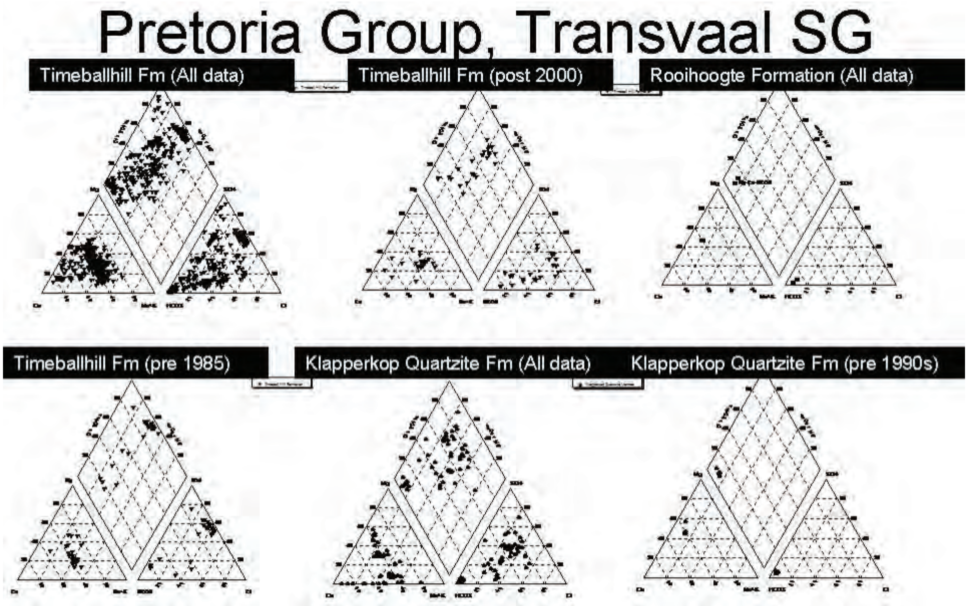

Figure 3-29. Trilinear diagram of groundwater sourced from the older Pretoria Group strata

3.2.5.8 Chuniespoort Group

The information presented in **Figure 3-30** represents the groundwater chemistry of those formations within the Malmani Subgroup which are differentiated in the DWA data base. As reflected in **Figure 3-31**, this differentiation is seldom made, and the hydrochemistry of the karst system is portrayed as a 'lumped' (undifferentiated) data set. Unsurprisingly, the differentiated data (**Figure 3-30**) reflect the CaMg-HCO_3 composition that characterises dolomitic groundwater.

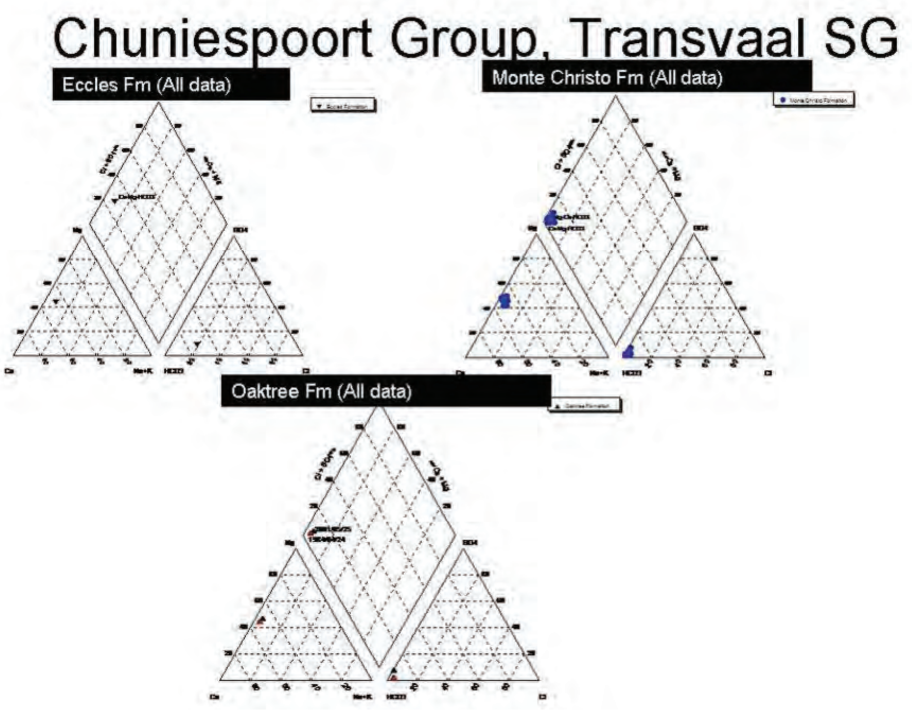

Figure 3-30. Trilinear diagram of groundwater sourced from differentiated Chuniespoort Group strata

The undifferentiated Malmani Subgroup analyses (**Figure 3-31**) 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. The reason why the post-2005 data set does not reflect this phenomenon to a greater extent, is that the stations represented in this data set are not focussed on monitoring the 'worst case' scenarios in this regard.

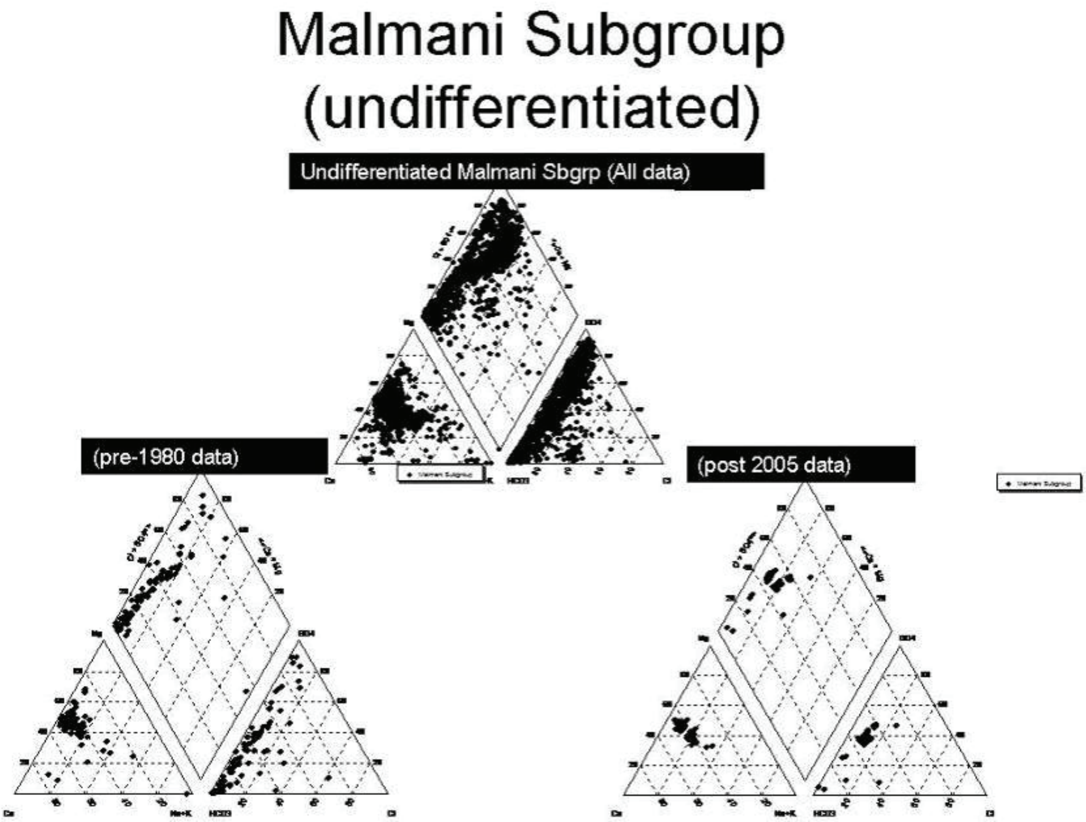

Figure 3-31. Trilinear diagram of groundwater sourced from undifferentiated Chuniespoort Group strata

3.2.5.9 Black Reef Formation

The Black Reef Formation (**Figure 3-32**) has predominantly fresh recharge (Ca-HCO_3 type), with some anion exchange between HCO_3 and Cl, where a more NaMgCa-Cl type water is present.

3.2.5.10 Platberg Group

The Platberg Group (**Figure 3-33**) of the Ventersdorp Supergroup, of which only the Rietgat Formation is penetrated in the Upper Vaal WMA, shows only fresh recharge type compositions (Ca-HCO_3), and therefore little or no impact from anthropogenic activity and only limited ion exchange.

3.2.5.11 Klipriviersberg Group

The Klipriviersberg Group (**Figure 3-34**) of the Ventersdorp Supergroup hosts a predominantly Ca-HCO_3 type water. Samples between 1985 and 2000 show progressively more SO_4-, Mg- and Ca-rich compositions, while only two and one sample respectively show this signature for pre-1985 and post 2000 data. The Alberton Formation shows no impact, and hence a Ca-HCO_3 type water characteristic of fresh recharge. The possibility of mine water mixing within this lithology exists.

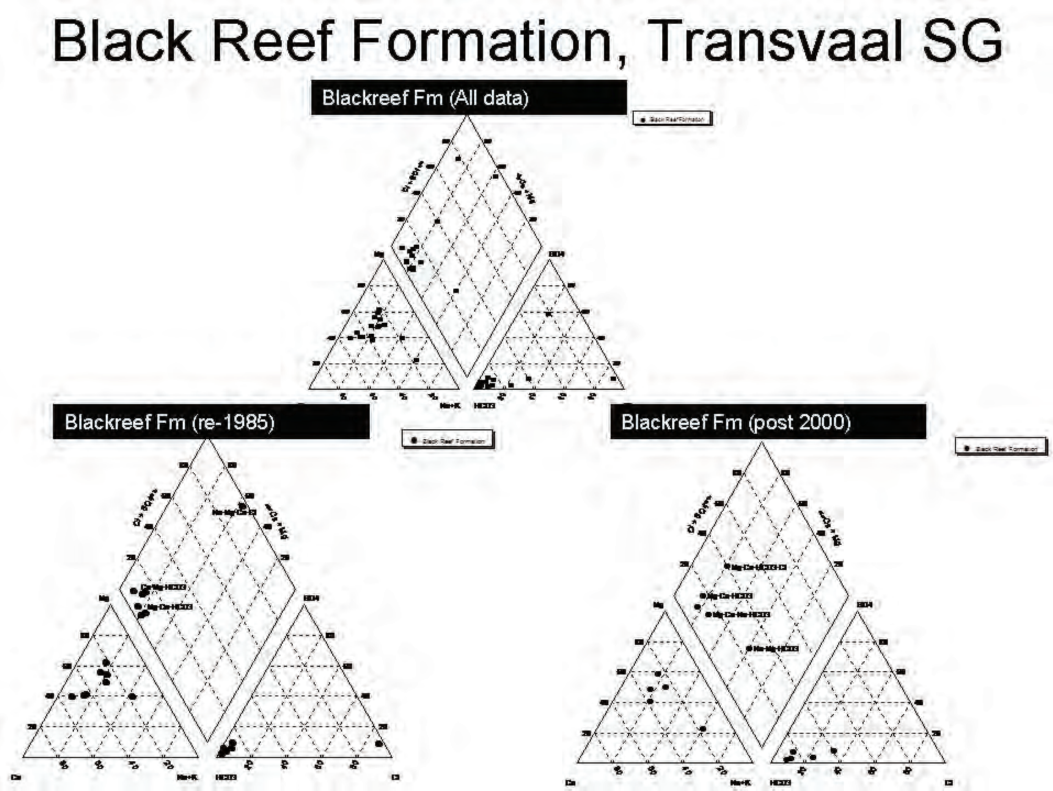

Figure 3-32. Trilinear diagram of groundwater sourced from Black Reef Formation strata

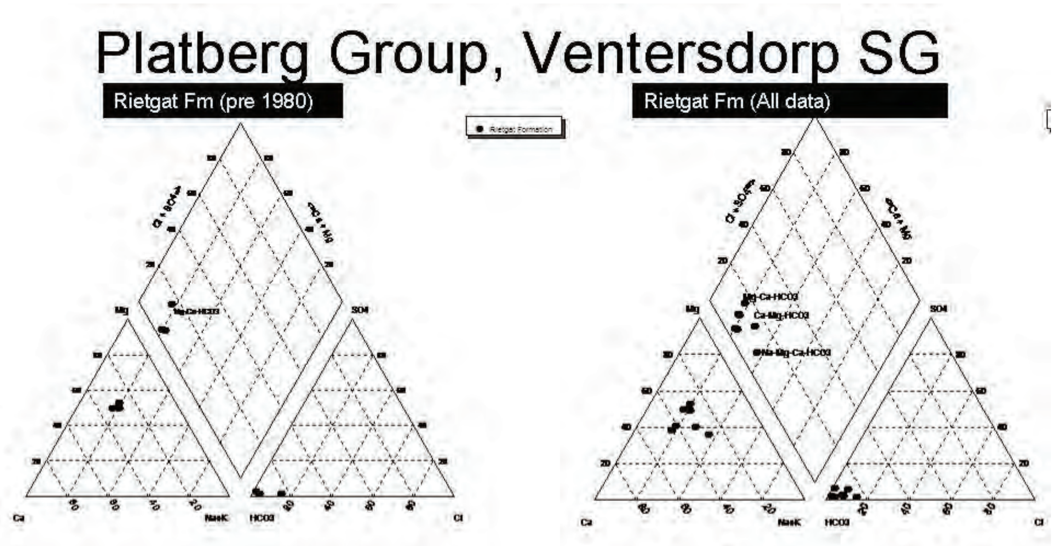

Figure 3-33. Trilinear diagram of groundwater sourced from Platberg Group strata

3.2.5.12 Central Rand Group

The Central Rand Group has few samples (**Figure 3-35**). There is a distinct grouping of samples with a Ca-HCO_3 composition, and another more MgCa-SO_4HCO_3 type water. The latter might be associated with either anion and cation exchange or the impact of acid mine water.

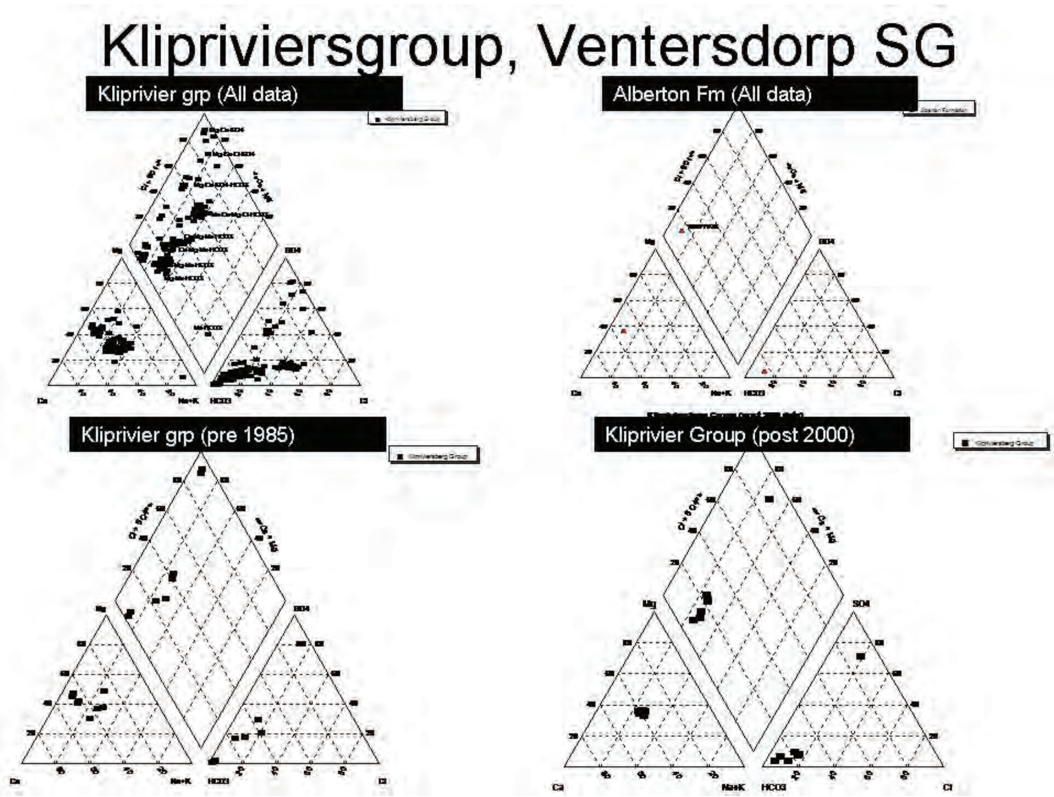

Figure 3-34. Trilinear diagram of groundwater sourced from Klipriviersberg Group strata

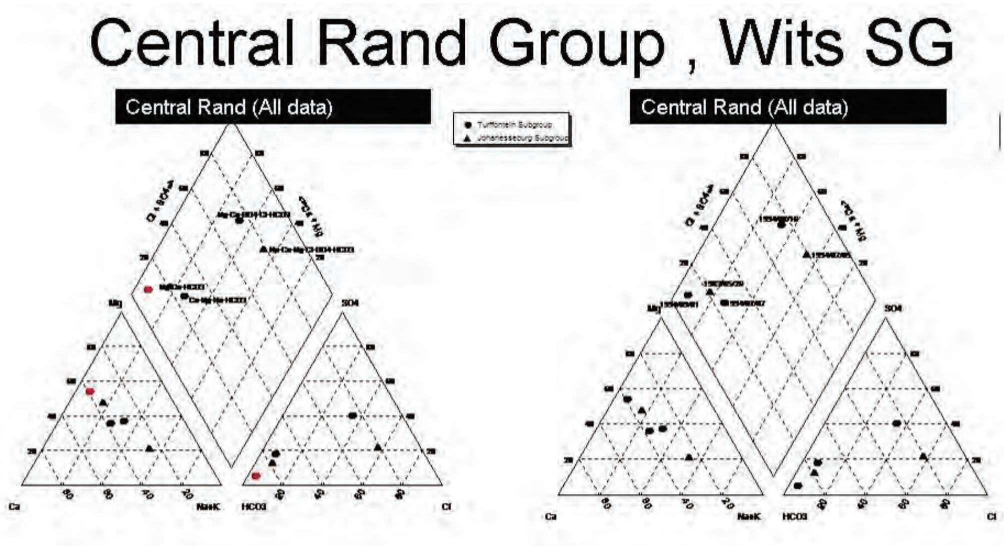

Figure 3-35. Trilinear diagram of groundwater sourced from Central Rand Group strata

3.2.5.13 West Rand Group

The West Rand Group (**Figure 3-36**) similarly hosts a predominantly Ca-HCO_3 type water with progressive enrichment of Ca, Mg and SO_4. Some anion exchange is also evident. 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. The Government Subgroup of the West Rand Group has some Na-HCO_3 type water which could indicate cation exchange between Ca and Na. The Jeppestown Subgroup tends toward a more MgCa-SO_4 composition that may indicate some influence of acid mine drainage.

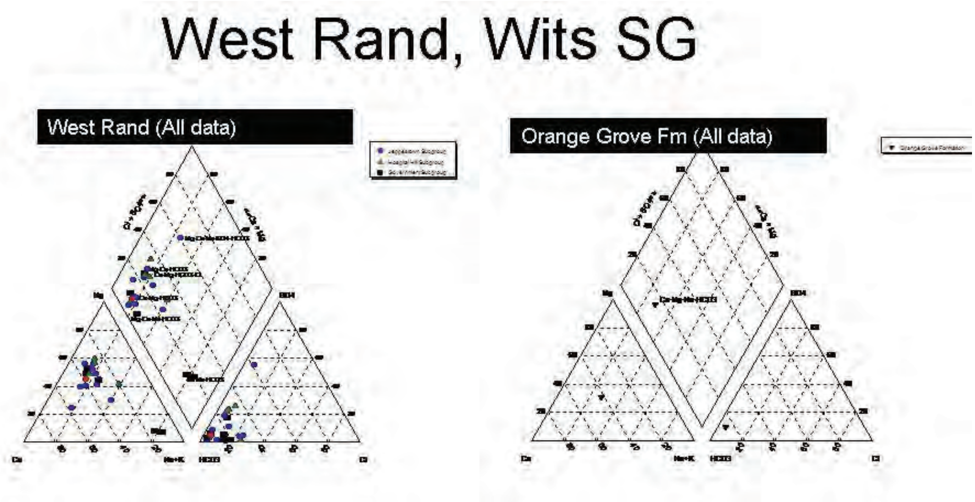

Figure 3-36. Trilinear diagram of groundwater sourced from West Rand Group strata

3.2.5.14 Dominium Group

The Dominion Group is represented by only one sample (**Figure 3-37**) which was collected during the 1970s and reflects a CaMg-HCO_3 composition, which is characteristic of recent recharge.

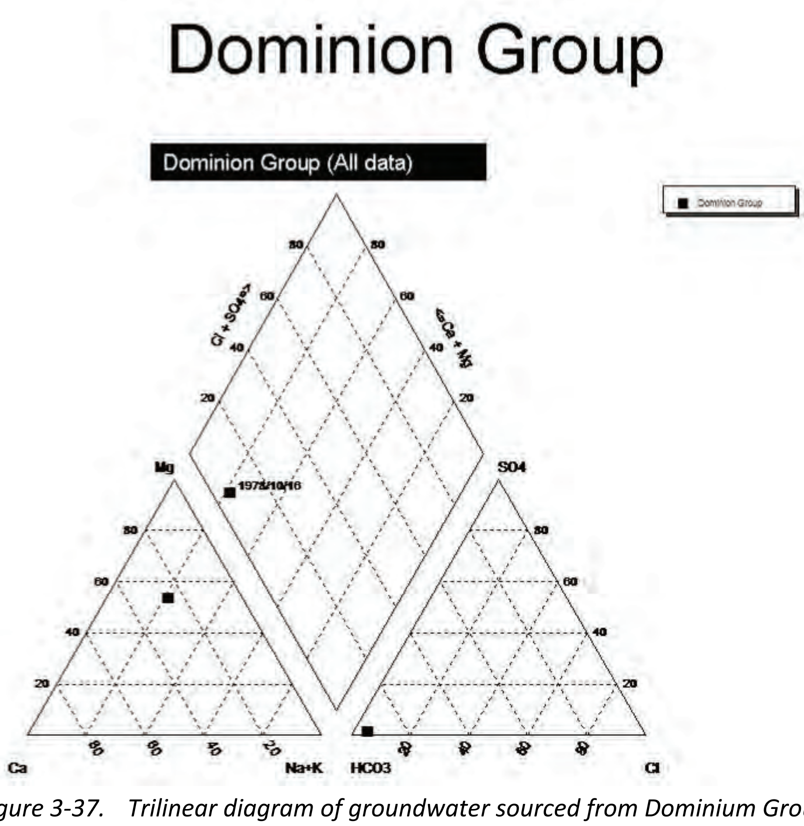

Figure 3-37. Trilinear diagram of groundwater sourced from Dominium Group strata

3.2.6 Bacteriological Quality

Although the DWA microbiological data base contains 1368 stations for the Upper Vaal WMA, only nine of these support records of any length (**Table 3-4**). The distribution of the active stations is shown in **Figure 3-39**. One station (1000013395) has a data record ranging from 2005-2008, while the other eight have data collected during 1995 and 1996. All the other stations are not actively monitored for bacteriological quality. Clearly this represents a severe shortcoming in the groundwater quality data base.

Table 3-4. Summary of bacteriological water quality in the Upper Vaal WMA

Station No.	No. of Data	Quaternary Catchment	GRU	Land Cover	*E. coli* (maximum)	Faecal coliforms (maximum)	Total coliforms	
							(max.)	(min.)
88540	4	C23J	9	Thicket, Bushland, Bush Clumps, High Fynbos	0	0	490	0
88710	4	C23J	9	Unimproved (natural) Grassland	1	1	170	17
88722	4	C23J	9	Unimproved (natural) Grassland	0	0	5600	0
88788	4	C23J	9	Unimproved (natural) Grassland	0	1	250	0
88789	4	C23J	9	Unimproved (natural) Grassland	4	4	10	0
88790	3	C23J	9	Unimproved (natural) Grassland	0	0	3600	7
88995	4	C23J	9	Unimproved (natural) Grassland	1	1	209	10
88996	2	C23J	9	Unimproved (natural) Grassland	0	0	140	0
1000013395	10	C12E	4a	Unimproved (natural) Grassland	21	33	140	62

The available long-term record for station 1000013395 is shown in **Figure 3-38**. This indicates that the *E. coli* and faecal coliform counts show a similar trend over time at this location. It is tentative in the extreme to interpret a decreasing trend in these variables on the basis of the last two values on record. The existence of only two records for the total coliform count renders an appraisal of this variable inconsequential. All points with data are listed below and categorised according to their GRU and landcover types.

The station 1000013395 is situated in GRU 4a, approximately 10 km south of Secunda. Land use activities in close proximity that may explain the poor bacteriological quality include a horse breeding farm and rural settlements in the town of Charles Cilliers. The other eight stations (**Table 3-4**) are located in close proximity to each other, and all intersect Pretoria Group strata south of the Elands Rand Gold Mine at distances ranging from 1 to 5 km from a low income formal settlement. The presence of a slimes dam 1 km to the north is not expected to contribute to the observed bacteriological quality.

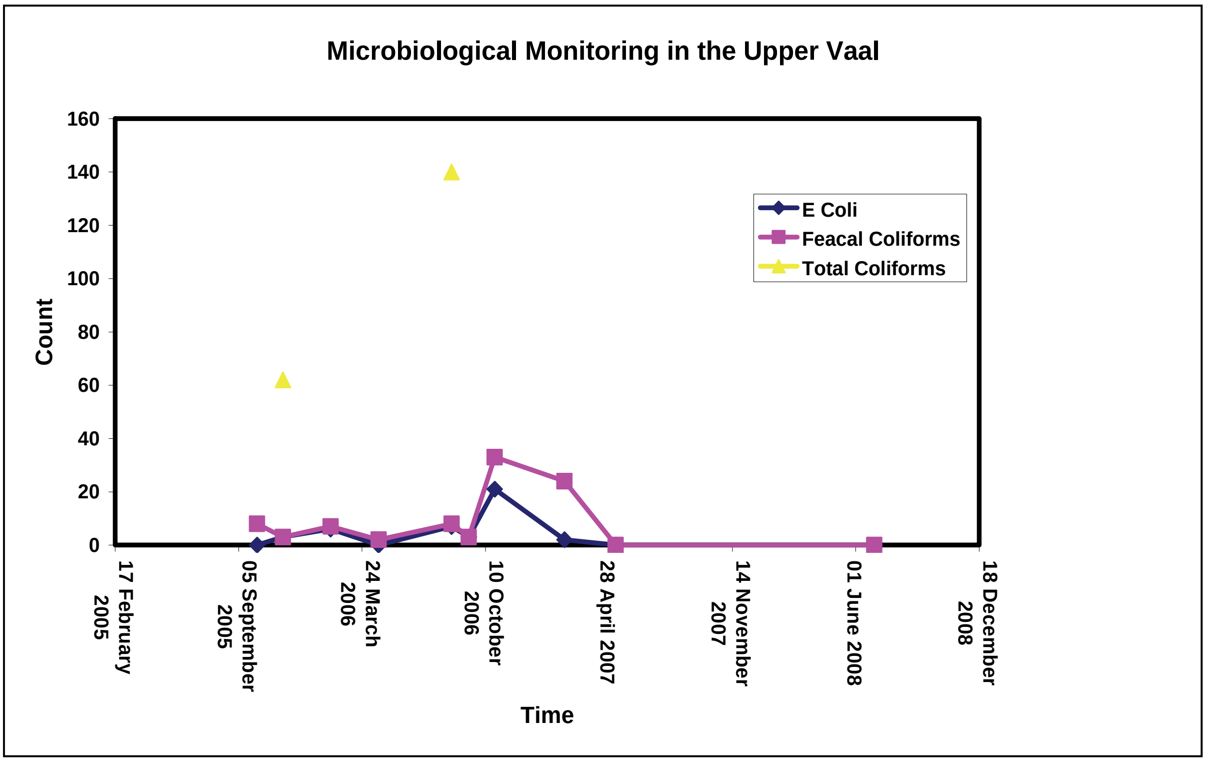

Figure 3-38. Microbiological determinants for the Upper Vaal WMA

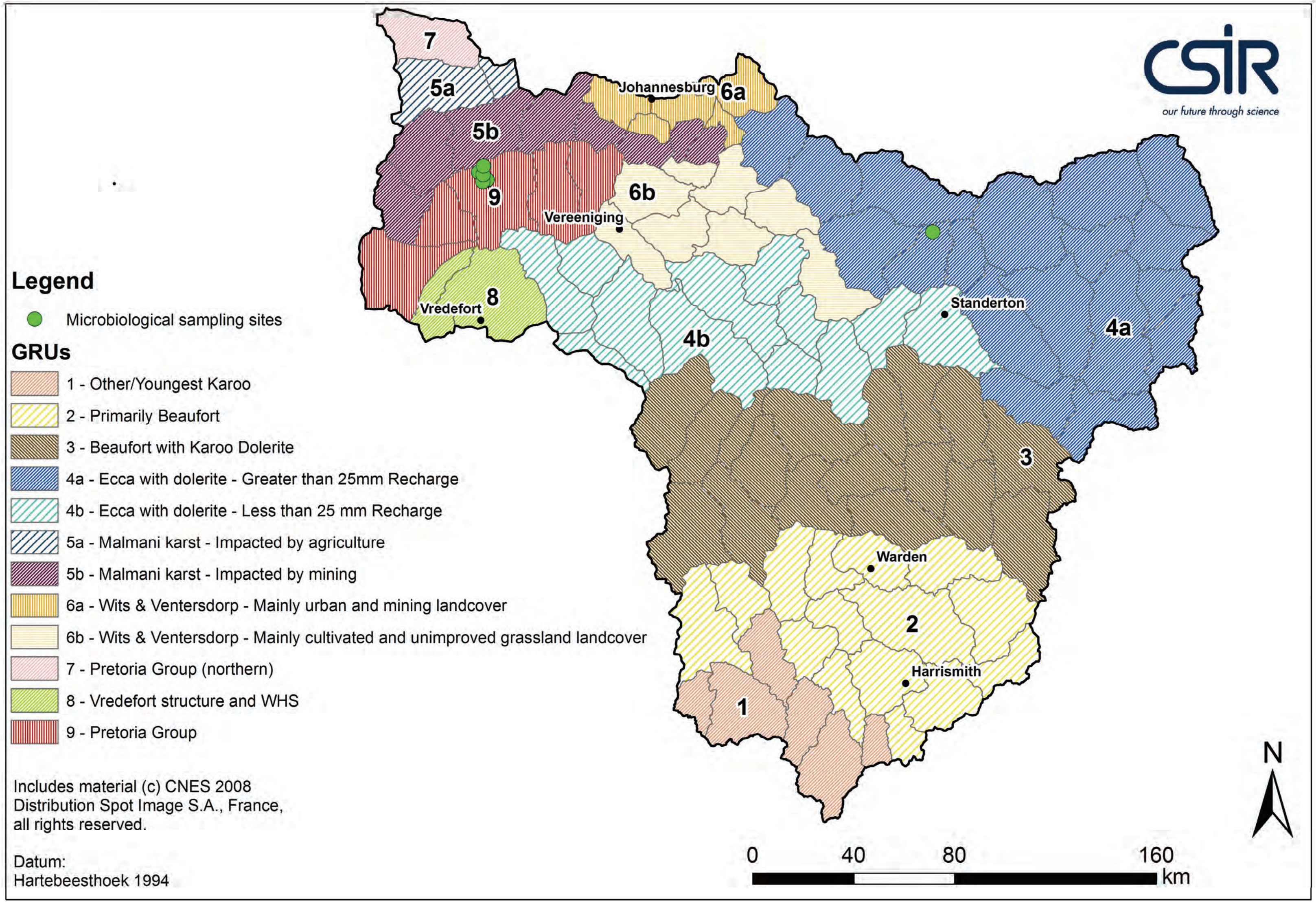

Figure 3-39. Distribution of microbiological sampling stations in the Upper Vaal WMA

3.2.7 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 1, 2, 3 and 4, and that of the older lithologies mainly with GRUs 5, 6, 7, 8 and 9.

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

Basic Lithology	Groundwater Resource Unit											
	1	2	3	4		5		6		7	8	9
				a	b	a	b	a	b			
Aeolian sand, calcrete, colluvium, floodplain deposits, alluvium					■		■		■		■	■
Dolerite, diabase, syenite	■	■		■	■		■		■			
Sandstone	■											
Mudstone & subordinate sandstone	■											
Sandstone, mudstone & shale	■	■										
Mudstone & sandstone		■										
Mudstone & subordinate sandstone		■	■	■								
Shale & subordinate sandstone			■	■			■					
Sandstone, shale & coal beds				■	■		■	■				
Shale							■					
Diamictite & shale								■				
Alkali granite											■	
Olivine gabbro, wehrite, alkali granite											■	
Diorite, albitite											■	
Harzburgite, norite, quartz norite/gabbro, granophyre											■	
Basic & ultrabasic rocks											■	
Diabase							■		■		■	■
Shale												■
Quartzite & shale												■
Shale & Quartzite										■		■
Andesite							■			■		■
Quartzite							■					
Ferruginous shale & quartzite							■		■	■		■
Quartzite, chert, conglomerate							■					
Chert-rich dolomite						■	■	■	■			
Chert-poor dolomite						■	■	■	■			
Quartzite, conglomerate						■	■		■			
Andesite							■					
Andesite, tuff							■	■	■		■	
Arenaceous, rudaceous rocks					■				■		■	
Quartzite, reddish ferruginous magnetic shale					■		■		■		■	
Quartzite, conglomerate, shale, interbedded lava							■					
Granite, gneiss									■		■	

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**. Encouragingly, this reveals the sufficiency of data for half (~52%) of the lithostratigraphic units. Of concern, however, is the paucity of data for 32% of the units. Although the tabulated information also indicates the scarcity (insufficiency) of data in 3 instances (16%), these do not present a concern due either to their localised occurrence or availability of data in other areas of occurrence outside the Upper Vaal WMA.

Table 3-6. Summary of groundwater quality data availability per lithostratigraphic 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			SPARSE
Mudstone & subordinate sandstone	Elliot Formation			SUFFICIENT
Sandstone, mudstone & shale	Molteno Formation			SPARSE
Mudstone & sandstone	Driekoppen & Verkykerskop Formation	Beaufort Group		SUFFICIENT
Mudstone & subordinate sandstone	Normandien & Estcourt Formation			
Shale & subordinate sandstone	Volksrust Formation	Ecca Group		SUFFICIENT
Sandstone, shale & coal beds	Vryheid Formation			
Shale	Pietermaritzburg Formation			
Diamictite & shale		Dwyka Group		SPARSE
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	SUFFICIENT
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	SPARSE
Conglomerate, sandstone	Bothaville Formation			
Andesite	Rietgat Formation			
Quartz porphyry	Makwassie Formation			
Conglomerate, calcareous shale	Kameeldoorns Formation			
Andesite, tuff		Klipriviersberg Group		SUFFICIENT
Arenaceous, rudaceous rocks		Central Rand Group	Witwatersrand Supergroup	SPARSE
Quartzite, ferruginous shale		West Rand Group		SUFFICIENT
Quartzite, conglomerate, shale, interbedded lava		Dominium Group		SPARSE
Granite, gneiss	Halfway House Granite Suite	Intrusive Complex		VERY SCARCE

4 AQUIFER DEPENDENT ECOSYSTEMS

The principal aquifer dependent ecosystems in the Upper Vaal WMA are the perennial rivers with groundwater-fed baseflow, springs, deep-rooted vegetation dependent on shallow water tables (mainly riparian vegetation) and stygobytes (cave-dwelling fauna) in the karstified dolomitic aquifers. The sections that follow summarise the understanding of groundwater dependency in the different type-settings and for vegetation types.

4.1 Aquifer Dependence and Vegetation Types

The primary information sources for assessing the occurrence, extent and importance of dependence on groundwater in aquifers 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 bioregion definition (**Figure 4-1)**, vegetation types (**Figure 4-2**) and wetlands. 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 not yet available.

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 subdivided into bioregions and the bioregions into vegetation types. There are 28 vegetation types in the Upper Vaal WMA which are grouped into 4 biomes, the dominant biome being Grassland which occupies about 93% of the area (**Table 4-1**). The wetlands data were taken from the current wetlands database maintained by the South African National Biodiversity Institute (http://bgis.sanbi.org/nwi/project.asp). Differences in the estimates of wetland areas between the vegetation map and the wetlands data set are due to refinements in the wetland dataset subsequent to the version that was used for the national vegetation map.

The national vegetation map (**Figure 4-2**) shows that the Azonal Biome in this WMA does not include the *Highveld Alluvial Vegetation* which occurs along rivers and is an important ecosystem for surface-ground water interactions and potential groundwater dependence. However, most of the rivers in the WMA are characterised by alluvial deposits which vary in extent depending roughly on the size of the river, the river gradient and the occurrence of erosion-resistant features such as dykes which trap sediment upstream. This is recognised as a separate vegetation type called *Alluvial Vegetation.* Information on its ecology and guidelines for groundwater management are provided, but its extent not mapped due to its easy recognition. Local-scale groundwater assessments will be needed to establish the resource quality objectives to apply in each case.

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 characterised by grasses and reeds. Savanna is characterised by an understorey of grasses and the presence of woody plants. Sometimes the woody plants are widespread but in other cases they are confined to certain areas such as rocky outcrops.

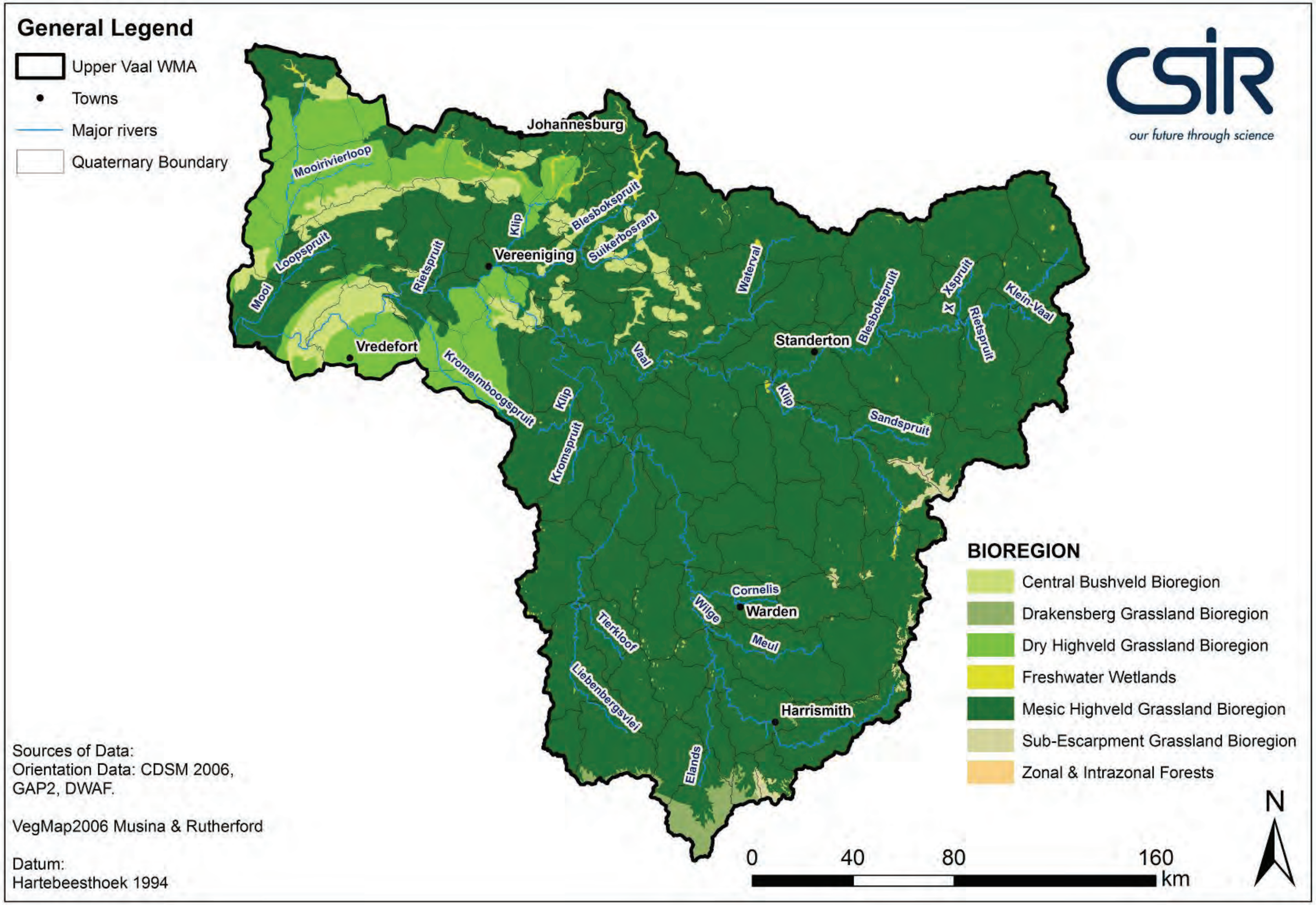

Figure 4-1. Bioregion map for the Upper Vaal WMA (Mucina and Rutherford, 2006)

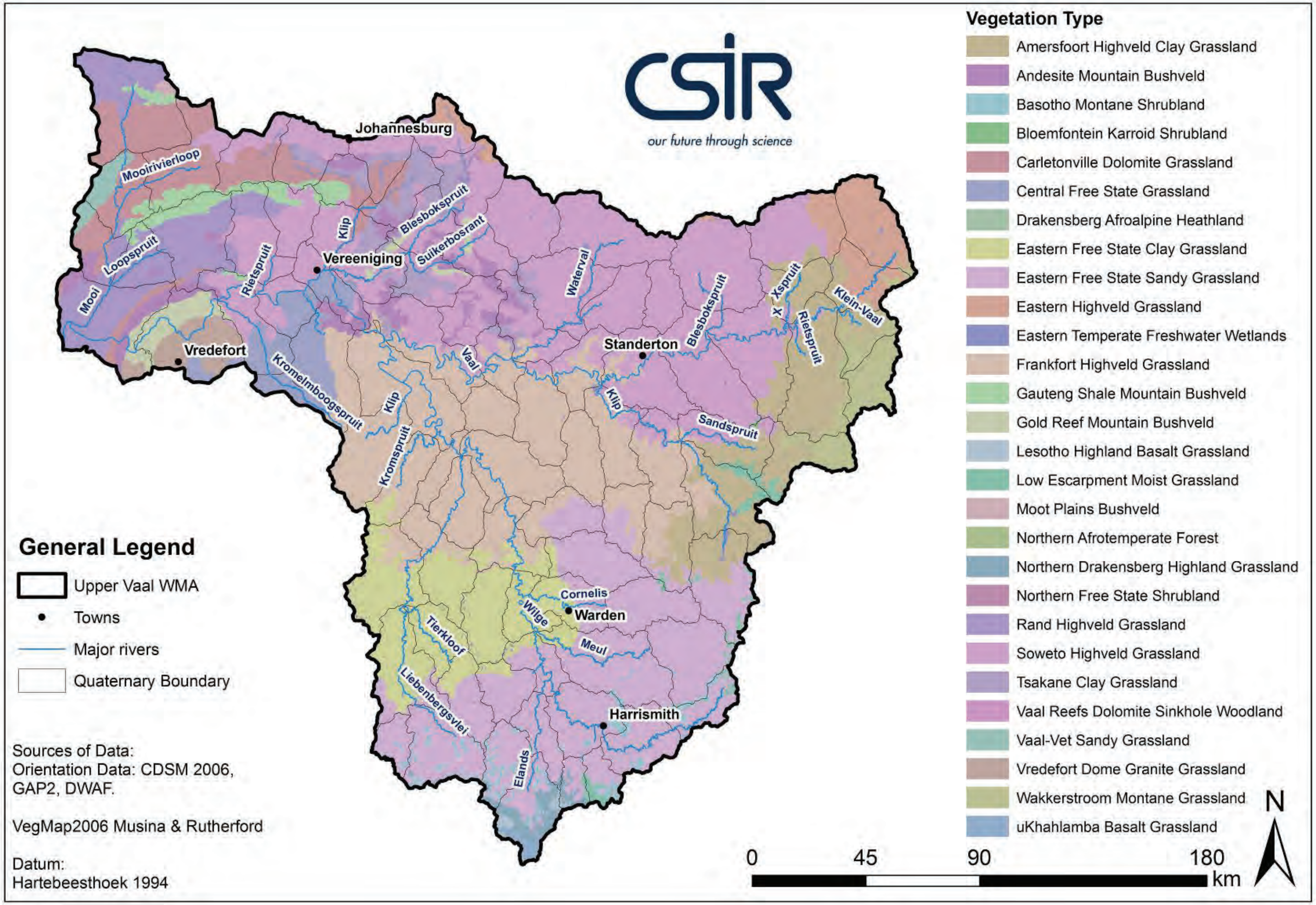

Figure 4-2. Vegetation map for the Upper Vaal WMA (Mucina and Rutherford, 2006)

Table 4-1. The biomes, bioregions and vegetation types of the Upper 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 the WMA	Wetlands (% of the veg. type)
Azonal	Freshwater Wetlands	Eastern Temperate Freshwater Wetlands	27169	0.49	73.69
Forest	Zonal & Intrazonal Forests	Northern Afrotemperate Forest	618	0.01	0.00
Grassland	Drakensberg Grassland	Drakensberg Afroalpine Heathland	1477	0.03	0.00
Grassland	Drakensberg Grassland	Lesotho Highland Basalt Grassland	15990	0.29	0.14
Grassland	Drakensberg Grassland	Northern Drakensberg Highland Grassland	30168	0.54	0.39
Grassland	Drakensberg Grassland	uKhahlamba Basalt Grassland	10161	0.18	0.01
Grassland	Dry Highveld Grassland	Bloemfontein Karroid Shrubland	1404	0.03	0.00
Grassland	Dry Highveld Grassland	Carletonville Dolomite Grassland	280416	5.05	0.78
Grassland	Dry Highveld Grassland	Central Free State Grassland	142212	2.56	1.14
Grassland	Dry Highveld Grassland	Vaal Reefs Dolomite Sinkhole Woodland	1	0.00	0.00
Grassland	Dry Highveld Grassland	Vaal-Vet Sandy Grassland	24785	0.45	0.53
Grassland	Dry Highveld Grassland	Vredefort Dome Granite Grassland	63013	1.14	1.11
Grassland	Mesic Highveld Grassland	Amersfoort Highveld Clay Grassland	365084	6.58	0.52
Grassland	Mesic Highveld Grassland	Basotho Montane Shrubland	46603	0.84	0.09
Grassland	Mesic Highveld Grassland	Eastern Free State Clay Grassland	397800	7.17	0.79
Grassland	Mesic Highveld Grassland	Eastern Free State Sandy Grassland	864538	15.57	0.82
Grassland	Mesic Highveld Grassland	Eastern Highveld Grassland	153618	2.77	2.56
Grassland	Mesic Highveld Grassland	Frankfort Highveld Grassland	952820	17.16	0.43
Grassland	Mesic Highveld Grassland	Northern Free State Shrubland	2144	0.04	0.02
Grassland	Mesic Highveld Grassland	Rand Highveld Grassland	252465	4.55	0.69
Grassland	Mesic Highveld Grassland	Soweto Highveld Grassland	1350235	24.32	0.86
Grassland	Mesic Highveld Grassland	Tsakane Clay Grassland	128381	2.31	1.44
Grassland	Mesic Highveld Grassland	Wakkerstroom Montane Grassland	111803	2.01	0.74
Grassland	Sub-Escarpment Grassland	Low Escarpment Moist Grassland	38649	0.70	0.49
Savanna	Central Bushveld	Andesite Mountain Bushveld	142731	2.57	0.63
Savanna	Central Bushveld	Gauteng Shale Mountain Bushveld	79966	1.44	0.31
Savanna	Central Bushveld	Gold Reef Mountain Bushveld	62931	1.13	1.07
Savanna	Central Bushveld	Moot Plains Bushveld	4482	0.08	1.54
Total area			5551662		

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 characterised by a dense overstorey of tall trees and are generally confined to kloofs and other fire refugia. The Azonal biome includes all the vegetation types which are strongly controlled by factors that 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 deposits, giving the alluvial vegetation features that differ markedly from 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 and groundwater-dependent ecosystems (GDEs).

