

DETERMINATION OF THE GROUNDWATER COMPONENT OF THE RESERVE: LIMPOPO WATER MANAGEMENT AREA

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1 INTRODUCTION

1.1 Preamble

Water resources in South Africa are managed according to the principles that underpin the National Water Act (NWA) (Act No. 36 of 1998), namely sustainability and equity. The goals of sustainability and equity are thus the guiding objectives of the National Water Act, but are accompanied by the fundamental tenets of water management in this country. Resource Directed Measures can be regarded as a resource based tool to protect and conserve water and hence strives to ensure water resources are afforded a level of protection that will assure a sustainable level of utilization for the future. To this end, RDM comprises three main interrelated components, namely:

- Resource Classification (i.e. Aquifer systems and classification and delineation of resource units)
- Reserve Quantification (i.e. Basic Human Needs requirements and the Ecological Reserve)
- Resource Quality Objectives (RQOs)

In order to support the process of water use licensing while at the same time giving effect to the Reserve, the Department of Water Affairs have requested a Groundwater Reserve assessment for the Limpopo Water Management Area (WMA). The Limpopo WMA forms the northern most water management area in the country and represents part of the South African portion of the Limpopo Basin which is also shared by Botswana, Zimbabwe and Mozambique. Groundwater plays a pivotal role in the Limpopo WMA, and constitutes the only dependable source of water for many users, especially for rural water supplies as well as industrial and mining development. Due to the variability with respect to the importance, sensitivity as well as demand and current use of groundwater, the confidence levels required in the GRDM results will vary with resultant differing levels of RDM determinations required.

The Limpopo WMA comprises an aerial extent of approximately 60 000 km² and consists of sixty eight quaternary catchments (Midgely et al. 1994). The main river systems in the Limpopo WMA include (Figure 1-1):

- Matlabas,
- Mokolo,
- Lephala,
- Mogalalkwena,
- Sand, and
- Nzhelele/Nwanedzi.



Figure 1-1. Location of the Limpopo Water Management Area.

1.1 Study Objectives

The **Primary Objective** of the study is to calculate an intermediate Groundwater Resource Directed Measure GRDM assessment yielding results at medium levels of confidence for the Limpopo WMA.

Issues to be addressed during this investigation include:

- The Limpopo WMA is experiencing an over-exploitation of groundwater resources in a number of catchments. Licensing and water demand management measures should be implemented to address the water deficit and to provide for the component of the Reserve.
 - Water for rural development and poverty relief (such as additional irrigation rights for resource-poor farmers) will have to be sourced through re-allocation from existing users.
- Economic growth and the resultant increase in water requirements in the main industrial and mining towns and in new mining developments.
 - The impacts of mining and industries (water quantity and quality) must be addressed.

Aspects that must be considered with respect to groundwater development and utilization:

- Describe aquifer systems and applicable aquifer classification systems, their nature and characteristics.
- List all groundwater users such as towns, rural communities, etc. and their respective groundwater use characteristics.
- Comment on spatial coverage of existing boreholes and their main uses (i.e. for domestic, agricultural, etc. purposes).
- Describe the characteristics/nature of the groundwater resource (i.e. both quantity and quality aspects).
- Describe potential pollution sources and their likely impact on the groundwater resources, together with their vulnerability to contamination.
- Where relevant/applicable, describe surface water/groundwater interaction in parts of the catchments underlain by major aquifers. Groundwater contribution to baseflow needs to be qualified for the different geological environments.

1.2 Secondary Objective

A secondary objective will be to ensure the transfer of technical skills to historically disadvantaged individuals and to enhance their marketability as prospective professional Hydrogeologist.

1.3 Groundwater Resource Directed Measures

The NWA (Act No. 36 of 1998) introduces a series of measures which together are intended to protect all water resources. These measures are referred to as Resource Directed Measures, and in the case of where it is related to groundwater, as Groundwater Resource Directed Measures (GRDM). The gazetted approach to RDM is described below:

1.3.1 Procedure for determining different classes of water resources

The class of a water resource must describe –

- a) the extent of use of the water resource;
- b) the Reserve;
- c) the resource quality objectives; and
- d) the determination of the allocable portion of a water resource for use.

Water resources must be classified into one of the following classes –

- a) **Class I water resource:** This is one –
 - (i) which is minimally used; and
 - (ii) in which the configuration of the ecological categories of the water resources within a catchment results in an overall condition of that water resource that is minimally altered from its pre-development condition.
- b) **Class II water resource:** This is one –
 - (i) which is moderately used; and
 - (ii) in which the configuration of ecological categories of the water resources within a catchment results in an overall condition of that water resource that is moderately altered from its pre-development condition.
- c) **Class III water resource:** This is one –
 - (i) which is heavily used; and
 - (ii) in which the configuration of ecological categories