4.2 Descriptions of the Biomes, Bioregions and Vegetation Types

4.2.1 Azonal Biome

The national vegetation map shows that this biome is represented in the WMA by one bioregion, Freshwater Wetlands, and one vegetation type. However, most of the rivers in the WMA are characterised by alluvial deposits which vary in extent depending on roughly on the size of the river, the river gradient and the occurrence of erosion-resistant features such as dykes which trap sediment upstream.

Eastern Temperate Freshwater Wetlands: These occupy only 0.49% of the area[1] but they are distributed across all the vegetation types in the WMA. The wetlands comprise a range of wetland types including perennial and seasonal lakes and vleis with aquatic and hygrophilous vegetation, temporarily inundated grasslands and ephemeral herblands (Mucina et al., 2006a). 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 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

[1] The national wetlands data set shows many more wetlands than are included in the national vegetation map. The percentage of each vegetation type which is in these additional wetlands is given in Table 4-1.

surface-groundwater interactions, degree of groundwater dependence or sensitivity to ground or surface water abstraction. Groundwater dependence should be considered as high and as a general characteristic of such ecosystems until detailed assessments have shown otherwise. 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 project.

Alluvial Vegetation: This description is based on the *Highveld Alluvial Vegetation* of the Azonal biome (Mucina et al., 2006a) which occurs further downstream on the rivers in the Middle Vaal WMA. 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 larger 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 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. Groundwater dependence should be considered a general characteristic of the ecosystems and dependence is likely to be high. 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.

4.2.2 Forest Biome

Northern Afrotemperate Forest (0.01%): These are the evergreen forests which are found in the upper reaches of the catchments along the Drakensberg escarpment and in Lesotho (Mucina et al., 2006a). They are confined to sheltered kloofs and rocky outcrops where there is protection from the frequent fires in the adjacent grasslands. The canopy layer is formed by a number of evergreen tree species with an understorey of smaller trees, shrubs, ferns and herbaceous species. The sites are often associated with stream source areas (seeps and springs) but the forest vegetation itself is likely to have a low groundwater dependence. The forests generally also occur in steep terrain where it is unlikely that the groundwater could be abstracted.

4.2.3 Grassland Biome

The Grassland biome comprises 93.2% of the WMA (**Table 4-1**) and is divided into four bioregions: the Drakensberg, Sub-escarpment, Mesic Highveld and Dry Highveld grasslands (Mucina et al., 2006b). The grasslands occur over a range of altitude and rainfall as well as a range of geologies and rock types, hydrogeological units and soil types.

Drakensberg grassland bioregion (1.0%): These grasslands are found on the basalts that for the crest and upper-slopes of the Drakensberg except for the *Northern Drakensberg Highland Grassland* which is found on the Clarens sandstone and mudstones of the Elliot formation. In some areas the basalts are deeply weathered and the weathered material stores large volumes of groundwater which is discharged during the dry season (Everson et al,. 1998; Everson, 2001). These grasslands also receive regular and often heavy snowfalls which are an important source of groundwater recharge. The vegetation is regarded as important for conservation as there are numerous endemics and specialised species (Mucina et al., 2006b).

Afro-alpine Heathland (0.03%); Is largely confined to Lesotho where it occurs on the highest mountain plateaus and ridges, mostly above 2900 masl. The terrain comprises rolling plateaux with steep slopes in places. The vegetation is short and dominated by short grasses and low shrubs. The plateaux contain numerous high altitude marshes or mires which include the sources of the Tugela, Orange and tributaries of the Vaal rivers. The ecology of these mires is controlled by the relationship between surface water accumulation and drainage and its effects on the soil moisture balance and level of the saturation or inundation.

Lesotho Highland (0.3%) and *uKahlamba Basalt Grasslands* (0.2%): Are found on the Drakensberg basalts in Lesotho, the Free State and Kwazulu-Natal from about 1 900 to 2900 masl. The terrain is a mixture of plateaux on the top of the basalts and moderate to steep slopes. The vegetation is quite variable, ranging from pure grasslands to shrublands. There are large marshes (sponges) on the plateaux and gentle upper slopes which are characterised by accumulations of peat and the abundance of *Kniphophia caulescens* (Red-hot poker). The tall, tufted grass, *Merxmuellera macowanii,* is a distinctive species which occurs along streamlines and water courses. The large areas of peat soils can accumulate and retain surface runoff which is released slowly to sustain river and stream flows during the dry season. Groundwater-surface water interactions are, therefore, important ecological factors which are controlled primarily by the terrain form and its effects on soil formation and peat accumulation. The marshes and wetlands can be very extensive but many are small and highly localised.

The *Northern Drakensberg Highland Grassland* (0.5%), in the Free State and KwaZulu-Natal, and *Low Escarpment Moist Grassland* (0.7%), which extends into Mpumalanga, both occur along the crest of the escarpment with the former grading into the latter as one moves northwards from the Lesotho. The former occurs mainly on the Clarens sandstone and Elliot formation (mudstone) and the latter on the Ecca and Beaufort Groups. They both are 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. Mist and fog occur frequently in these areas. Studies further north in the Soutpansberg have shown that fog and mist deposition can affect the water balance (Olivier and Van Heerden, 1999; Olivier and De Rautenbach, 2002) but its importance in the study area still needs to be quantified.

In all these vegetation types, groundwater-surface water interactions are important ecological factors. Groundwater dependent ecosystems are localised, occurring where alluvium accumulates along rivers and in terrain forms where sediment and water accumulate or there are geological contacts or structures which control groundwater movement.

Mesic Highveld Grassland bioregion (83.3%): These vegetation types comprise most of the WMA and 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 (0.8%): Occurs on the upper layers of the mud- 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* (0.04%) 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.

Wakkerstroom Montane Grasslands (2.0%): In Mpumalanga and KwaZulu-Natal, are the northern counterpart of *Low Escarpment Moist Grasslands* and occur along the eastern boundary of the Vaal River catchment. They occur on the mudstones and shales of the Madzaringwe and Volksrust Formations with numerous dolerite intrusions. They comprise short grassland with *Leucosidea* dominated thickets and forest patches in rocky areas. The topography is gently undulating except where there are rocky outcrops. The *Eastern Highveld Grasslands* (2.8%) in Gauteng and Mpumalanga are similar, occurring mainly on sandy soils derived from the Madzaringwe Formation. There are few dolerite intrusions so the rocky areas are fewer and less extensive and there is a lower prevalence of woody species. The *Frankfort Highveld Grasslands* (17.2%) also are similar but occur mainly on the mudstones, shales and occasional sandstones of the Adelaide Subgroup (Beaufort Group) and dolerite intrusions in the Free State. The *Amersfoort Highveld Clay Grassland* (6.6%) occurs on vertic clay soils in the eastern uplands of the Vaal River catchment among the undulating plains formed from the Madzaringwe Formation (in the north) and the Volksrust Formation and Adelaide Subgroup In the south) and on doleritic intrusions. The similar *Soweto Highveld Grassland* (24.3%) in Mpumalanga and Gauteng comprises dense, tufted grasslands found on the gently undulating topography underlain by the shales, sandstones and mudstones of the Madzaringwe Formation with frequent dolerite intrusions. Small wetlands, occasional pans and limited rocky outcrops (mainly dolerites) occur in the grasslands and narrow alluvial strips are found along most watercourses. *Tsakane Clay Grassland* (2.3%) occurs on flat to slightly undulating plains and low hills underlain by the basaltic lava of the Klipriviersberg Group as well as on the sedimentary Madzaringwe Formation in Gauteng and Mpumalanga. The *Rand Highveld Grassland* (4.6%) is found from Pretoria to Witbank in areas between rocky ridges with a sparse, species-rich shrubland or woodland (*Protea, Olea*) on the rocky ridges. The underlying rocks are the quartzites of the Witwatersrand Supergroup and Pretoria Group and the Selons River Formation (Transvaal Supergroup). Soils vary from deep to shallow and rocky on the quartzite ridges. *Eastern Free State Clay Grassland* (7.2%) 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* (15.6%) 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 have been included in the vegetation map (Mucina et al., 2006a). Groundwater-surface water interactions occur along the drainage lines and in wetlands but are localised rather than a general characteristic of the vegetation type. The drainage lines are often invaded by *Acacia mearnsii* (Black wattle), willows, poplars and other invasive alien species.

Dry Highveld Grassland bioregion (9.2%): 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 to 2 years. The *Central Free State Grassland* (2.6%) is found on clayey soils derived from the mudstones and sandstones of the Adelaide Subgroup in the Free State and extends a little into Gauteng. The dense, short grasslands are often overgrazed resulting in encroachment by shrubs and *Acacia karoo*. The *Vaal-Vet Sandy Grassland* (0.5%) occurs aeolian and colluvial sands overlying gently undulating plains and hills formed by the Ecca Group and Ventersdorp Supergroup (andesite, basement gneiss). The *Vredefort Dome Granite Grassland* (1.1%) 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. In these dry grasslands, GDEs will be rare and localised and often associated with drainage lines or settings where sediments and water accumulate.

Only one hectare of the *Vaal Reefs Dolomite Sinkhole Woodland* occurs in this WMA (more occurs in the Middle Vaal WMA). This woodland is associated with sinkholes in the undulating landscape formed dolomites of the Malmani Subgroup and prominent, rocky, chert ridges. 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 dolomitic 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* (5.1%) 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 the higher lying compartments into lower ones (Nel et al., 1995; Colvin et al., 2007). The dolomitic aquifers support rare or endemic flora and fauna, 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.

Bloemfontein Karroid Shrubland (0.03%) occurs as isolated patches on the dolerite dykes and sills intruding into the Adelaide Subgroup in the Free State and south-west Mpumalanga. 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.

4.2.4 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 (Table 4-1): *Central Free State Grassland* and *Vredefort Dome Granite Grassland*. In the mesic grasslands they are relatively frequent in the *Eastern Highveld Grassland* and *Tsakane Clay Grassland*.

4.2.5 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 (5.2%): The *Andesite Mountain Bushveld* occurs in the Gauteng, North-West, Mpumalanga and Free State provinces on hillslopes and ridges formed from the tholeitic basalt of the Kliprivierberg 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. The *Gauteng Shale Mountain Bushveld* occurs mainly on the ridge of the Gatsrand south of Carletonville-Westonaria-Lenasia. The terrain comprises low, broken ridges with variable slopes and a high percentage of rock cover formed from the shales, clastic sediments and andesites of the Pretoria Group as well as the Malmani dolomites. *Gold Reef Mountain Bushveld* is widespread, occurring in the North-West, Gauteng, Free State and Mpumalanga provinces. 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. The *Moot Plains Bushveld* is found in the North-West and Gauteng provinces both south and north of the Magaliesberg on a diverse suite of well-drained soils formed from the clastic sediments, carbonates and volcanics of the Pretoria Group and the Malmani Subgroup dolomites. The woody vegetation cover varies from open to closed with a range of tree (*Acacia, Rhus*) and shrub species, many of which are known to be deep-rooted, and an understorey of grasses and herbs.

These vegetation types all include a number of tree and shrub species with the potential to grow deep root systems and access 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 types often contain alluvial deposits where there may be GDEs. Both the *Moot Plains Bushveld* and *Gold Reef Mountain Bushveld* types have more than 1% of their area mapped as wetlands (**Table 4-1**).

4.3 Synthesis of Groundwater Ecosystem Dependence

The preceding sections have described 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 dolomites which contain large quantities of groundwater in solution cavities (Colvin et al., 2007). 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 ADEs in these formations which makes them potentially highly sensitive to groundwater abstraction.

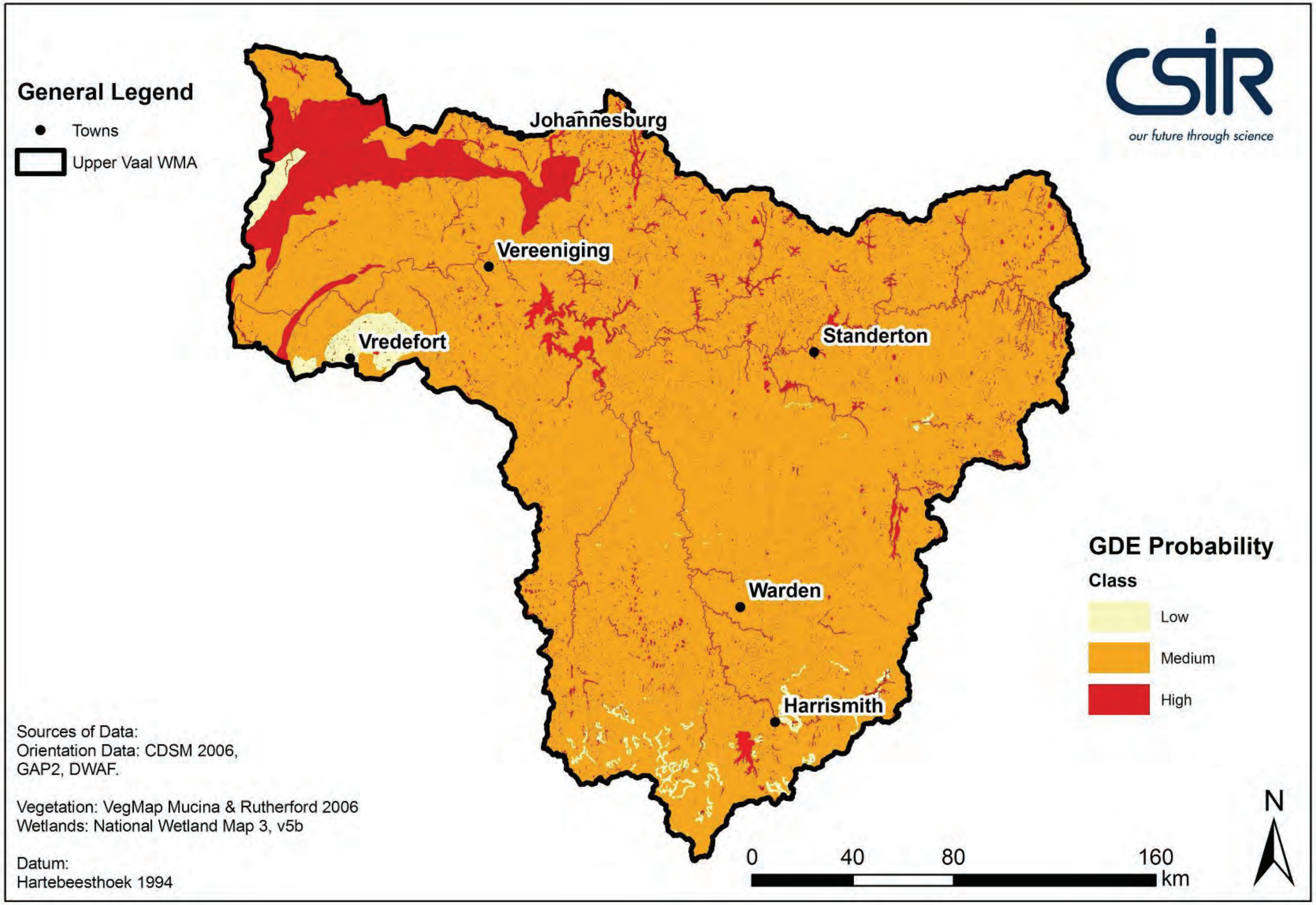

Figure 4-3. Probability of aquifer dependence for different vegetation types in the Upper Vaal WMA

Table 4-2. A synthesis of the probability of occurrence, likely extent and characteristics of aquifer-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 Drakensberg Afroalpine Heathland	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	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
		Northern Afrotemperate Forest	Forest patches in sheltered kloofs or rocky areas, groundwater interactions low, dependence low
Medium	Localised, occurring in specific settings	Lesotho Highland Basalt Grassland Northern Drakensberg Highland Grassland uKhahlamba Basalt Grassland Low Escarpment Moist 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	Amersfoort Highveld Clay Grassland Eastern Free State Clay Grassland Eastern Free State Sandy Grassland Eastern Highveld Grassland Frankfort Highveld Grassland Rand Highveld Grassland Soweto Highveld Grassland Tsakane Clay Grassland Wakkerstroom Montane 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	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	Moot Plains Bushveld Gold Reef Mountain Bushveld Andesite Mountain Bushveld Gauteng Shale Mountain Bushveld	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.
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	Eastern Temperate Freshwater Wetlands	These wetlands occur throughout the WMA across a wide variety of rock, aquifer and vegetation types. Most of them

Probability	Extent	Vegetation type	Description
	typical feature of these ecosystems and to be expected unless there is evidence that the ecosystem is not groundwater dependent		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.
		Alluvial Vegetation	Alluvial & riparian vegetation, mixture of surface and groundwater dependent types. Not shown on the national vegetation map in this WMA but alluvial systems are present along most river systems, particularly the higher order rivers.

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**).

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)
C11A	721	743	49.99	9.62	C22J	669	633	11.81	1.03
C11B	536	705	30.72	5.2	C22K	434	644	8.3	0.94
C11C	450	765	34.54	4.02	C23A	258	612	3.07	0.75
C11D	373	702	20.98	2.84	C23B	701	619	8.8	2.23
C11E	1157	697	64.04	7.8	C23C	1069	609	14.74	3.11
C11F	931	705	53.58	5.13	C23D	510	664	9.12	6.53
C11G	433	659	19.61	2.67	C23E	850	631	9.99	8.93
C11H	1104	664	93.79	7.21	C23F	1324	605	54.93	8.91
C11J	1002	658	63.2	5.06	C23G	613	597	8.26	5.59
C11K	340	633	15.84	2.7	C23H	451	604	5.65	5.4
C11L	948	675	58.86	7.91	C23J	890	620	18.49	3.36
C11M	796	637	41.13	2.38	C23K	396	607	7.57	2.18
C12A	485	614	14.23	2.64	C23L	1211	612	23.91	5.84
C12B	479	631	18.44	2.64	C81A	382	882	63.19	6.24
C12C	666	605	16.52	3.47	C81B	576	763	60.68	6.9
C12D	899	667	61.69	4.11	C81C	250	730	20.51	2.9
C12E	498	641	17.08	2.75	C81D	195	735	17.66	1.81
C12F	835	635	*27.54*	*5.29*	C81E	643	658	40.96	4
C12G	571	640	19.46	3.59	C81F	689	892	108.38	10.27
C12H	355	618	7.93	1.73	C81G	435	722	16.83	4.46
C12J	344	615	7.47	1.72	C81H	358	638	9.08	2.71
C12K	479	657	15.06	2.66	C81J	392	612	12.28	1.91
C12L	887	648	25.9	5.14	C81K	359	623	18.74	1.91
C13A	595	779	55.45	4.19	C81L	795	740	75.62	4.51
C13B	616	683	35.08	3.02	C81M	1093	662	71.09	7.7
C13C	837	724	59.58	5.08	C82A	582	670	30.08	4.78
C13D	896	698	55.51	5.77	C82B	493	660	29.48	3.04
C13E	603	699	37.55	3.86	C82C	353	646	17.92	2.01
C13F	611	692	36.61	3.76	C82D	572	623	19.75	2.95
C13G	435	674	21.87	3.31	C82E	623	666	29.67	4.75
C13H	589	628	20.84	2.59	C82F	484	639	18.92	2.9
C21A	707	674	16.71	3.58	C82G	581	655	25.57	3.08
C21B	431	697	11.54	3.09	C82H	783	614	25.19	3.8
C21C	438	674	9.97	2.96	C83A	746	692	29.9	5.46
C21D	446	698	12.27	3.74	C83B	251	668	10.03	1.03
C21E	629	691	16.44	4.79	C83C	828	663	32.13	4.49
C21F	427	704	12.02	3.08	C83D	465	650	9.31	2.63
C21G	463	667	10.93	2.92	C83E	426	654	14.08	2.55
C22A	548	695	26.87	5.99	C83F	875	637	24.09	4.69
C22B	392	691	18.66	4.79	C83G	695	647	17.34	4.53
C22C	465	684	21.38	5.97	C83H	547	646	14.09	4.29
C22D	345	701	17.38	4.8	C83J	222	641	8.14	1
C22E	532	669	14.09	5.97	C83K	548	635	17.83	3.46
C22F	440	655	9.04	2.63	C83L	826	641	26.64	5.19
C22G	831	613	14.11	1.08	C83M	1100	639	33.18	6.83
C22H	454	639	8.38	1.54					

The full baseflow calculations are shown in **Appendix C**. 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**.

WRP baseflow as a percentage of mean annual runoff per quaternary catchment is shown in **Figure 5-6**. The coefficient of variation for all baseflow estimates (WRP, Sami, Hughes and Pitman, excluding Schultz) is shown in **Figure 5-7**.

It remains perplexing that the various methods of baseflow derivation return the significant variance in values observed in **Appendix C**. Clearly, the integrated modelling of surface water and groundwater resources will not yield reliable, rigorous and consistent results if this interface is not understood.

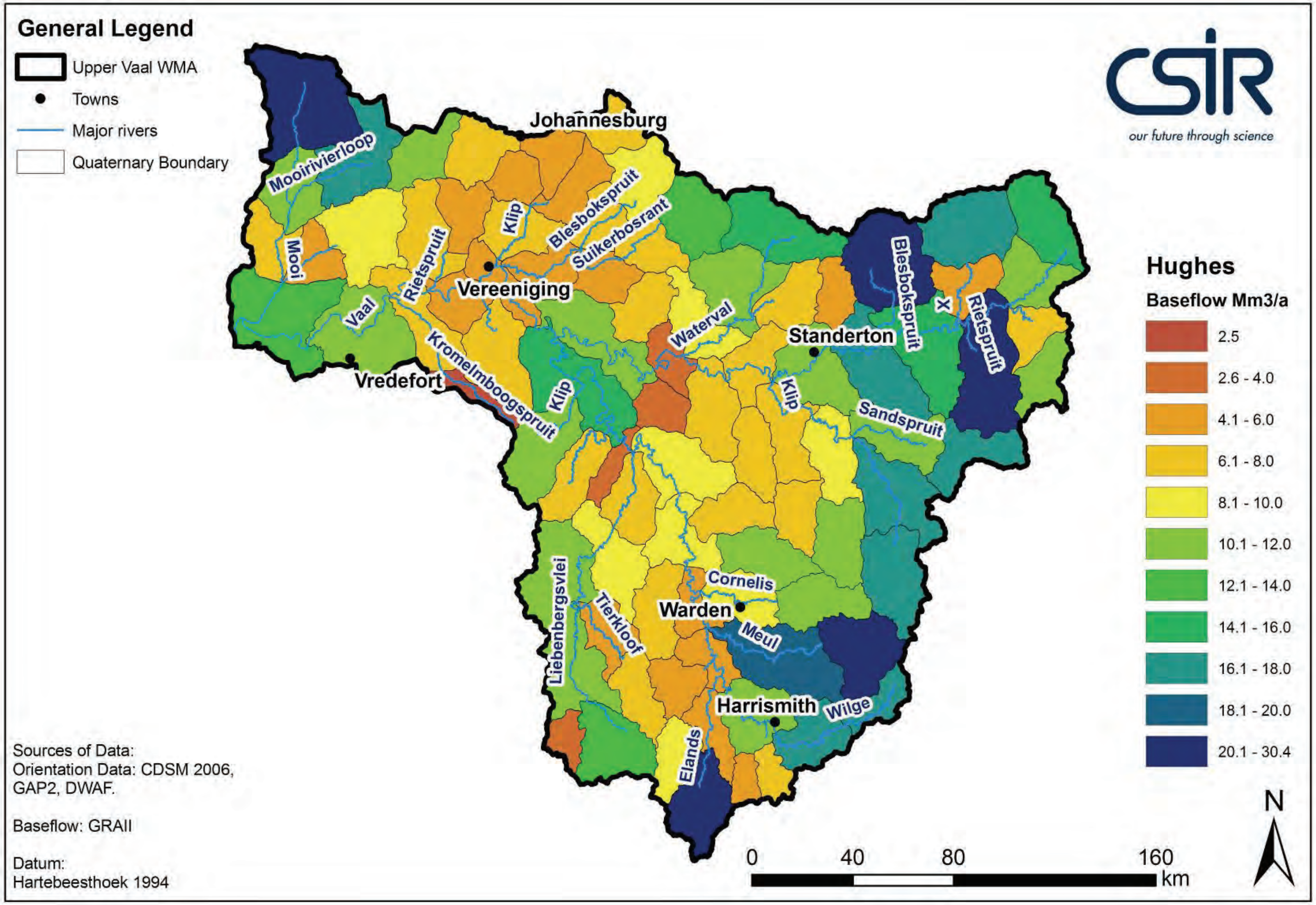

Figure 5-1. Baseflow estimate for the Upper Vaal WMA per quaternary catchment by Hughes (values in Mm^3/a)

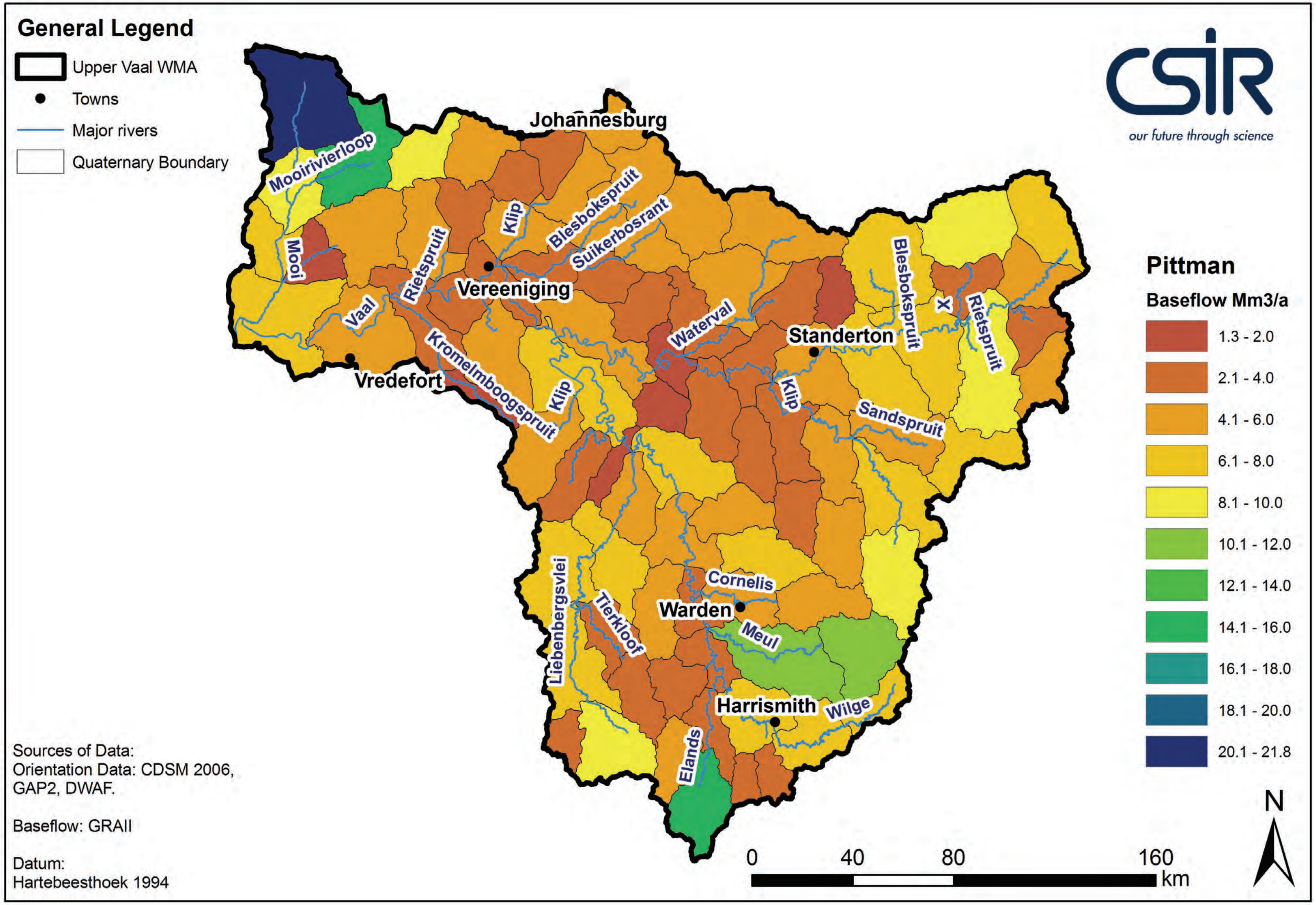

Figure 5-2. Baseflow estimate for the Upper Vaal WMA based on Pitman (values in Mm^3/a)

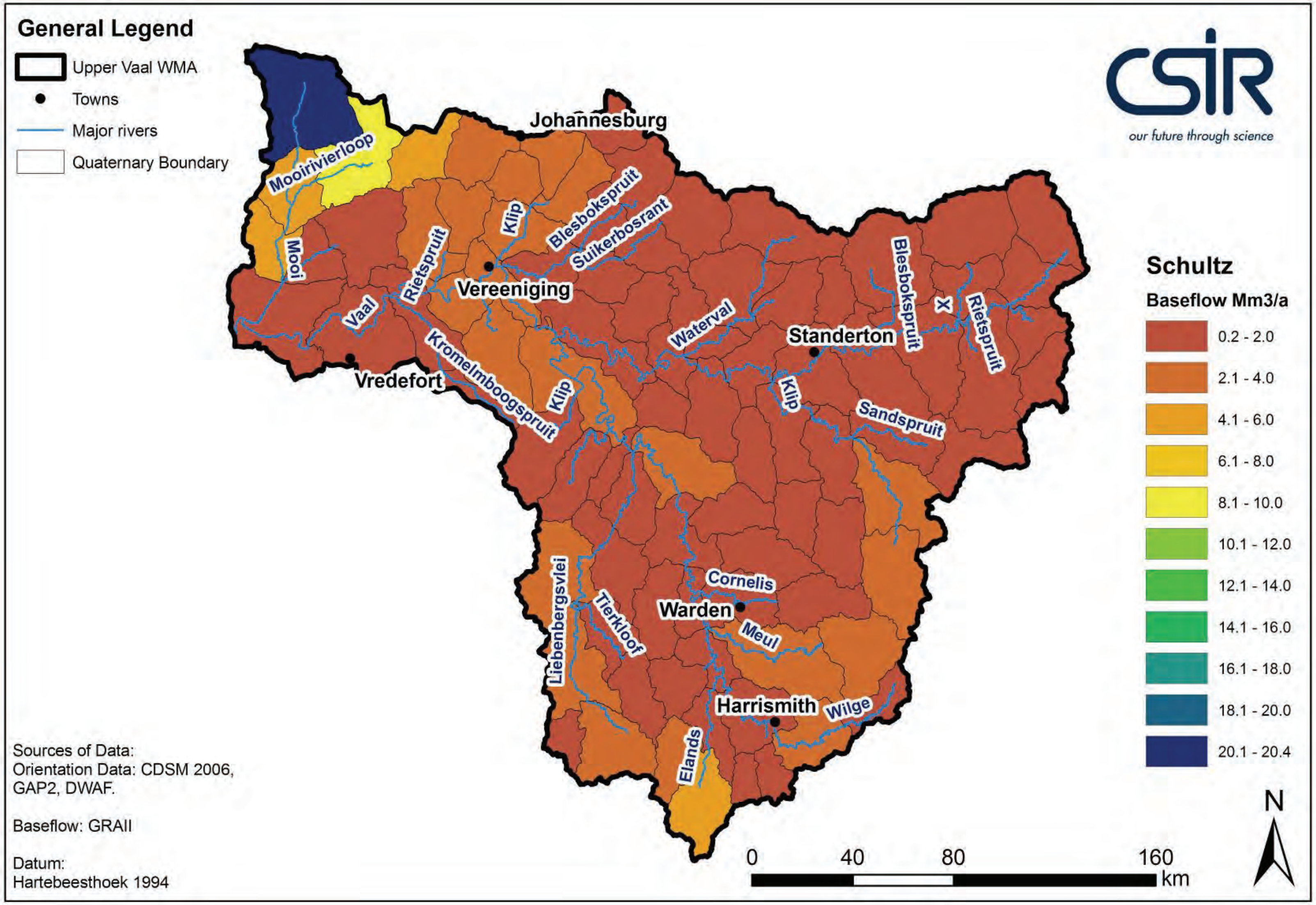

Figure 5-3. Baseflow estimate for the Upper Vaal WMA based on Schultz (values in Mm^3/a)

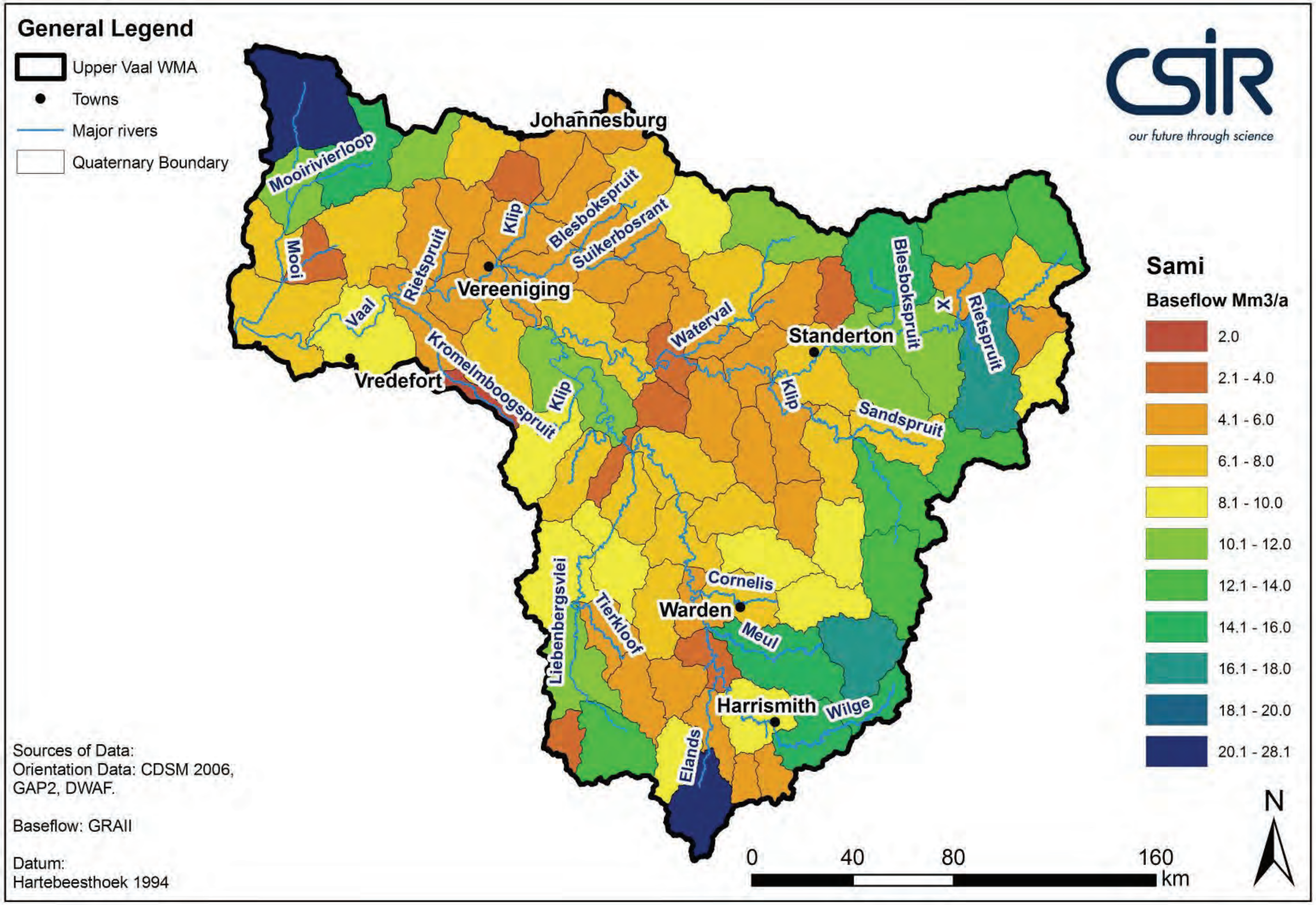

Figure 5-4. Baseflow estimate for the Upper Vaal WMA based on Sami from GRAII (values in Mm^3/a)

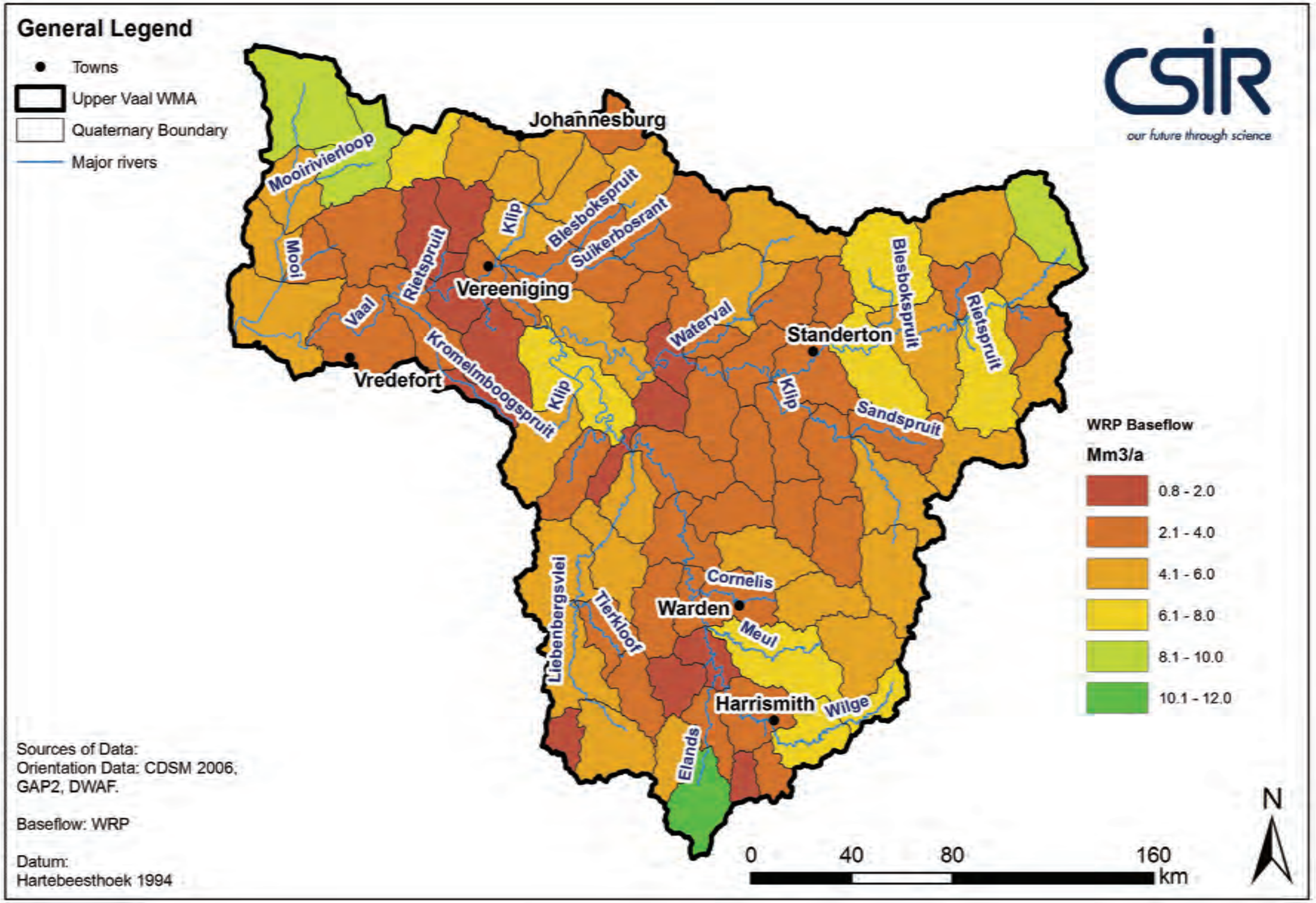

Figure 5-5. WRP baseflow for the Upper Vaal WMA based on hydrograph separation using WRP streamflow data

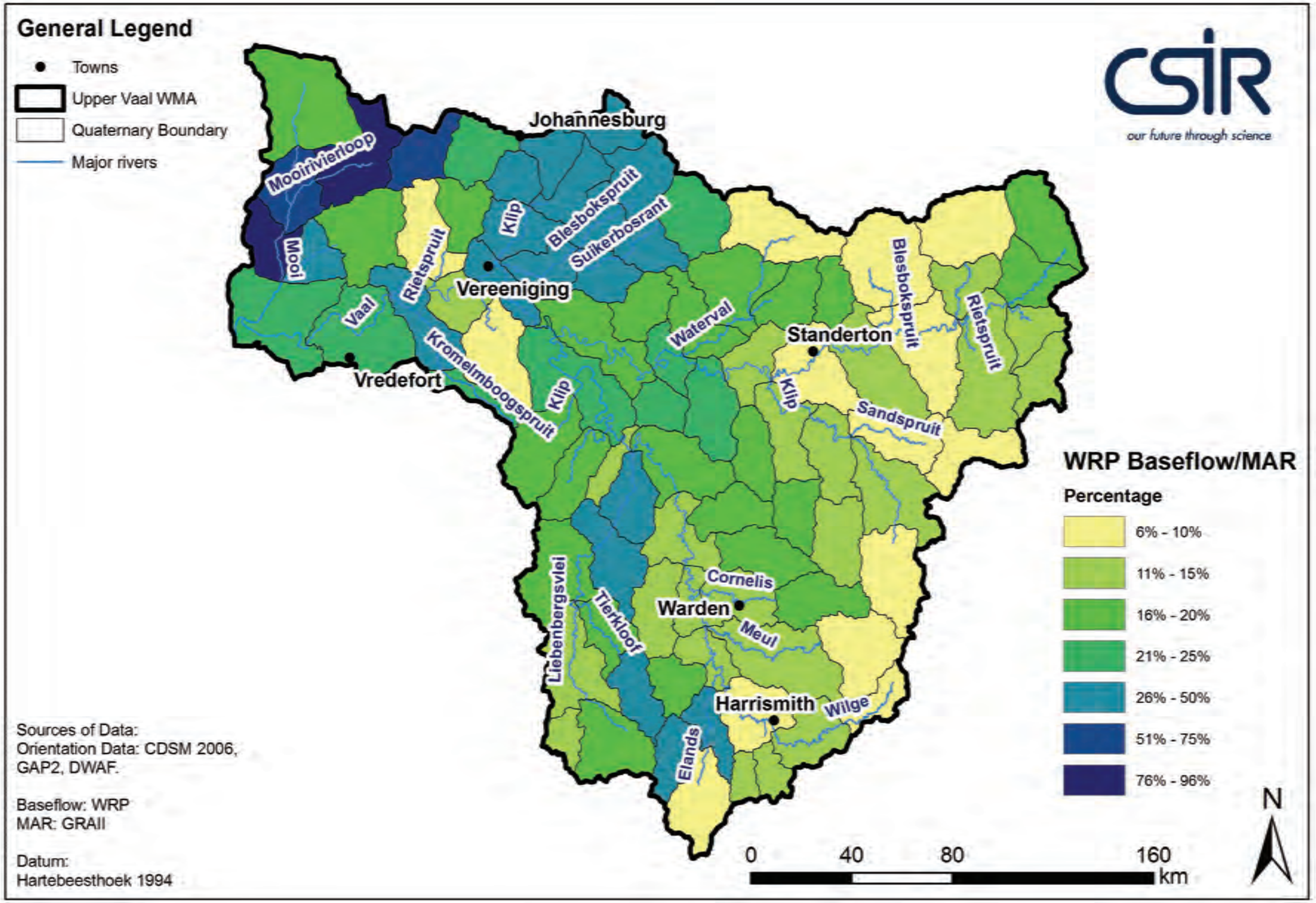

Figure 5-6. WRP baseflow values for the Upper Vaal WMA as a percentage of mean annual runoff

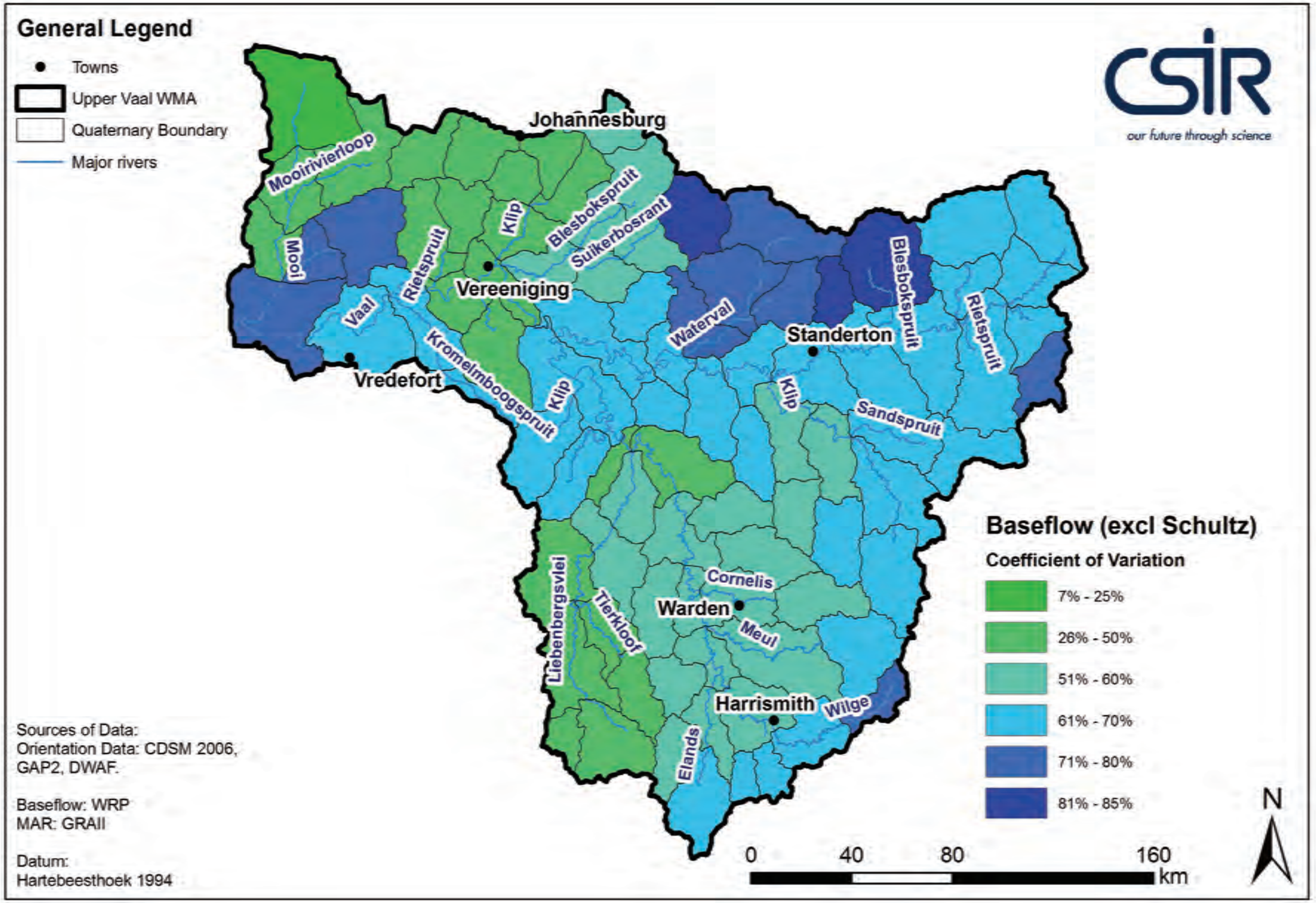

Figure 5-7. Coefficient of variation values for baseflow estimates of Sami, WRP, Hughes and Pitman (excluding Schultz)

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**, which reflects the distribution of the nine GRUs identified in the Upper Vaal WMA.

Three of the GRUs are each subdivided into two subunits in order to accommodate regional differences in recharge (GRUs 4a and 4b), differences in the nature of land use impacts (GRUs 5a and 5b), and regional differences in land cover (GRUs 6a and 6b). The association of GRUs with the footprint of quaternary catchments facilitates the geospatial definition of each GRU. This convenience necessarily sacrifices a measure of hydrogeological accuracy, since it is common cause that the distribution of geological strata seldom follows the hydrological boundaries that surface water catchments. Nevertheless, the extent to which the GRU footprints honour their underpinning geological framework is shown in **Figure 6-2**.

6.2 Physical Description of the GRUs

6.2.1 GRU 1

This GRU is associated with the youngest sedimentary strata of the Karoo Supergroup occupying the highest elevation in the extreme southern corner of the study area. These strata are represented by sandstones, mudstone and siltstones of the Molteno, Elliot and Clarens Formations and basalt of the Drakensberg Formation. This GRU represents the largely pristine headwater regions of the Liebenbergsvlei River (tertiary catchment C82) south of Bethlehem, and the Wilge River (tertiary catchment C81) around Phuthaditjhaba. These regions are characterised by higher groundwater recharge and baseflow conditions that support the surface water systems.

6.2.2 GRU 2

Groundwater resource unit 2 is underlain mainly by Beaufort Group sediments and represents a transition zone between GRU 1 to the south and GRU 3 to the north. The scarcity of subhorizontal dolerite sill intrusions associated with this GRU distinguishes it both geologically and hydrogeologically from GRU 3. Dolerite occurrences in GRU 2 are of a subvertical dyke-like nature that reflect much more discrete structures than sill intrusions. The recharge conditions might be described as moderate, and baseflow conditions as high to moderate. Elevated recharge conditions occur along the south-eastern boundary of this GRU. Estimated groundwater use is low, and the ratio thereof to estimated recharge similarly not a concern.

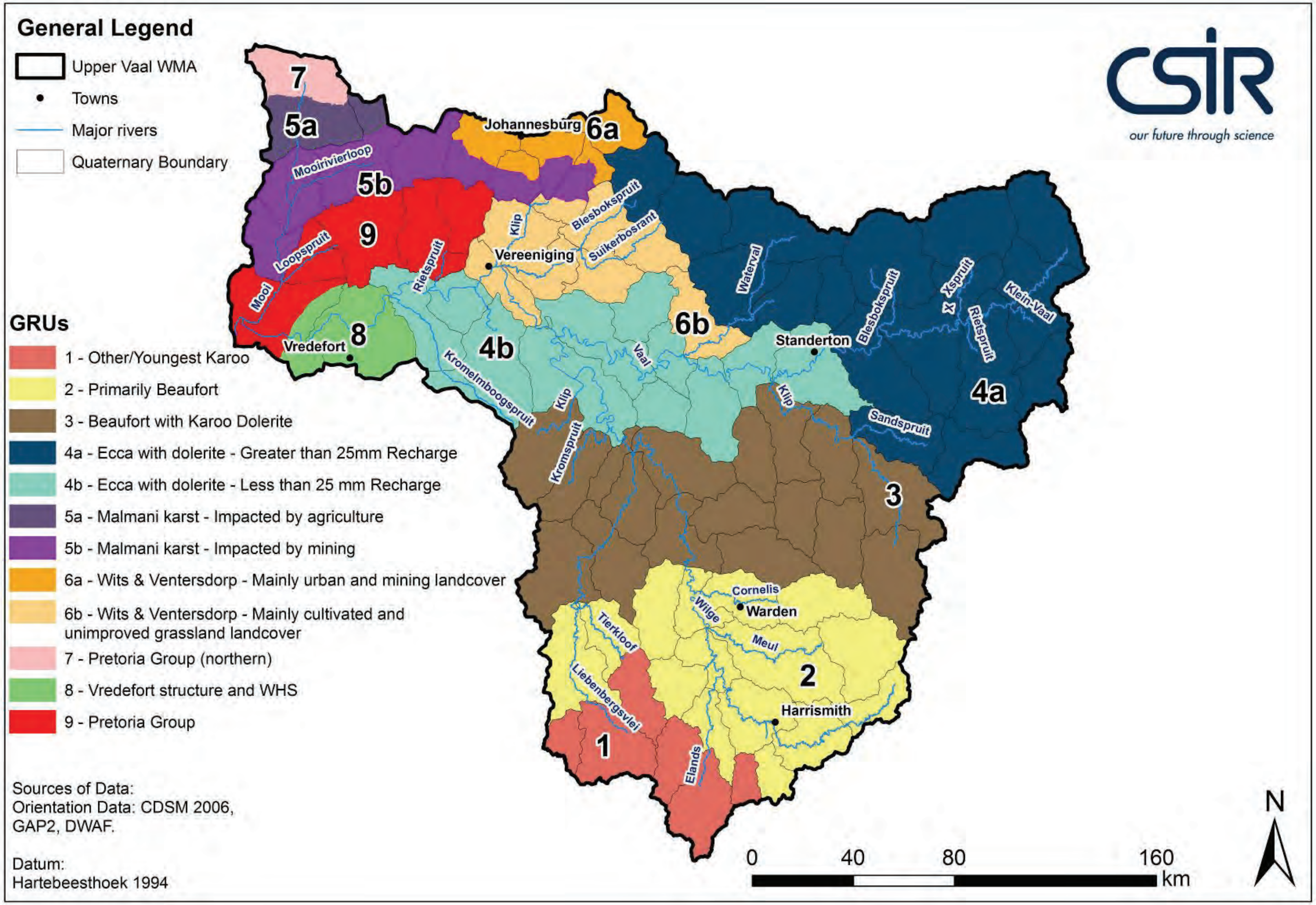

Figure 6-1. Geographic definition of groundwater resource units (GRUs) in the study area

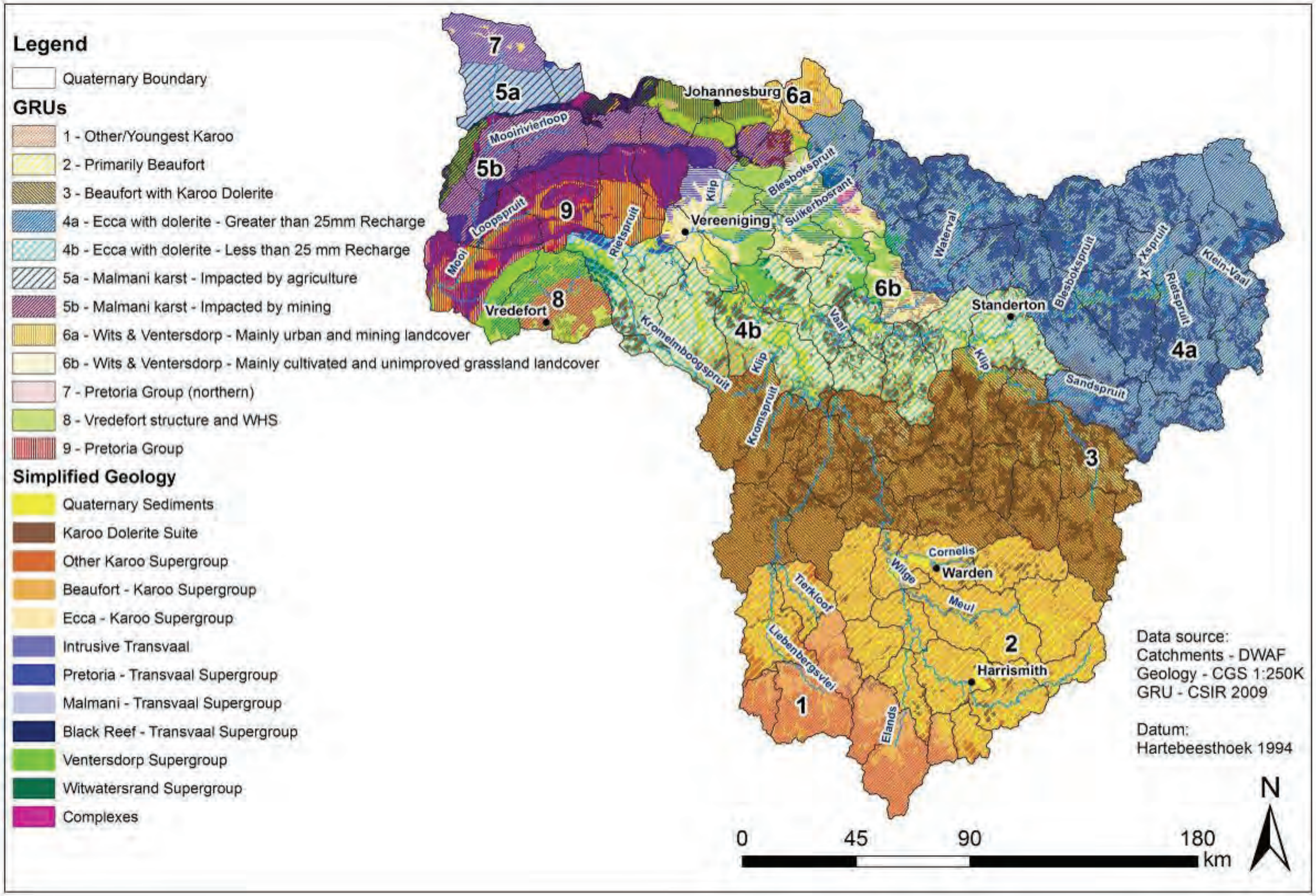

Figure 6-2. Simplified geological map of the study area illustrating the congruence between geology and the defined GRUs

6.2.3 GRU 3

This GRU is characterised by numerous dolerite sill intrusions that intersect the Beaufort Group sediments. Whilst Baran and Dziembowski (2003) suggest that borehole yields are similar irrespective of lithology (argillaceous versus arenaceous strata) intersected and presence or absence of dolerite intrusions, the latter are considered the reason for the poorer recharge conditions that characterise this GRU. Similar to GRU 2, the estimated groundwater use is low, and the ratio thereof to estimated recharge similarly not a concern

6.2.4 GRU 4

6.2.4.1 GRU 4a

Groundwater resource unit 4a encompasses the north-eastern portion of the study area where sedimentary strata of primarily the Vryheid Formation of the Ecca Group receive an estimated recharge in excess of 25 mm/a. These strata are also extensively intruded by dolerite sills. This GRU also represents the headwaters of the Vaal River, and is further characterised by coal mining activities that constitute the most important economic land use activity, followed by agriculture. The coal mining activities represent a concern for the potentially negative impact on groundwater resources in the GRU (McCarthy and Pretorius, undated; NPC, 2011; WWF-SA, 2011). The footprints of the various coal fields in the study area are shown in **Figure 6-4**.

6.2.4.2 GRU 4b

Straddling the Vaal River through the centre of the Upper Vaal WMA, GRU 4b encompasses sedimentary strata of the Vryheid Formation that receive an estimated recharge of less than 25 mm/a. These strata are also less extensively intruded by dolerite sills than GRU 4a. The magnitude of estimated groundwater use is typically less than 0.5 Mm^3/a except in quaternary catchment C12L due to an industry-related use of ~3.6 Mm^3/a. This GRU also hosts coal mining activities south of the Vaal River in the vicinity of Sasolburg.

6.2.5 GRU 5

6.2.5.1 GRU 5a

GRU 5a encompasses that portion of the Malmani Subgroup dolomitic strata which hosts extensive irrigated agriculture that is based on the karst groundwater resources. The sustainable utilisation of these resources in terms of both their socio-economic and ecological importance is a critical aspect of GRDM that needs to be considered.

6.2.5.2 GRU 5b

GRU 5b encompasses that portion of the Malmani Subgroup dolomitic strata which hosts the extensive mining activity associated with the gold mining industry. This GRU extends from the East Rand Goldfield south-east of Johannesburg to the Carletonville Goldfield in the Far West Rand. A significant 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. Those compartments that have not been dewatered are at risk from contamination association with acid mine drainage (AMD). The complexity of issues that attend concerns in this regard pose extreme challenges for a GRDM assessment.

6.2.6 GRU 6

6.2.6.1 GRU 6a

The older geological strata associated with the Witwatersrand and Ventersdorp Supergroups that underlie the extensively urbanised and industrialised environment of the Witwatersrand form this GRU. The highly impacted nature and modified character of the landscape in this GRU similarly requires a GRDM assessment that takes cognisance of these circumstances.

6.2.6.2 GRU 6b

Hosting a similar geological and hydrogeological environment as GRU 6a, this groundwater resource unit encompasses mainly cultivated and unimproved grassland landcover. It also hosts the impacted Klip and Blesbokspruit Rivers that drain the south and south-eastern portions of the highly urbanised and industrialised East Rand.

6.2.7 GRU 7

Located in the extreme north-western part of the study area, this GRU encompasses the younger sedimentary strata of the Pretoria Group. Characterised by a comparatively high baseflow regime and moderate recharge potential, this GRU remains in a largely natural condition.

6.2.8 GRU 8

The association of GRU 8 with the Vredefort Dome impact structure recognises the significance of this area as a UNESCO World Heritage Site. It is important that the concept of groundwater resource directed measures (GRDM) also provides protection for such areas. Encompassing granite and gneiss exhumed by the meteorite impact at its core, and surrounded by deformed Witwatersrand and Ventersdorp Supergroup strata, this GRU is also bisected by the Vaal River.

6.2.9 GRU 9

Also encompassing sedimentary strata associated mainly with the Pretoria Group, GRU 9 is characterised by a relatively low baseflow regime and moderate recharge potential. Land use activities in this GRU are dominated by agriculture in the form of rainfed irrigation and cattle farming, and to a lesser extent by gold mining activities. The ‘megadump’ being planned by Harmony Gold Mining Company, and which has solicited much negative publicity, will be located in this GRU.

6.3 Synthesis

A synthesis of the occurrence and distribution of lithological units amongst the respective GRUs is presented in **Table 6-1** and **Figure 6-3**. The combination of this information reflects the dominance of the younger strata (<354 Ma) that build GRUs 1, 2, 3 and 4 in the upper reaches of the WMA, the much older strata (>2050 Ma) underlying GRUs 5, 6 and 7, and the strata of "intermediate" age (1000-2050 Ma) together with older strata that form GRUs 8 and 9.

Table 6-1. Summary of the lithology per groundwater resource unit in the Upper Vaal WMA (modified after Table 2-1)

Basic Lithology	Groundwater Resource Unit												Era (Age)	
	1	2	3	4		5		6		7	8	9		
				a	b	a	b	a	b					
Aeolian sand, calcrete, colluvium, alluvium					■		■		■		■	■	Late Cenozoic (<10000 yrs)	
Dolerite, diabase, syenite	■	■		■	■		■		■				(~144 Ma)	Mesozoic
Sandstone	■													
Mudstone & subordinate sandstone	■													
Sandstone, mudstone & shale	■	■											(~250 Ma)	
Mudstone & sandstone		■											(~250 Ma)	Palaeozoic
Mudstone & subordinate sandstone		■	■	■										
Shale & subordinate sandstone			■	■			■							
Sandstone, shale & coal beds				■	■		■	■						
Shale							■							
Diamictite & shale								■					(~354 Ma)	
Alkali granite											■		(~1000 Ma)	Mokolian
Olivine gabbro, wehrite, alkali granite											■			
Diorite, albitite											■			
Harzburgite, norite, quartz norite/gabbro, granophyre											■			
Basic & ultrabasic rocks											■			
Diabase							■		■		■	■	(~2050 Ma)	
Shale												■	(~2050 Ma)	Vaalian
Quartzite & shale												■		
Shale & Quartzite										■		■		
Andesite							■			■		■		
Quartzite							■							
Ferruginous shale & quartzite							■		■	■		■		
Quartzite, chert, conglomerate							■							
Chert-rich dolomite						■	■	■	■					
Chert-poor dolomite						■	■	■	■					
Quartzite, conglomerate						■	■		■				(~2650 Ma)	
Andesite							■						(~2650 Ma)	Randian
Andesite, tuff							■	■	■		■		(~2780 Ma)	
Arenaceous, rudaceous rocks					■				■		■		(~2780 Ma)	
Quartzite, reddish ferruginous magnetic shale					■		■		■		■			
Quartzite, conglomerate, shale, interbedded lava							■						(~3100 Ma)	
Granite, gneiss									■		■		Swazian (>3100 Ma)	

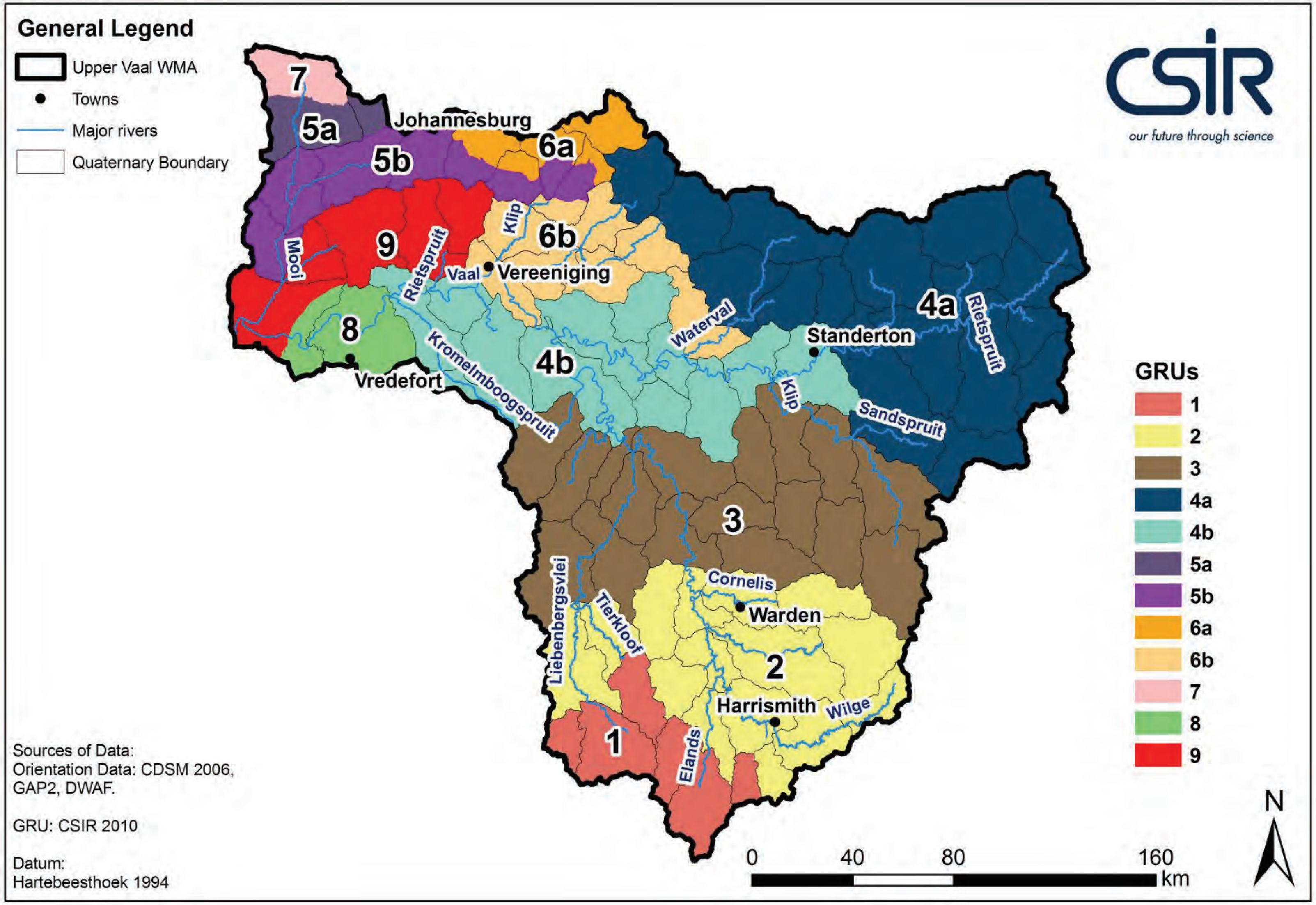

Figure 6-3. Final map showing GRUs as defined for the Upper Vaal WMA

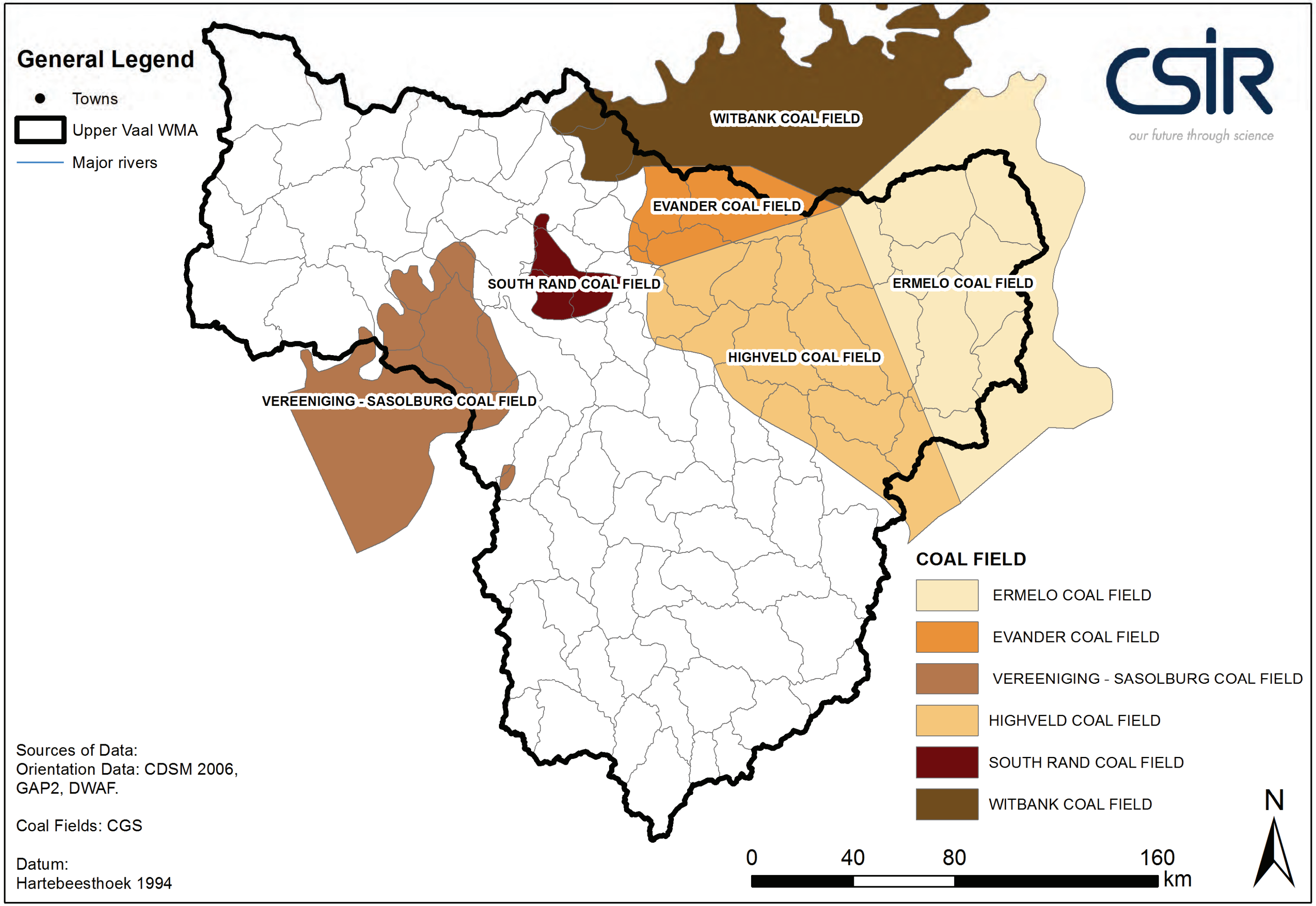

Figure 6-4. Geographic distribution of coalfields in the Upper Vaal WMA

7 DEGREE OF IMPACT AND PRESENT STATUS OF GROUNDWATER RESOURCES

7.1 Provisional Identification of Potentially Impacting Land Uses

A provisional assessment of land use activities considered to possess a potentially harmful impact on the environment yields the results summarised in **Table 7-1**. The sub-areas most likely to experience these impacts are also identified. It is evident that the greatest threats to the groundwater environment in the UVWMA are related to the impacts of acid mine drainage (AMD) associated with both gold and coal mining activities. The greatest concern in this regard is considered to be the Lower Wonderfontein Spruit, where the impact of groundwater rebound on extensively dewatered dolomitic compartments is a disconcerting unknown, and the impact of mine water contamination on downstream surface and groundwater resources (not only radioactive elements but also heavy metals such as iron, lead, manganese, arsenic and cadmium) utilised by private landowners is the subject of increasing media (and therefore public) attention. These circumstances are nowhere better illustrated than in the Mayoral Imbizo held in Potchefstroom on 6 December 2007 to air concerns in this regard. The trigger for this event was the press article in Beeld of 29 November 2007 (Tempelhoff, 2007).

The DWAFs Vaal River System Overarching ISP (2004b) recognises the following as main challenges for water quality management.

- Expansion of urban and industrial areas.
- Expansion of coal mining in the UVWMA.
- Acid mine drainage management from defunct gold and coal mines.
- Pollution from sulfurous discharges to the atmosphere. This should include aeolian (wind-borne) pollution of radioactive material from gold mine tailings dams.

The existence of numerous forums in the study area is recognised as an opportunity for the project to establish its credentials with the broad spectrum of forum members. A provisional list of forums and I&AP groupings is presented in **Table 7-2**. It will need to be established which of these forums (a) is active and (b) have a groundwater component within their focus area.

The PSP has attended the following forum and general public meetings.

- The Eastern Basin Technical Working Group.
- The Western Basin Technical Working Group and Monitoring Sub-group.
- The Mayoral Imbizo held in Potchefstroom on 6 December 2007.

Recognition of the various forums is not only important for establishing communication with I&APs, but also for the possibility that some of these entities might already have debated, researched and developed certain objectives. An example is the Leeu/Taaiboschspruit Forum (LTF) in the Vereeniging-Sasolburg coal field, which has proposed water quality objectives for both the Taaibosch Spruit and the Leeu Spruit (LTF, undated).

Table 7-1. Summarised provisional identification of potentially impacting land use activities.

Land Use Activity	Sub-area	Nature of Impact
GOLD MINING Carletonville Goldfield Central Rand Goldfield West Rand Goldfield East Rand Goldfield Evander Goldfield Klerksdorp Goldfield	 C2 C2 C2 C1 C1 C2	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, and the reworking of older sand dumps. The uraniferous nature of the ore-bearing deposits poses an additional environmental concern.
COAL MINING Highveld Coalfield Ermelo Coalfield Vereeniging-Sasolburg Coalfield South Rand Coalfield	 C2 C1 C2 C1 C1	The typically much shallower nature of coal mines, exemplified by surface (opencast) mines, distinguishes them from gold mines. The practice of high extraction mining raises concerns for land subsidence and rupture of overlying aquifers. The disposal of mine water during operations is a concern. The coal-bearing deposits do not present a concern for radioactivity.
POWER GENERATION Lethabo power station Tutuka power station Majuba power station	 C2 C1 C1	Impacts on the groundwater environment associated with these facilities are fly ash disposal, coal stockpiles and dirty water dams. Operated by Eskom, these facilities generally boast groundwater monitoring systems.
INDUSTRY Mittal Steel (Vanderbijlpark) SAPPI Enstra (Springs) Sasol 1 (Sasolburg) Sasol 2 & 3 (Secunda) AECI (Modderfontein)	 C2 C1 C2 C1 C2	Impacts from industry vary according to the nature of the specific industry. Metal industries face disposal of saline liquids, slimes, slag and phenol. The paper industry is faced with the disposal of dark-coloured liquors from plant-based organics having a high oxygen demand and high salt loads (especially chloride). The chemicals industry disposes of saline liquids, ash, tar, phenol and other organics.
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	The potential impacts of municipal landfills on the groundwater environment, especially those facilities that the DWAF 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.

7.2 Considering the National Land Cover Data

National land cover maps for South Africa together with hazard ratings with respect to pollution have been used together with chemistry to evaluate the degree to which certain areas with a particular type of land cover have been impacted.

The maximum allowable concentrations were used as a guideline or indicator of exceedance in both **Table 7-4** and **Table 7-5**. **Table 7-3** shows the various categories for each water quality variable and their respective concentrations used as guidelines for South African drinking water Standards. **Table 7-5** shows that some areas which rank as low hazards actually have concentrations exceeding maximum allowable concentrations. The lack of some data from privately owned areas, e.g. mine records not in data base, may affect the results. **Table 7-5** shows that majority of the land cover areas in the Upper Vaal WMA have elevated concentrations of SO_4, Mg and Ca which may well be as a result of low pH conditions produced by acid mine drainage, causing dissolution of Ca and Mg in dolomite and limestone aquifers. NO_3 and F may be linked to natural and anthropogenic sources. It appears that farming and natural grasslands as well as industrial land cover areas show elevated concentrations of these elements. It also shows that surfaced based mining to some extent yields less damage than underground mining and mine tailings or waste. It also seems like land cover is not necessarily the controlling factor of the degree to which an area is polluted, as areas showing a zero hazard risk seems to contain elevated concentrations, and other areas which carry a 4 hazard rating have little or no elevated concentrations.

Table 7-2. Forums and other I&AP groupings in the study area

Forum	Brief description
GOVERNMENTAL	
Government Task Team (GTT) for Mine Closure and Water Management	Established by DME, DWAF and DEAT. Current projects are the Water Ingress Project & the Mine Closure Programme.
	Established by DME. Function taken over by GTT?
Carletonville Goldfield	
State Co-ordinating Technical Committee (SCTC)	Established by the mining houses in 1964. Focus is on the prevention of ground subsidence due to dewatering.
Far West Rand Dolomitic Association (FWRDA)	
West Rand Goldfield	
Western Basin Technical Working Group	Established and chaired by DWAF.
Western Basin Monitoring Sub-group	Established and chaired by DWAF.
East Rand Goldfield	
Eastern Basin Technical Working Group	Established and chaired by DWAF.
Klerksdorp Goldfield	
KOSH Inter-mine Forum/Water Task Team	Established by the mining houses.
Vereeniging-Sasolburg Coal Field	
Leeu Taaiboschspruit Forum (LTF)	Established and chaired by DWAF.
QUASI-GOVERNMENTAL	
Klip River Forum	
Waterval Forum	
Blesbokspruit Forum	
Grootdraai Forum	
Vaal Dam Forum	
Vaal River Barrage Reservoir Forum	
Wilge River Forum	
Mooi River Catchment Forum	
Wonderfontein Action Group	
Harmony/Sasol Groundwater Interaction	
NON-GOVERNMENTAL (ENVIRONMENTAL LOBBY)	
Save the Vaal Environment (SAVE)	Focus is the Vaal upstream of the Barrage
Public Environmental Arbiters (PEA)	A broad grouping grown out of the Potch Petitioners
Potchefstroom Petitioners (PP)	Focus is the Lower Wonderfontein Spruit
Randfontein Environmental Action Group (REAG)	Focus is the Upper Wonderfontein and Tweelopie spruits

Table 7-3. Standard for drinking water quality in South Africa after SANS (2011a)

SANS (2011a)	EC (mS/m)	TDS (mg/L)	F (mg/L)	NO_3 (mg N/L)	SO_4 (mg/L)	Mg (mg/L)	Ca (mg/L)	Cl (mg/L)
Standard limit(1)	170	1200	1.5	11	500	n.s.	n.s.	300

(1) Health-related standard based on the consumption of 2 L of water per day by a person of a mass of 60 kg over a period of 70 years

Table 7-4. National Land Coverages with hazardous rating and variables linked to salinity and total ions in solution. Underlined values relate to concentrations above the maximum allowable for the specific variable

Hazard Rating	National Land Cover Type	Ave_ EC	Max_EC	Ave_TDS	Max_TDS	Ave_Cl	Max_Cl
1	Cultivated, temporary, commercial, dryland	65	393	463	2419	33	937
3	Cultivated, temporary, commercial, irrigated	61	333	457	3021	22	168
1	Degraded Unimproved (natural) Grassland	27	30	214	234	2	2
1	Forest Plantations (Pine spp)	33	49	243	337	15	93
1	Improved Grassland	85	201	634	1367	45	188
4	Mines & Quarries (mine tailings, waste dumps)	85	162	656	1407	34	99
4	Mines & Quarries (surface-based mining)	55	141	465	1732	15	74
4	Mines & Quarries (underground / subsurface mining)	68	165	504	1373	13	22
0	Thicket, Bushland, Bush Clumps, High Fynbos	62	285	473	2329	23	573
0	Unimproved (natural) Grassland	71	590	511	2880	36	993
2	Urban / Built-up (residential)	131	801	670	757	37	67
2	Urban / Built-up (residential, formal suburbs)	66	186	505	1513	32	176
3	Urban / Built-up (residential, formal township)	45	162	336	1187	21	153
3	Urban / Built-up (residential, informal squatter camp)	121	132	785	832	151	225
3	Urban / Built-up (residential, informal township)	23	34	188	274	2	5
2	Urban / Built-up (smallholdings, grassland)	57	403	423	2752	35	889
3	Urban / Built-up, (commercial, education, health, IT)	33	46	250	352	2	4
3	Urban / Built-up, (commercial, mercantile)	42	42	348	348	4	4
4	Urban / Built-up, (industrial / transport : heavy)	67	118	507	902	36	108
4	Urban / Built-up, (industrial / transport : light)	136	160	1144	1302	53	68
0	Wetlands	82	419	571	2627	64	942
	(blank)/Unclassified	77	328	632	2007	47	768

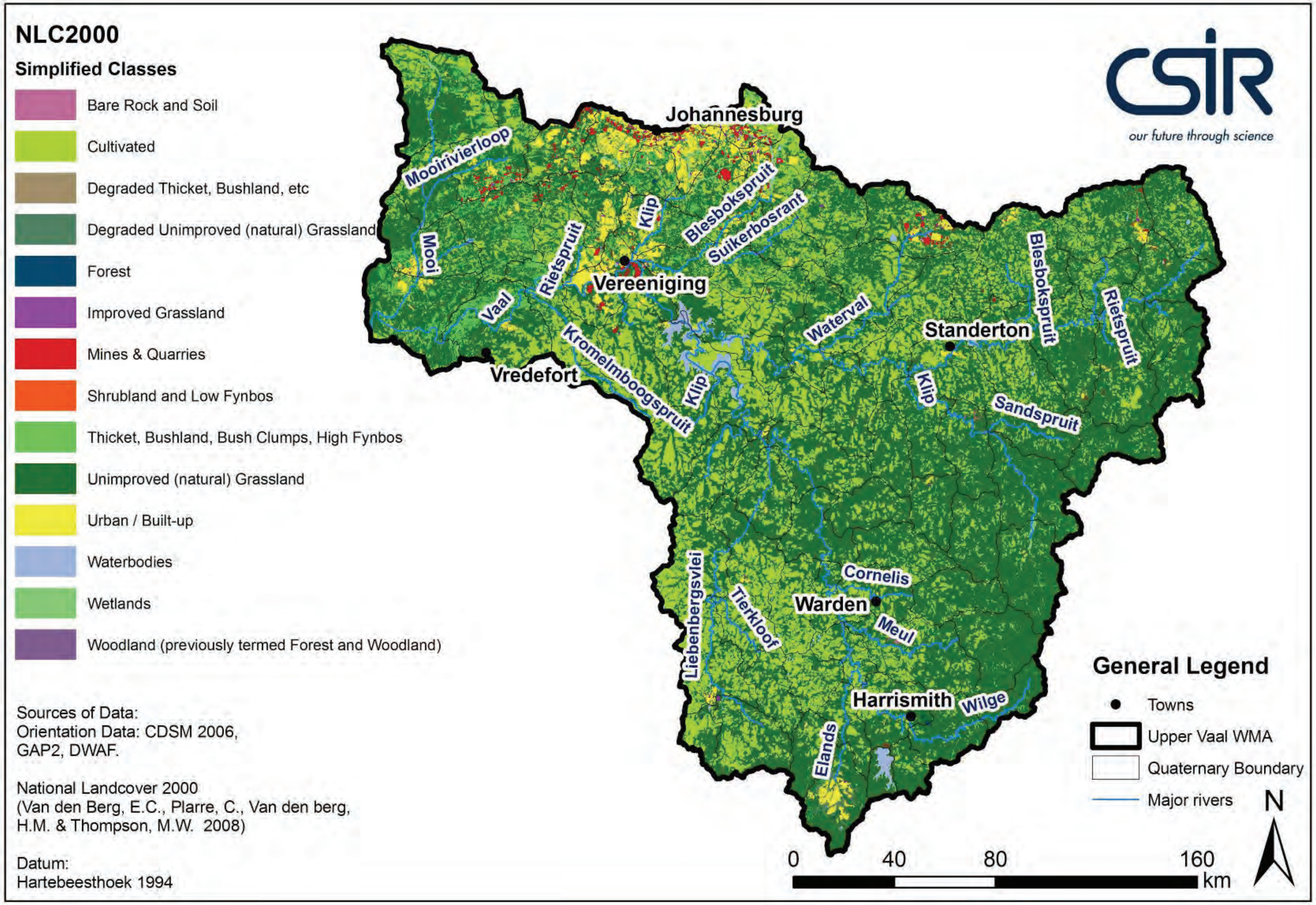

Figure 7-1. National Land Cover 2000 for the Upper Vaal WMA (Van den Berg, E.C., Plarre, C., Van den berg, H.M. & Thompson, M.W., 2008)

Table 7-5. National Land Cover linked to hazard rating. Chemistry variables linked to activities in the study area, shaded cells denote concentrations above the standard limit as per ***Table 7-3***

Hazard Rating	National Land Cover Type	Ave_F	Max_F	Ave_NO_3	Max_NO_3	Ave_SO_4	Max_SO_4	Ave_Mg	Max_Mg	Ave_Ca	Max_Ca
1	Cultivated, temporary, commercial, dryland	0.4	8.7	4	67	102	913	25	117	56	577
3	Cultivated, temporary, commercial, irrigated	0.1	0.8	2	45	180	814	28	131	59	245
1	Degraded Unimproved (natural) Grassland	0.2	0.2	0	1	2	2	8	9	29	30
1	Forest Plantations (Pine spp)	0.1	0.2	2	10	13	30	18	27	27	47
1	Improved Grassland	0.3	0.6	6	26	187	578	49	102	70	146
4	Mines & Quarries (mine tailings, waste dumps)	0.1	0.6	1	18	222	706	57	110	84	207
4	Mines & Quarries (surface-based mining)	0.6	2.6	0	1	34	205	7	26	49	321
4	Mines & Quarries (underground / subsurface mining)	0.1	0.4	1	9	215	885	44	97	66	217
0	Thicket, Bushland, Bush Clumps, High Fynbos	0.1	1.1	3	93	94	1425	36	216	58	340
0	Unimproved (natural) Grassland	0.2	4.0	4	134	141	1274	33	176	59	299
2	Urban / Built-up (residential)	0.4	1.3	5	8	61	75	37	40	78	90
2	Urban / Built-up (residential, formal suburbs)	0.3	2.3	3	18	83	679	30	116	60	208
3	Urban / Built-up (residential, formal township)	0.1	0.3	2	12	58	531	27	100	34	168
3	Urban / Built-up (residential, informal squatter camp)	0.1	0.1	6	7	287	298	77	91	85	109
3	Urban / Built-up (residential, informal township)	0.2	0.4	1	2	5	9	8	15	20	36
2	Urban / Built-up (smallholdings, grassland)	0.2	1.7	3	62	97	1679	30	234	47	399
3	Urban / Built-up, (commercial, education, health, IT)	0.1	0.4	1	2	7	12	21	30	28	40
3	Urban / Built-up, (commercial, mercantile)	0.4	0.4	0	0	17	17	30	30	41	41
4	Urban / Built-up, (industrial / transport : heavy)	0.4	1.0	4	8	65	120	28	55	50	87
4	Urban / Built-up, (industrial / transport : light)	0.3	0.8	0	0	418	533	55	75	167	212
0	Wetlands	0.1	0.3	6	69	219	1013	48	247	76	395
	(blank)/Unclassified	0.4	1.3	3	14	70	280	37	67	62	102

Table 7-6. Dominant land use (%) as per the NLC classification in the Upper Vaal WMA

GRU	Thicket, Bushland, Bush Clumps, High Fynbos	Unimproved (natural) Grassland	Improved Grassland	Waterbodies	Wetlands	Cultivated, temporary, commercial, irrigated	Cultivated, temporary, commercial, dryland	Urban / Built-up (residential, formal suburbs)	Urban / Built-up (residential, formal township)	Urban / Built-up (residential, informal township)	Urban / Built-up (smallholding, grassland)	Mines & Quarries (mine tailings, waste dumps)
1	0.93	65.41	0.09	2.77	0.75	0.03	21.97	0.07	0.21	2.47	1.03	0.00
2	0.65	67.77	0.03	0.47	0.91	1.51	27.85	0.14	0.13	0.01	0.00	0.00
3	0.77	74.43	0.01	0.27	0.62	0.99	22.46	0.07	0.08	0.01	0.00	0.00
4a	0.60	71.66	0.14	0.81	0.92	0.40	22.82	0.48	0.17	0.18	0.23	0.23
4b	1.39	51.67	0.06	5.13	0.62	1.50	37.03	0.62	0.34	0.09	0.87	0.09
5a	7.60	72.54	0.00	0.21	0.61	0.50	18.45	0.00	0.00	0.00	0.00	0.00
5b	9.07	58.56	0.45	0.49	2.47	1.92	13.90	2.94	2.27	0.55	2.16	1.82
6a	8.26	24.11	2.35	1.55	4.46	0.19	8.35	19.43	6.79	0.93	3.73	5.94
6b	4.85	57.37	0.38	0.65	1.15	1.89	24.00	1.86	0.61	0.09	3.47	0.25
7	13.52	44.97	0.23	0.23	2.63	12.17	25.12	0.18	0.25	0.00	0.00	0.00
8	19.40	62.51	0.05	1.19	0.60	0.26	14.38	0.52	0.54	0.00	0.00	0.04
9	9.35	61.63	0.07	0.47	0.88	0.65	19.23	0.82	2.09	0.44	2.26	0.54

The remainder of the land cover is made up of: forest plantations (Eucalyptus, Pine, Acacia and mixed spp.); bare rock and soil (natural, erosion dongas and gullies); degraded unimproved (natural) grassland; cultivated, temporary, subsistence, dryland agriculture; urban/ built-up (residential, mixed, hostels, education, health, IT, informal squatter camp, commercial, mercantile, industrial (heavy and light transport) and mines and quarries (underground and surface-based mining).

7.3 Historical Trends in Chemical Data

All chemistry data for the Upper 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 would give 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.

7.3.1 GRU 1

Contains 22 boreholes of which only one borehole has time series data which spans the period 1996 to 2007. No data are available for pH values at this station. The TDS for GRU 1 (**Figure 7-2**) shows an overall slight decreasing trend for the last decade.

BH number	No. of records	Period	Geology	Land Cover
89927	19	1996-2007	Karoo Dolerite	Unimproved natural grasslands

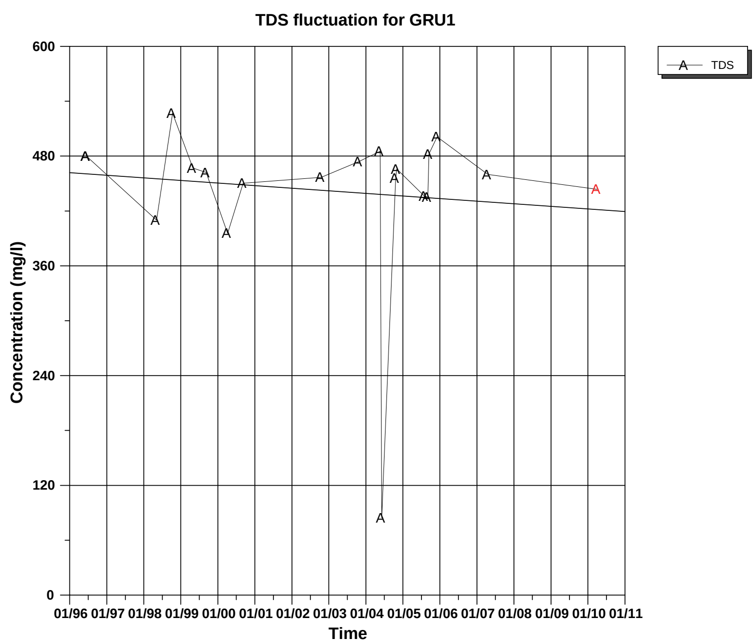

Figure 7-2. TDS changes over time for GRU1

7.3.2 GRU 2

GRU 2 contains 24 boreholes of which one borehole has time series data that spans the period 2000 up to 2007. TDS and pH were plotted for this borehole as an indication of changes within the area over time. The TDS values (**Figure 7-3**) show an overall decline from 2000 up to 2008. The pH levels (**Figure 7-4**) show an overall increase with time.

BH number	No. of records	Period	Geology	Land Cover
177412	13	2000-2007	Normandien Formation	Urban Built up residential

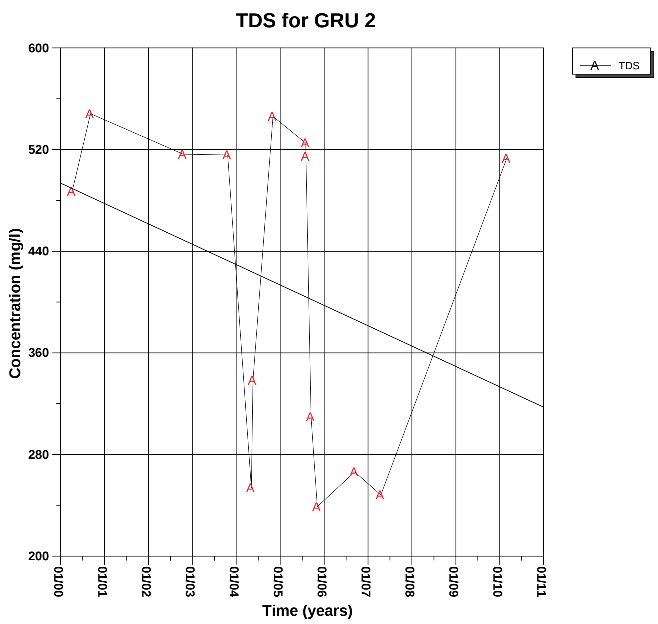

Figure 7-3. TDS fluctuation over time for GRU 2

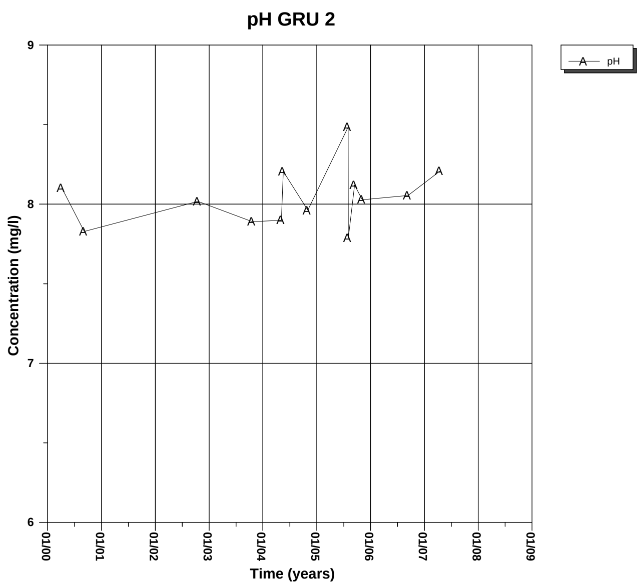

Figure 7-4. pH fluctuation over time for GRU 2

7.3.3 GRU 3

This GRU contains six boreholes, two of which have time series data ranging from 2000 to 2005. An overall decreasing trend occurs in the pH levels (**Figure 7-5**) for this GRU. Two boreholes with lengthy time series TDS data show an overall decline in TDS (**Figure 7-6**).

BH number	No. of records	Period	Geology	Land Cover
1000005917	5	2003-2005	Volksrust Formation	Unimproved natural grasslands
182738	5	2000-2005	Volksrust Formation	Unimproved natural grasslands

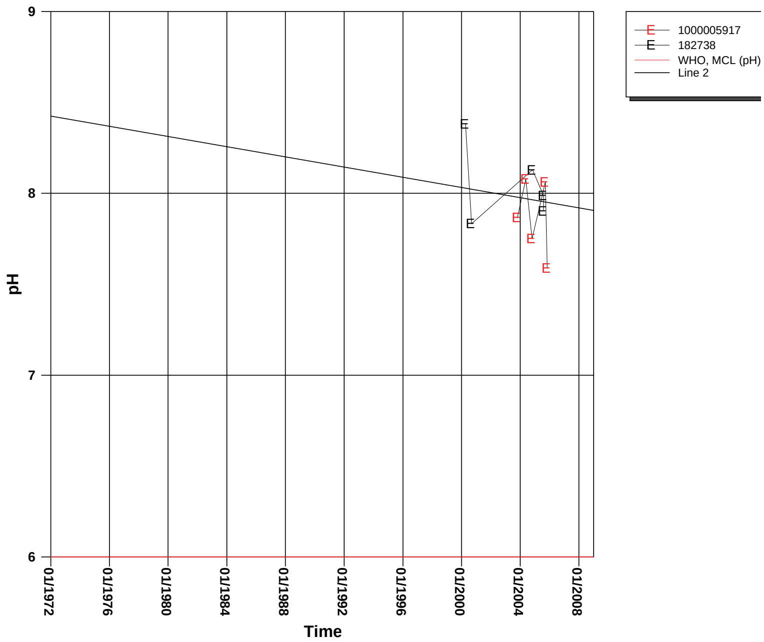

Figure 7-5. pH for GRU 3, data ranging from 2000 to 2008

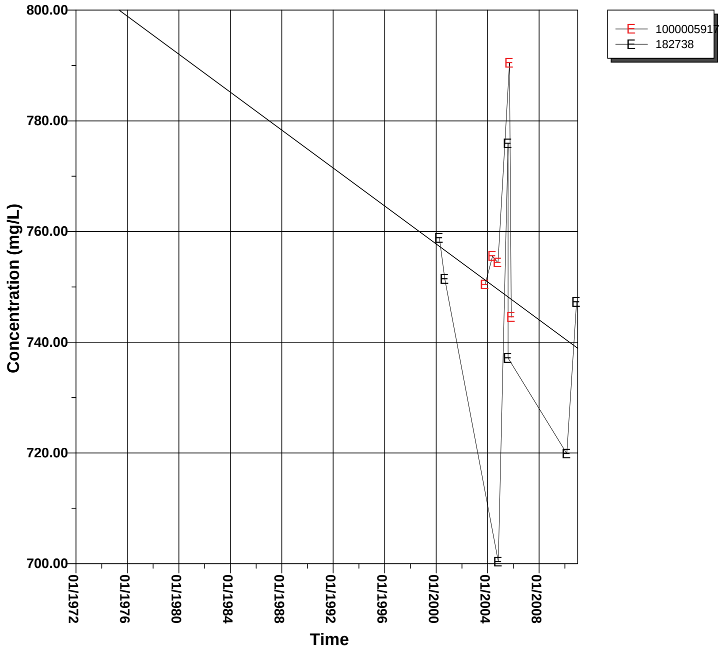

Figure 7-6. TDS trends for GRU 3 based on the borehole with the longest time series data

7.3.4 GRU 4a

This GRU contains 49 boreholes, of which only 2 have time series records. These records run from 1995 to 2008. Both these stations indicate similar increasing trends for pH and TDS (**Figure 7-7** and **Figure** 7-8).

BH number	No. of records	Period	Geology	Land Cover
89718	24	1995-2006		
90100	23	1995-2006	Volksrust Formation	Urban Built up residential

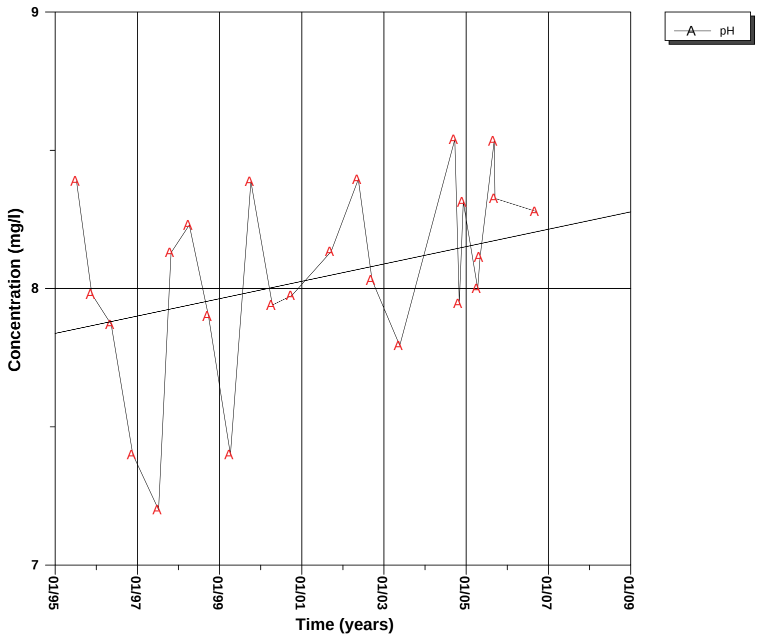

Figure 7-7. Trend of pH for GRU 4a

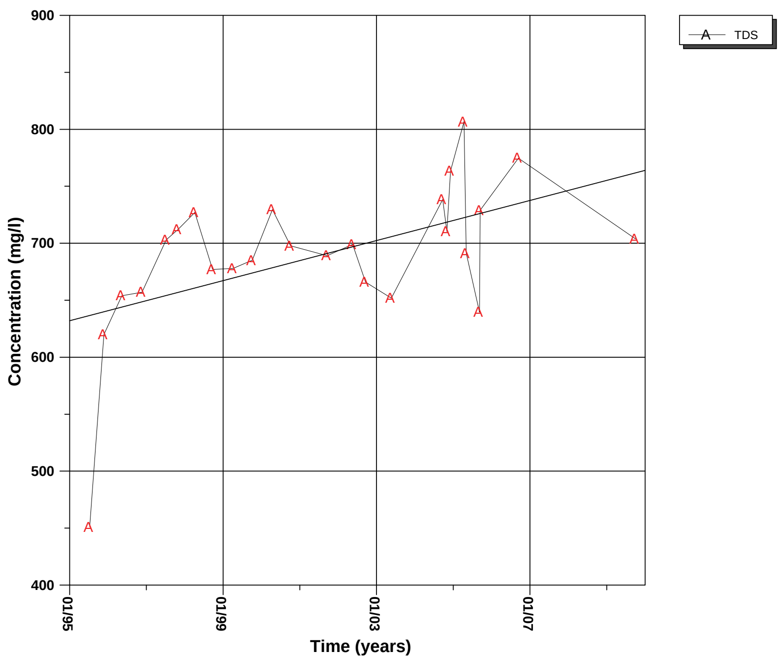

Figure 7-8. Trend in TDS for GRU 4a

7.3.5 GRU 4b

This GRU contains 34 boreholes and a total of 35 records. Hence no time series data is available for chemistry for this GRU.

7.3.6 GRU 5a

Contains 13 boreholes and a total of 52 records. Only one borehole has time series chemical data ranging from 1997 to 2003. **Figure 7-9** shows an overall decreasing trend in pH for GRU 5a.

BH number	No. of records	Period	Geology	Land Cover
90720	37	1997-2003	Monte Christo Formation	Unimproved natural grasslands

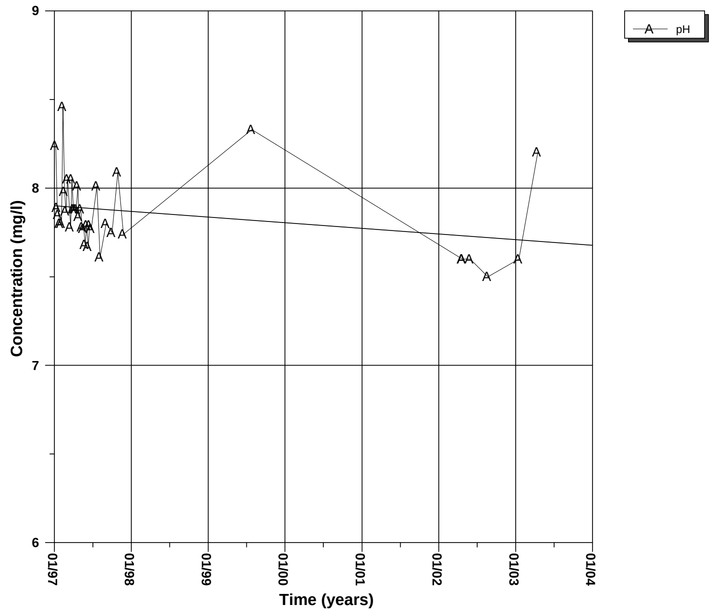

Figure 7-9. Trend of pH data for GRU 5a based on the longest time series record

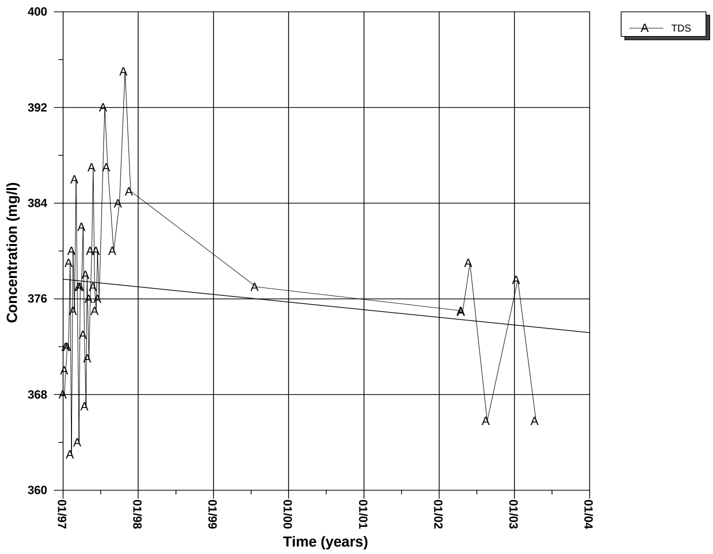

Figure 7-10. TDS trend for GRU 5a from 1997 up to 2003

Figure 7-10 shows an initial increase in TDS during the 1997/1998 period with an overall decreasing trend from then up to 2004.

7.3.7 GRU 5b

This GRU has 413 boreholes drilled in it and a total of 2168 records for these boreholes. Of the 413 boreholes, four have time series data that stretches over more than a decade, while other boreholes that have time series data have time series of less than five years, two boreholes were selected as representative of the varying trends in the GRU. The trend in pH is generally increasing with time.

BH number	No. of records	Period	Geology	Land Cover
165054	320	1985-1990	Malmani Subgroup	Cultivated temporary commercial
88876	30	1981-1985	Malmani subgroup	Unimproved natural grasslands
89825	14	1997-2007	Malmani Subgroup	Unimproved natural grasslands
90621	307	1979-2008	Malmani Subgroup	Bushveld, thicket, high fynbos
90622	323	1969-2008	Malmani Subgroup	Unimproved natural grasslands
90635	341	1978-2001	Malmani Subgroup	Unimproved natural grasslands

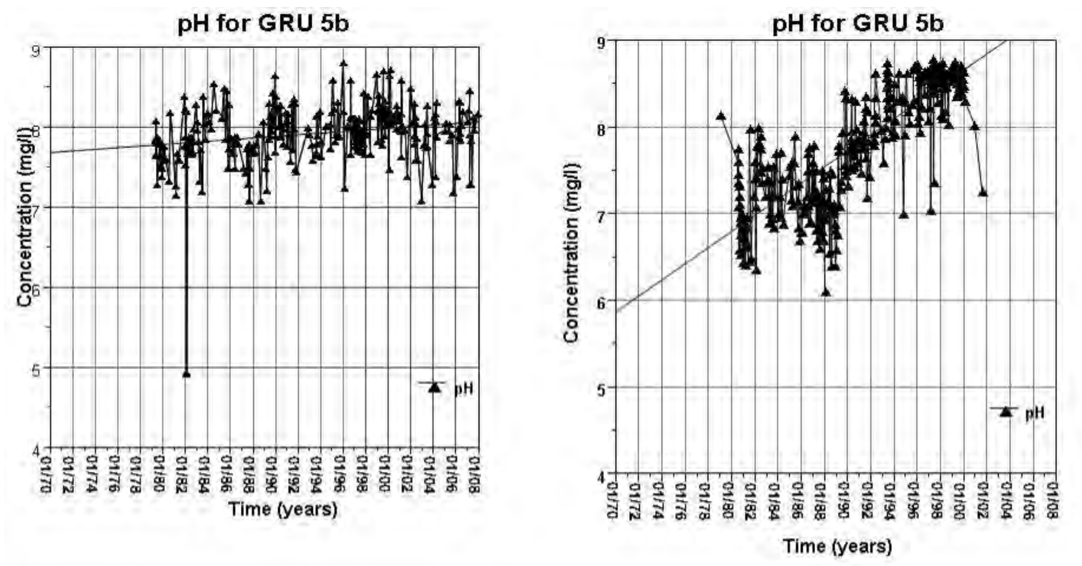

Figure 7-11. pH trends for two boreholes with the longest time series data in GRU 5b

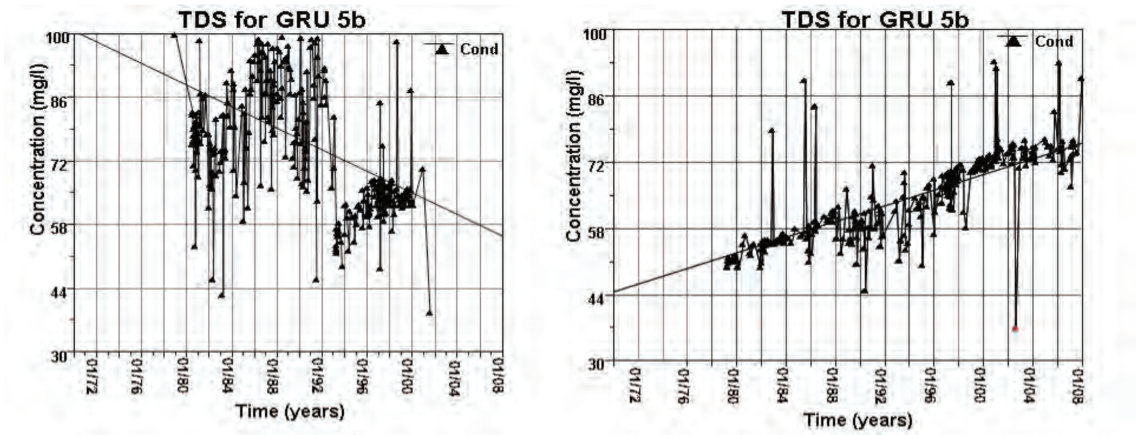

Figure 7-12. TDS trends for two boreholes with the longest time series data in GRU 5b

7.3.8 GRU 6a

Contains 25 boreholes with a total of 57 records. There are two boreholes with time series data ranging over two years (1998-1999). A representative borehole was selected that reflects the trend in TDS (**Figure 7-13**) over a limited time period.

BH number	No. of records	Period	Geology	Land Cover
88770	12	1998-1999	Klipriviersberg Group	Unimproved natural grassland
88771	12	1998-1999	Vryheid Formation	Urban built up industrial

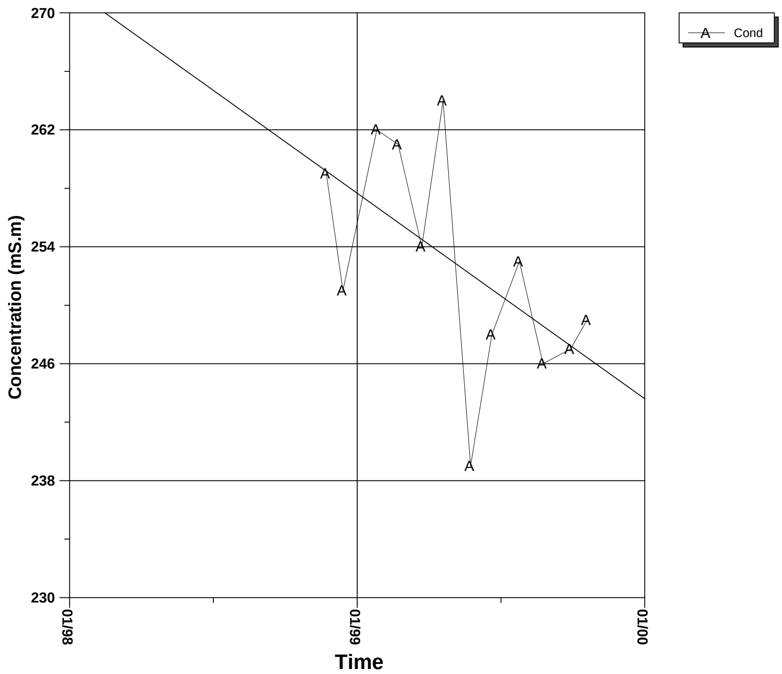

Figure 7-13. Salinity as an indicator of trend in water quality for GRU 6a based on two years of data

7.3.9 GRU 6b

This GRU contains 118 boreholes with a total of 226 records. Two points have time series data; one (BH 88854) ranging from 1984 to 1990, while the other (89981) ranges from 1997 to 2008.

BH number	No. of records	Period	Geology	Land Cover
88854	60	1984-1990	Klipriviersberg Group	Unimproved natural grasslands
89981	23	1997-2009	Alluvium	Unimproved natural grasslands

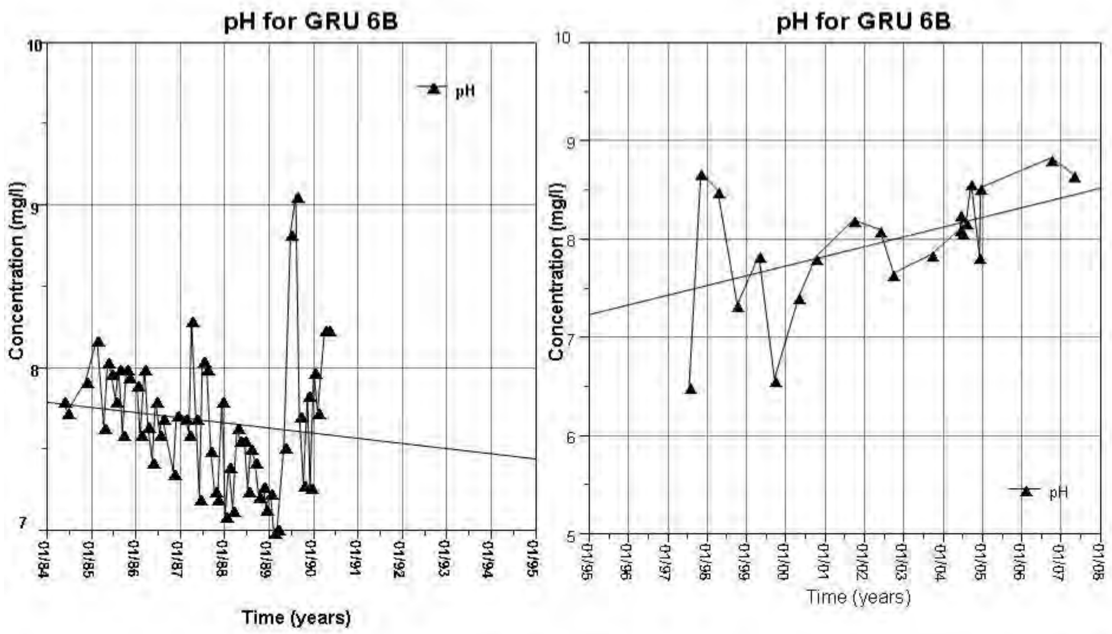

Figure 7-14. Trend in pH based on the longest available time series data in GRU 6b

It appears that some boreholes show an increasing trend in pH while others show a decreasing trend (**Figure 7-14**). This may be due to varying levels of impact at the specific location of the boreholes.

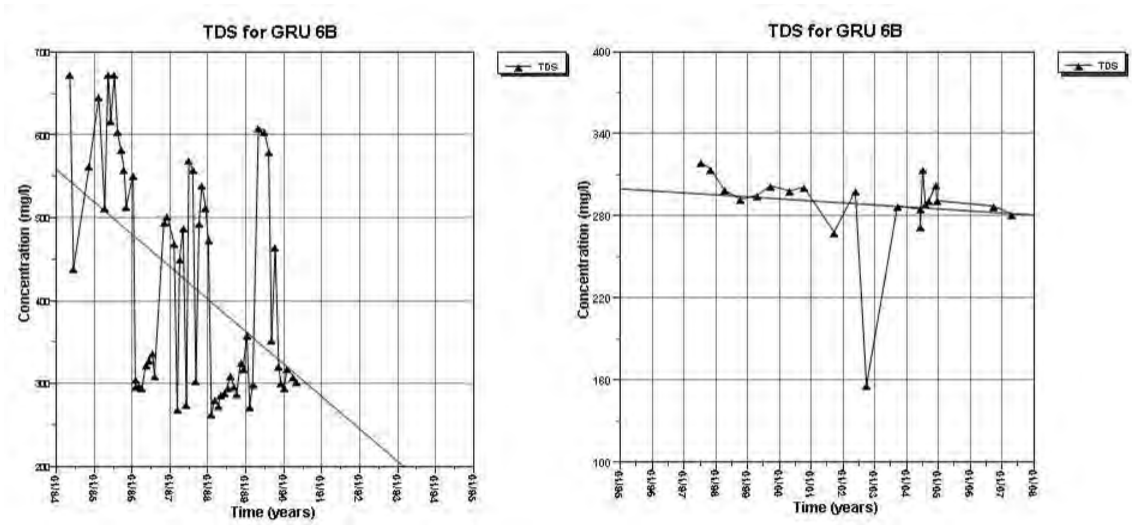

Figure 7-15. Trend in TDS for selected boreholes for the historical record of sampling for GRU 6b

An overall decreasing trend in TDS (**Figure 7-15**) occurred for GRU 6b for the duration of the sampling record.

7.3.10 GRU 7

Contains 8 boreholes of which only one has a time series record ranging from 2000 to 2007.

BH number	No. of records	Period	Geology	Land Cover
182744	14	2000-2009	Hekpoort Formation	Thicket, bushland, Fynbos

An overall slightly increasing trend in both pH (
Figure 7-16) and TDS (**Figure 7-17**) occurs at this position.

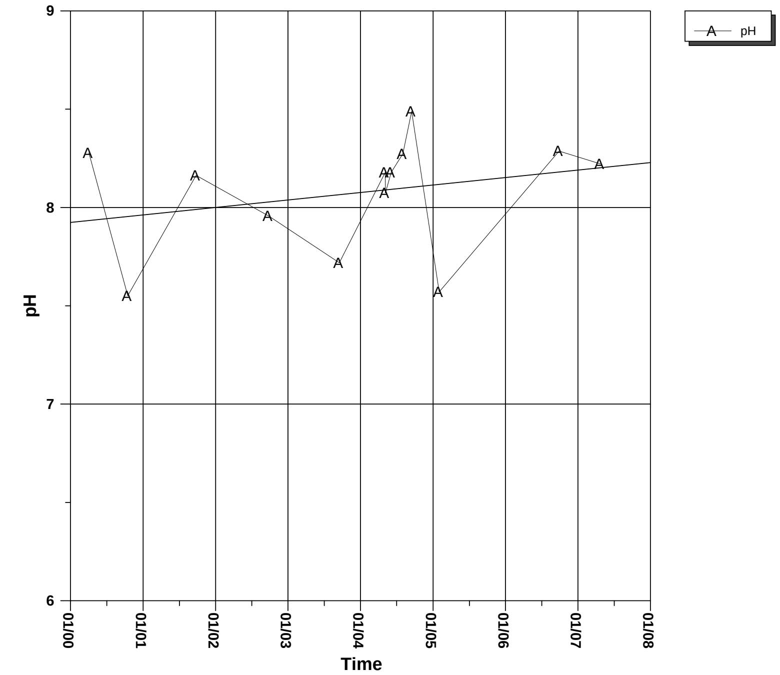

Figure 7-16. Trend in pH for GRU 7 based on one borehole with long-term data

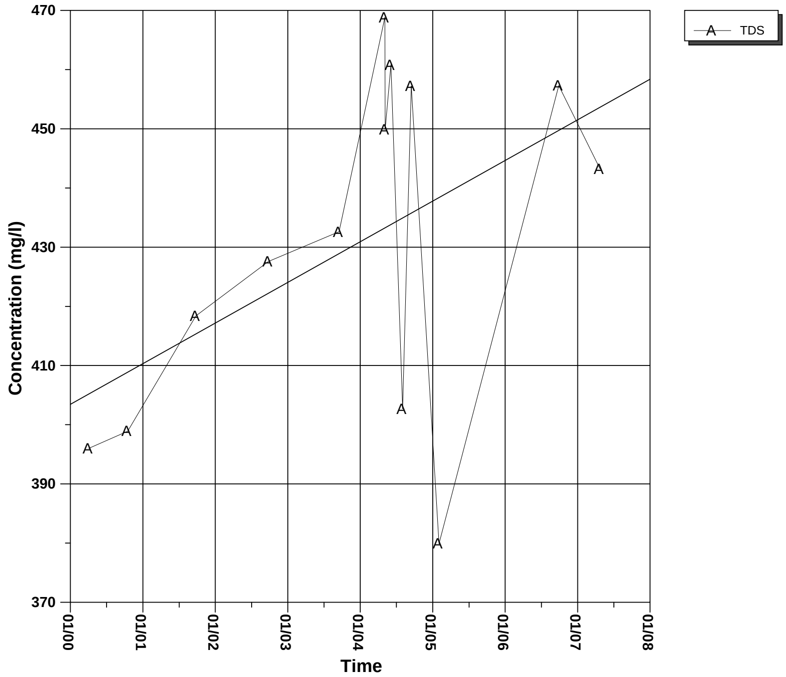

Figure 7-17. Trend in TDS for GRU 7 using borehole with long time series data

7.3.11 GRU 8

Contains 36 boreholes with 65 records in total. Only one of these has long-term time series data ranging from 1995 to 2007.

BH number	No. of records	Period	Geology	Land Cover
89686	24	1995-2009	Inlandsee Leocogranophyre /Gneiss	Unimproved natural grasslands

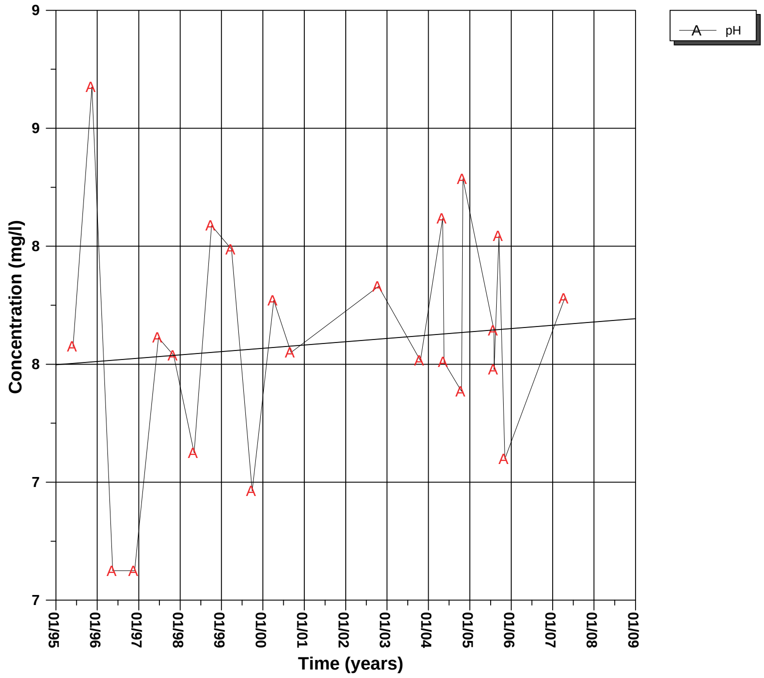

Figure 7-18. Trend in pH for long-term time series data ranging from 1995-2009.

An overall increasing pH trend (**Figure 7-18**) occurred for the borehole with long-term data in GRU 8, while TDS shows an overall decreasing trend (**Figure 7-19**).

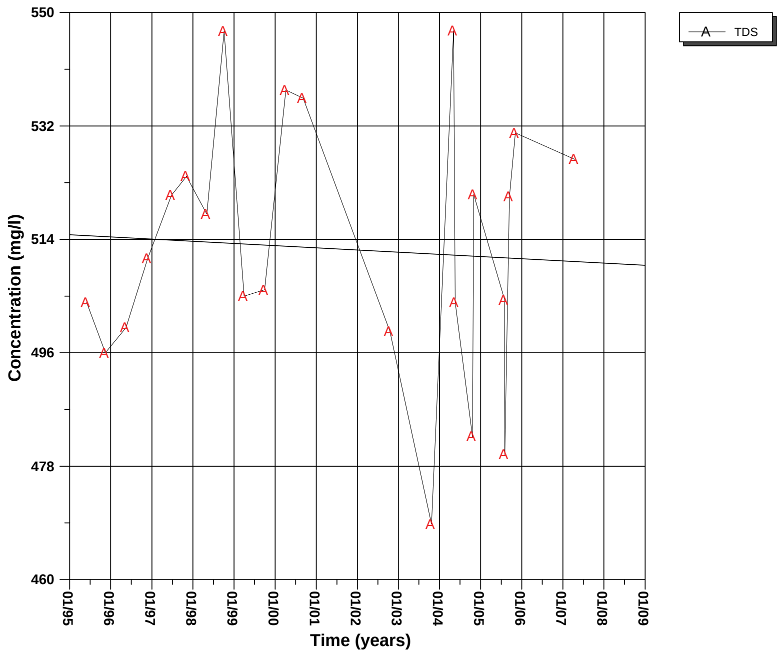

Figure 7-19. Trend in TDS for long-term time series data ranging from 1995-2009.

7.3.12 GRU 9

This GRU contains a total of 85 boreholes with a total of 429 records. Only station 90641 has a long-term time series record and more than 200 records. The borehole shows an overall increasing trend in pH (**Figure 7-20**) and an overall decreasing trend in TDS (**Figure 7-21**) over the 9-year sampling record.

BH number	No. of records	Period	Geology	Land Cover
90641	222	2000-2009	Timeball Hill Formation	Unimproved natural grasslands

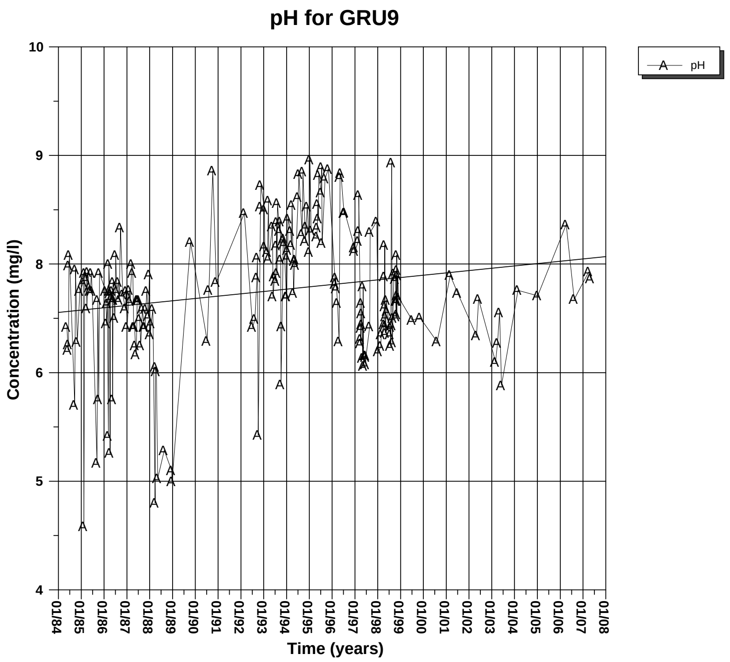

Figure 7-20. Trend in pH over a 9-year time series record for borehole 90641 in GRU 9

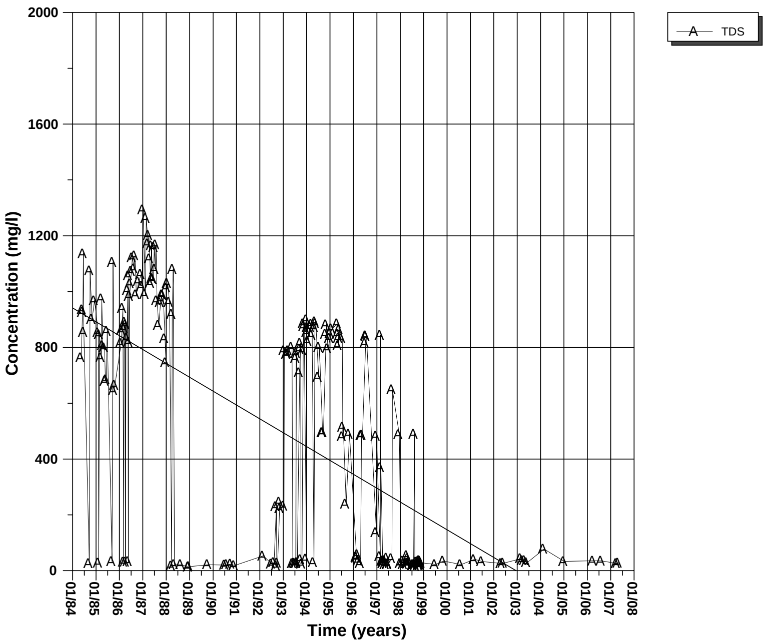

Figure 7-21. Trend of TDS for GRU 9 based on a 9-year sampling record at station 90641.

7.4 Microbiological Sampling

Due to the paucity of existing data for the area, sampling was undertaken at DWA ZQM stations monitored as indicators of background chemistry. Extreme care was exercised when sampling to ensure that contamination of the sample did not occur. Where groundwater was sampled from village taps and water outlets, this was taken into consideration while sampling and when interpreting the results. Most samples were collected from wind pumps, taps and installed pumps at village boreholes, so no pumps were required. Sterile sample bottles were used for every sample collected.

The selected sites were situated in close proximity of potential pollution sources to the local groundwater. The tap/pump was allowed to run for 5 to 10 minutes before sampling. Only taps at the well head were sampled where possible. There were cases where no access was possible where taps at a distance were sampled. The end of the pipe was held away from the sample bottle while the sample was being taken. It was not allowed to touch the sample bottle. The cap was replaced on the sample bottle immediately and tightened well. The recommended sample volume was used. No preservatives were added to the sample. The tightly closed and properly labelled sample bottle was placed immediately in a cool box with ice. The cool box was kept out of direct sunlight. The samples were delivered to the laboratory within 6 hours. Samples were kept on ice up to the time of delivery to the laboratory.

Field data recorded at each sampling site is presented together with a brief description of each site in the following sections.

7.4.1 Station ZQMDBY1

This station is a borehole located on the property of the grain silo at Derby. The sampling point is an irrigation spout located some 75 m from the borehole. Land use in the vicinity comprises the urban residential area of the small town of Derby.

EC = 10.1 mS/m
pH = 6.12
T = 21.7 °C

7.4.2 Station ZQMBOO2

This station is also an irrigation spout on the grounds of the Primary School at Boons. The irrigation spout is fed from an elevated reservoir located some 100 m from the sampling position. The mouth of the irrigation spout had to be cleared of debris (pebbles) prior to the sample being taken.

EC = 51.4 mS/m
pH = 6.70
T = 24.3 °C

7.4.3 Station ZQMDSD2

This station is located in the Suikerbosrand Nature Reserve. The land cover in the area is natural savanna grasslands. Activities or land uses in the vicinity of the station include hotels, holiday accommodation, bush and shrubs, animals.

EC = 35 mS/m
pH = 6.77
T = 23.4 °C

7.4.4 Station ZQMSEC1

This station is situated at a nursery close to Secunda. Secunda/Sasol is situated downstream from the station. The town is about 2 km away, while informal settlements are situated 10 km away. There is also mining activity up stream. The sample was collected at a tap connected to a constantly pumping borehole. The tap is about 20 m away from the actual borehole.

EC = 95.7 mS/m
pH = 6.81
T = 20 °C

7.4.5 Station ZQMMGZ1

Located on private property, the borehole that represents this station is used as a town water supply. The dominant land use is a small town, residential properties, natural grasslands, and maize and potato farming. Flush toilets were present in this area, there are some areas of informal housing.

EC = 32.7 mS/m
pH = 6.87
T = 22.8 °C

7.4.6 Conclusion

Sampling stations ZQMDBY1 and ZQMBOO2 exhibit slightly elevated total coliform levels compared to the guideline values (**Table 7-7**). Station ZQMSEC1 reveals unacceptably high levels of both *E. coli* and Total coliform bacteria.

Table 7-7. Results of microbiological monitoring

Sampling point	Date	*E. coli*	Guideline	Total Coliform	Guideline	Laboratory
ZQMDBY1	03/03/2010	0	0	**22**	5	CSIR
ZQMBOO2	03/03/2010	**9**	0	**36**	5	CSIR
ZQMDSD2	04/03/2010	0	0	0	5	CSIR
ZQMSEC1	04/03/2010	**7300**	0	**10050**	5	CSIR
ZQMMGZ1	04/03/2010	0	0	0	5	CSIR
E. coli levels of >1 per 100 mL are unacceptable. Treatment-based guideline for Total Coliform is a maximum of 5 counts per 100 mL.						

7.5 Groundwater Chemistry per Tertiary Catchment

Whereas the assessment made in **section 3.2.5** is based on lithology, a similar assessment has also been carried out based on tertiary and quaternary catchment footprints. Land cover was considered as a grouping more specifically to evaluate impacts using more recent data. Data were subdivided into two periods to evaluate impact, i.e. pre-1985 for the delineation of reference conditions, and post-2000 for the delineation of recent conditions. Where post-2000 were not available, post-1990 data were used as proxy for more recent conditions.

7.5.1 Tertiary Catchment C11

Tertiary catchment C11 shows three distinct water types, namely Na-Cl, Na-HCO_3 (ostensibly dominant in C11H) and Ca-HCO_3 types (in C11C, C11D and C11E). A closer look at **Figure 7-22** indicates that the Na-Cl type water pre-dates 1985. It is postulated that this analysis represents a site- and incident-specific sampling episode. The more recent (post-1985) data reflects a variation between a Ca-HCO_3 and a Na-HCO_3 composition.

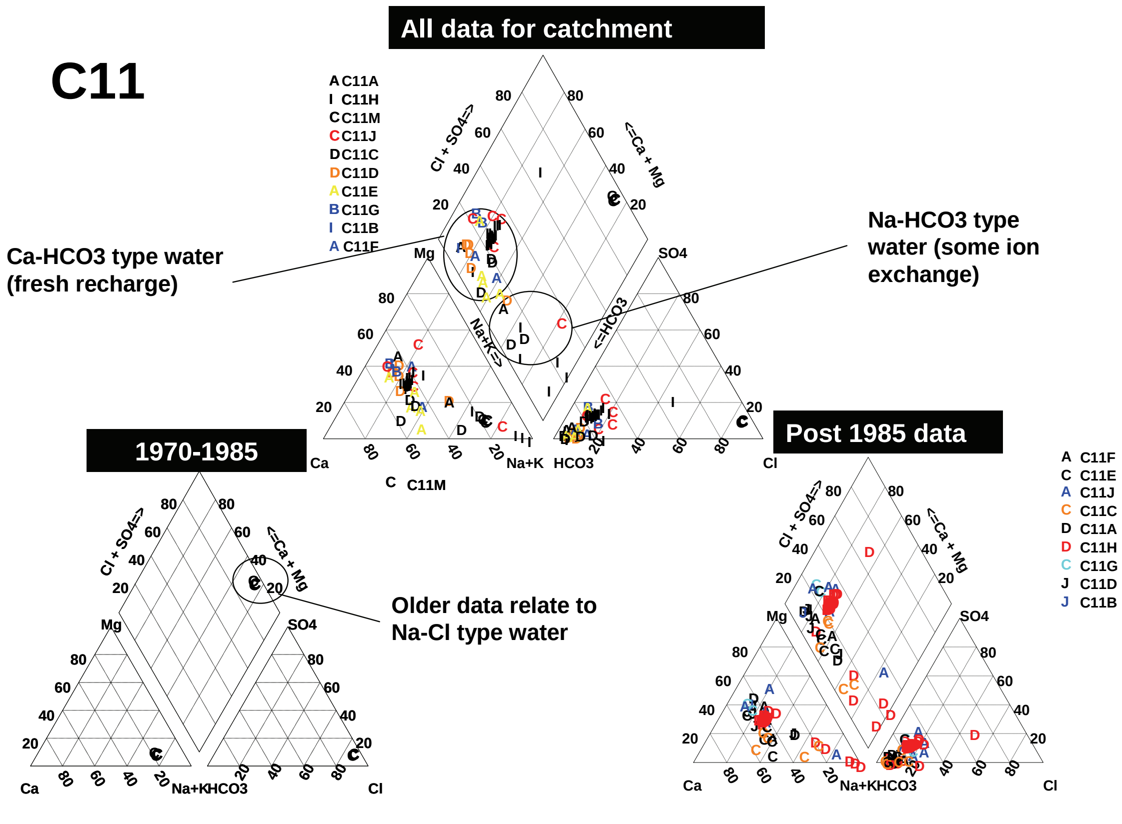

Figure 7-22. Trilinear diagram of groundwater chemistry for tertiary catchment C11. Quaternary catchments represented by colour-coded symbols

7.5.2 Tertiary Catchment C12

Catchment C12 shows predominantly Ca-HCO_3 type waters, with some evolution toward a more SO_4 rich composition in quaternary catchment C12D (**Figure 7-23**). The latter hosts the coal mining activities of Sasol Coal around Secunda, which provides an explanation for this water composition.

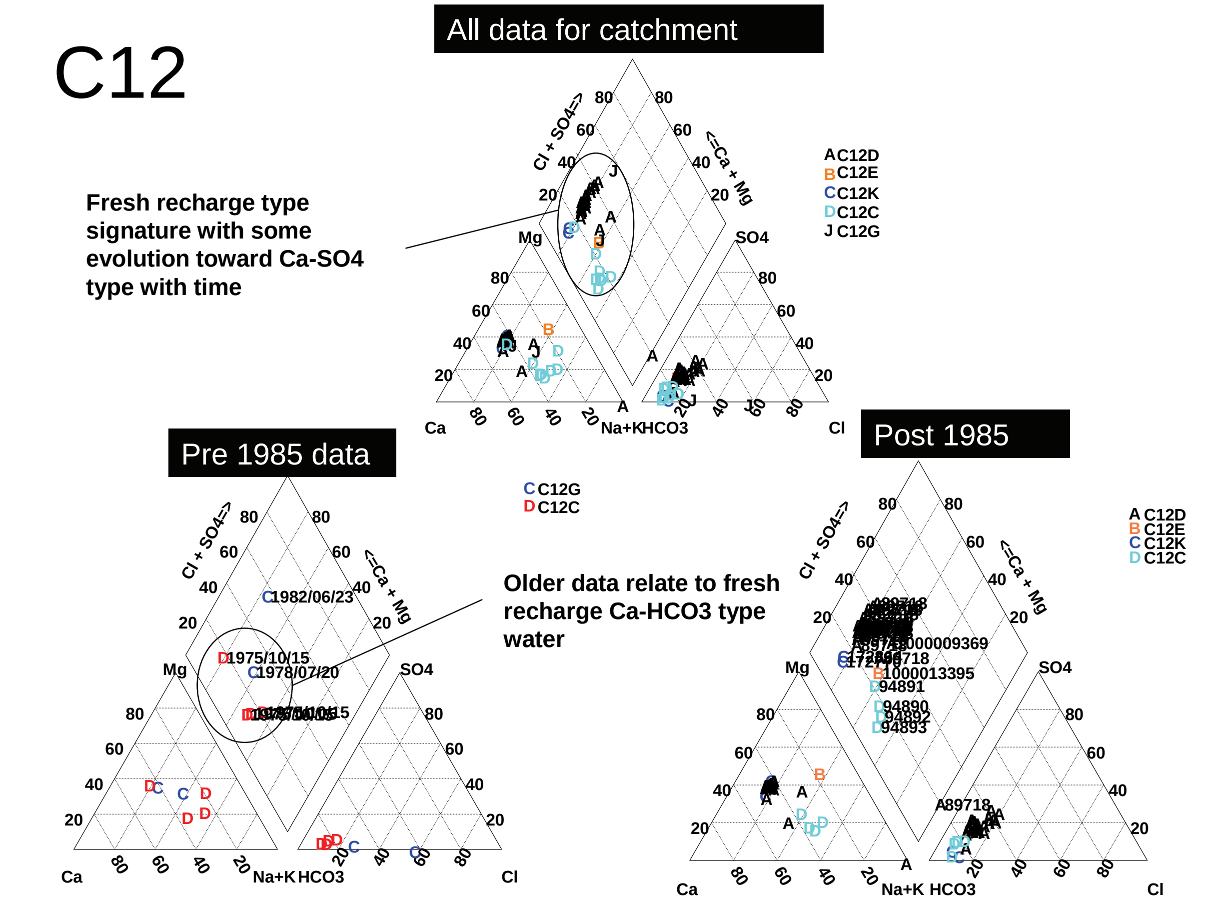

Figure 7-23. Trilinear diagram of groundwater chemistry for tertiary catchment C12. Quaternary catchments represented by colour-coded symbols

7.5.3 Tertiary Catchment C13

Tertiary catchment C13 shows a similar result with older data representing a Na-Cl type water, while more recent data shows a $Ca\text{-}HCO_3$ and $Na\text{-}HCO_3$ type water. There is also a limited amount of data for this catchment. This may be as a result of the data evaluation and screening process.

7.5.4 Tertiary Catchment C21

Secondary catchment C2 hosts much of the historic (defunct) and current gold mining activities in the study area. This suggests that the impacts of acid mine drainage might reasonably be expected to be manifested in this catchment in the form of low pH and elevated concentrations of Fe and SO_4. From a major inorganic chemistry perspective, such impacts are manifested as water with a very definitive $Ca\text{-}SO_4$ composition.

Figure 7-25 shows that both early and recent data for C21 shows the effects of acid mine drainage. One can also detect deterioration of some $Ca\text{-}HCO_3$ water with time toward more Ca-Mg-SO4 type water. The majority of the analyses, however, have the signature of fresh recharge with some ion exchange between Ca and Na.

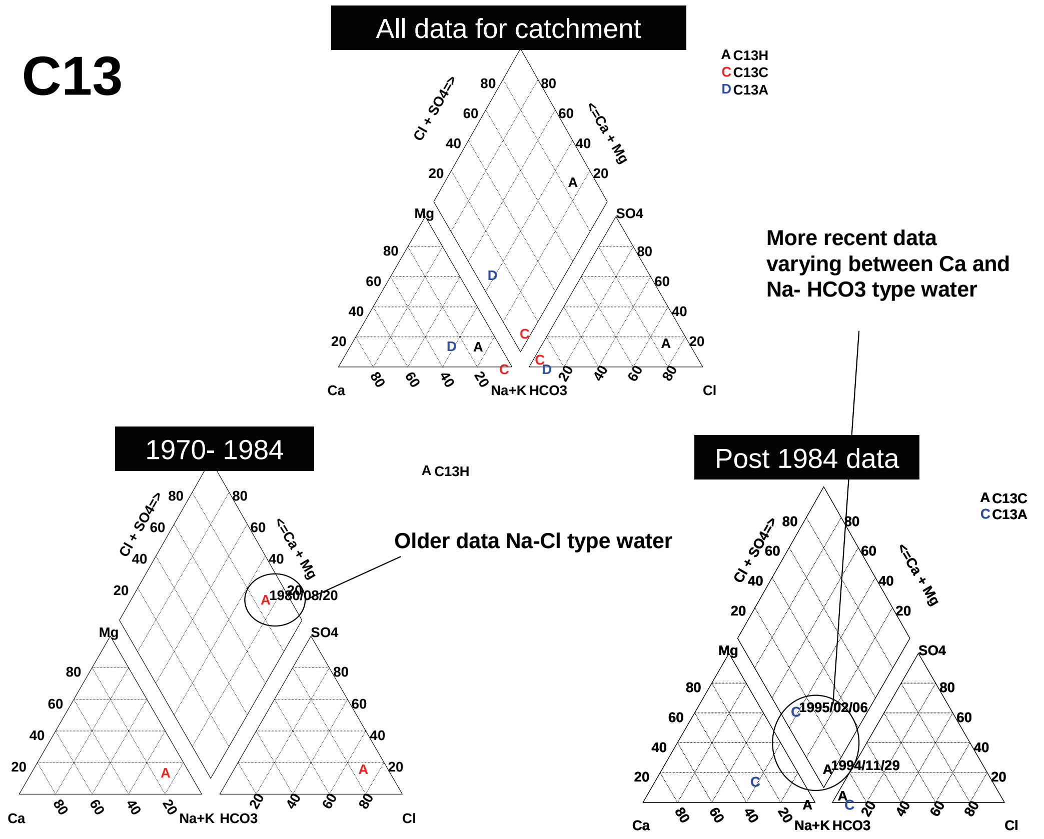

Figure 7-24. Trilinear diagram of groundwater chemistry for tertiary catchment C13. Quaternary catchments represented by colour-coded symbols

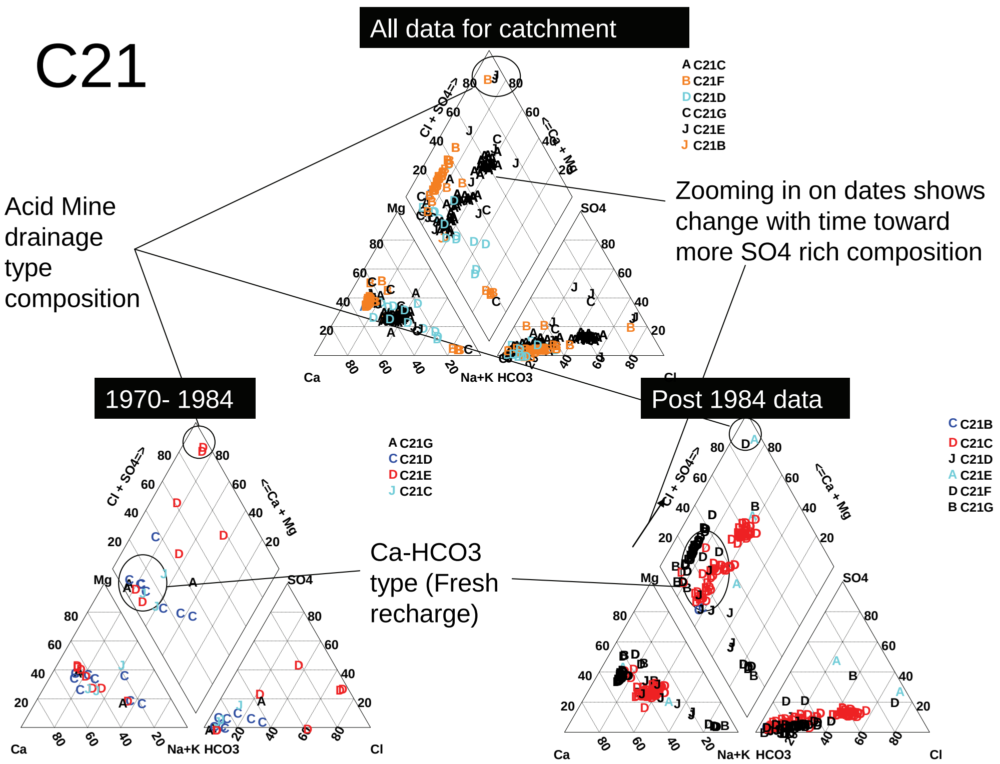

Figure 7-25. Trilinear diagram of groundwater chemistry for tertiary catchment C21. Quaternary catchments represented by colour-coded symbols

7.5.5 Tertiary Catchment C22

Catchment C22 appears to be significantly affected by acid mine drainage especially in more recent years. The pre-1985 data shows primarily Ca-HCO_3 and Mg-HCO_3 type waters, with some analyses reflecting a more Ca/Mg-SO_4 type water (**Figure 7-26**). The recent (post-1984) data also indicates the presence of a Na-Cl type water.

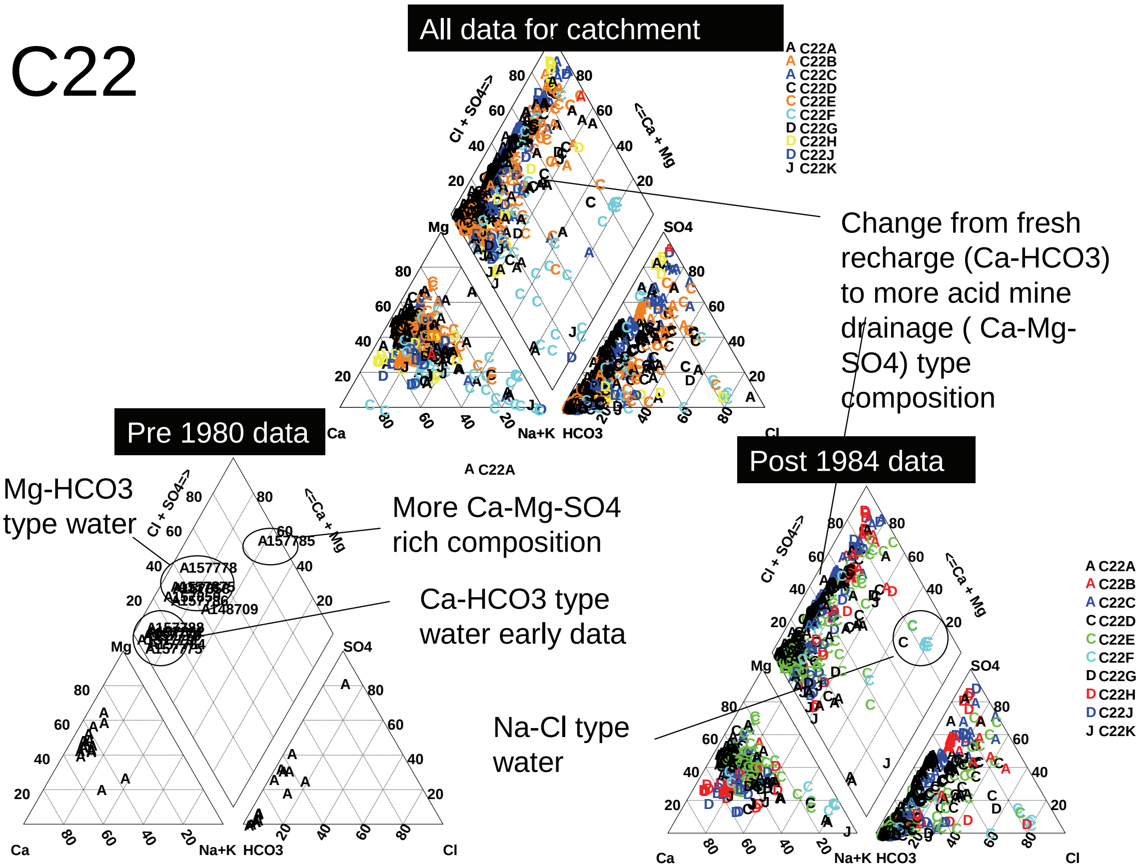

Figure 7-26. Trilinear diagram of groundwater chemistry for tertiary catchment C22. Quaternary catchments represented by colour-coded symbols

7.5.6 Tertiary Catchment C23

Catchment C23 shows a similarity in groundwater chemical composition to that of catchment C22. It would appear that the Ca-SO_4 composition associated with mine water is especially prevalent in quaternary catchments C23D, C23E and C23.

7.5.7 Tertiary Catchment C81

Figure 7-28 indicates that Tertiary catchment C81 is characterised only by analyses for 1972 and 1983. The data reflects a mostly Na-HCO_3 type water with a secondary Ca-HCO_3 composition also present.

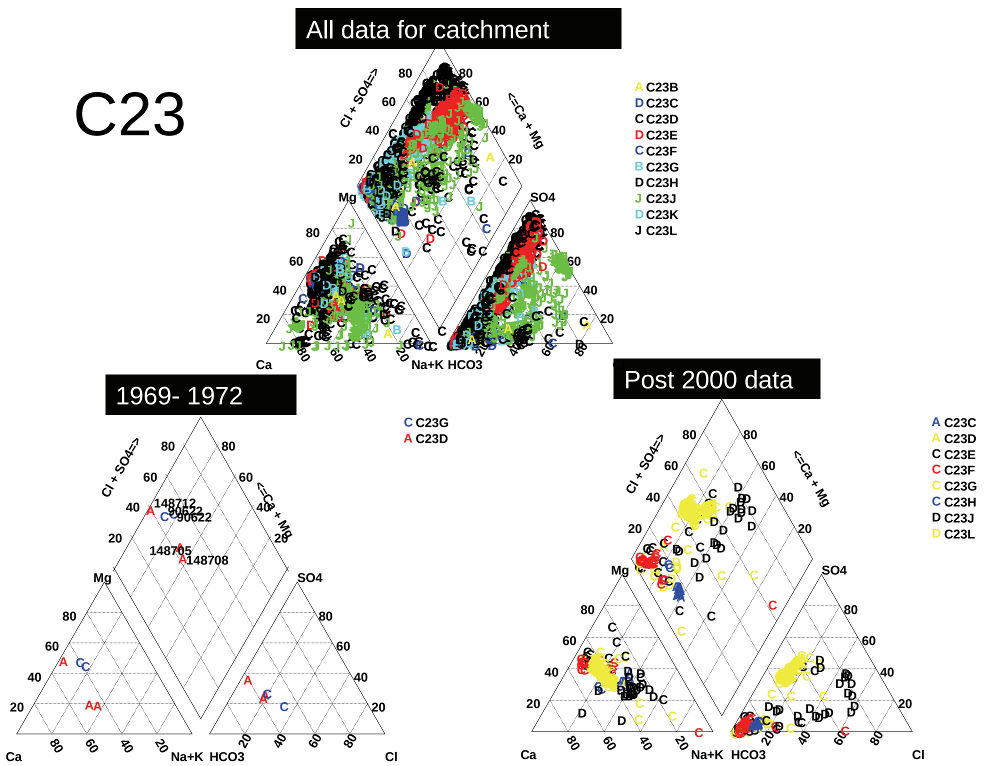

Figure 7-27. Trilinear diagram of groundwater chemistry for tertiary catchment C23. Quaternary catchments represented by colour-coded symbols

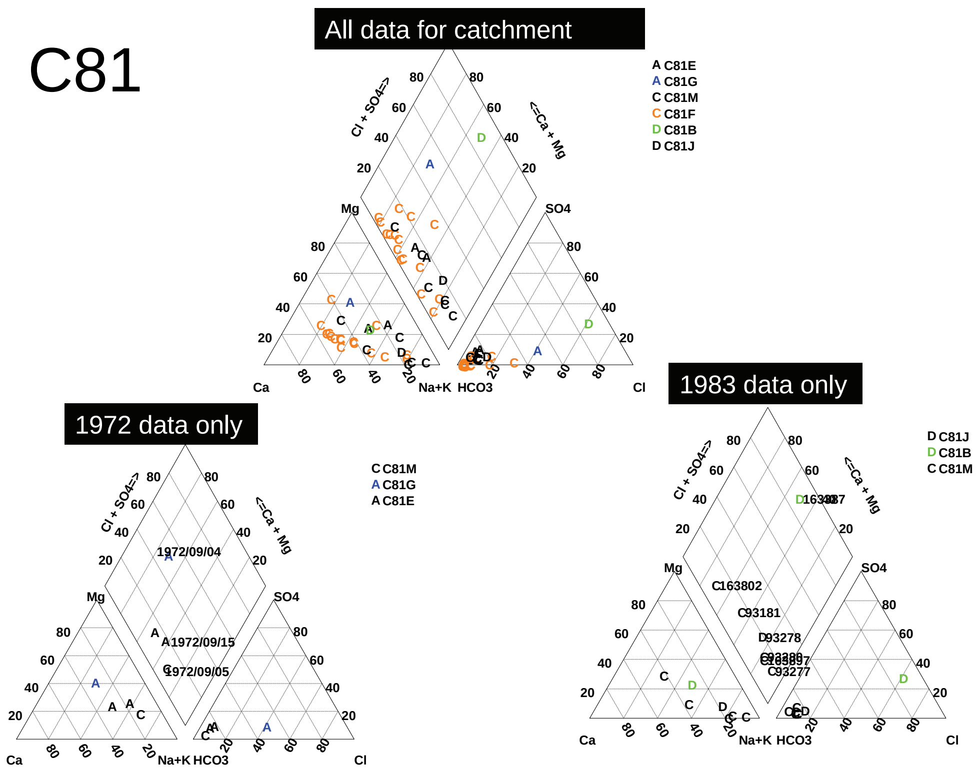

Figure 7-28. Trilinear diagram of groundwater chemistry for tertiary catchment C81. Quaternary catchments represented by colour-coded symbols

7.5.8 Tertiary Catchment C82

Groundwater data for C82 shows a similar trend of cation exchange for data collected during the 1970s and 1980s, while more recent data shows two distinct groupings of water type for two different quaternary catchments. These are predominantly Ca to Na HCO_3 and predominantly Mg-HCO_3 type waters. These could be linked to the geology in the specific areas and the data is from the recently (10-year time series) established "zqm" data set which monitors predominantly pristine conditions for aquifer systems.

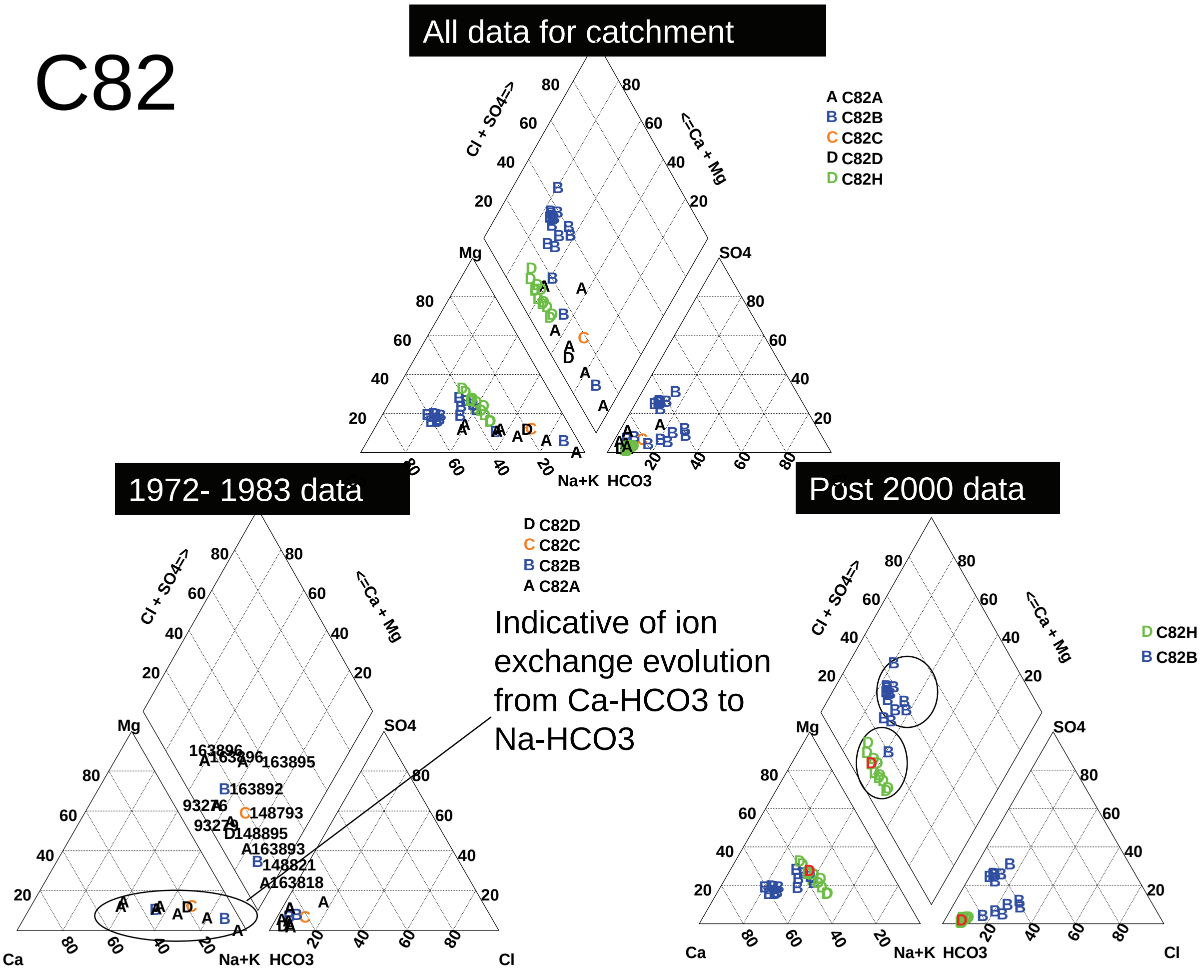

Figure 7-29. Trilinear diagram of groundwater chemistry for tertiary catchment C82. Quaternary catchments represented by colour-coded symbols

7.5.9 Tertiary Catchment C83

Tertiary catchment C83 shows a similar grouping of data collected during the 1970s and 1980s representing a typical cation exchange type signature, with water types varying from Ca-HCO_3 dominant to Na-HCO_3 dominant, while recent data shows Ca-HCO_3 and is a reflection of largely pristine groundwater quality in the catchment.

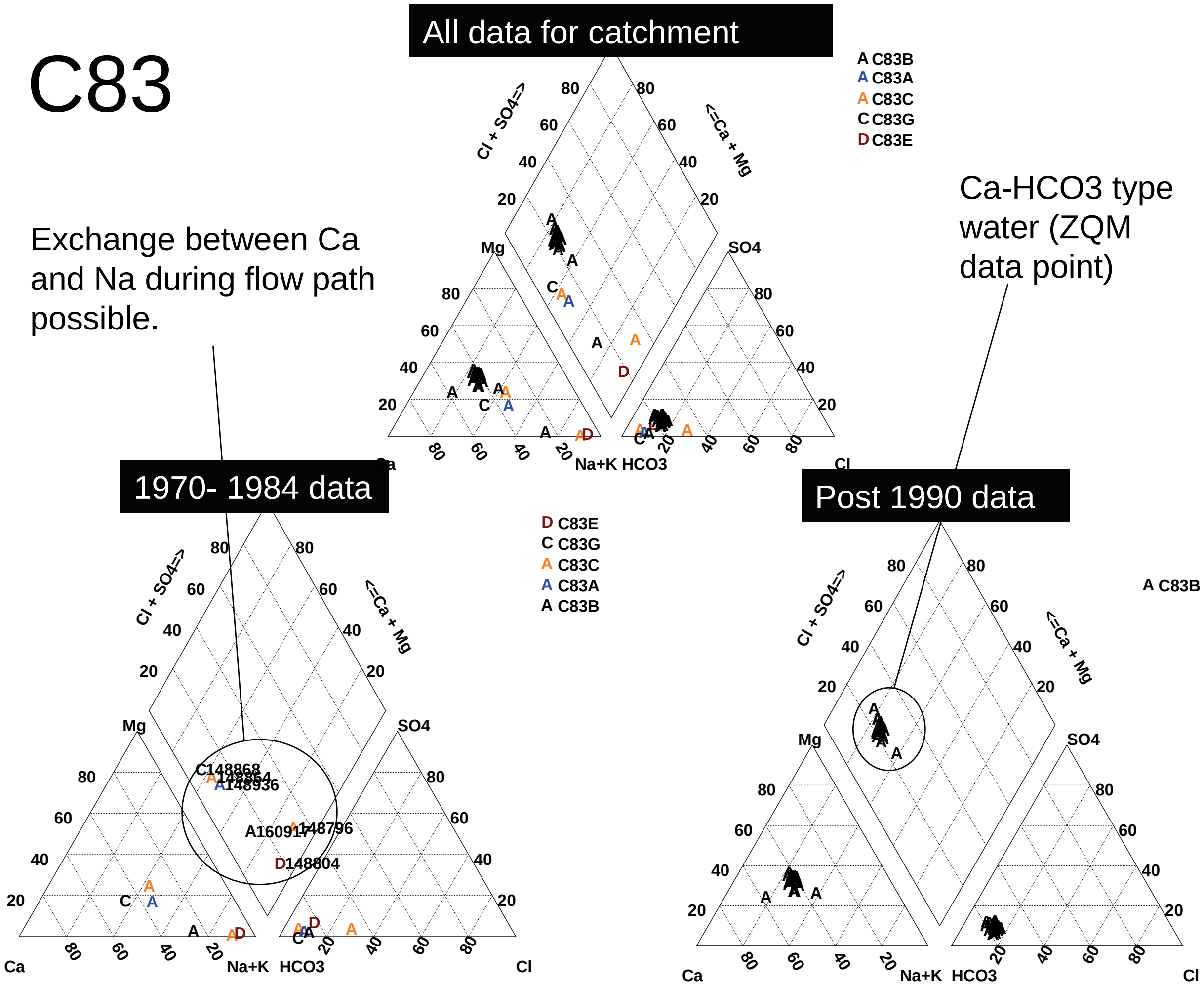

Figure 7-30. Trilinear diagram of groundwater chemistry for tertiary catchment C83. Quaternary catchments represented by colour-coded symbols

7.5.10 Summary Overview of Groundwater Quality per Tertiary Catchment

The information presented in **Table 7-8** summarises the range of concentrations associated with specific variables in each Tertiary catchment. The Tertiary catchment level was used because certain quaternary catchments lacked sufficient data for a statistically robust evaluation.

Table 7-8. Minimum, median and maximum concentrations of variables per Tertiary catchment for the Upper Vaal WMA; bold and underlined values denote exeedance of SANS (2011a) health-related limit

Tertiary Catchment (# of samples)	Concentration Ranges for Selected Variables per Tertiary Catchment (columns represent Min-Median-Max. respectively, inclusive of natural and impacted data points)														
	pH			EC (µS/cm)			SO_4 (mg/L)			NO_3 (mg/L as N)			F (mg/L)		
C11 (64)	5.2	8.0	8.6	16.9	76.1	801	4	50.8	198	0.02	2.8	**71**	0.1	0.33	**8.4**
C12 (40)	7.2	7.9	8.5	21.4	80.6	108	2	76.6	142	0.04	3	14.3	0.05	0.28	1.3
C13 (3)	8.1	8.1	8.3	30.4	31.5	328	2	11	298	x	x	x	0.47	0.74	1.3
C21 (127)	6.2	7.7	**9.8**	5.3	48.1	419	2	21.7	**554**	0.02	0.28	**69.3**	0.05	0.34	**3.5**
C22 (532)	x	X	x	3.8	46.6	525	2	24.4	**1679**	0.02	1.2	**134**	0.05	0.12	**2.6**
C23 (2412)	**4.0**	7.8	**12.3**	2.1	66.8	590	2	120.4	**913**	0.02	1.7	**67.5**	0.05	0.13	**8.7**
C81 (27)	6.7	7.7	8.7	16.2	33.9	419	2	6.2	**617**	0.02	0.45	17.6	0.05	0.3	**4.2**
C82 (37)	7.5	8.0	8.9	22.2	60.1	90	7.2	21.2	112	0.02	0.47	5.4	0.1	0.493	**4**
C83 (30)	x	x	x	14.2	57.7	73	2	31.5	41	0.02	0.94	2.7	0.154	0.31	**2.3**

Table 7-8 shows the minimum, median and maximum concentrations of the variables pH, EC, SO_4, NO_3-N and F per Tertiary catchment. Bold underlined values denote values that exceed the SANS (2011a) health-related limit for the consumption of 2 L/d by a 60 kg person over a period of 70 years. The exceedances associated with Tertiary catchments C21, C22 and C23 are particularly evident and not unexpected under circumstances where these catchments host both active and defunct mining activities associated primarily with gold.

7.5.11 Acid Mine Drainage

The situation regarding the potential water quality impacts associated with the occurrence of acid mine drainage (AMD) in the Witwatersrand Goldfield is a clearly recognised concern of the DWA. This is demonstrated by the fast-tracked feasibility study for the long-term solution project managed by the Directorate Water Resource Planning Systems (D:WRPS). The concern, however, is primarily informed by the impact of AMD on the surface water quality of the Vaal River System below Vaal Dam. The only goldfield currently actively decanting is the West Rand Goldfield, the so-called Western Basin. This basin has discharged into quaternary catchment A21D of the Crocodile (West) and Marico WMA, a headwater catchment of the Crocodile River upstream of Hartbeespoort Dam, since late-August 2002. The receiving environment includes the carbonate strata (Malmani Subgroup dolomite) of the Zwartkrans Compartment, which supports a portion of the Cradle of Humankind World Heritage Site. These circumstances provide a real-time example of the potential impact of AMD on a karst aquifer, and the result is informative for similar circumstances that may develop elsewhere where AMD and karst groundwater resources share the subsurface environment. AMD losses to the karst aquifer from an influent (losing) surface drainage have been measured in the range 13 ML/d to ~35 ML/d. The data presented in **Table 7-9** characterise the chemical character of the treated (neutralised) AMD prior to its loss into the aquifer.

Table 7-9. Statistical analysis of AMD-impacted surface water chemistry ~6400 m downstream of the mine water source in the Western Basin (from Hobbs, 2011)

Variable	Statistical Parameter							SANS (2011a)[(1)]
	n	5%ile	Mean	Median	95%ile	Std. Dev.	CoV (%)	
pH ($-\log_{10}[H^+]$)	54	3.3	—	7.2	8.0	1.4	21.4	5.0-9.7
EC (mS/m)	52	86	**172**	**158**	**296**	76.3	44.4	<170
TDS (mg/L)	44	583	**1262**	**1150**	**2300**	602.8	47.8	<1200
Ca (mg/L)	53	108.0	**243.2**	**210.7**	**482.1**	123.3	50.7	n.s.
Mg (mg/L)	52	32.1	60.7	55.9	**109.2**	22.8	37.6	n.s.
Na (mg/L)	53	21.4	70.0	44.0	141.7	45.1	64.4	<200
K (mg/L)	52	1.3	4.1	3.8	7.1	2.3	56.2	n.s.
Cl (mg/L)	53	13.7	23.2	20.8	36.1	7.9	34.3	<300
SO_4 (mg/L)	52	295.0	**915.5**	**811.1**	**1847.6**	526.7	57.5	<500
HCO_3 (mg/L)	47	11.8	39.2	36.5	77.2	19.7	50.3	n.s.
NO_3+NO_2 (mg N/L)	47	0.60	1.15	0.98	2.04	0.6	49.5	<11
Fe (mg/L)	52	0.01	**2.68**	0.01	**10.11**	11.8	439.0	<2
Mn (mg/L)	52	0.01	**14.30**	**7.99**	**60.37**	19.3	134.8	<0.5
Al (mg/L)	53	0.01	**1.38**	0.09	**8.57**	3.0	217.4	<0.3
Electrical balance (%)	46	–8.2	1.1	0.8	12.8	8.5	737.2	±5

(1) Standard health-related limit for consumption of 2 L/d over 70 years by a 60 kg person
Bold text denotes value exceeds standard limit as described in note (1)

The karst groundwater in proximity to the losing surface water drainage is most recently (February 2012) characterised by the chemical compositions presented in **Table 7-10**. The sources of this karst groundwater are boreholes located within 300 m of the stream, and represent the chemistry after a decade of mine water discharge in the stream. Although a number of the karst groundwater chemistry variables exceed the SANS (2011a) standard health-related limit, the concentrations compared to that of the surface water reduce considerably with distance from the losing drainage.

Table 7-10. Comparison of recent AMD-impacted surface water chemistry and karst groundwater chemistry in proximity to a losing stream in the Western Basin (from Hobbs, in prep.)

Variable	**Source of Water**				**SANS (2011a)[(1)]**
	Surface water	**Karst groundwater (distance in metres from stream)**			
		~25 m	**~270 m**	**~290 m**	
Date of sample	20/02/2012	21/02/2012	05/09/2011	05/09/2011	—
pH (–$\log_{10}[H^+]$)	**2.8**	6.4	8.2	7.8	5.0-9.7
EC (mS/m)	**305**	**289**	**213**	**193**	<170
TDS (mg/L)	**3190**	**2789**	**1899**	**1752**	<1200
Ca (mg/L)	543	566	295	266	n.s.
Mg (mg/L)	—	145	123	115	n.s.
Na (mg/L)	—	92	87	82	<200
K (mg/L)	—	9	4.2	4.7	n.s.
Cl (mg/L)	—	34	41	52	<300
SO_4 (mg/L)	**2690**	**1870**	**1154**	**985**	<500
Alkalinity (mg $CaCO_3$/L)	—	53	152	182	n.s.
Acidity (mg $CaCO_3$/L)	456	—	—	—	n.s.
Fe (mg/L)	**65**	—	0.07	0.025	<2
Mn (mg/L)	**45**	—	0.003	0.002	<0.5
Al (mg/L)	**<1**	—	0.03	0.111	<0.3

(1) Standard health-related limit for consumption of 2 L/d over 70 years by a 60 kg person
Bold text denotes value exceeds standard limit as described in note (1)

In light of the above, it would appear that the resilience of groundwater resources to anthropogenic impacts is substantial. This is particularly true for the dolomitic formations, and might explain the relative "obscurity" of mining-related impacts on groundwater quality in the Witwatersrand goldfields and Mpumalanga coalfields, for example. This must not be interpreted as implying that no such impact exists. It is much rather the case that instances of this nature 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. This finds support in the WWF-SA (2011) discussion on the prediction of impacts of potential AMD formation on water quality.

7.6 Groundwater Levels

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 more than 100 records and which spanned a measurement period of more than ten years. The distribution of these stations is shown in **Figure 7-32**, and the data presented per GRU in **Appendix B**. These records were interrogated to identify possible impacts, mainly anthropogenic, on the groundwater level in the study area.

The GRU-specific tables in **Appendix B** present statistical functions associated with the groundwater level data as well as the dominant outcrop lithology and land cover. As a means to interpret the overall trend of groundwater levels, i.e. whether it is increasing or decreasing, the slope of each individual data set was calculated. The variability in the data set is represented with the R^2 function. In addition, the minimum and maximum recorded water levels with their associated dates of occurrence are presented as well as the average water level and standard deviation.

An indication of the slopes associated with groundwater level hydrographs in GRUs 5a, 5b, 6b and 9 is shown in **Figure 7-31**. Apart from largely neutral slopes, negative slopes are in greater evidence than positive slopes. This is particularly true for GRUs 5b and 6b, both of which host extensive active and defunct mining activity in the form of gold (mainly GRU 5b) and coal (mainly GRU 6b).

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 set exhibited a temporal scale from approximately 1980 to 2009, and contained all stations which are located within the study area. The stations identified as well as the applicable rainfall statistics are presented in Table 7-11. The extremely poor R^2 values and, even more pointedly, the unacceptably large (»0.05) P-values (probability values) suggest that very little statistical substance can be afforded the deduced trends.

Table 7-11. Rainfall statistics for the Upper Vaal WMA per GRU

GRU	Station Name	Station Number	Slope	P-Value	R^2
1	Witsieshoek	0298512 6	-2.64	0.52	0.02
	Bethesda	0332199 7	-5.69	0.27	0.05
2	Wasklip	0333546 4	-5.7000	0.9382	0.0024
3	Tygerfontein	0369785 3	0.5497	0.8866	0.0007
4a	Morgenzon Municipality	0442194A7	-5.4155	0.8806	0.0041
	Secunda	0478330 3	8.6039	0.0691	0.1311
	Sundra	0477071 3	3.2685	0.4724	0.0186
4b	Cornelia – SAPS station	0404614 1	-0.8137	0.8251	0.0018
5a	Ventersdorp	0473559A3	10.4885	0.3732	0.0727
5b	Carletonville	0474680 9	0.3370	0.9087	0.0005
	Zuurbekom	0475528 8	-3.5794	0.3653	0.0294
	Vereeniging Kliprivier	0476145 0	-11.9511	0.0087	0.2285
6a	Johannesburg Goudkoppies	0475736A2	-5.2115	0.5848	0.0169
	Boksburg – East Rand	0476403 2	8.9898	0.1777	0.0775
	Boksburg-Municipality	0476433 4	-15.0045	0.0124	0.2334
6b	Heidelberg 1	0476660A1	-6.6297	0.3042	0.0502
	Vereeniging	0438784 3	-14.0130	0.0796	0.1908
7	Dwarsfontein	0511120 6	-0.1182	0.9641	0.0001
8	Vredefort	0437660 7	-8.6000	0.0316	0.1545
9	Potchefstroom Mimosa Park	0437452 7	2.8316	0.3194	0.0354
	Westonaria Kloof Gold Mine	0475174 4	-1.8980	0.6016	0.0099

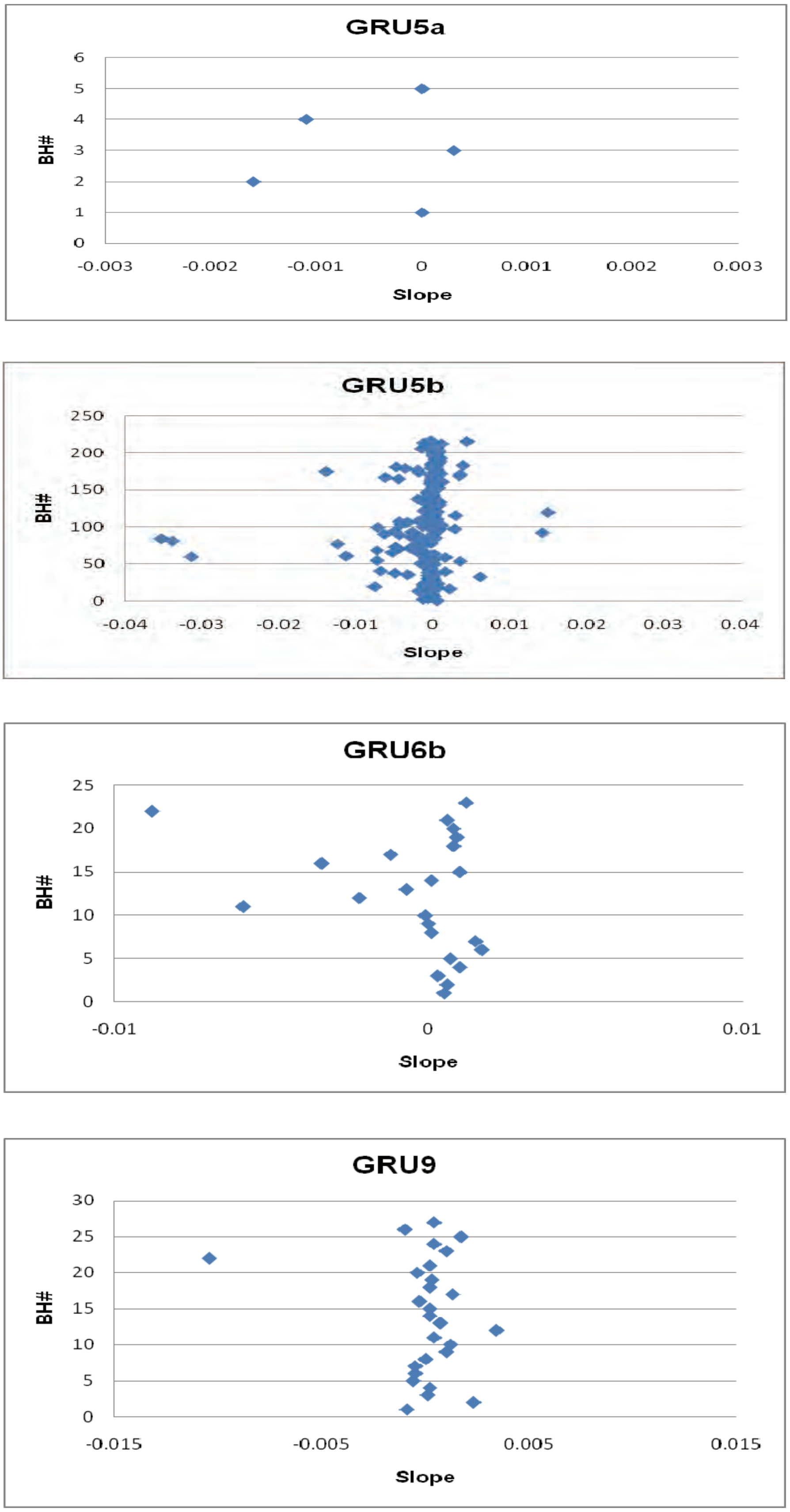

Figure 7-31. The slope of the groundwater level hydrographs, per GRU, for all boreholes which support long-term water level data in the Upper Vaal WMA

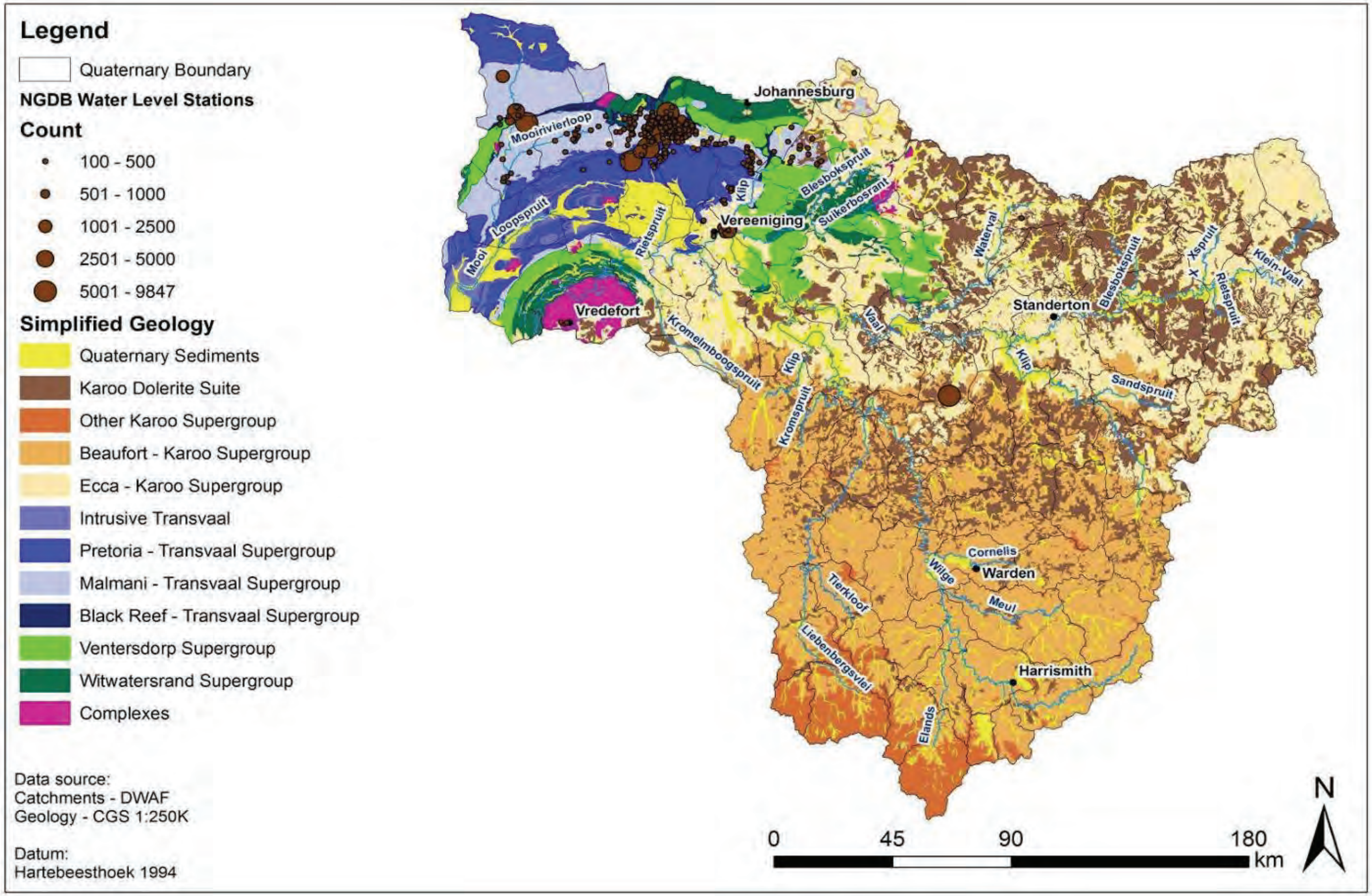

Figure 7-32. Distribution of water level monitoring stations with more than 100 recorded values superimposed on the simplified geology map

GRU 1, GRU 2, GRU 3 and GRU 7 do not support groundwater level monitoring stations that exhibit a temporal scale of >10 years and >100 values. These values are referred to as 'the criteria' in the following text.

In GRU 4a (**Appendix B**), one site is identified which meets the criteria (**Figure 7-33**). The borehole is located in an area dominated by the Karoo Dolerite Suite lithology and where land use is dominated by unimproved/natural grasslands.

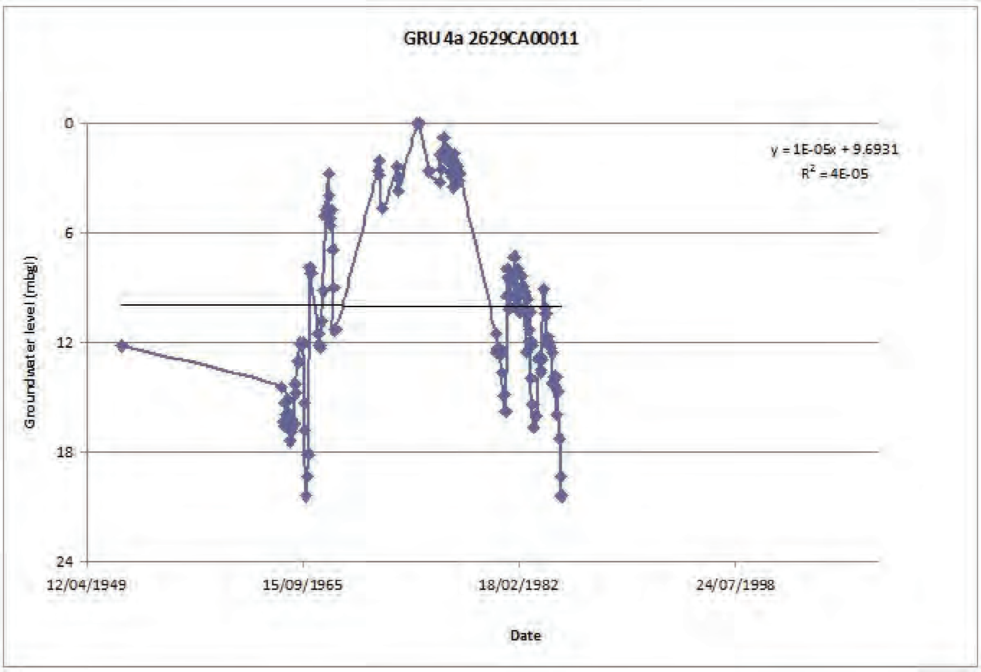

Figure 7-33. Long-term hydrograph for a monitoring station in GRU 4a

The groundwater level is observed to vary between 0.06 and 20.45 m bgl. The overall slope of the groundwater level hydrograph is, however, relatively flat. The R^2 value of «0.8 indicates that the data set exhibits variability. Three rainfall stations are identified in this GRU (Figure 7-33). The slope of the long-term rainfall data shows large variations, i.e. between -5.4155 to 8.6039, with an average 2.1523. This large variation is interpreted to be a result of heterogeneity in rainfall distribution characteristics. Inadequate groundwater level data within this GRU inhibits the identification of any conclusive impacts on groundwater levels. The one borehole in this GRU does not reflect any impact from anthropogenic activities. Further evidence for this is provided in **Figure 2-11**, which illustrates that between 0 and 10% of recharge is used in the GRU.

In GRU 4b (**Appendix B**) one site is identified that meets the criteria (**Figure 7-34**). Unfortunately this record terminates in the mid-1970s. The borehole is located in an area dominated by the Karoo Dolerite Suite lithology and unimproved/natural grasslands. Groundwater levels are observed to vary between 0.55 to 6.20 m bgl. The overall trend of the groundwater level hydrograph is negative. The R^2 value of 0.46 indicates that the data set exhibits variability. One rainfall station identified in this GRU (Figure 7.34) exhibits a slope of -0.8137. Inadequate groundwater level data within this GRU precludes the identification of any conclusive impacts on groundwater levels. Support for this is provided in **Figure 2-11**, which illustrates that between 0-2% of recharge is used in the GRU.

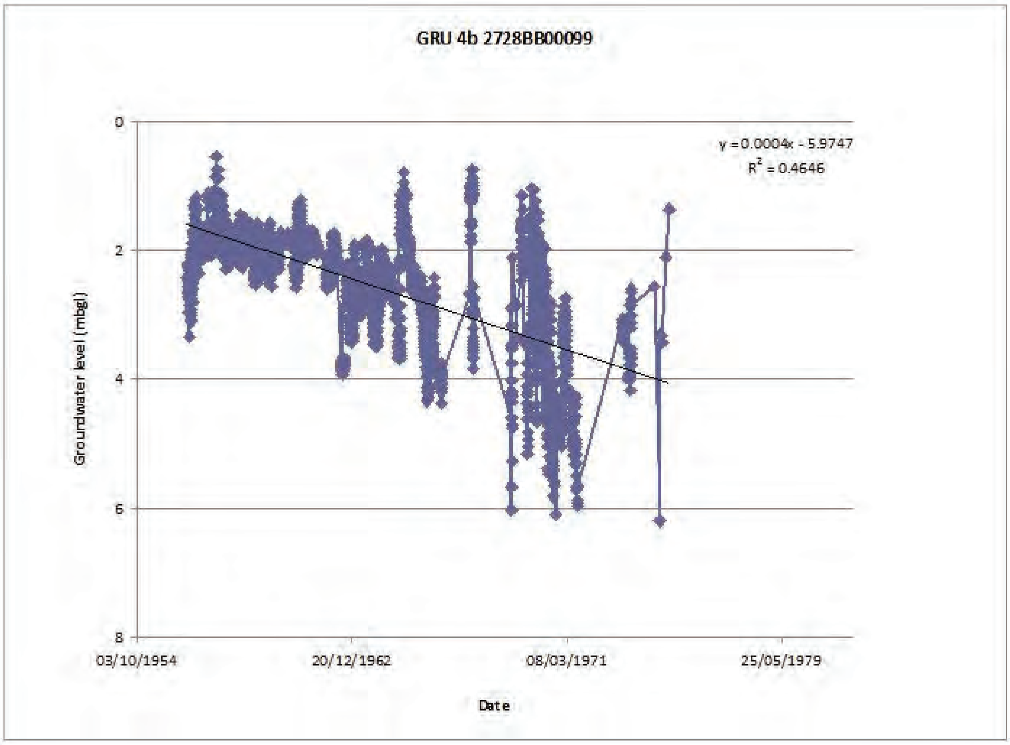

Figure 7-34. Long-term hydrograph for a monitoring station in GRU 4b

In GRU 5a (**Appendix B**), five sites meet the criteria. The dominant outcrop lithology and land cover in the areas where the boreholes are located is the Chuniespoort Group (dolomite) and unimproved/natural grasslands respectively. Groundwater levels are observed to vary between 0.87 and 34.40 m bgl. The overall groundwater level trends are relatively flat, as per the example in **Figure 7-35**. The slopes of the hydrographs range between -0.0016 and 0.0003, with an average of -0.0005. R^2 values «0.8 indicate variability.

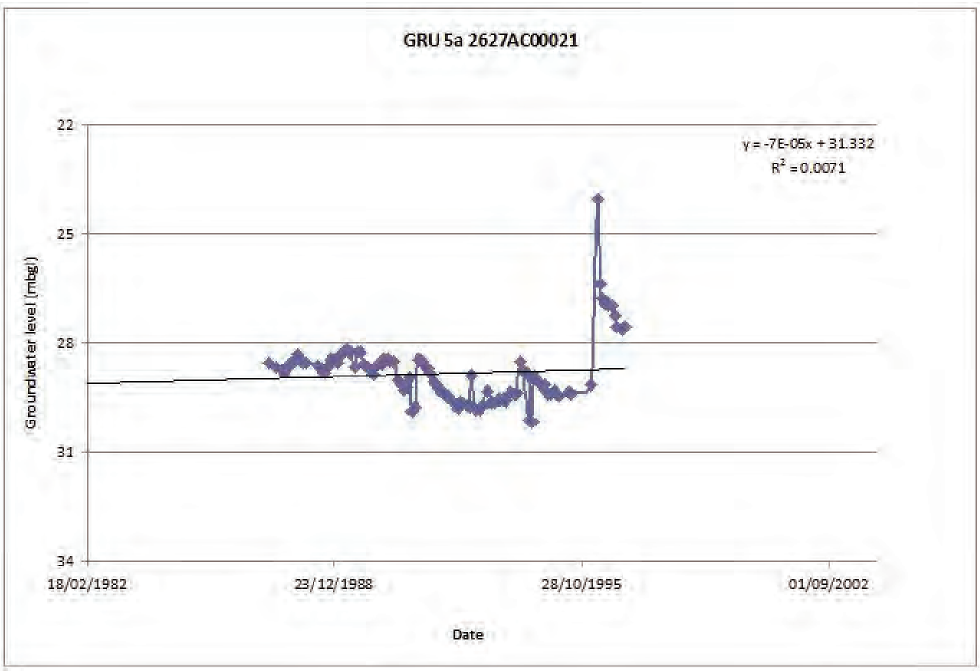

Figure 7-35. Long-term hydrograph for a monitoring station in GRU 5a

No rainfall stations are identified in GRU 5a. Data from a rainfall station located at Ventersdorp ~30 km west of this GRU exhibits a positive slope of 10.49, which is indicative of an overall increase in annual rainfall amounts. **Figure 2-11** illustrates excessive groundwater abstraction within this GRU, i.e. between 10 and 103% of recharge. This is however not observed in the slope of the groundwater level hydrograph, which suggests that the general increase in annual rainfall could be buffering the effects of over-abstraction. A slight overall decrease in groundwater level was observed at stations 2627AA00106 and 2627AC00021.

In GRU 5b (**Appendix B**, **Figure 7-41**) 217 sites exist that meet the criteria. The dominant outcrop lithology is the Chuniespoort Group (dolomite). Land cover is dominated by unimproved/natural grasslands as well as cultivated, temporary and commercial dryland and irrigated agriculture. Groundwater levels vary between 0.04-156.64 m bgl. The slopes of the hydrographs range between 0.0352 and 0.0150, with an average of 0.0010. R^2 values <0.8 indicate variability. Three rainfall stations occur in this GRU (Figure 7-36). The slope of the long-term rainfall data shows large variations of between -11.9511 to 0.3370, with an average -5.0645. This large variation is interpreted to be a result of heterogeneity in rainfall distribution characteristics.

All boreholes in this GRU that exhibit a slope of less than -0.005 (**Appendix B**) are interpreted to be impacted. These monitoring points are located in areas where land use is dominated by natural grasslands, dryland and irrigated agriculture, forest plantations and mines and quarries. These land uses could potentially be impacting groundwater levels through vegetative water use and abstraction for irrigation and mine dewatering. An example of the decline, albeit of largely historical relevance, is illustrated in **Figure 7-36**. In addition, declining annual rainfall amounts could also be affecting groundwater recharge. The average slope of the groundwater level hydrograph in this GRU, however, suggests that these impacts are localised. Groundwater use as a percentage of recharge varies between 0-3% in this GRU (**Figure 2-11**).

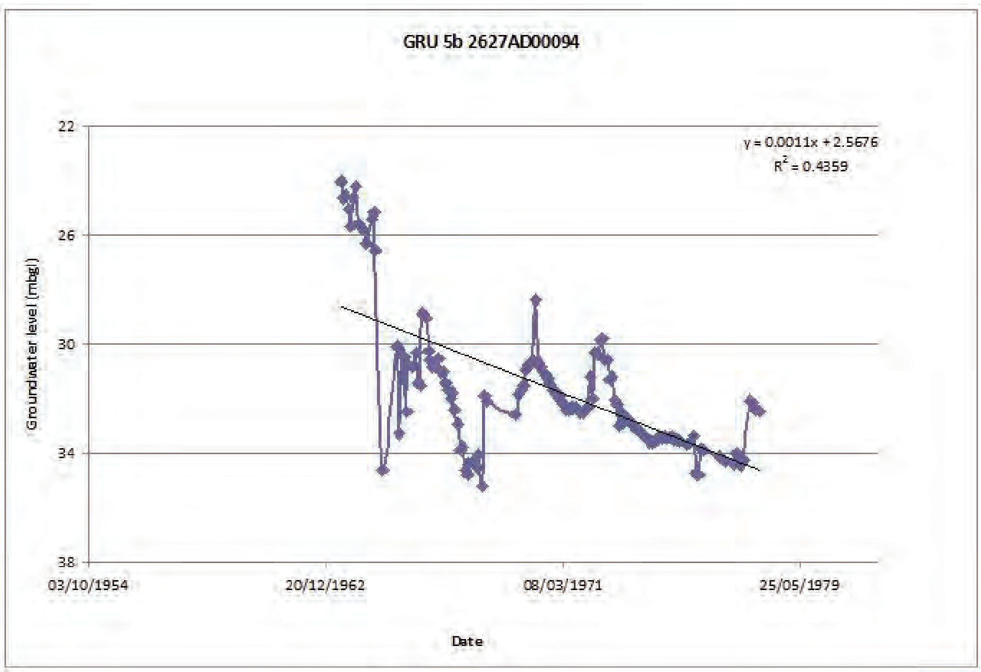

Figure 7-36. Long-term hydrograph for a monitoring station in GRU 5b

In GRU 6a (**Appendix B**) one groundwater level monitoring station meets the criteria (**Figure 7-37**). The borehole is sited in an area dominated by the Ecca Group lithology and unimproved/natural grasslands land cover. Groundwater levels are observed to vary between 6.70-14.28 m bgl. The overall trend of the groundwater level hydrograph is slightly positive, exhibiting a slope of 0.0002. The R^2 value of «0.8 again reflects variability. Three rainfall stations identified in this GRU (Figure 7.37) reflect a slope in the range -15.0045 and 8.9898, with an average of -3.7421. Insufficient groundwater level data prohibits the identification of any conclusive impacts on groundwater levels, although station 2628AB00010 reflects no negative impact from anthropogenic activities or declining annual rainfall. **Figure 2-11** illustrates that between 5-25% of recharge is used in the GRU.

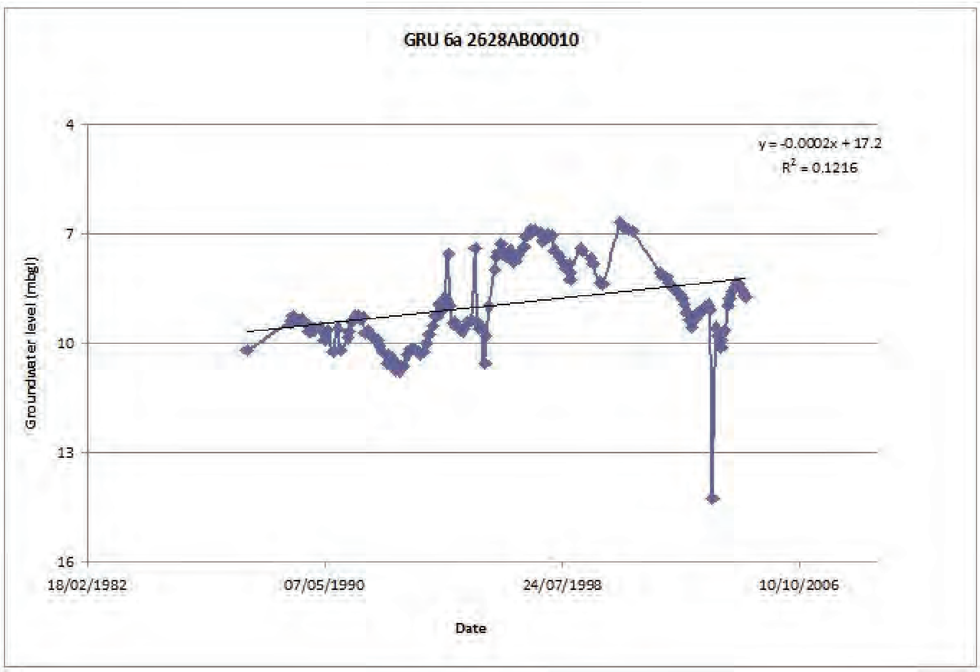

Figure 7-37. Long-term hydrograph for a monitoring station in GRU 6a

In GRU 6b (**Appendix B**) 23 sites meet the criteria. The dominant lithologies in these localities are the Chuniespoort Group (dolomite) and Ecca Group (sedimentary strata). Land cover is variable (**Appendix B**). Groundwater levels reflect significant variations between 0.90-62.83 m bgl. The overall trends of the groundwater level hydrographs are, however, neutral. This is illustrated in **Figure 7-38**, which also reflects the characteristic response of periodic recharge and water level recession. The slopes of the hydrographs range between -0.0088 and 0.0017, with an average of -0.0005. R^2 values <0.8 indicate variability. Two rainfall stations are identified in this GRU (Figure 7.38). Both data sets exhibit a negative slope, i.e. -6.6297 and -14.0130, suggesting that annual rainfall is decreasing. Groundwater level trends that exhibit a slope of less than -0.002 are interpreted to show signs of moderate impact. These monitoring points are located in urban and natural grassland areas, which suggest that the impact could either be a result of abstraction or declining annual rainfall. Groundwater use as a percentage of recharge varies between 0-25% in this GRU (**Figure 2-11**).

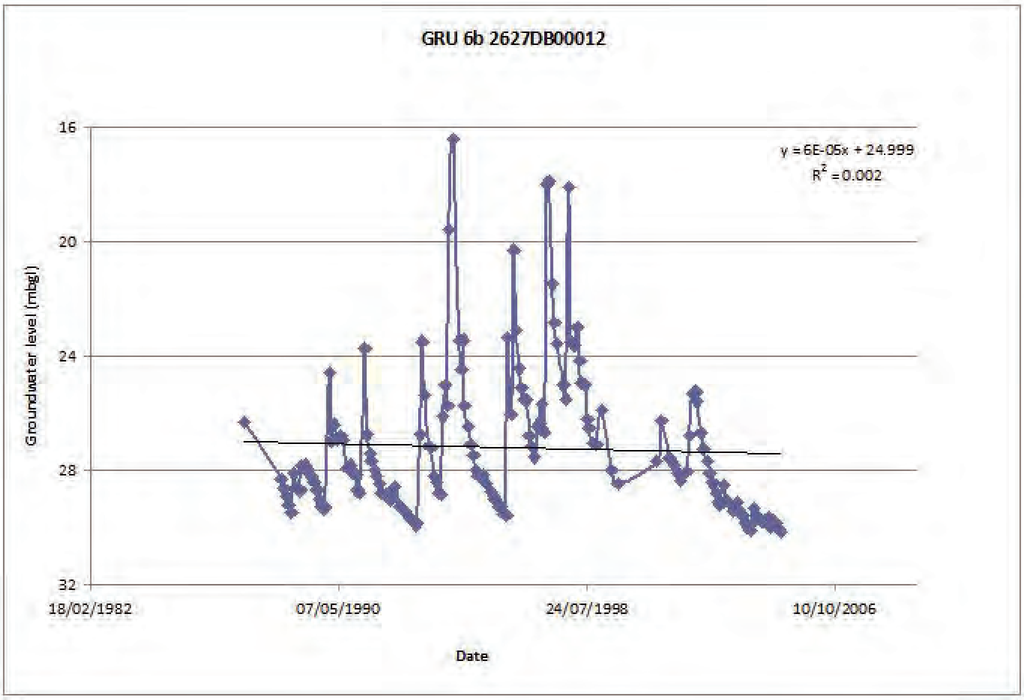

Figure 7-38. Long-term hydrograph for a monitoring station in GRU 6b

In GRU 8 (**Appendix B**) three sites meet the criteria. The dominant outcrop lithology is Basement Granites (Swazian). Land cover is dominated by unimproved/natural grasslands and forest (eucalyptus) plantations. Groundwater levels vary between 0.12 and 15.00 m bgl (e.g. **Figure 7-39**). The overall groundwater level trends are relatively flat, with slopes ranging between -0.0025 and 0.0002, and an average of -0.0007. R^2 values <0.8 indicate variability. One rainfall station is identified in this GRU. The slope of the long-term rainfall data is -8.6000, suggesting an overall decrease in annual rainfall. Groundwater use, as a percentage of recharge, varies between 0 and 2% within this GRU (**Figure 2-11**).

In GRU 9 (**Appendix B**) 27 sites meet the criteria. The dominant outcrop lithology is Pretoria Group sedimentary strata. Land cover is dominated by unimproved/natural grasslands as well as cultivated, temporary and commercial dryland agriculture. Groundwater levels reflect rather extreme values in the range 0.57-162.76 m bgl. The overall trends are relatively flat, with slopes between -0.0104 and 0.0034. R^2 values <0.8 reflect variability. Two rainfall stations are located in this GRU (Figure 7-40). The slope of the long-term rainfall data varies between -1.8980 and 2.8316, with an average -0.4668. This large variation is interpreted to be a result of heterogeneity in rainfall distribution characteristics. One monitoring station (2627BC00088) shows a more pronounced negative slope, when compared to the rest. This station is located in an area where land use is dominated by natural grasslands, and the response is therefore not readily attributable to specific circumstances. Groundwater use as a percentage of recharge varies between 0-2% in this GRU (**Figure 2-11**).

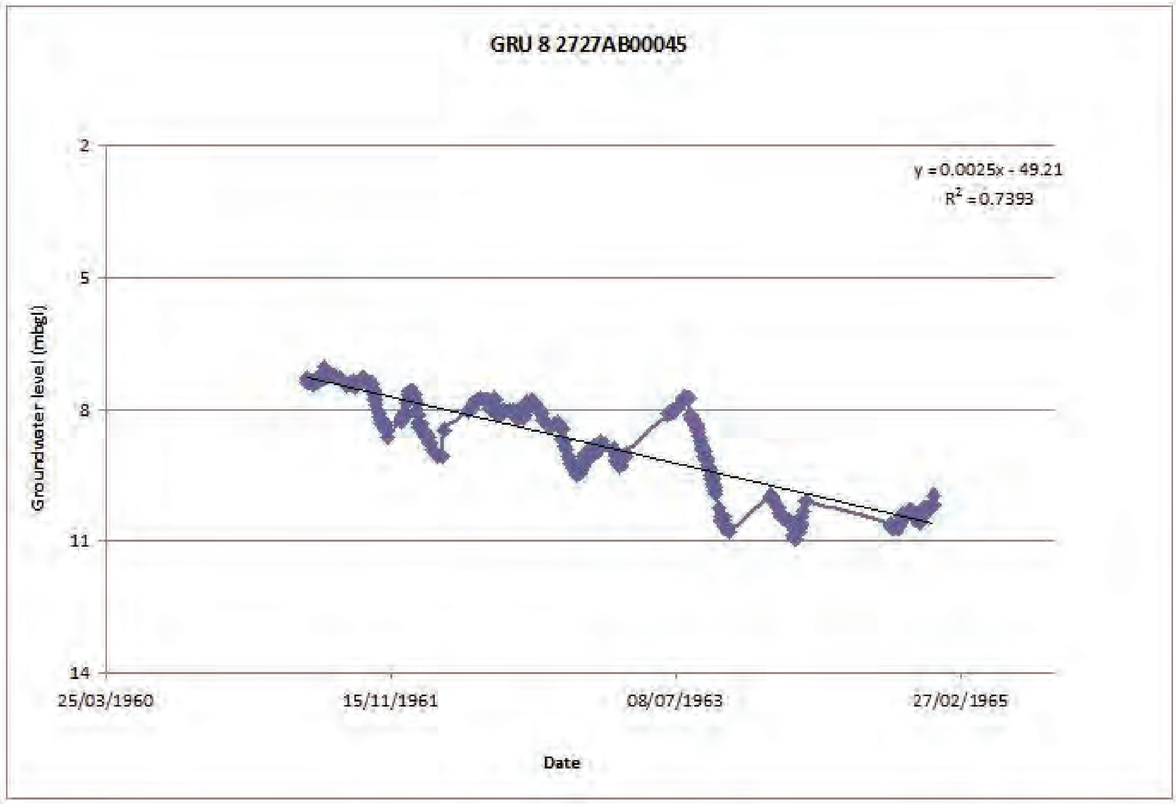

Figure 7-39. Long-term hydrograph for a monitoring station in GRU 8

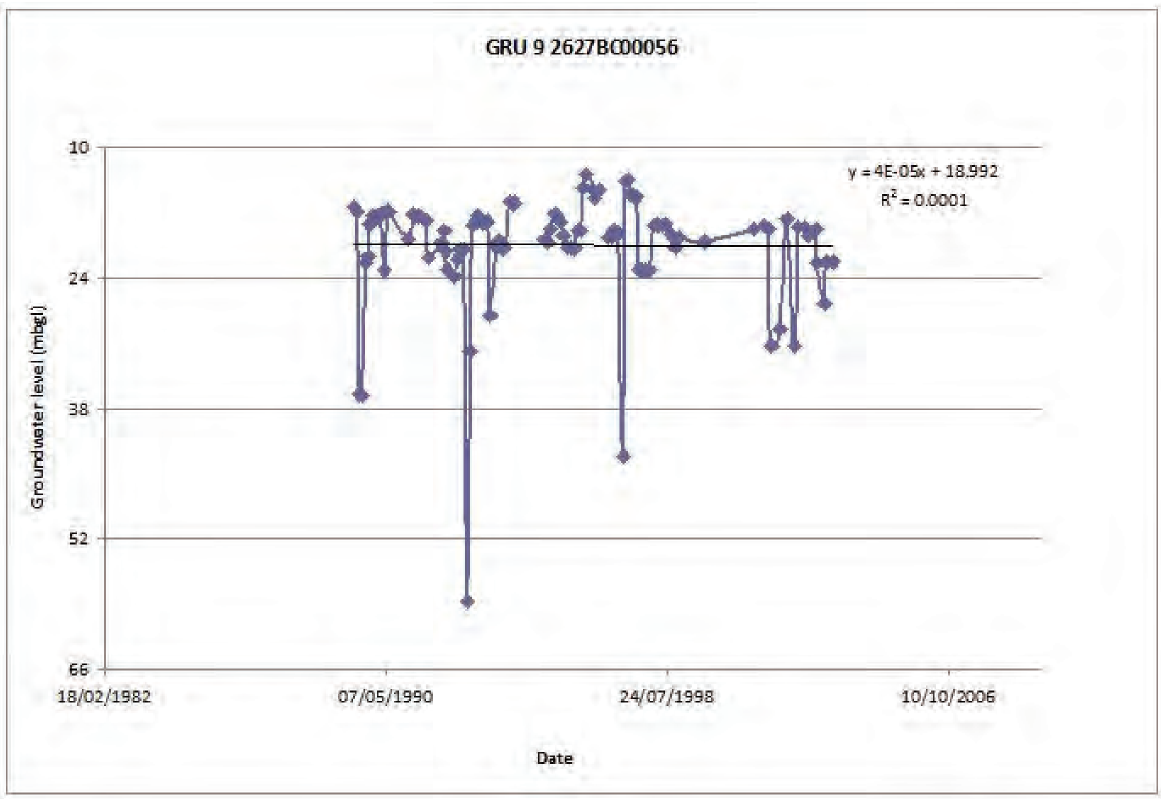

Figure 7-40. Long-term hydrograph for a monitoring station in GRU 9

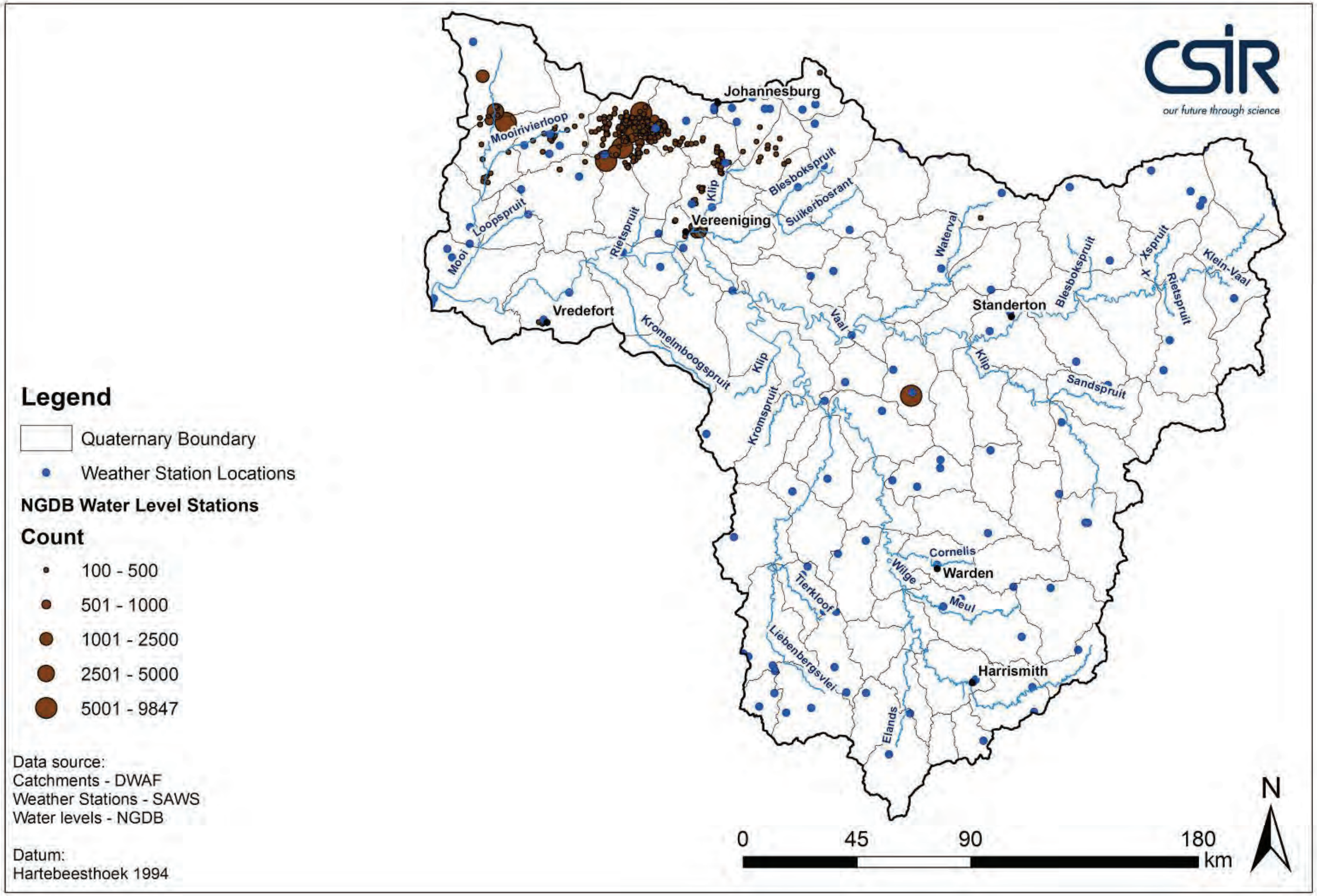

Figure 7-41. Groundwater level monitoring stations and rainfall stations in the Upper Vaal WMA

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

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

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 hydrogeological 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 1

8.1.1.1 Groundwater Quantity

There are no long-term water level records that describe the temporal behaviour of groundwater rest levels in this GRU. However, since land use in this GRU is dominated by unimproved (natural) grassland (~65% 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 from the reference conditions. The groundwater contribution of 21.22 Mm^3/a to the baseflow in this GRU represents ~21% of the estimated groundwater recharge of 103.42 Mm^3/a.

8.1.1.2 Groundwater Quality

Out of a total of 22 stations, only one (**Table 8-4**) provides an 11-year record of groundwater chemistry in this GRU. This record does not include pH values, leaving only TDS values as a measure of the long-term water quality trend at this station. The slight decrease in TDS values over time is sufficiently insignificant to accept that this variable remained essentially unchanged in the period of record.

8.1.1.3 Discussion

The hydrogeological environment of GRU 1 is assessed as being only slightly modified from its natural status, and is therefore assigned a present ecological state (PES) category of B. This is based mainly on the ~22% of GRU area that supports cultivated temporary commercial dryland agriculture, and the ~4% of area that supports urban/built-up land uses, including ~2.5% of residential informal townships. The latter constitute the most significant threat to the groundwater resources of GRU 1, but their localised nature assigns a limited geographic impact to this threat.

8.1.2 GRU 2

8.1.2.1 Groundwater Quantity

As in the case of GRU 1, there are no long-term water level records that describe the temporal behaviour of groundwater rest levels in GRU 2. The land use in GRU 2, however, is dominated to an even greater extent (~68% of the area) by unimproved (natural) grassland than GRU 1. It is therefore similarly reasonable to expect that groundwater rest levels have not been impacted upon to the extent that the present status differs from the reference conditions. The groundwater contribution of 63.04 Mm3/a to the baseflow in this GRU represents ~22% of the estimated groundwater recharge of 289.64 Mm3/a. The similarity with that determined for GRU 1 (~21%) reflects the comparative homogeneity of groundwater recharge and baseflow conditions that characterise the similar hydrogeological environments.

8.1.2.2 Groundwater Quality

Out of a total of 24 stations, only one (**Table 8-4**) provides a 7-year record of groundwater chemistry in this GRU. The TDS and pH values provide a measure of the long-term water quality trend at this station. The significant variance reflected in the TDS record discounts the apparent decreasing trend, and it is more reasonable to accept that this variable remained essentially unchanged in the period of record. Similarly, the pH trend suggests a slight increase that more probably reflects a constancy that indicates little or no change in this variable.

8.1.2.3 Discussion

With ~28% of the area supporting cultivated temporary commercial dryland agriculture, the hydrogeological environment of GRU 2 is assessed as being very slightly modified from its natural status, and is therefore assigned a present ecological state (PES) category of B. This finds support in the observation reported earlier that ~68% of the area constitutes unimproved (natural) grassland, and that <0.5% constitutes urban/built-up land uses of all types. The threat to the current groundwater environment is therefore assessed as low to insignificant.

8.1.3 GRU 3

8.1.3.1 Groundwater Quantity

Again there are no long-term water level records that describe the temporal behaviour of groundwater rest levels in GRU 3. The land use in this GRU is dominated to an even greater extent (~74% of the area) by unimproved (natural) grassland than in either GRU 1 or GRU 2. It is therefore even more reasonable to expect that groundwater rest levels have not been impacted upon to the extent that the present status differs from the reference conditions. The groundwater contribution of 62.06 Mm^3/a to the baseflow in this GRU represents ~23% of the estimated groundwater recharge of 265.43 Mm^3/a. The similarity with that determined for GRU 1 (~21%) and GRU 2 (~22%) again reflects the comparative homogeneity of groundwater recharge and baseflow conditions that characterise the similar hydrogeological environments.

8.1.3.2 Groundwater Quality

Two of the six stations that provide groundwater quality data in this GRU support a record that in one instance dates back to 2000, and in the other instance to 2003 (**Table 8-4**). Unfortunately the record of both these stations terminates in 2005. Nevertheless, the pH and TDS trends again indicate comparatively little change in these variables.

8.1.3.3 Discussion

Together with the ~74% extent of unimproved (natural) grassland, the ~22% of cultivated temporary commercial dryland agriculture constitutes ~96% of comparatively undisturbed land use that suggests a very slightly modified hydrogeological environment. The groundwater regime in GRU 3 is consequently assigned a present ecological state (PES) category of B. The threat to the current groundwater environment is therefore assessed as low to insignificant.

8.1.4 GRU 4a

8.1.4.1 Groundwater Quantity

A single station in this GRU supports a groundwater rest level record that spans a period of >10 years and provides >100 values. Although the difference between the minimum (shallowest) and maximum (deepest) water rest level depth is in the order of 20 m, the mean value of ~10 m below ground level (bgl) is accompanied by a standard deviation of only ~5 m. It is also observed that the record reveals no distinct trend in groundwater rest level and, for all practical purposes, has remained essentially constant in the period of record. These observations are in keeping with a GRU in which ~72% of the area comprises of unimproved (natural) grassland, and a further ~23% by cultivated temporary commercial dryland agriculture. The groundwater contribution of 92.80 Mm^3/a to the baseflow in GRU 4a represents ~20% of the estimated groundwater recharge of 465.49 Mm^3/a. The potentially considerable threat posed by coal mining activity in GRU 4a is illustrated in **Figure 8-1**, which shows the extent of both current mining activities and, more pertinently, that of new mining applications being considered by the Department of Mineral Resources. The impact of these activities on the substantial groundwater contribution to baseflow is beyond quantification at present.

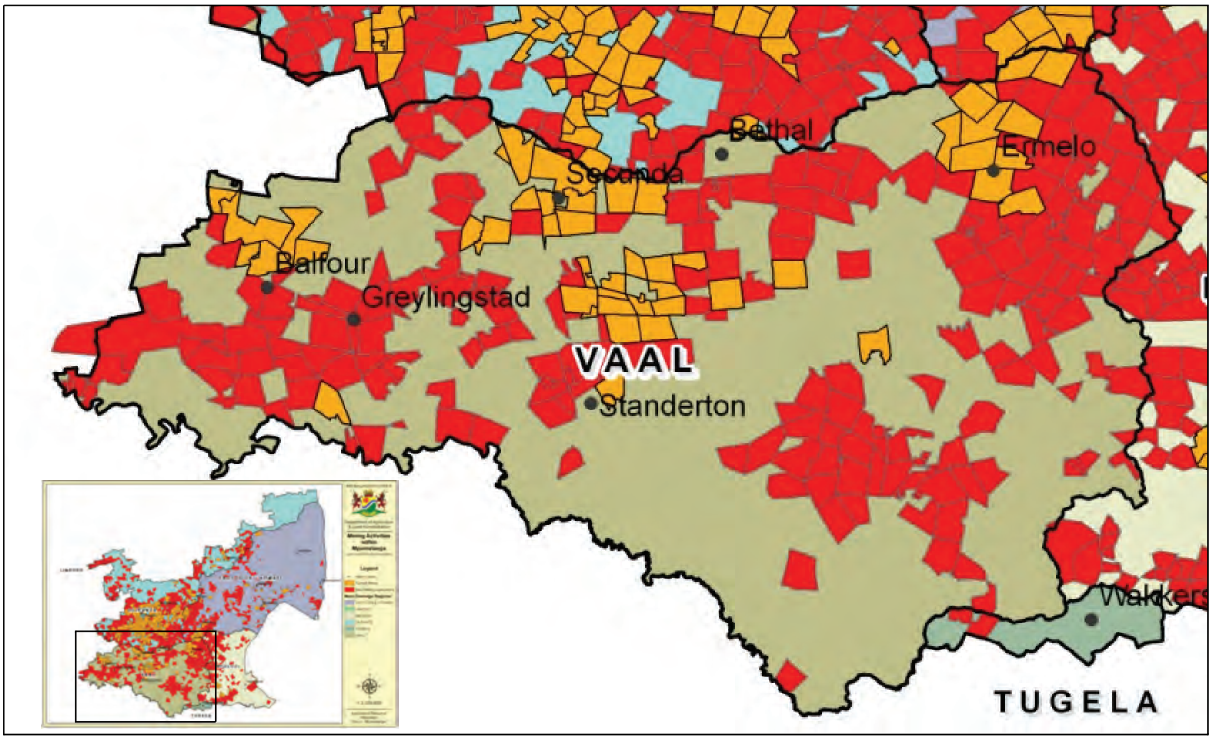

Figure 8-1. Distribution of current (orange) and potentially new (red) coal mining activities in GRU 4a (after McCarthy and Pretorius (undated), from Department of Agriculture and Land Administration, Mpumalanga Province)

8.1.4.2 Groundwater Quality

Although this GRU hosts 49 stations with groundwater chemistry data, only two of these support a lengthy period of record of 11 years each (**Table 8-4**). It is apparent that both the pH and the TDS variables, respectively, indicate a rise over time. However, it is extremely tenuous to equate these trends to the general hydrogeological response in the GRU. For example, the impact of coal mining activities (historical, current and future) in the north-eastern and eastern parts of this GRU is poorly addressed by the available groundwater quality data. The threat posed by coal mining activity described in **section 8.1.4.1** applies equally to the impact on water quality in the receiving surface and subsurface environments, and is beyond quantification within the context of this study.

8.1.4.3 Discussion

The dominance of the 'low impact' land uses in this GRU is severely compromised by the potentially considerable threat posed by coal mining activity in GRU 4a. This threat is illustrated in **Figure 8-1**, which shows the extent of both current mining activities and, more pertinently, that of new mining applications being considered by the Department of Mineral Resources. The impact of these activities on the substantial groundwater contribution to baseflow, and also the impact on water quality in the receiving surface and subsurface environments, is beyond quantification at present. Nevertheless, the situation raises grave concern for the present ecological state (PES) of groundwater resources in the GRU. A PES category of BC is assigned to the groundwater regime on the basis of current coal mining activity in the GRU.

8.1.5 GRU 4b

8.1.5.1 Groundwater Quantity

As in the case of GRU 4a, a single station in GRU 4b supports a groundwater rest level record that spans a period of >10 years and provides >100 values. However, the difference between the shallowest and deepest water rest level depth is in the order of only 6 m. Further, the mean value of ~2.4 m bgl is accompanied by a minor standard deviation of only ~0.9 m. As in the case of GRU 4a, the record again reveals no distinct trend in groundwater rest level and, for all practical purposes, has remained essentially constant in the period of record. These observations most probably reflect the situation where ~52% of the GRU comprises of unimproved (natural) grassland, and a further ~37% by cultivated temporary commercial dryland agriculture. The groundwater contribution of 28.10 Mm^3/a to the baseflow in GRU 4b represents ~16% of the estimated groundwater recharge of 178.98 Mm^3/a. This is notably less than the 20-25% observed in GRUs 1, 2, 3 and 4a, and possibly reflects the lower rainfall (and associated recharge) that characterises GRU 4b.

8.1.5.2 Groundwater Quality

Despite the existence of 34 stations reflecting groundwater chemistry information in this GRU, none of these support a length of record that constitutes a time series (**Table 8-4**). There is therefore no information available to indicate a trend in this regard.

8.1.5.3 Discussion

The ~90% extent of comparatively undisturbed land use in GRU 4b suggests a very slightly modified hydrogeological environment. The groundwater regime in this GRU is consequently assigned a present ecological state (PES) category of BC, and the threat to the current groundwater environment is assessed as low.

8.1.6 GRU 5a

8.1.6.1 Groundwater Quantity

A total of five stations in GRU 5a support a groundwater rest level record that spans a period of >10 years and provides >100 values. Four of these stations are associated with the dolomitic strata of the Chuniespoort Group, and the fifth with Quaternary sediments. The latter supports the lowest minimum (~0.9 m), mean (~3.5 m) and maximum (~5.3 m) depth to groundwater rest level values, and is further characterised by a standard deviation of only ~0.7 m. There is no trend discernible in this variable.

The karst water levels reveal a slightly greater standard deviation (smallest ~0.9 m, greatest ~3.9 m), with a minimum depth of ~1.8 m and a maximum depth of ~34 m. The average depth ranges from 4 to 29 m bgl. The five long-term water level records again do not reveal a discernible trend. This is possibly explained by the observation that ~80% of the land cover in this GRU represents unimproved (natural) grassland and thicket, bushland, bush clumps and high fynbos. The groundwater contribution of 6.5 Mm^3/a to the baseflow in this GRU represents only ~7% of the estimated groundwater recharge of 90.3 Mm^3/a. This is in keeping with the endoreic nature of many surface water drainages in karst terrain.

8.1.6.2 Groundwater Quality

A long-term groundwater chemistry record is available for only one station (**Table 8-4**) out of 13 that carry water quality information in this GRU. This record spans 7 years, and graphs of the pH and TDS variables do not indicate a trend. It is postulated that these variables remained essentially unchanged in the period of record.

8.1.6.3 Discussion

The indication that groundwater use in GRU 5a amounts to between 10 and 103% of groundwater recharge (**Figure 2-11**) suggests that groundwater levels in this GRU might be expected to exhibit a declining trend due to over-exploitation. The situation that has developed in the Steenkoppies Compartment to the east (and outside of the Upper Vaal WMA), where over-abstraction for irrigated agriculture has severely impacted on the flow of Maloney's Eye and the downstream Magalies River (Holland et al., 2009), is an example of what could occur in the absence of meaningful and appropriate groundwater management. The groundwater regime in this GRU is assigned a present ecological state (PES) category of BC, and the threat to the current groundwater environment is assessed as low.

8.1.7 GRU 5b

8.1.7.1 Groundwater Quantity

The existence of 217 stations in this GRU with a groundwater rest level record that spans a period of >10 years and provides >100 values testifies to the importance attached to the karst groundwater regime that builds this GRU. This importance derives as much from the water supply potential of these strata, as it does from the impact of their intentional dewatering to facilitate gold mining at depth beneath these formations. The latter impact is demonstrated by the fact that 24 of the 25 stations that support a mean depth to groundwater rest level of >75 m bgl in the WMA are located in GRU 5b. It is also observed that 15 of these stations reflect a maximum depth to groundwater rest level >100 m bgl. As might be expected, Figure 7-41 shows that most of these stations are located in the vicinity of Westonaria in the Carletonville Goldfield where the Gemsbokfontein, Venterspost, Bank and Oberholzer Compartments remain dewatered.

The water level data for GRU 5b presented in **Appendix B** was interrogated to derive the summarised information presented in **Table 8-2.** This shows that the karst aquifers associated with the Chuniespoort Group generally support shallower depths to groundwater rest level than the weathered and fractured aquifers of the Ecca Group. The former are also characterised by a standard deviation that is half of that which characterises the sedimentary strata. This reflects the greater capacity of the karst aquifers to absorb stresses imposed by drivers such as recharge and abstraction, than that of the weathered and fractured Karoo aquifers.

Table 8-2. Summary of depth to groundwater rest level data in GRU 5b

Data Set	Statistical Variable				
	n	**Mean Minimum (m bgl)**	**Mean (m bgl)**	**Mean Maximum (m bgl)**	**Mean Standard Deviation (m)**
Whole set	217	28.8	38.1	46.5	3.6
Chuniespoort Group	168	27.8	35.6	43.4	3.2
Ecca Group	33	38.9	56.1	67.0	6.1

An analysis of water rest level trends indicates that 120 of the 217 stations in GRU 5b exhibit hydrographs characterised by a negative slope indicative of a declining trend in groundwater rest level over the periods of record. The analysis also indicates that 15 of these stations are amongst the 24 that support a mean depth to groundwater rest level of >75 m bgl (**Figure 8-2**). This observation suggests that the negative impact of mine-related dewatering in the Carletonville Goldfield still continues. However, **Figure 8-2** also shows that some of the stations in this GRU that support a mean depth to groundwater rest level of >75 m bgl, also exhibit a positive water level trend. These stations are more widely distributed across the GRU (**Figure 8-2**), although a few also occur in the Carletonville Goldfield.

8.1.7.2 Groundwater Quality

Despite the existence of 413 stations for which groundwater chemistry data is available, only four stations (**Table 8-4**) provide a >10-year record of data, and a further two a record length of ~5 years limited to the 1980s. The pH and TDS trends for two of the long-term records (stations 90621 and 90622 in **Table 8-4**) located in the western part of the GRU in quaternary basin C23G, exhibit an equivocal trend in the case of station 90621, and an increasing pH and TDS trend over the 30-year period of record in the case of station 90622.

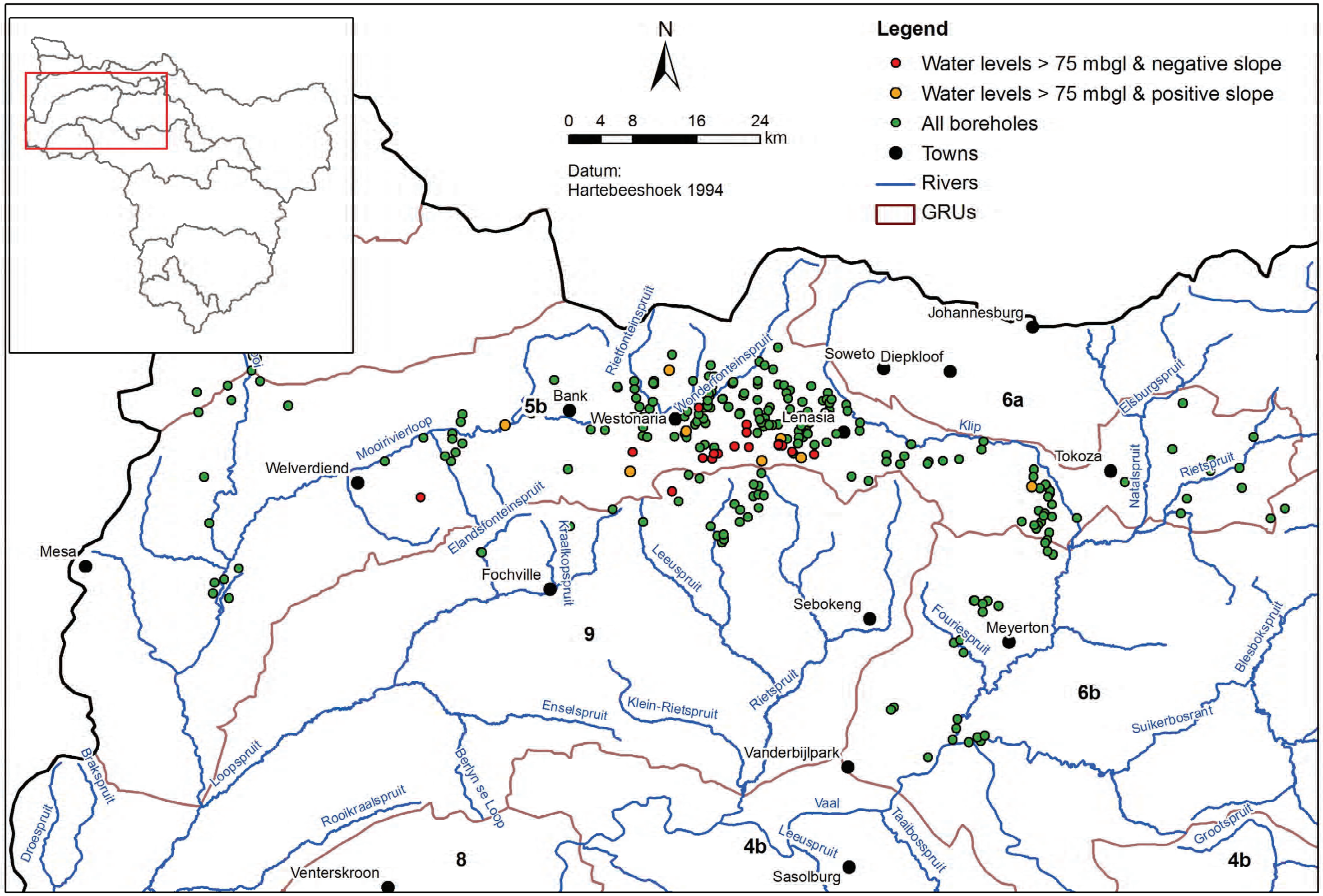

Figure 8-2. Distribution of boreholes with depths to rest water level >75 m bgl. Note colour-coded trend analysis

8.1.7.3 Discussion

The significant impact of gold mining activities on the groundwater environment in GRU 5b is manifested in both the quantity and quality of water resources in this GRU. These impacts have been extensively documented in the literature, e.g. Coetzee et al. (2006), Ogola and Nenghovela (2007), Rösner and Van Schalkwyk (2000), Winde (2006, 2009, 2010a and 2010b), Winde and Sandham (2004) and Winde and Stoch (2010). The primary concerns relate to rewatering of the dewatered dolomitic compartments and the associated rejuvenation of springs following the cessation of mining activities, as well as the impact on water quality associated with potential radiogenic contamination of water resources. Whilst the rewatering concern pertains to future impacts on groundwater quantity (the Carletonville Goldfield has a further ~30 years to 'closure'), the water quality concern has already manifested itself in the surface water resources and sediments of the Wonderfontein Spruit. These circumstances, together with the ~5% of land use comprising urban built-up areas (all types) in this GRU, account for the PES category of D assigned to GRU 5b.

8.1.7.4 Groundwater Quality

Despite the existence of 413 stations for which groundwater chemistry data are available, only four stations (**Table 8-4**) provide a >10-year record of data, and a further two a record length of ~5 years limited to the 1980s. The pH and TDS trends for two of the long-term records (stations 90621 and 90622 in **Table 8-4**) located in the western part of the GRU in quaternary basin C23G, exhibit an equivocal trend in the case of station 90621, and an increasing pH and TDS trend over the 30-year period of record in the case of station 90622.

8.1.7.5 Discussion

The significant impact of gold mining activities on the groundwater environment in GRU 5b is manifested in both the quantity and quality of water resources in this GRU. These impacts have been extensively documented in the literature, e.g. Coetzee et al. (2006), Ogola and Nenghovela (2007), Rösner and Van Schalkwyk (2000), Winde (2006, 2009, 2010a and 2010b), Winde and Sandham (2004) and Winde and Stoch (2010). The primary concerns relate to rewatering of the dewatered dolomitic compartments and the associated rejuvenation of springs following the cessation of mining activities, as well as the impact on water quality associated with potential radiogenic contamination of water resources. Whilst the rewatering concern pertains to future impacts on groundwater quantity (the Carletonville Goldfield has a further ~30 years to 'closure'), the water quality concern has already manifested itself in the surface water resources and sediments of the Wonderfontein Spruit. These circumstances, together with the ~5% of land use comprising urban built-up areas (all types) in this GRU, account for the PES category of D assigned to GRU 5b.

8.1.8 GRU 6a

8.1.8.1 Groundwater Quantity

A single station in this GRU provides a long-term (>10 years) groundwater rest level record that comprises >100 values. The borehole intersects sedimentary strata of the Ecca Group in an area of land use dominated by unimproved (natural) grassland. Under these circumstances, the range of 6.7

to 14.3 m bgl around an average of 8.9 m bgl associated with this variable at this station, are considered 'normal' for this environment. The comparatively small standard deviation of 1.2 m supports the absence of a discernible trend in the hydrograph, and suggests a relative constancy in this variable over time. It should be considered, however, that ~30% of the land cover in this GRU comprises urban built-up and peri-urban areas supporting a variety of related land uses (e.g. residential formal suburbs and townships, informal townships and smallholdings). This GRU exhibits the greatest modification from its natural state of all 12 GRUs in the study area.

8.1.8.2 Groundwater Quality

Out of a total of 25 stations in this GRU, only two (**Table 8-4**) provide a 2-year record of groundwater chemistry for the late-1990s. For all practical purposes, there is no data available on the basis of which the present status of groundwater quality in GRU 6a can be gauged.

8.1.8.3 Discussion

Since it is unrealistic to evaluate either the quantity or the quality of groundwater resources in this GRU on the basis of the available information, the considerable modification of land cover from the natural in this GRU suggests that the overall PES must be assigned a category D.

8.1.9 GRU 6b

8.1.9.1 Groundwater Quantity

This GRU hosts the third largest number of stations (23) with a groundwater rest level record that spans a period of >10 years and provides >100 values. The majority of these stations intersect either sedimentary strata of the Ecca Group or dolomitic rocks of the Chuniespoort Group. The information presented in **Table 8-3** reflects a statistical analysis of the groundwater rest level data for these stations. The analysis indicates the generally deeper nature of the karst groundwater rest levels compared to the sedimentary strata. Whilst this is in contrast to the observation made regarding this relationship for GRU 5b (see **section 8.1.7** and **Table 8-2**), the mean standard deviation value for the Chuniespoort Group data set remains smaller than that for the Ecca Group data set. This supports the more forgiving nature of the karst aquifers in response to stresses compared to Karoo aquifers. As might be expected, the Quaternary sediments are characterised by much shallower water rest level values commensurate with the typically near-surface, unconfined and intergranular character of the associated alluvial aquifers. Apart from natural veld and unimproved (natural) grassland that make up ~62% of the land cover in this GRU, cultivated temporary commercial dryland represents a further 24% of the GRU footprint.

Table 8-3. Summary of depth to groundwater rest level data in GRU 6b

Data Set	Statistical Variable				
	n	Mean Minimum (m bgl)	Mean (m bgl)	Mean Maximum (m bgl)	Mean Standard Deviation (m)
Whole set	23	18.3	26.2	34.2	3.2
Chuniespoort Group	7	28.7	36.5	44.8	2.1
Ecca Group	11	17.9	25.2	33.8	3.8
Quaternary sediments	5	4.5	13.6	20.1	3.2

8.1.9.2 Groundwater Quality

This GRU hosts only one station with a long-term groundwater chemistry record spanning ~12 years. A shorter record spanning ~6 years terminates in 1990 (**Table 8-4**). The pH and TDS trends associated with the longer record are reflected in **Figure 7-14** and **Figure 7-15** respectively. Whereas the pH trend is positive (rising), the TDS trend appears to have stabilised after an initial fall. The observation that this station intersects alluvium indicates that it is not representative of the 'hard rock' Witwatersrand and Ventersdorp Supergroup strata that build this GRU. The absence of long-term groundwater quality data for the latter lithologies is identified as a shortcoming.

8.1.9.3 Discussion

The insufficiency of groundwater level and groundwater quality information on which to gauge the PES of groundwater resources in this GRU even semi-quantitatively indicates that land cover type and extent might again be applied as a measure in this regard. The overall PES is assigned a category D on the basis that ~33% of the GRU area encompasses cultivated temporary commercial dryland agriculture and other 'unnatural' land cover.

8.1.10 GRU 7

8.1.10.1 Groundwater Quantity

There are no stations in this GRU that support a long-term groundwater rest level monitoring record. This is identified as a serious shortcoming in the data base that characterises GRU 7. However, the land cover in GRU 7 is dominated by a combination of natural veld and unimproved (natural) grassland (~58%) and cultivated temporary commercial irrigated and dryland (~37%), making a total of ~95%. Under these circumstances, it is unlikely that any impact that manifests negatively on the reference conditions will be identifiable from routine monitoring activities unless these are targeted at specific impacts.

8.1.10.2 Groundwater Quality

Hosting eight stations that provide groundwater chemistry information, this GRU can report only one station that supports a 7-year record (**Table 8-4**) of time series data amounting to 14 values, i.e. the equivalent of an analysis every 6 months.

8.1.10.3 Discussion

Since it is unrealistic to evaluate either the quantity or the quality of groundwater resources in this GRU on the basis of the available information, the largely natural character of the physical environment suggests that any negative impacts which occur will be localised, and that the overall present status in regard to this aspect must be regarded as a category B.

8.1.11 GRU 8

8.1.11.1 Groundwater Quantity

The land cover in GRU 8 is dominated by a combination of natural veld and unimproved (natural) grassland (~82%). Encompassing the Vredefort Dome World Heritage Site, this GRU should enjoy the 'protection' offered it by the relevant Management Authority. According to Van der Walt et al. (2007), the main groundwater use in the area is for domestic and livestock water supply. These authors enumerated 205 boreholes for water level information, and report a median depth to groundwater rest level of 15.4 m below surface. No evidence of large-scale groundwater use was reported.

8.1.11.2 Groundwater Quality

The study by Van der Walt et al. (2007) found that 112 out of 163 groundwater samples met the Class I guideline criteria set out in SANS (2006) for drinking water standards. Further, that boreholes producing groundwater of an unacceptable quality for drinking were located in close proximity to the Vaal River. These sources exhibited nitrate levels >50 mg/L.

8.1.11.3 Discussion

In light of the above, it is apparent that the groundwater quantity component of the hydrogeological environment is still largely unaffected by land use activities and anthropogenic impacts, whereas groundwater quality is probably compromised in an area restricted to the course of the Vaal River through this GRU. These circumstances suggest that the overall present status in regard to groundwater resources in GRU 8 might be regarded as a category B except in proximity to the Vaal River, where a PES category of D might be assigned.

8.1.12 GRU 9

8.1.12.1 Groundwater Quantity

The land cover in GRU 9 is dominated by a combination of natural veld and unimproved (natural) grassland (~71%) and cultivated temporary commercial irrigated and dryland agriculture (~20%) making a total of ~91%. Under these circumstances, it is unlikely that any impact that manifests negatively on the reference conditions will be identifiable from routine monitoring activities unless these are targeted at specific impacts.

8.1.12.2 Groundwater Quality

Hosting 85 stations that provide groundwater chemistry information, this GRU can report only one station that supports a 9-year record (**Table 8-4**) of time series data amounting to 222 values, i.e. the equivalent of an analysis every ~2 months. The record reveals an overall increasing trend in pH and an overall decreasing trend in TDS over the sampling period.

8.1.12.3 Discussion

The insufficiency of groundwater level and groundwater quality information on which to gauge the PES of groundwater resources in this GRU even semi-quantitatively indicates that land cover type and extent might again be applied as a measure in this regard. The overall PES is assigned a category BC on the basis that ~20% of the GRU area encompasses cultivated temporary commercial dryland agriculture and other ‘unnatural’ land cover.

Table 8-4. Summary of groundwater chemistry stations and related information per GRU

GRU	Station No.	No. of Records	Period	Surface Geology	Land Cover
1	89927	19	1996-2007	Karoo Dolerite	Unimproved natural grasslands
2	177412	13	2000-2007	Normandien Formation	Urban Built up residential
3	1000005917	5	2003-2005	Volksrust Formation	Unimproved natural grasslands
	182738	5	2000-2005	Volksrust Formation	Unimproved natural grasslands
4a	89718	24	1995-2006		
	90100	23	1995-2006	Volksrust Formation	Urban built-up residential
4b	Nil				
5a	90720	37	1997-2003	Monte Christo Formation	Unimproved natural grasslands
5b	165054	320	1985-1990	Malmani Subgroup	Cultivated temporary commercial
	88876	30	1981-1985	Malmani Subgroup	Unimproved natural grasslands
	89825	14	1997-2007	Malmani Subgroup	Unimproved natural grasslands
	90621	307	1979-2008	Malmani Subgroup	Bushveld, thicket, high fynbos
	90622	323	1969-2008	Malmani Subgroup	Unimproved natural grasslands
	90635	341	1978-2001	Malmani Subgroup	Unimproved natural grasslands
6a	88770	12	1998-1999	Klipriviersberg Group	Unimproved natural grassland
	88771	12	1998-1999	Vryheid Formation	Urban built-up industrial
6b	88854	60	1984-1990	Klipriviersberg Group	Unimproved natural grasslands
	89981	23	1997-2009	Alluvium	Unimproved natural grasslands
7	182744	14	2000-2009	Hekpoort Formation	Thicket, bushland, fynbos
8	89686	24	1995-2009	Inlandsee Complex	Unimproved natural grasslands
9	90641	222	2000-2009	Timeball Hill Formation	Unimproved natural grasslands

8.1.13 Synthesis of Groundwater PES Assessment

The outcome of the present ecological state assessment for each GRU in the study area is summarised in **Table 8-5**. As illustrated in **Figure 8-3**, this indicates that ~42% of the study area supports a B category PES, ~44% a BC category PES, and ~14% a D category PES.

Table 8-5. Synthesis of proposed present ecological state (PES) per GRU for the Upper Vaal WMA

Groundwater Resource Unit	Present Ecological State		Proportion of Study Area (%)
	Category	Description	
1	B	Slightly modified	5.0
2	B	Slightly modified	14.6
3	B	Slightly modified	19.1
4a	BC	Slightly to moderately modified	23.0
4b	BC	Slightly to moderately modified	13.2
5a	BC	Slightly to moderately modified	1.6
5b	D	Significantly modified	5.4
6a	D	Significantly modified	2.3
6b	D	Significantly modified	6.2
7	B	Slightly modified	1.1
8	B	Slightly modified	2.6
9	BC	Slightly to moderately modified	5.9

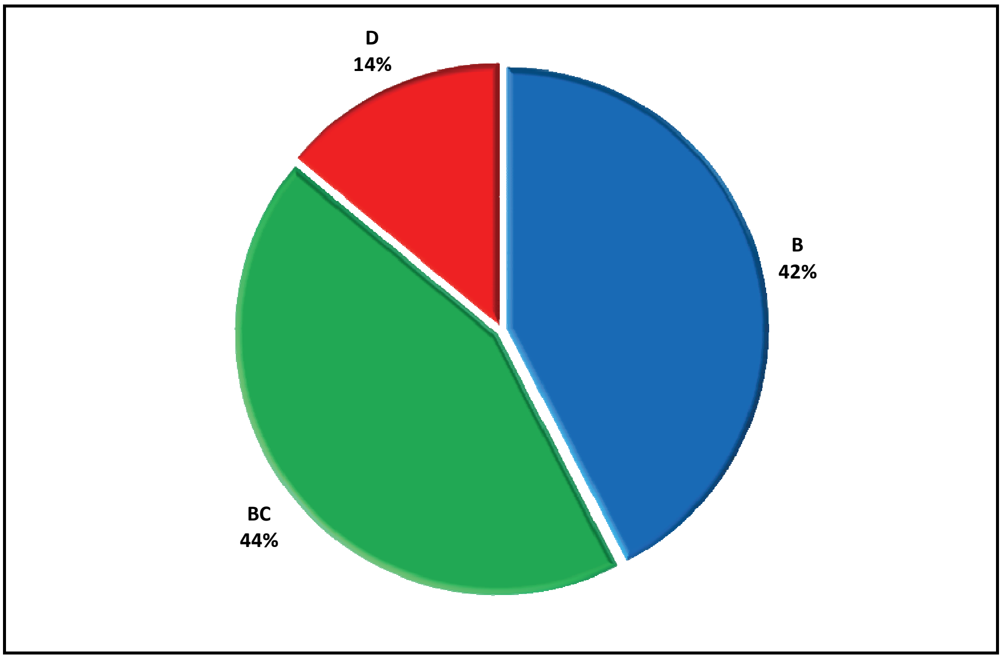

Figure 8-3. Percentage of study area categorised by present groundwater ecological status category

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

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

The total mean groundwater recharge amounts to ~1916 Mm^3/a, or ~78% of the ~2453 Mm^3/a mean annual runoff (Middleton and Bailey, 2011). Total annual groundwater use amounts to ~4.4% (~84 Mm^3) of the total mean annual groundwater recharge. The groundwater component of baseflow accounts for a further ~39% (~744 Mm^3) of the total mean annual groundwater recharge. This is 2.5 times the 299 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 ~1.3% (~24 Mm^3) of the total mean annual groundwater recharge.

The groundwater "loss" components listed above together account for ~44% (~852 Mm^3) of the total mean annual groundwater recharge. This theoretically leaves ~1063 Mm^3/a of groundwater in storage, not all of which is available for allocation to water users because of limitations imposed on accessible abstraction. It is more reasonable to accept that not more than 50% of the remaining groundwater in storage is available for allocation. This amounts to ~532 Mm^3/a, which represents ~28% on average (within the range 34.9-1.7%) of the total mean annual groundwater recharge. Against this background, it must be noted that WR2005 (Middleton and Bailey, 2011) reports a utilisable groundwater exploitation potential (UGEP) for the Upper Vaal WMA of 564 Mm^3/a. This is in reasonable agreement with the value arrived at by this study.

The aggregation of the groundwater Reserve quantities to the GRU level as represented in **Table 8-6** masks those quaternary catchments that exhibit small allocable groundwater quantities. This indicates that the quaternary catchment is in 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 D**, and indicate that 11 (~12%) of the 91 quaternary catchments in the study area exhibit this characteristic. Significantly, eight of these catchments are associated with GRUs 6a and 6b which are underlain by older Randian strata and support the highly urbanised and industrialised portions of Gauteng Province. Two of the remaining three catchments are associated with the dolomitic strata in GRUs 5a and 5b.

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 result of this determination, based on the information presented in **Table 3-3** as reference, is presented in **Table 8-7**. The veracity of the results is given credence by the electrical balance values which are all within the ±5% error margin for acceptability.

Table 8-6. Summary of the quantity component of the preliminary groundwater Reserve for the Upper Vaal WMA

Preliminary Groundwater Reserve Quantity Component Parameter		**Groundwater Resource Unit**												**Total**
		1	**2**	**3**	**4a**	**4b**	**5a**	**5b**	**6a**	**6b**	**7**	**8**	**9**	***Mean***
Recharge	Area (km^2)	2118.5	8755.3	10144.4	13839.7	6667.1	871.5	2559.7	1900.3	2897.2	622.1	1068.7	3709.1	55 516
	Mean annual precipitation (mm)	744	683	659	678	629	618	666	693	679	605	609	619	*657*
	Mean groundwater recharge (% MAP)	6.5	5.6	4.9	5.7	5.2	7.0	6.9	3.0	3.1	4.3	3.6	3.8	*5.0*
	Mean groundwater recharge (Mm^3/a)	107.2	335.7	332.3	537.8	219.1	38.5	116.8	36.6	61.4	16.0	23.1	84.0	1915.8
Use	Groundwater use (Mm^3/a)	0.54	1.33	12.64	10.35	6.26	6.99	37.20	3.72	1.95	0.13	0.60	1.98	83.9
Reserve	Groundwater component of baseflow (Mm^3/a)	67.1	115.8	88.0	207.6	58.6	10.7	37.2	25.1	53.7	7.5	15.0	53.3	744.4
	Population at minimum living level	246 618	81 914	74 808	192 064	134 469	14 239	506 371	714 795	258 923	1115	42 653	361 060	2 641 254
	Basic human needs Reserve (Mm^3/a)	2.25	0.75	0.68	1.75	1.23	0.13	4.62	6.52	2.36	0.01	0.39	3.29	24.10
	Total Reserve (Mm^3/a)	69.3	116.5	88.7	209.3	59.9	10.8	41.8	31.6	56.0	7.5	20.5	56.6	768.5
Allocation	Allocable groundwater (Mm^3/a)	18.69	108.93	115.46	159.07	76.50	10.36	18.88	0.62	1.70	4.22	3.59	12.67	531.70
	Allocable groundwater (% of Reserve)	27.0	93.5	130.2	76.0	127.7	95.9	45.2	1.9	3.0	52.3	17.5	22.4	*69.2*
	Allocable groundwater (% of recharge)	17.4	32.5	34.8	29.6	34.9	26.9	16.2	1.7	2.8	26.3	15.1	15.1	*27.8*

Table 8-7. Preliminary determination of the groundwater quality component of the Reserve for the study area

Chemistry Variable	**Groundwater Resource Unit**									**SANS (2011a)[(1)]**
	1	**2**	**3**	**4a 4b**	**5a 5b**	**6a 6b**	**7**	**8**	**9**	
pH (–$\log_{10}[H^+]$)	7.2	7.9	7.9	7.7	7.8	7.5	7.7	7.9	7.5	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	5.0-9.7	5.0-9.7	
EC (mS/m)	31.5	52	74	55	56.5	50.3	57.8	81	50.3	<150
	34.7	57.2	81.4	60.5	62.2	55.3	63.6	89.1	55.3	
Ca (mg/L)	26.5	32.5	58.0	39.0	55.0	34.5	46.3	43.0	34.5	<150
	29.2	35.8	63.8	42.9	60.5	38.0	50.9	47.3	38.0	
Mg (mg/L)	8.0	13.5	37.0	19.5	32.0	23.3	24.3	28.0	23.3	<70
	8.8	14.9	40.7	21.5	35.2	25.6	26.7	30.8	25.6	
Na + K (mg/L)	31.6	66.8	39.1	39.0	18.1	25.2	31.7	54.6	25.2	<200
	34.7	73.4	43.0	42.9	19.9	27.7	34.9	60.1	27.7	
Cl (mg/L)	7.5	37.0	46.0	34.5	15.0	24.0	35.1	24.0	24.0	<200
	8.3	40.7	50.6	38.0	16.5	26.4	38.7	26.4	26.4	
SO_4 (mg/L)	10.2	50.1	62.3	46.7	20.3	32.5	59.9	32.5	32.5	<400
	11.2	55.1	68.6	51.4	22.4	35.8	65.8	35.8	35.8	
T. Alk. (mg $CaCO_3$/L)	142	177.0	209.0	156.2	191.0	135.5	153.4	272.0	135.5	n.s.
	156.2	194.7	229.9	171.8	210.1	149.1	168.8	299.2	149.1	
NO_3 (mg N/L)	1.5	2.4	4.8	1.4	1.8	6.5	4.9	4.6	6.5	<11
	1.7	2.6	5.3	1.5	1.9	7.2	5.4	5.1	7.2	
Electrical balance (%)	2.5	2.1	2.1	1.9	1.1	3.4	3.1	2.1	3.4	≤5%
Chemical character	Ca-HCO_3	Na-HCO_3	Mg-HCO_3	Ca-HCO_3	CaMg-HCO_3	Mg-HCO_3	Ca-HCO_3	Na-HCO_3	Mg-HCO_3	—
Count (n)	16	39	69	175	2127	141	474	29		—

(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

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 hydrogeological environment might replicate the present ecological state of this environment. The PES categorisation per GRU shown in **Table 8-5** provides the framework for the setting of the proposed desired status category and management class as per **Table 8-8**.

Table 8-8. 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 (%)
1	Good	B	Good	5.0
2	Good	B	Good	14.6
3	Good	B	Good	19.1
4a	Fair	C	Fair	23.0
4b	Fair	C	Fair	13.2
5a	Fair	C	Fair	1.6
5b	Fair	D	Fair	5.4
6a	Fair	D	Fair	2.3
6b	Fair	D	Fair	6.2
7	Good	B	Good	1.1
8	Good	B	Good	2.6
9	Fair	C	Fair	5.9

It is evident from **Table 8-8** 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 8-8 shows that five of the 12 GRUs are classified as "Good". These GRUs together represent ~42% 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 GRUs 5b, 6a and 6b which are assigned a present ecological state of D (**Table 8-5**) mainly because of the impact from mining activity in these GRUs, compounded in the case of GRU 5b by its dolomitic character. Degeneration of these GRUs to a "Poor" class is possible if water resources management efforts do not address the potential mine water impacts.

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 hydrogeological 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 RQOs for the various groundwater resource units identified in the Upper 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 2.3.1** that ~75% of the Upper 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 7% 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 ~93% 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 (~14%) of the study area that reflects a significantly modified category “D” present ecological state (**Table 8-5**) and proposed desired status category and management class (**Table 8-8**). This implies that the remaining ~86% 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 ~744 Mm^3/a groundwater contribution to baseflow in the WMA (**Table 8-6**).

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 8-7**). 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**, 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 8-9**, 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 8-9. 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 **Table 8-7**
Sulphate	mg SO_4/L	400	Not specified	Not specified	400	As per **Table 8-7**
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 **Table 8-7**
Chloride	mg Cl/L	200	100	Not specified	100	As per **Table 8-7**
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 **Table 8-7**
Magnesium	mg Mg /L	100	Not specified	Not specified	100	As per **Table 8-7**
Sodium	mg/L Na	200	70	Not specified	70	As per **Table 8-7**
Potassium	mg K/L	50	Not specified	Not specified	50	As per **Table 8-7**
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 Upper Vaal WMA indicates the following.

- That the Upper Vaal WMA is readily subdivided into 12 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 hydrogeological assessment unit).

- That ~42% of the WMA (representing five GRUs) supports a B category (slightly modified) present ecological state, ~44% (representing four GRUs) supports a BC category (slightly to moderately modified) PES, and ~14% (representing three GRUs) supports a D category (significantly modified) PES.

- That total mean annual groundwater recharge amounts to ~1916 Mm^3.

- That the groundwater contribution to baseflow accounts for ~744 Mm^3/a (~39%) of the total mean annual groundwater recharge.

- That total annual groundwater use accounts for ~84 Mm^3 (~4.4%) of the total mean annual groundwater recharge.

- That the amount of allocable groundwater amounts to ~532 Mm^3/a; this is in reasonable agreement with the utilisable groundwater exploitation potential of 564 Mm^3/a obtained in WR2005.

- That eleven (~12%) of the 91 quaternary catchments reflect cautionary circumstances indicative of experiencing unacceptable groundwater "stress"; eight of these catchments are associated with the highly urbanised and industrialised portions of Gauteng Province, and two of the remaining three with the carbonate strata supporting karst aquifers in the WMA.

- That comparatively simple and uniform RQOs can be applied in regard to groundwater levels across the ~93% 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 hydrogeological environment). The remaining 7% 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 (~14%) 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 ~86% (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 ~744 Mm^3/a groundwater contribution to baseflow in the WMA.

It is concluded that the GRDM assessment of the Upper Vaal WMA has advanced the understanding of the groundwater resources environment in this area despite the challenges posed by a paucity of regionally extensive hydrogeological 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. LITERATURE SURVEY

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APPENDIX B. GROUNDWATER LEVEL DATA

B.1 DESCRIPTION

Method:Water levels

Groundwater level (mbgl) data were requested from DWA from the National Groundwater Database (NGDB), for all catchments in the Middle and Upper Vaal Water Management Areas (WMA). These included the following tertiary catchments:

- C11,C12,C13,C21,C22,C23,C81,C82 and C83 (Upper Vaal WMA), and
- C24,C25,C41,C42,C43,C60 and C70 (Middle Vaal WMA.

The data were sent as a series of Excel spreadsheets in csv formats and text files (txt), which were then combined into one Excel spreadsheet. As the water level data had no GPS co-ordinates attached it was joined to the Basic site information tables in ArcGIS 9.3 to produce a spatial layer of water levels for both the Upper and Middle Vaal WMA's.

In Excel the data were summarised as a pivot table containing fields for average, maximum and minimum water levels as well as the count, i.e. number of times sampled. The data which were sent as text files had different site ID's, but were linked, to those in the Excel spreadsheets (from the basic site information tables) by using the code "other identifier", which were also joined to the spatial layer in ArcGIS 9.3.

After the geology and GRU's were identified for the Upper Vaal, the groundwater level monitoring sites, which intersected with and were contained within each geological unit and GRU were extracted. From this all site ID's with more than 100 records and with sampling periods extending into 2009, were extracted and collated in an Excel spreadsheet.

The data were filtered and checked for discrepancies using graphical (scatter plots) analysis and standard deviations. Missing values, denoted either as 999.99 or 0 were removed from the data set. The time series data were then analyzed using the R-squared (RSQ) function in Excel. The slope of the data (water level vs. time) were used to identify any downward or upward trends in water levels. Average water levels, as well as minimum and maximum levels and their corresponding dates of measurement were also calculated and identified. The data is presented per GRU as a series of tables in B.2 TABULATED DATA.

B.2 TABULATED DATA

GRU 4a

Site ID	Outcrop Lithology	Land Cover	Maximum Value (mbgl)	Maximum Date	Minimum Value (mbgl)	Minimum Date	Average (mbgl)	Standard Deviation	R^2	Slope
2629CA00011	Karoo Dolerite	Unimproved (natural) Grassland	20.45	04/04/1985	0.06	06/05/1974	10.05	5.34	0	0

GRU 4b

Site ID	Outcrop Lithology	Land Cover	Maximum Value (mbgl)	Maximum Date	Minimum Value (mbgl)	Minimum Date	Average (mbgl)	Standard Deviation	R^2	Slope
2728BB0009 9	Karoo Dolerite	Unimproved (natural) Grassland	20.45	10/09/1974	0.06	24/10/1957	2.43	0.86	0.46	-0.0004

GRU 5a

Site ID	Outcrop Lithology	Land Cover	Maximum Value (mbgl)	Maximum Date	Minimum Value (mbgl)	Minimum Date	Average (mbgl)	Standard Deviation	R^2	Slope
2627AA00001	Chuniespoort Group	Unimproved (natural) Grassland	8.16	04/07/2001	1.80	09/05/1989	4.59	0.96	0	0
2627AA00106			34.40	31/01/1979	9.25	31/08/1970	28.43	3.92	0.56	-0.0016
2627AA00108			14.53	31/07/1979	4.68	29/11/1980	9.06	1.74	0.06	0.0003
2627AC00021			30.17	15/06/1994	24.05	02/04/1996	28.83	0.88	0.01	-0.0011
2627AC00175	Quaternary	Wetlands	5.33	18/01/1996	0.87	07/03/2000	3.47	0.70	0	0

GRU 5b

Site ID	Outcrop Lithology	Land Cover	Maximum Value (mbgl)	Maximum Date	Minimum Value (mbgl)	Minimum Date	Average mbgl)	Standard Deviation	R^2	Slope
2627AC00001	Swazian	Unimproved (natural) Grassland	19.02	08/06/1995	12.03	23/04/1996	15.55	1.67	0.19	0.0006
2627AC00002	Black Reef Formation	Cultivated, temporary, commercial, irrigated	37.50	21/03/1964	6.56	16/06/1974	20.69	5.26	0.13	0.0005
2627AC00003	Platberg group	Unimproved (natural) Grassland	27.69	05/06/1989	19.71	16/06/1978	23.99	2.69	0.41	-0.0012
2627AC00004	Chuniespoort Group	Cultivated, temporary, commercial, dryland	8.44	21/10/1986	3.81	08/04/1976	6.80	1.04	0.40	-0.0005
2627AC00171		Unimproved (natural) Grassland	14.35	17/11/2004	1.22	27/06/1997	5.37	2.07	0.06	-0.0004
2627AC00176	Swazian	Unimproved (natural) Grassland	10.18	25/07/1983	4.47	07/03/1978	8.04	1.28	0.27	-0.0006
2627AC00208	Chuniespoort Group	Unimproved (natural) Grassland	13.55	14/07/1961	8.90	12/04/1967	11.06	0.50	0.01	0.0002
2627AC00209			6.22	28/05/1984	2.25	19/09/1978	5.24	0.57	0.00	0.0000
2627AC00210			6.46	24/11/2004	4.65	16/06/1978	5.37	0.29	0.00	0.0000
2627AC00211			6.90	04/12/1972	0.73	02/03/1981	4.47	1.29	0.13	-0.0002
2627AC00212			16.67	28/05/1984	8.97	18/08/1964	15.16	0.93	0.04	-0.0001
2627AD00001			43.23	23/12/1992	30.78	07/12/1978	37.15	4.14	0.77	-0.0012
2627AD00002			41.41	25/10/1995	30.48	13/04/1971	35.98	2.78	0.57	-0.0005
2627AD00003	Chuniespoort Group	Thicket, Bushland, Bush Clumps, High Fynbos	39.56	25/10/1995	15.23	13/04/1971	31.85	6.31	0.53	-0.0018
2627AD00004	Chuniespoort Group	Urban / Built-up (residential, formal suburbs)	73.40	22/01/1996	69.02	13/04/1978	71.34	0.98	0.51	-0.0002
2627AD00060			48.30		34.20	24/06/1997	42.66	3.24	0.05	-0.0001
2627AD00067	Chuniespoort Group	Cultivated, temporary,	72.45		39.04	14/02/1978	64.30	8.30	0.06	0.0022

Site ID	Outcrop Lithology	Land Cover	Maximum Value (mbgl)	Maximum Date	Minimum Value (mbgl)	Minimum Date	Average mbgl)	Standard Deviation	R^2	Slope
		commercial, dryland								
2627AD00077	Chuniespoort Group	Urban / Built-up (residential, formal suburbs)	25.52		18.99	16/03/1978	21.52	1.22	0.00	0.0000
2627AD00081	Chuniespoort Group	Unimproved (natural) Grassland	49.77		28.24	04/05/1977	44.47	5.03	0.02	0.0007
2627AD00093	Chuniespoort Group	Thicket, Bushland, Bush Clumps, High Fynbos	57.43		23.01	02/10/1963	43.27	9.65	0.87	-0.0075
2627AD00094	Chuniespoort Group	Unimproved (natural) Grassland	35.20		24.06	04/07/1963	31.60	2.54	0.44	-0.0011
2627AD00100			33.75		27.74	15/05/1962	30.07	1.53	0.72	-0.0010
2627AD00120			147.02		125.12	25/02/1970	133.87	3.59	0.75	-0.0012
2627AD00121			114.36		95.22	28/05/1970	108.76	3.51	0.04	0.0007
2627AD00122			65.38		55.26	11/09/1979	61.22	2.36	0.01	0.0002
2627AD00124			66.00		56.42	10/11/1978	61.50	2.48	0.02	0.0003
2627BA00019			19.22		10.32	19/05/1981	14.69	1.57	0.00	0.0000
2627BA00020			19.70		3.54	16/03/1978	11.73	3.68	0.01	-0.0004
2627BA00023			25.22		19.56	04/04/1997	23.02	0.81	0.01	0.0000
2627BB00001	West Rand Group	Urban / Built-up (smallholdings, grassland)	14.26		1.50	30/06/1997	10.10	2.83	0.04	0.0002
2627BB00035	Chuniespoort Group	Mines & Quarries (mine tailings, waste dumps)	14.57		8.76		11.36	1.08	0.23	-0.0005
2627BB00036	Chuniespoort Group	Cultivated, temporary, commercial, dryland	36.08		28.47		31.75	1.24	0.03	0.0001
2627BC00001	Chuniespoort Group	Unimproved (natural) Grassland	79.19		13.20		27.97	19.09	0.84	0.0062
2627BC00006	Chuniespoort Group	Wetlands	23.15		13.00	26/09/1978	17.37	1.49	0.08	-0.0003

Site ID	Outcrop Lithology	Land Cover	Maximum Value (mbgl)	Maximum Date	Minimum Value (mbgl)	Minimum Date	Average mbgl)	Standard Deviation	R^2	Slope
2627BC00007	Chuniespoort Group	Unimproved (natural) Grassland	38.00		28.24		35.31	1.94	0.27	-0.0005
2627BC00008	Chuniespoort Group	Urban / Built-up (smallholdings, grassland)	65.19		48.13		54.18	4.65	0.79	-0.0032
2627BC00009			40.02		31.27		34.38	1.44	0.17	0.0003
2627BC00010	Chuniespoort Group	Urban / Built-up, (commercial, education, health, IT)	77.79		32.30		55.47	13.75	0.78	-0.0049
2627BC00011			35.13		23.02		30.42	2.41	0.41	-0.0005
2627BC00012	Ecca Group	Thicket, Bushland, Bush Clumps, High Fynbos	35.55		6.88		17.89	5.47	0.13	0.0017
2627BC00013	Chuniespoort Group	Unimproved (natural) Grassland	62.34		6.33		38.28	13.32	0.90	-0.0067
2627BC00014	Chuniespoort Group	Thicket, Bushland, Bush Clumps, High Fynbos	10.95		3.29		5.47	1.95	0.04	-0.0002
2627BC00015			10.56		1.90		6.63	1.93	0.22	-0.0004
2627BC00016	Chuniespoort Group	Cultivated, temporary, commercial, dryland	18.55		1.25		10.32	3.48	0.02	-0.0002
2627BC00017	Chuniespoort Group	Urban / Built-up (smallholdings, grassland)	15.00		1.95		9.27	2.14	0.18	-0.0003
2627BC00018	Chuniespoort Group	Unimproved (natural) Grassland	17.60		1.66		12.25	2.69	0.35	-0.0006
2627BC00019			16.53		1.00		10.35	3.04	0.35	-0.0006
2627BC00020			17.20		0.49		11.49	2.68	0.04	-0.0002
2627BC00021	Chuniespoort Group	Cultivated, temporary, commercial, dryland	52.33		46.92		50.74	1.01	0.33	-0.0003
2627BC00022	Chuniespoort Group	Unimproved (natural) Grassland	79.16		72.61		76.62	1.76	0.21	0.0002

Site ID	Outcrop Lithology	Land Cover	Maximum Value (mbgl)	Maximum Date	Minimum Value (mbgl)	Minimum Date	Average mbgl)	Standard Deviation	R^2	Slope
2627BC00023	Chuniespoort Group	Unimproved (natural) Grassland	22.83		7.09		11.03	2.37	0.61	-0.0015
2627BC00024	Chuniespoort Group	Urban / Built-up (smallholdings, grassland)	14.27		2.18		10.45	1.89	0.00	0.0000
2627BC00025	Chuniespoort Group	Cultivated, temporary, commercial, dryland	25.20		13.25		18.33	2.46	0.29	-0.0006
2627BC00026	Chuniespoort Group	Mines & Quarries (underground / subsurface mining)	69.52		13.70		25.12	14.73	0.48	0.0036
2627BC00027	Chuniespoort Group	Unimproved (natural) Grassland	35.57		19.44		30.42	3.86	0.70	-0.0072
2627BC00028			20.13		16.15		18.48	0.80	0.01	0.0001
2627BC00029	Chuniespoort Group	Urban / Built-up, (commercial, mercantile)	12.35		2.43		7.96	1.58	0.06	0.0001
2627BC00046	Ecca Group	Cultivated, temporary, commercial, dryland	65.79		62.76		64.76	0.78	0.48	-0.0009
2627BC00047			112.02		101.31		105.40	2.62	0.53	0.0017
2627BC00048	Ecca Group	Urban / Built-up (smallholdings, grassland)	156.64		100.81		124.08	14.20	0.98	-0.0313
2627BC00049	Chuniespoort Group	Cultivated, temporary, commercial, dryland	111.75		88.39		100.43	7.31	0.60	-0.0112
2627BC00050	Chuniespoort Group	Urban / Built-up, (commercial, education, health, IT)	66.22		42.32		50.53	5.05	0.49	-0.0012
2627BC00052	Ecca Group	Unimproved (natural) Grassland	37.04		23.30		30.01	2.40	0.28	-0.0003

Site ID	Outcrop Lithology	Land Cover	Maximum Value (mbgl)	Maximum Date	Minimum Value (mbgl)	Minimum Date	Average mbgl)	Standard Deviation	R^2	Slope
2627BC00053	Chuniespoort Group	Urban / Built-up (smallholdings, grassland)	43.00		33.00		35.87	1.01	0.13	0.0002
2627BC00075	Chuniespoort Group	Unimproved (natural) Grassland	21.00		0.05		10.56	5.50	0.40	-0.0017
2627BC00086			104.38		91.22		99.13	3.84	0.42	-0.0052
2627BC00087	Chuniespoort Group	Cultivated, temporary, commercial, dryland	144.20		71.43		77.23	6.78	0.25	-0.0019
2627BC00091	Chuniespoort Group	Unimproved (natural) Grassland	27.54		19.93		25.74	0.91	0.51	-0.0011
2627BC00092	Ecca Group	Unimproved (natural) Grassland	84.20		36.40		55.97	16.47	0.70	-0.0072
2627BC00093	Chuniespoort Group	Unimproved (natural) Grassland	68.01		40.90		52.28	6.26	0.69	-0.0026
2627BC00094			22.26		2.26		12.26	6.51	0.85	-0.0043
2627BC00096	Chuniespoort Group	Urban / Built-up (smallholdings, grassland)	88.60		73.05		80.69	4.35	0.73	-0.0029
2627BC00097	Chuniespoort Group	Cultivated, temporary, commercial, dryland	21.41		8.36		15.01	4.19	0.92	-0.0027
2627BC00099	Ecca Group	Urban / Built-up (smallholdings, grassland)	95.36		70.93		80.38	7.42	0.74	-0.0048
2627BC00102	Chuniespoort Group	Forest Plantations (Pine spp)	79.92		35.50		64.06	6.54	0.54	-0.0023
2627BC00103	Ecca Group	Forest Plantations (Pine spp)	59.33		48.00		55.06	3.26	0.70	-0.0012
2627BC00105	Chuniespoort Group	Unimproved (natural) Grassland	16.10		4.96		10.10	2.24	0.58	-0.0013
2627BC00109			55.54		34.43		48.30	6.05	0.75	-0.0123
2627BC00110	Chuniespoort Group	Cultivated, temporary,	46.60		29.03		30.01	1.67	0.00	-0.0002

Site ID	Outcrop Lithology	Land Cover	Maximum Value (mbgl)	Maximum Date	Minimum Value (mbgl)	Minimum Date	Average mbgl)	Standard Deviation	R^2	Slope
		commercial, dryland								
2627BC00122	Chuniespoort Group	Urban / Built-up (residential, formal township)	11.11		7.69		9.56	0.92	0.61	-0.0011
2627BC00123			11.26		7.67		9.62	0.95	0.69	-0.0013
2627BC00126	Chuniespoort Group	Unimproved (natural) Grassland	119.37		56.38		95.51	16.01	0.90	-0.0338
2627BC00128	Chuniespoort Group	Urban / Built-up (smallholdings, grassland)	48.90		46.92		47.53	0.26	0.24	-0.0003
2627BC00130	Chuniespoort Group	Unimproved (natural) Grassland	16.85		12.35		14.22	1.11	0.70	-0.0018
2627BC00131	Chuniespoort Group	Cultivated, temporary, commercial, dryland	130.28		61.62		96.43	18.41	0.87	-0.0352
2627BC00133			30.63		27.67		29.20	0.78	0.00	0.0004
2627BC00135	Chuniespoort Group	Unimproved (natural) Grassland	19.52		13.05		15.18	1.23	0.89	-0.0027
2627BC00136			14.38		7.96		11.09	1.55	0.83	-0.0016
2627BC00137			21.30		6.79		9.90	2.52	0.00	0.0000
2627BC00140			29.91		13.75		18.93	2.30	0.67	-0.0043
2627BC00144			92.73		58.08		72.82	10.72	0.69	-0.0062
2627BC00170			43.56		36.10		41.87	1.15	0.18	0.0003
2627BC00174	Ecca Group	Cultivated, temporary, commercial, dryland	123.90		5.69		118.45	21.66	0.42	0.0143
2627BC00176	Chuniespoort Group	Unimproved (natural) Grassland	30.99		14.99		23.33	3.74	0.80	-0.0026
2627BC00177			67.27		39.24		49.18	7.66	0.80	-0.0049
2627BC00180	Chuniespoort Group	Urban / Built-up (residential, formal suburbs)	12.19		3.76		8.58	1.70	0.45	0.0008
2627BC00181	Chuniespoort Group	Urban / Built-up, (commercial,	15.77		4.12		11.59	2.20	0.00	0.0000

Site ID	Outcrop Lithology	Land Cover	Maximum Value (mbgl)	Maximum Date	Minimum Value (mbgl)	Minimum Date	Average mbgl)	Standard Deviation	R^2	Slope
		mercantile)								
2627BC00182	Ecca Group	Unimproved (natural) Grassland	89.98		57.45		65.68	6.79	0.30	0.0029
2627BC00183	Ecca Group	Urban / Built-up (residential, formal suburbs)	24.35		5.30		13.27	2.96	0.12	0.0010
2627BC00188	Ecca Group	Wetlands	136.22		24.17		90.12	38.38	0.15	-0.0071
2627BC00203	Ecca Group	Unimproved (natural) Grassland	54.61		26.85		36.51	4.21	0.11	-0.0012
2627BC00204	Chuniespoort Group	Cultivated, temporary, commercial, dryland	15.51		2.15		10.24	3.63	0.00	0.0000
2627BC00205	Chuniespoort Group	Unimproved (natural) Grassland	43.50		8.57		27.70	8.26	0.07	0.0012
2627BC00207			98.00		71.46		87.60	6.58	0.30	-0.0041
2627BC00209			42.40		16.55		26.04	3.03	0.02	-0.0003
2627BC00211			66.96		49.95		56.82	4.90	0.65	-0.0035
2627BC00212			81.22		32.00		58.23	10.04	0.33	-0.0032
2627BC00213	Chuniespoort Group	Cultivated, temporary, commercial, dryland	51.47		27.30		38.12	6.77	0.65	-0.0043
2627BC00215			54.75		39.10		51.32	4.07	0.24	-0.0018
2627BC00221			19.57		14.80		17.25	0.73	0.13	0.0001
2627BC00222	Chuniespoort Group	Unimproved (natural) Grassland	9.80		1.00		4.03	2.76	0.07	0.0006
2627BC00227			22.49		11.17		16.26	2.30	0.06	0.0001
2627BC00231			36.33		26.65		30.04	1.78	0.34	-0.0007
2627BC00232	Chuniespoort Group	Urban / Built-up, (commercial, mercantile)	13.21		6.06		10.38	1.41	0.10	-0.0003
2627BC00234	Chuniespoort Group	Improved Grassland	61.00		41.10		50.59	3.58	0.09	-0.0006
2627BC00246	Ecca Group	Unimproved (natural) Grassland	26.57		11.81		20.40	3.95	0.56	0.0030

Site ID	Outcrop Lithology	Land Cover	Maximum Value (mbgl)	Maximum Date	Minimum Value (mbgl)	Minimum Date	Average mbgl)	Standard Deviation	R^2	Slope
2627BC00253	Chuniespoort Group	Unimproved (natural) Grassland	75.89		72.57		74.55	0.89	0.26	0.0003
2627BC00254	Chuniespoort Group	Cultivated, temporary, commercial, dryland	74.33		67.88		70.58	1.46	0.00	0.0000
2627BC00257	Ecca Group	Urban / Built-up, (commercial, mercantile)	13.39		1.62		10.17	2.30	0.03	0.0003
2627BC00258			113.98		30.36		85.71	26.23	0.70	0.0150
2627BD00002	Ecca Group	Unimproved (natural) Grassland	30.26		18.33		23.86	2.19	0.28	0.0006
2627BD00004	Ecca Group	Cultivated, temporary, commercial, irrigated	29.76		23.62		26.52	1.83	0.62	-0.0011
2627BD00008	Chuniespoort Group	Thicket, Bushland, Bush Clumps, High Fynbos	10.05		6.99		8.49	0.65	0.01	0.0000
2627BD00009			20.79		16.64		19.32	0.65	0.09	-0.0001
2627BD00010	Chuniespoort Group	Unimproved (natural) Grassland	26.12		14.95		18.68	2.13	0.07	-0.0003
2627BD00012	Chuniespoort Group	Thicket, Bushland, Bush Clumps, High Fynbos	9.54		4.86		6.92	0.94	0.50	-0.0005
2627BD00013	Pretoria Group	Cultivated, temporary, commercial, irrigated	34.37		21.28		32.63	1.46	0.11	0.0003
2627BD00014	Chuniespoort Group	Unimproved (natural) Grassland	34.77		29.33		31.72	1.58	0.07	-0.0003
2627BD00015			50.15		45.50		48.43	1.16	0.20	0.0003
2627BD00016			62.92		52.61		61.33	1.07	0.00	0.0009
2627BD00017			44.25		40.00		41.30	0.68	0.03	-0.0001
2627BD00018	Pretoria Group	Unimproved (natural) Grassland	54.88		30.74		49.44	2.17	0.05	-0.0002

Site ID	Outcrop Lithology	Land Cover	Maximum Value (mbgl)	Maximum Date	Minimum Value (mbgl)	Minimum Date	Average mbgl)	Standard Deviation	R^2	Slope
2627BD00020	Chuniespoort Group	Urban / Built-up (smallholdings, grassland)	38.59		30.24		34.68	2.71	0.60	-0.0005
2627BD00021	Chuniespoort Group	Cultivated, temporary, commercial, dryland	39.99		30.35		34.66	2.24	0.68	0.0010
2627BD00022	Ecca Group	Unimproved (natural) Grassland	10.90		3.86		6.91	1.31	0.17	-0.0002
2627BD00024	Chuniespoort Group	Urban / Built-up (smallholdings, grassland)	53.75		44.92		49.66	1.55	0.83	-0.0014
2627BD00026			16.97		8.70		13.95	1.19	0.05	-0.0001
2627BD00027	Chuniespoort Group	Unimproved (natural) Grassland	89.03		28.26		68.99	9.88	0.13	-0.0019
2627BD00028			45.92		40.20		44.33	1.19	0.12	0.0002
2627BD00029			47.21		32.16		43.36	1.55	0.51	-0.0006
2627BD00030			14.45		8.81		12.40	1.52	0.17	-0.0003
2627BD00031			36.00		27.80		32.86	2.05	0.00	0.0000
2627BD00032			20.70		10.60		16.93	1.65	0.06	0.0001
2627BD00035			11.44		6.18		9.35	0.94	0.09	-0.0002
2627BD00036			24.61		16.82		21.19	2.04	0.19	-0.0005
2627BD00037	Chuniespoort Group	Urban / Built-up (residential, formal suburbs)	14.13		7.34		11.03	1.11	0.05	-0.0001
2627BD00038	Chuniespoort Group	Unimproved (natural) Grassland	76.07		54.99		65.26	3.91	0.17	-0.0006
2627BD00039	Quaternary	Urban / Built-up, (industrial / transport : light)	36.72		27.30		31.90	2.54	0.20	-0.0004
2627BD00040	Ecca Group	Cultivated, temporary, commercial, dryland	55.81		48.38		51.71	1.13	0.12	0.0002
2627BD00041	Chuniespoort	Unimproved	80.12		41.77		50.28	7.76	0.00	0.0003

Site ID	Outcrop Lithology	Land Cover	Maximum Value (mbgl)	Maximum Date	Minimum Value (mbgl)	Minimum Date	Average mbgl)	Standard Deviation	R^2	Slope
2627BD00042	Group	(natural) Grassland	44.75		41.92		43.07	0.41	0.05	0.0001
2627BD00043	Chuniespoort Group	Urban / Built-up (smallholdings, grassland)	36.21		26.50		31.33	1.86	0.07	0.0003
2627BD00044	Chuniespoort Group	Unimproved (natural) Grassland	66.64		22.92		33.34	3.55	0.17	0.0008
2627BD00045	Chuniespoort Group	Urban / Built-up (smallholdings, grassland)	82.67		70.23		78.09	2.08	0.01	0.0001
2627BD00047	Chuniespoort Group	Unimproved (natural) Grassland	74.67		21.69		59.33	6.37	0.00	0.0002
2627BD00048			49.60		40.04		45.88	2.40	0.06	0.0003
2627BD00050	Ecca Group	Unimproved (natural) Grassland	130.92		68.86		97.96	6.01	0.02	0.0005
2627BD00051			83.92		31.69		79.78	3.61	0.00	-0.0001
2627BD00052	Chuniespoort Group	Unimproved (natural) Grassland	51.24		45.07		47.74	1.14	0.13	-0.0002
2627BD00054	Chuniespoort Group	Cultivated, temporary, commercial, dryland	49.62		42.52		46.98	1.24	0.07	0.0002
2627BD00055	Pretoria Group	Unimproved (natural) Grassland	66.56		50.66		55.23	3.17	0.41	0.0013
2627BD00056			67.15		52.42		64.38	2.37	0.02	-0.0002
2627BD00057	Ecca Group	Unimproved (natural) Grassland	62.15		52.39		57.55	2.49	0.00	0.0001
2627BD00058			71.14		56.21		66.89	2.68	0.00	0.0000
2627BD00059			91.80		83.33		87.98	2.44	0.86	-0.0044
2627BD00060			64.02		51.21		59.27	2.56	0.00	0.0000
2627BD00061			95.48		25.44		89.07	6.21	0.25	-0.0061
2627BD00062	Chuniespoort Group	Cultivated, temporary, commercial, dryland	47.08		34.65		39.44	2.38	0.14	0.0004
2627BD00063	Chuniespoort Group	Forest Plantations (Pine spp)	47.49		46.93		47.30	0.12	0.24	0.0035
2627BD00068	Chuniespoort	Unimproved	25.96		16.65		21.73	2.24	0.19	-0.0002

Site ID	Outcrop Lithology	Land Cover	Maximum Value (mbgl)	Maximum Date	Minimum Value (mbgl)	Minimum Date	Average mbgl)	Standard Deviation	R^2	Slope
2627BD00081	Group	(natural) Grassland	89.41		71.65		86.69	2.99	0.06	0.0036
2627BD00087			76.67		68.85		73.10	2.38	0.71	0.0011
2627BD00089	Chuniespoort Group	Mines & Quarries (surface-based mining)	56.95		38.34		42.69	3.00	0.09	0.0005
2627BD00094	Ecca Group	Urban / Built-up (residential, formal township)	66.28		63.65		64.82	0.57	0.53	-0.0018
2627BD00114	Chuniespoort Group	Unimproved (natural) Grassland	101.86		79.35		90.14	7.51	0.92	-0.0138
2627BD00120			28.80		21.60		26.38	1.98	0.37	0.0006
2627BD00121	Chuniespoort Group	Cultivated, temporary, commercial, dryland	24.90		20.80		23.25	1.22	0.63	-0.0019
2627BD00122	Chuniespoort Group	Unimproved (natural) Grassland	34.92		27.63		32.42	1.86	0.34	0.0006
2627BD00124			57.58		51.09		54.94	1.80	0.86	-0.0035
2627BD00126	Ecca Group	Forest Plantations (Pine spp)	55.01		46.25		51.17	2.06	0.01	-0.0001
2627BD00127	Ecca Group	Unimproved (natural) Grassland	42.75		37.51		40.06	1.78	0.98	-0.0047
2627BD00128	Chuniespoort Group	Urban / Built-up (smallholdings, grassland)	45.49		38.63		42.41	1.97	0.08	0.0005
2627BD00255	Ecca Group	Urban / Built-up (residential, formal township)	36.63		21.20		24.55	2.80	0.23	0.0040
2627CA00001	Ecca Group	Unimproved (natural) Grassland	8.40		5.79		6.94	0.68	0.76	-0.0001
2627CA00194	Chuniespoort Group	Unimproved (natural) Grassland	17.92		8.60		13.31	1.25	0.01	0.0000
2628AC00001	Chuniespoort Group	Cultivated, temporary, commercial,	69.57		53.63		57.42	2.42	0.50	0.0008

Site ID	Outcrop Lithology	Land Cover	Maximum Value (mbgl)	Maximum Date	Minimum Value (mbgl)	Minimum Date	Average mbgl)	Standard Deviation	R^2	Slope
		dryland								
2628AC00002	Pretoria Group	Unimproved (natural) Grassland	58.00		43.27		55.25	2.26	0.51	0.0009
2628AC00003	Chuniespoort Group	Unimproved (natural) Grassland	45.00		36.48		41.43	2.13	0.59	0.0009
2628AC00004			47.79		34.68		44.94	2.21	0.51	0.0009
2628AC00005			60.68		35.77		48.84	2.57	0.39	0.0009
2628AC00007	Chuniespoort Group	Cultivated, temporary, commercial, irrigated	25.22		18.08		23.38	1.46	0.36	0.0005
2628AC00008	Chuniespoort Group	Unimproved (natural) Grassland	32.31		13.24		20.92	1.87	0.15	0.0004
2628AC00010	Chuniespoort Group	Cultivated, temporary, commercial, dryland	34.85		17.35		28.63	2.59	0.38	0.0010
2628AC00015	Chuniespoort Group	Forest Plantations (Pine spp)	100.21		30.50		95.96	5.80	0.07	0.0009
2628AC00017	Chuniespoort Group	Unimproved (natural) Grassland	35.15		27.24		30.38	1.29	0.26	0.0004
2628AC00018			40.10		34.17		37.21	1.33	0.08	0.0002
2628AC00019	Chuniespoort Group	Cultivated, temporary, commercial, irrigated	28.92		17.22		20.78	1.43	0.19	0.0003
2628AC00020			37.89		27.02		30.42	1.63	0.25	0.0004
2628AC00021	Chuniespoort Group	Unimproved (natural) Grassland	46.22		20.46		28.64	2.40	0.02	0.0002
2628AC00022			61.29		47.87		52.00	2.32	0.38	0.0007
2628AC00023			58.00		46.53		50.38	2.18	0.50	0.0008
2628AC00024			3.23		0.67		1.75	0.56	0.13	0.0001
2628AC00025			58.01		51.19		54.62	2.15	0.56	0.0009
2628AC00026	Pretoria Group	Thicket, Bushland, Bush Clumps, High Fynbos	61.74		16.20		20.43	3.98	0.02	0.0002
2628AC00027	Chuniespoort	Cultivated,	6.16		0.06		1.20	0.76	0.01	0.0000

Site ID	Outcrop Lithology	Land Cover	Maximum Value (mbgl)	Maximum Date	Minimum Value (mbgl)	Minimum Date	Average mbgl)	Standard Deviation	R^2	Slope
	Group	temporary, commercial, dryland								
2628AC00029	Chuniespoort Group	Urban / Built-up (residential, formal suburbs)	22.59		4.03		9.62	4.72	0.22	-0.0014
2628AC00032	Chuniespoort Group	Unimproved (natural) Grassland	42.72		14.06		32.81	3.17	0.01	0.0002
2628AC00036	Chuniespoort Group	Urban / Built-up, (commercial, mercantile)	21.40		12.33		15.64	1.76	0.43	0.0006
2628AC00040	Karoo dolerite suite	Unimproved (natural) Grassland	6.40		1.42		2.77	0.57	0.12	0.0001
2628AC00041	Chuniespoort Group	Cultivated, temporary, commercial, dryland	68.00		54.68		58.16	2.09	0.41	0.0007
2628AC00042	Chuniespoort Group	Unimproved (natural) Grassland	7.97		2.87		6.34	0.65	0.02	0.0000
2628AC00043	Chuniespoort Group	Thicket, Bushland, Bush Clumps, High Fynbos	20.43		1.06		2.64	1.48	0.00	0.0000
2628AC00045	Chuniespoort Group	Unimproved (natural) Grassland	28.34		12.24		20.20	3.48	0.44	0.0012
2628AD00002	Quaternary	Cultivated, temporary, commercial, dryland	26.14		12.80		16.96	2.29	0.78	-0.0011
2628AD00005	Chuniespoort Group	Wetlands	2.69		0.34		1.32	0.54	0.06	-0.0001
2628AD00006	Karoo dolerite suite	Cultivated, temporary, commercial, dryland	29.98		0.89		23.06	9.92	0.73	0.0045

Site ID	Outcrop Lithology	Land Cover	Maximum Value (mbgl)	Maximum Date	Minimum Value (mbgl)	Minimum Date	Average mbgl)	Standard Deviation	R^2	Slope
2628AD00007	Quaternary	Unimproved (natural) Grassland	32.02		0.04		1.53	2.50	0.03	-0.0002

GRU 6a

Site ID	Outcrop Lithology	Land Cover	Maximum Value (mbgl)	Maximum Date	Minimum Value (mbgl)	Minimum Date	Average (mbgl)	Standard Deviation	R^2	Slope
2628AB00010	Ecca Group	Unimproved (natural) Grassland	14.28	02/10/2003	6.70	26/07/2000	8.94	1.17	0.12	0.0002

GRU 6b

Site ID	Outcrop Lithology	Land Cover	Maximum Value (mbgl)	Maximum Date	Minimum Value (mbgl)	Minimum Date	Average (mbgl)	Standard Deviation	R^2	Slope
2627DB00001	Chuniespoort Group	Urban / Built-up (smallholdings, grassland)	57.19	14/02/1991	49.06	02/04/1998	53.66	1.93	0.25	0.0005
2627DB00002			62.83	25/05/1994	40.49	26/02/1998	54.93	2.33	0.19	0.0006
2627DB00003	Ecca Group	Urban / Built-up (smallholdings, grassland)	58.78	08/11/1994	51.11	02/04/1998	55.86	1.92	0.26	0.0003
2627DB00004			53.98	23/07/1997	44.14	02/04/1998	48.84	1.98	0.23	0.0010
2627DB00005			36.92	18/01/1996	21.71	26/11/2002	30.74	2.38	0.26	0.0007
2627DB00007	Ecca Group	Cultivated, temporary, commercial, dryland	18.80	08/11/2001	3.45	25/03/1998	11.60	3.69	0.25	0.0017
2627DB00008	Ecca Group	Unimproved (natural) Grassland	23.03	10/11/1994	5.43	06/01/1998	12.86	3.87	0.36	0.0015
2627DB00009	Quaternary	Cultivated, temporary, commercial, dryland	40.77	08/06/1988	13.45	19/01/1999	38.66	2.65	0.01	0.0001

Site ID	Outcrop Lithology	Land Cover	Maximum Value (mbgl)	Maximum Date	Minimum Value (mbgl)	Minimum Date	Average (mbgl)	Standard Deviation	R^2	Slope
2627DB00010	Chuniespoort Group	Unimproved (natural) Grassland	55.93	14/12/2004	49.94	11/11/1997	54.31	1.20	0	0
2627DB00012	Ecca Group	Urban / Built-up, (industrial / transport : heavy)	30.12	15/12/2004	16.43	11/02/1994	27.21	2.57	0	-0.0001
2627DB00027	Ecca Group	Urban / Built-up (residential, formal suburbs)	20.63	16/10/1986	4.56	15/08/1983	12.12	3.54	0.64	-0.0059
2627DB00030	Ecca Group	Unimproved (natural) Grassland	13.53	27/09/1988	8.09	28/06/1983	10.84	1.10	0.70	-0.0022
2627DB00032	Quaternary	Improved Grassland	11.26	04/10/1985	0.90	27/02/1989	3.79	1.87	0.03	-0.0007
2627DB00033	Quaternary	Thicket, Bushland, Bush Clumps, High Fynbos	4.80	27/06/1986	1.80	27/02/1989	3.34	0.42	0.02	0.0001
2627DB00035	Ecca Group	Urban / Built-up (residential, formal suburbs)	8.60	10/10/1984	3.00	29/01/1986	6.07	1.19	0.27	0.0010
2627DB00037	Quaternary	Improved Grassland	34.28	22/01/1998	2.10	27/11/1985	15.62	10.10	0.93	-0.0034
2627DB00040	Quaternary	Thicket, Bushland, Bush Clumps, High Fynbos	9.37	25/11/1985	4.37	12/12/1982	6.51	0.93	0.35	-0.0012
2628AC00011	Chuniespoort Group	Unimproved (natural) Grassland	39.05	15/01/1990	25.11	06/03/2002	29.18	2.02	0.51	0.0008
2628AC00012			37.72	18/07/1991	13.79	19/07/1999	31.72	2.40	0.42	0.0009
2628AC00013			30.90	10/10/1997	11.25	06/03/2002	16.93	2.22	0.37	0.0008
2628AC00016			30.22	10/10/1997	11.40	06/03/2002	15.12	2.32	0.23	0.0006
2628AD00001	Karoo Dolerite Suite	Unimproved (natural) Grassland	62.07	18/12/2003	1.35	20/11/1991	18.74	17.86	0.88	-0.0088
2628CA00002	Ecca Group	Unimproved (natural) grassland	45.08	13/12/1995	38.20	02/04/1998	42.82	2.05	0.37	0.0012

GRU 8

Site ID	Outcrop Lithology	Land Cover	Maximum Value (mbgl)	Maximum Date	Minimum Value (mbgl)	Minimum Date	Average (mbgl)	Standard Deviation	R^2	Slope
2727AB00043	Swazian	Unimproved (natural) Grassland	10.22	26/10/1970	0.12	08/02/1978	6.87	2.61	0.05	0.0002
2727AB00044		Forest Plantations (Eucalyptus spp)	15.00	25/06/1972	3.30	28/10/1982	10.42	2.13	0.02	0.0002
2727AB00045		Unimproved (natural) Grassland	10.96	14/03/1964	7.05	27/06/1961	8.78	1.10	0.74	-0.0025

GRU 9

Site ID	Outcrop Lithology	Land Cover	Maximum Value (mbgl)	Maximum Date	Minimum Value (mbgl)	Minimum Date	Average (mbgl)	Standard Deviation	R^2	Slope
2627AD00080	Pretoria Group	Unimproved (natural) Grassland	54.00	01/10/1970	41.61	23/01/1959	51.95	1.50	0.63	-0.0009
2627AD00083	Pretoria Group	Waterbodies	39.88	01/11/1965	3.44	27/01/1999	20.14	13.24	0.90	0.0023
2627BC00002		Unimproved (natural) Grassland	10.88	09/09/1971	1.48	14/03/1976	9.09	1.32	0.02	0.0001
2627BC00003			10.28	23/10/1986	0.57	15/03/1978	5.26	2.09	0.10	0.0002
2627BC00051			20.22	20/12/1995	10.56	18/03/1978	14.19	2.38	0.67	-0.0006
2627BC00054	Pretoria Group	Thicket, Bushland, Bush Clumps, High Fynbos	34.26	13/11/1991	17.55	24/05/1996	24.98	2.97	0.09	-0.0005
2627BC00055	Pretoria Group	Unimproved (natural) Grassland	47.43	28/09/1994	14.66	27/06/1997	23.82	3.81	0.06	-0.0005
2627BC00056	Pretoria Group	Cultivated, temporary, commercial, dryland	58.76	16/09/1992	12.87	20/03/1996	20.52	6.12	0	0
2627BC00058	Pretoria Group	Unimproved (natural) Grassland	27.42	21/09/1992	5.09	27/06/1997	12.32	5.52	0.10	0.0010
2627BC00062			48.98	12/02/1990	9.64	27/06/1997	29.88	7.48	0.03	0.0012
2627BC00063			38.21	01/09/1993	5.58	20/03/1996	25.04	7.58	0.01	0.0004
2627BC00065	Intrusive Rock	Cultivated,	34.67	24/10/1990	4.31	03/06/1997	19.40	8.10	0.39	0.0034

Site ID	Outcrop Lithology	Land Cover	Maximum Value (mbgl)	Maximum Date	Minimum Value (mbgl)	Minimum Date	Average (mbgl)	Standard Deviation	R^2	Slope
		temporary, commercial, dryland								
2627BC00066	Pretoria Group	Unimproved (natural) Grassland	30.95	06/10/1993	3.52	24/07/1997	16.25	6.43	0.03	0.0007
2627BC00071			8.17	05/04/1995	2.68	03/06/1997	4.41	1.27	0.05	0.0002
2627BC00074	Pretoria Group	Cultivated, temporary, commercial, dryland	24.82	21/01/1995	11.15	08/01/1998	18.27	3.32	0.01	0.0002
2627BC00077			88.00	06/10/2004 17/11/2004	71.06	04/04/1997	73.20	2.44	0.04	-0.0003
2627BC00078			51.74	11/07/1991	31.76	02/05/1997	38.83	3.20	0.53	0.0013
2627BC00079			28.67	17/07/2004	12.55	03/06/1997	21.89	3.48	0.01	0.0002
2627BC00080	Pretoria Group	Unimproved (natural) Grassland	18.10	07/10/1993	7.76	25/04/1991	13.26	2.08	0.05	0.0003
2627BC00081			28.40	01/10/2003	12.42	29/04/1998	22.48	3.27	0.04	-0.0004
2627BC00082			37.35	07/02/1996	22.26	27/06/1997	32.15	2.20	0.03	0.0002
2627BC00088			162.76	13/07/2004	62.03	23/01/2003	109.60	32.95	0.74	-0.0104
2627BC00108	Pretoria Group	Urban / Built-up (residential, formal suburbs)	24.10	28/05/1973	13.97	16/03/1988	19.52	2.82	0.58	0.0010
2627BC00148	Pretoria Group	Cultivated, temporary, commercial, irrigated	20.13	13/02/1974	6.10	13/02/1978	15.70	3.04	0.06	0.0004
2627BC00155	Pretoria Group	Thicket, Bushland, Bush Clumps, High Fynbos	27.70	15/11/1969	13.71	12/02/1982	19.87	5.19	0.82	0.0017
2627BC00194	Pretoria Group	Unimproved (natural) Grassland	49.63	18/11/1971	17.59	15/05/1968	30.35	2.94	0.17	-0.0010
2627BC00274	Pretoria Group	Cultivated, temporary, commercial, dryland	14.90	07/06/1995	3.08	23/01/2002	8.65	2.04	0.09	0.0004

APPENDIX C. BASEFLOW DATA

																		Virgin Conditions		Modified Conditions	
QUAT	AREA	MAP	MAR	BASE FLOW	WRP BF /MAR	BASE FLOW	BASE FLOW	BASE FLOW	BASE FLOW	BASE FLOW	Mean	Std Deviation	Co of Var	Co of Var	hughes BF	Gwater Baseflow	Gwater Baseflow	Baseflow	G'water B'flow	Baseflow	G'water B'flow
			(WR 2005)	WRP		SCHULZE	WRP	PITT-MAN	HUGHES	SAMI	Excl Schulze	Excl Schulze	All	Excl Schulze			Sami				
	km2	mm/a	Mm3/a	Mm3/a	%	Mm3/a	Mm3/a	Mm3/a	Mm3/a	Mm3/a	Mm3/a	Mm3/a	%	%	% of MAR	% of MAR	Mm3/a	Mm3/a	Mm3/a	Mm3/a	Mm3/a
C11A	721	743	49.99	9.62	19%	1.09	9.62	7.50	15.91	12.04	11.27	3.61	60	32	32	13%	6.46	12.04	6.46	12.01	6.43
C11B	536	705	30.72	5.2	17%	0.80	5.2	4.72	10.40	7.88	7.05	2.63	62	37	34	15%	4.60	7.88	4.60	7.85	4.56
C11C	450	765	34.54	4.02	12%	0.72	4.02	5.18	11.91	9.29	7.60	3.66	71	48	34	13%	4.39	9.29	4.39	9.28	4.38
C11D	373	702	20.98	2.84	14%	0.56	2.84	3.28	7.09	5.39	4.65	1.97	65	42	34	15%	3.17	5.39	3.17	4.72	2.50
C11E	1157	697	64.04	7.8	12%	1.69	7.8	9.83	21.49	16.23	13.84	6.24	67	45	34	15%	9.74	16.23	9.74	16.22	9.73
C11F	931	705	53.58	5.13	10%	1.34	5.13	8.19	16.64	12.49	10.61	5.02	69	47	31	14%	7.56	12.49	7.56	12.38	7.46
C11G	433	659	19.61	2.67	14%	0.59	2.67	3.12	5.91	4.35	4.01	1.45	60	36	30	15%	3.00	4.35	3.00	4.34	2.99
C11H	1104	664	93.79	7.21	8%	0.69	7.21	6.62	22.11	15.25	12.80	7.35	81	57	24	7%	6.76	15.25	6.76	15.24	6.75
C11J	1002	658	63.2	5.06	8%	1.34	5.06	7.11	15.72	11.07	9.74	4.70	69	48	25	11%	6.76	11.07	6.76	11.07	6.76
C11K	340	633	15.84	2.7	17%	0.19	2.7	1.67	5.62	3.69	3.42	1.68	74	49	35	11%	1.82	3.69	1.82	3.69	1.81
C11L	948	675	58.86	7.91	13%	1.34	7.91	7.39	16.31	11.58	10.80	4.12	62	38	28	11%	6.77	11.58	6.77	11.56	6.75
C11M	796	637	41.13	2.38	6%	1.24	2.38	5.09	10.25	7.11	6.21	3.32	70	53	25	11%	4.69	7.11	4.69	7.10	4.69
C12A	485	614	14.23	2.64	19%	0.98	2.64	2.38	6.19	4.58	3.95	1.79	61	45	43	23%	3.26	4.58	3.26	4.57	3.25
C12B	479	631	18.44	2.64	14%	0.91	2.64	2.59	6.20	4.53	3.99	1.73	60	43	34	17%	3.18	4.53	3.18	4.53	3.17

C12C	666	605	16.52	3.47	21%	1.34	3.47	3.00	7.78	5.70	4.99	2.20	59	44	47	25%	4.19	5.70	4.19	5.68	4.17
C12D	899	667	61.69	4.11	7%	0.85	4.11	5.39	14.95	10.42	8.72	4.97	78	57	24	9%	5.27	10.42	5.27	10.42	5.26
C12E	498	641	17.08	2.75	16%	0.49	2.75	2.54	7.47	5.21	4.49	2.33	73	52	44	16%	2.80	5.21	2.80	5.21	2.80
C12F	835	635	*27.54*	*5.29*	19%	0.75	*5.29*	4.09	11.52	7.97	7.22	3.30	69	46	42	16%	4.43	7.97	4.43	7.97	4.43
C12G	571	640	19.46	3.59	18%	0.53	3.59	2.91	8.43	5.84	5.19	2.49	71	48	43	16%	3.17	5.84	3.17	5.84	3.17
C12H	355	618	7.93	1.73	22%	0.36	1.73	1.74	3.61	2.40	2.37	0.89	60	37	46	19%	1.54	2.40	1.54	2.40	1.54
C12J	344	615	7.47	1.72	23%	0.33	1.72	1.69	3.41	2.31	2.28	0.80	59	35	46	20%	1.49	2.31	1.49	2.31	1.49
C12K	479	657	15.06	2.66	18%	0.49	2.66	2.97	6.00	4.05	3.92	1.51	62	39	40	16%	2.36	4.05	2.36	4.05	2.36
C12L	887	648	25.9	5.14	20%	0.88	5.14	5.32	10.16	6.82	6.86	2.32	59	34	39	16%	4.12	6.82	4.12	6.82	4.12
C13A	595	779	55.45	4.19	8%	1.83	4.19	7.85	16.08	12.30	10.10	5.18	69	51	29	12%	6.54	12.30	6.54	12.30	6.54
C13B	616	683	35.08	3.02	9%	1.65	3.02	4.87	10.19	7.93	6.50	3.18	63	49	29	15%	5.42	7.93	5.42	7.93	5.42
C13C	837	724	59.58	5.08	9%	2.41	5.08	8.45	17.31	13.30	11.04	5.37	65	49	29	14%	8.14	13.30	8.14	13.30	8.14
C13D	896	698	55.51	5.77	10%	2.51	5.77	7.71	16.13	12.49	10.52	4.68	61	45	29	15%	8.23	12.49	8.23	12.49	8.23
C13E	603	699	37.55	3.86	10%	1.68	3.86	5.25	10.96	8.45	7.13	3.20	61	45	29	15%	5.55	8.45	5.55	8.45	5.55
C13F	611	692	36.61	3.76	10%	1.63	3.76	5.07	9.76	7.54	6.53	2.66	57	41	27	14%	5.16	7.54	5.16	7.54	5.16
C13G	435	674	21.87	3.31	15%	1.24	3.31	3.22	6.50	5.05	4.52	1.57	52	35	30	16%	3.57	5.05	3.57	4.52	3.04
C13H	589	628	20.84	2.59	12%	1.50	2.59	3.06	6.36	5.03	4.26	1.75	53	41	31	19%	3.99	5.03	3.99	5.03	3.99
C21A	707	674	16.71	3.58	21%	0.37	3.58	4.38	12.20	8.64	7.20	4.01	79	56	73	29%	4.78	8.64	4.78	8.59	4.73
C21B	431	697	11.54	3.09	27%	1.04	3.09	4.14	6.04	5.16	4.61	1.28	50	28	52	36%	4.16	5.16	4.16	4.94	3.94
C21C	438	674	9.97	2.96	30%	1.02	2.96	3.85	5.51	4.73	4.26	1.10	48	26	55	40%	3.97	4.73	3.97	4.60	3.84
C21D	446	698	12.27	3.74	30%	1.06	3.74	4.28	6.03	5.18	4.81	1.01	47	21	49	34%	4.20	5.18	4.20	4.36	3.39
C21E	629	691	16.44	4.79	29%	1.47	4.79	5.85	8.30	7.07	6.50	1.52	47	23	51	35%	5.82	7.07	5.82	6.86	5.60
C21F	427	704	12.02	3.08	26%	1.02	3.08	4.23	6.00	5.09	4.60	1.25	50	27	50	34%	4.04	5.09	4.04	4.52	3.48
C21G	463	667	10.93	2.92	27%	1.06	2.92	3.94	5.38	4.68	4.23	1.05	47	25	49	37%	4.03	4.68	4.03	4.65	4.00
C22A	548	695	26.87	5.99	22%	3.33	5.99	5.15	7.13	6.37	6.16	0.82	26	13	27	20%	5.37	6.37	5.37	5.00	4.01
C22B	392	691	18.66	4.79	26%	2.43	4.79	3.65	5.15	4.33	4.48	0.65	26	14	28	20%	3.75	4.33	3.75	2.93	2.35
C22C	465	684	21.38	5.97	28%	2.84	5.97	4.23	5.98	5.03	5.30	0.84	27	16	28	20%	4.38	5.03	4.38	5.00	4.35
C22D	345	701	17.38	4.8	28%	2.14	4.8	3.31	4.56	3.86	4.13	0.68	29	16	26	19%	3.27	3.86	3.27	1.89	1.30

C22E	532	669	14.09	5.97	42%	3.13	5.97	4.52	6.34	5.43	5.57	0.79	25	14	45	34%	4.81	5.43	4.81	4.54	3.92
C22F	440	655	9.04	2.63	29%	2.07	2.63	3.52	4.77	4.27	3.80	0.93	32	25	53	44%	4.01	4.27	4.01	4.22	3.96
C22G	831	613	14.11	1.08	8%	3.82	1.08	5.57	7.83	7.20	5.42	3.04	54	56	55	49%	6.93	7.20	6.93	6.74	6.47
C22H	454	639	8.38	1.54	18%	2.14	1.54	3.41	4.49	4.12	3.39	1.31	40	39	54	46%	3.89	4.12	3.89	4.05	3.83
C22J	669	633	11.81	1.03	9%	3.08	1.03	4.88	6.46	5.92	4.57	2.45	52	54	55	48%	5.62	5.92	5.62	5.68	5.38
C22K	434	644	8.3	0.94	11%	2.07	0.94	3.34	4.57	4.16	3.25	1.62	50	50	55	47%	3.91	4.16	3.91	3.82	3.57
C23A	258	612	3.07	0.75	24%	0.19	0.75	1.34	2.45	2.04	1.64	0.75	68	46	80	53%	1.64	2.04	1.64	1.92	1.52
C23B	701	619	8.8	2.23	25%	0.49	2.23	3.79	6.95	5.71	4.67	2.08	68	45	79	52%	4.54	5.71	4.54	5.32	4.15
C23C	1069	609	14.74	3.11	21%	0.70	3.11	5.35	10.78	8.32	6.89	3.36	71	49	73	43%	6.27	8.32	6.27	7.74	5.70
C23D	510	664	9.12	6.53	72%	5.29	6.53	9.84	10.99	10.55	9.48	2.02	30	21	120	115%	10.49	10.55	10.49	5.62	5.57
C23E	850	631	9.99	8.93	89%	8.11	8.93	15.05	16.56	15.97	14.12	3.52	31	25	166	160%	15.97	15.97	15.97	0.04	0.04
C23F	1324	605	54.93	8.91	16%	20.42	8.91	21.85	23.77	22.97	19.37	7.02	31	36	43	42%	22.97	22.97	22.97	22.69	22.69
C23G	613	597	8.26	5.59	68%	5.36	5.59	9.87	10.81	10.44	9.18	2.42	32	26	131	126%	10.44	10.44	10.44	8.11	8.11
C23H	451	604	5.65	5.4	96%	4.04	5.4	7.44	7.93	7.71	7.12	1.17	26	16	140	136%	7.69	7.71	7.69	7.44	7.42
C23J	890	620	18.49	3.36	18%	0.46	3.36	4.81	9.88	6.09	6.03	2.80	71	46	53	25%	4.65	6.09	4.65	5.51	4.07
C23K	396	607	7.57	2.18	29%	0.25	2.18	1.98	4.02	2.50	2.67	0.93	62	35	53	26%	1.97	2.50	1.97	2.26	1.72
C23L	1211	612	23.91	5.84	24%	0.75	5.84	6.30	12.59	7.79	8.13	3.09	64	38	53	26%	6.10	7.79	6.10	7.10	5.42
C81A	382	882	63.19	6.24	10%	1.67	6.24	7.07	17.32	15.75	11.59	5.75	69	50	27	6%	3.52	15.75	3.52	15.75	3.51
C81B	576	763	60.68	6.9	11%	2.15	6.9	7.78	16.40	14.48	11.39	4.76	61	42	27	7%	4.51	14.48	4.51	14.48	4.51
C81C	250	730	20.51	2.9	14%	0.90	2.9	3.10	6.43	5.64	4.52	1.79	59	40	31	10%	1.96	5.64	1.96	5.64	1.95
C81D	195	735	17.66	1.81	10%	0.87	1.81	2.44	5.19	4.59	3.51	1.64	62	47	29	9%	1.53	4.59	1.53	4.59	1.53
C81E	643	658	40.96	4	10%	2.01	4	6.04	10.68	9.08	7.45	3.00	56	40	26	11%	4.61	9.08	4.61	9.07	4.61
C81F	689	892	108.38	10.27	9%	4.79	10.27	14.12	30.35	28.09	20.71	10.00	64	48	28	8%	8.17	28.09	8.17	28.09	8.16
C81G	435	722	16.83	4.46	27%	2.17	4.46	5.66	9.45	8.76	7.08	2.40	50	34	56	25%	4.25	8.76	4.25	8.76	4.25
C81H	358	638	9.08	2.71	30%	1.09	2.71	3.08	5.48	4.63	3.97	1.30	50	33	60	28%	2.52	4.63	2.52	4.62	2.52
C81J	392	612	12.28	1.91	16%	1.06	1.91	3.02	4.82	4.02	3.44	1.26	51	37	39	20%	2.51	4.02	2.51	4.02	2.51
C81K	359	623	18.74	1.91	10%	1.03	1.91	2.91	4.66	3.88	3.34	1.19	51	36	25	12%	2.34	3.88	2.34	3.88	2.34
C81L	795	740	75.62	4.51	6%	2.88	4.51	10.18	20.38	17.89	13.24	7.26	70	55	27	8%	6.18	17.89	6.18	17.89	6.18

C81M	1093	662	71.09	7.7	11%	3.45	7.7	10.49	18.36	15.48	13.01	4.80	54	37	26	11%	7.82	15.48	7.82	15.47	7.82
C82A	582	670	30.08	4.78	16%	1.80	4.78	5.76	10.80	9.38	7.68	2.87	56	37	36	14%	4.18	9.38	4.18	9.38	4.18
C82B	493	660	29.48	3.04	10%	1.47	3.04	4.63	8.40	7.27	5.84	2.44	58	42	28	12%	3.48	7.27	3.48	7.27	3.48
C82C	353	646	17.92	2.01	11%	1.03	2.01	3.14	5.43	4.73	3.83	1.55	56	40	30	14%	2.42	4.73	2.42	4.73	2.42
C82D	572	623	19.75	2.95	15%	1.63	2.95	4.63	7.64	6.61	5.46	2.09	53	38	39	19%	3.78	6.61	3.78	6.60	3.77
C82E	623	666	29.67	4.75	16%	1.85	4.75	6.04	10.60	9.18	7.64	2.71	54	35	36	15%	4.37	9.18	4.37	9.18	4.37
C82F	484	639	18.92	2.9	15%	1.39	2.9	4.16	6.97	6.02	5.01	1.83	53	37	37	17%	3.25	6.02	3.25	6.02	3.25
C82G	581	655	25.57	3.08	12%	1.71	3.08	5.40	9.11	7.92	6.38	2.69	57	42	36	16%	3.99	7.92	3.99	7.92	3.99
C82H	783	614	25.19	3.8	15%	2.12	3.8	6.11	9.18	7.93	6.76	2.34	50	35	36	19%	4.89	7.93	4.89	7.93	4.88
C83A	746	692	29.9	5.46	18%	3.65	5.46	8.13	13.02	12.64	9.81	3.65	49	37	44	24%	7.04	12.64	7.04	12.64	7.04
C83B	251	668	10.03	1.03	10%	1.15	1.03	2.31	3.72	3.65	2.68	1.28	55	48	37	23%	2.27	3.65	2.27	3.65	2.27
C83C	828	663	32.13	4.49	14%	3.48	4.49	7.45	10.95	10.69	8.40	3.05	46	36	34	22%	7.16	10.69	7.16	10.69	7.16
C83D	465	650	9.31	2.63	28%	1.96	2.63	3.77	6.11	5.97	4.62	1.70	46	37	66	43%	4.04	5.97	4.04	5.97	4.04
C83E	426	654	14.08	2.55	18%	1.74	2.55	3.62	5.29	5.21	4.17	1.33	43	32	38	26%	3.61	5.21	3.61	5.21	3.60
C83F	875	637	24.09	4.69	19%	2.25	4.69	7.53	10.74	9.34	8.07	2.61	50	32	45	24%	5.72	9.34	5.72	5.20	1.57
C83G	695	647	17.34	4.53	26%	1.88	4.53	6.32	9.33	8.06	7.06	2.09	49	30	54	27%	4.69	8.06	4.69	8.06	4.68
C83H	547	646	14.09	4.29	30%	1.47	4.29	4.87	7.31	6.27	5.69	1.37	46	24	52	25%	3.50	6.27	3.50	6.27	3.50
C83J	222	641	8.14	1	12%	0.57	1	1.93	2.73	2.37	2.01	0.75	53	37	33	17%	1.38	2.37	1.38	2.37	1.38
C83K	548	635	17.83	3.46	19%	1.11	3.46	3.07	7.54	6.01	5.02	2.13	60	42	42	15%	2.66	6.01	2.66	6.00	2.66
C83L	826	641	26.64	5.19	19%	1.67	5.19	4.79	11.23	8.94	7.54	3.09	59	41	42	15%	3.96	8.94	3.96	8.94	3.96
C83M	1100	639	33.18	6.83	21%	2.15	6.83	6.38	14.11	11.17	9.62	3.69	57	38	43	15%	5.14	11.17	5.14	11.16	5.13

APPENDIX D. 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
1	C81F	688.0	236987	892	46.15	7.5	0.35	42.98	2.16	0.66	0.33
1	C81G	434.5	3855	722	19.86	6.3	0.09	9.12	0.04	10.61	5.31
1	C83A	745.5	3635	692	31.27	6.1	0.07	12.06	0.03	19.11	9.55
1	C83B	250.5	2141	668	9.95	5.9	0.03	2.91	0.02	7.00	3.50
Total		2118.5	246618		107.24		0.54	67.08	2.25	37.37	18.69
Mean				*744*		*6.47*					
2	C81A	381.9	323	882	22.72	6.7	0.05	15.86	0.00	6.81	3.40
2	C81B	575.5	1374	763	26.44	6.0	0.08	13.14	0.01	13.20	6.60
2	C81C	249.7	230	730	9.88	5.4	0.03	3.76	0.00	6.08	3.04
2	C81D	194.8	216	735	8.31	5.8	0.03	3.38	0.00	4.91	2.45
2	C81E	642.4	21029	658	22.34	5.3	0.10	8.27	0.19	13.78	6.89
2	C81H	357.8	1227	638	12.37	5.4	0.04	5.89	0.01	6.43	3.21
2	C81J	391.6	1496	612	12.88	5.4	0.06	1.38	0.01	11.44	5.72
2	C81K	359.1	793	623	12.34	5.5	0.05	4.99	0.01	7.28	3.64
2	C81L	793.4	689	740	35.97	6.1	0.11	16.93	0.01	18.92	9.46
2	C81M	1091.7	2936	662	38.82	5.4	0.16	12.34	0.03	26.30	13.15
2	C82A	581.7	1303	670	21.75	5.6	0.08	0.00	0.01	21.65	10.83
2	C82B	493.0	4736	660	16.88	5.2	0.07	0.00	0.04	16.77	8.38
2	C82C	353.1	978	646	12.39	5.4	0.07	5.27	0.01	7.04	3.52
2	C82D	571.6	1849	623	19.50	5.5	0.16	5.35	0.02	13.97	6.98
2	C83C	827.5	39056	663	30.60	5.6	0.10	9.91	0.36	20.24	10.12
2	C83D	464.6	1761	650	17.05	5.6	0.05	4.54	0.02	12.44	6.22
2	C83E	426.0	1918	654	15.46	5.6	0.11	4.72	0.02	10.62	5.31
Total		8755.3	81914		336		1.33	115.75	0.75	217.87	108.93
Mean				*683*		*5.6*					
3	C13C	836.2	5970	724	35.96	5.9	0.04	14.54	0.05	21.32	10.66
3	C13D	894.6	1742	698	32.67	5.2	0.11	9.80	0.02	22.75	11.37
3	C13E	602.1	1130	699	21.94	5.2	0.01	6.31	0.01	15.61	7.80
3	C13F	610.6	1525	692	19.25	4.6	0.03	5.01	0.01	14.19	7.10

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
	C13G	434.0	15885	674	14.14	4.8	0.01	3.02	0.14	10.97	5.48
	C13H	588.4	1688	628	15.36	4.2	0.02	2.18	0.02	13.14	6.57
	C82E	622.1	1725	666	20.73	5.0	0.04	5.34	0.02	15.34	7.67
	C82F	483.1	827	639	14.02	4.5	0.01	2.67	0.01	11.34	5.67
	C82G	580.3	1086	655	18.14	4.8	0.09	5.16	0.01	12.87	6.43
	C82H	782.1	1537	614	20.70	4.3	0.19	3.29	0.01	17.21	8.60
	C83F	874.8	2266	637	32.35	5.8	11.23	10.93	0.02	10.16	5.08
	C83G	694.9	14040	647	24.23	5.4	0.21	7.26	0.13	16.63	8.32
	C83H	546.7	4173	646	16.23	4.6	0.24	3.42	0.04	12.53	6.27
	C83J	221.5	18257	641	6.68	4.7	0.11	1.52	0.17	4.89	2.44
	C83K	547.6	943	635	16.63	4.8	0.24	3.55	0.01	12.83	6.41
	C83L	825.4	2014	641	23.21	4.4	0.05	3.97	0.02	19.17	9.58
Total		10144.4	74808		332.23		12.64	87.98	0.68	230.93	115.46
Mean				*659*		*4.9*					
4a	C11A	719.4	1955	743	38.93	7.3	0.00	23.54	0.02	15.37	7.69
	C11B	534.7	2142	705	26.49	7.0	0.09	14.45	0.02	11.93	5.97
	C11C	448.8	1277	765	22.16	6.5	0.14	11.92	0.01	10.09	5.05
	C11D	371.7	965	702	17.05	6.5	0.17	8.12	0.01	8.75	4.38
	C11E	1154.7	23889	697	46.63	5.8	1.26	18.56	0.22	26.59	13.29
	C11F	929.1	31634	705	39.67	6.1	0.39	15.61	0.29	23.39	11.69
	C11G	431.7	1460	659	17.01	6.0	0.22	6.29	0.01	10.48	5.24
	C11H	1102.8	33924	664	40.16	5.5	1.38	13.57	0.31	24.90	12.45
	C11J	1000.6	3106	658	36.15	5.5	0.48	11.06	0.03	24.59	12.29
	C11K	340.0	2970	633	11.47	5.3	0.31	3.28	0.03	7.85	3.93
	C11L	946.9	6416	675	32.74	5.1	0.49	10.02	0.06	22.17	11.08
	C12B	478.4	2461	631	14.40	4.8	0.13	3.51	0.02	10.75	5.37
	C12C	665.6	4257	605	18.66	4.6	0.17	7.29	0.04	11.17	5.58
	C12D	898.4	53555	667	32.75	5.5	3.78	9.37	0.49	19.12	9.56
	C12E	497.3	1960	641	16.87	5.3	0.26	5.01	0.02	11.59	5.80
	C12F	834.1	3241	635	29.46	5.6	0.36	10.02	0.03	19.05	9.52
	C12G	570.4	6797	640	21.20	5.8	0.20	8.04	0.06	12.89	6.45
	C13A	593.5	2807	779	27.18	5.9	0.21	11.85	0.03	15.10	7.55
	C13B	615.0	2395	683	21.93	5.2	0.27	6.29	0.02	15.34	7.67

GRU	Quaternary Catchment	Area (km²)	Population	MAP (mm)	Recharge		Groundwater Use (Mm³/a)	Groundwater Component of Baseflow (Mm³/a)	Basic Human Needs (Mm³/a)	Allocable Groundwater	
					(Mm³/a)	% MAP				Total (Mm³/a)	50% of Total
	C21A	706.6	4853	674	26.89	5.6	0.06	9.77	0.04	17.02	8.51
Total		13839.7	192064		537.80		10.35	207.57	1.75	318.13	159.07
Mean				*678*		*5.7*					
4b	C11M	795.2	38506	637	23.38	4.6	0.43	4.54	0.35	18.06	9.03
4b	C12A	484.1	758	614	12.10	4.1	0.00	1.59	0.01	10.50	5.25
4b	C12H	355.1	16104	618	11.26	5.1	0.08	8.86	0.15	2.18	1.09
4b	C12J	344.3	627	615	9.67	4.6	0.17	0.58	0.01	8.92	4.46
4b	C12K	478.7	2739	657	19.93	6.3	0.09	7.55	0.02	12.26	6.13
4b	C12L	886.5	2116	648	31.99	5.6	3.77	11.57	0.02	16.63	8.32
4b	C22G	830.4	2596	613	25.77	5.1	0.47	0.00	0.02	25.28	12.64
4b	C22K	433.8	58152	644	18.27	6.5	0.34	7.86	0.53	9.54	4.77
4b	C23A	258.0	1028	612	7.39	4.7	0.12	1.04	0.01	6.22	3.11
4b	C23B	701.1	2152	619	27.63	6.4	0.40	8.14	0.02	19.07	9.54
4b	C83M	1100.0	9691	639	31.72	4.5	0.39	6.91	0.09	24.33	12.17
Total		6667.1	134469		219.13		6.26	58.63	1.23	153.00	76.50
Mean				*629*		*5.2*					
5a	C23E	170.0	12981	631	7.17	6.7	6.85	2.27	0.12	-2.06	-1.03
5a	C23F	701.5	1258	605	31.34	7.4	0.15	8.41	0.01	22.78	11.39
Total		871.5	14239		38.51		6.99	10.67	0.13	20.72	10.36
Mean				*618*		*7.03*					
5b	C22A	224.8	212223	695	11.00	7.0	0.58	2.89	1.94	5.60	2.80
5b	C23D	510.1	99677	664	25.79	7.6	4.93	6.53	0.91	13.43	6.71
5b	C23G	613.1	1605	597	27.18	7.4	2.32	9.01	0.01	15.84	7.92
5b	C23E	680.0	51925	631	28.67	6.7	27.38	9.07	0.47	-8.25	-4.13
5b	C22B	140.9	85323	691	6.28	6.5	0.53	1.12	0.78	3.86	1.93
5b	C22C	176.8	36508	684	8.18	6.8	0.01	3.87	0.33	3.97	1.98
5b	C22D	214.0	19110	701	9.64	6.4	1.45	4.68	0.17	3.33	1.67
Total		2559.7	506371		116.75		37.20	37.16	4.62	37.77	18.88
Mean				*666*		*6.91*					
6a	C22A	323.6	305394	695	8.56	3.8	0.83	4.15	2.79	0.79	0.40
6a	C22B	250.5	151686	691	4.94	2.9	0.94	1.99	1.38	0.63	0.31
6a	C22C	121.0	24979	684	2.74	3.3	0.01	2.64	0.23	-0.14	-0.07
6a	C22D	131.2	11713	701	2.60	2.8	0.89	2.87	0.11	-1.27	-0.63

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
	C21D	445.8	180660	698	8.56	2.8	0.84	5.78	1.65	0.29	0.15
	C21E	628.2	40363	691	9.21	2.1	0.22	7.69	0.37	0.93	0.47
Total		1900.3	714795		36.60		3.72	25.12	6.52	1.24	0.62
Mean				*693*		*2.95*					
6b	C22C	167.5	34586	684	3.80	3.3	0.01	3.66	0.32	-0.19	-0.10
	C21B	430.6	19019	697	9.70	3.2	0.23	7.97	0.17	1.33	0.67
	C21C	437.9	8820	674	9.85	3.3	0.13	7.75	0.08	1.89	0.94
	C21F	426.6	71170	704	9.49	3.2	0.59	8.26	0.65	-0.01	0.00
	C21G	462.4	2339	667	9.38	3.0	0.03	8.07	0.02	1.26	0.63
	C22E	532.1	13549	669	12.13	3.4	0.91	10.47	0.12	0.63	0.32
	C22F	440.2	109440	655	7.01	2.4	0.05	7.48	1.00	-1.53	-0.76
Total		2897.2	258923		61.36		1.95	53.66	2.36	3.39	1.70
Mean				*679*		*3.13*					
7	C23F	622.1	1115	605	16.04	4.3	0.13	7.46	0.01	8.44	4.22
Total		as above	as above		as above		as above	as above	as above	as above	as above
Mean				*as above*		*as above*					
8	C23C	1068.7	42653	609	23.13	3.6	0.60	14.95	0.39	7.19	3.59
	C23L	363.3	12225	612	7.33	3.3	0.22	5.01	0.11	1.99	1.00
Total	C23C	1068.7	42653		23.13		0.60	14.95	0.39	7.19	3.59
Mean				*609*		*3.6*					
9	C22H	454.2	282162	639	9.35	3.2	0.07	4.81	2.57	1.90	0.95
	C22J	668.7	14856	633	15.25	3.6	0.24	10.89	0.14	3.99	2.00
	C23H	451.2	8385	604	12.43	4.6	0.27	6.96	0.08	5.12	2.56
	C23J	890.3	25528	620	19.05	3.5	0.63	12.12	0.23	6.06	3.03
	C23K	395.9	1605	607	10.76	4.5	0.26	6.86	0.01	3.62	1.81
	C23L	847.7	28524	612	17.11	3.3	0.51	11.69	0.26	4.65	2.32
Total		3708.1	361060		83.95		1.98	53.33	3.29	25.35	12.67
Mean				*619*		*3.77*					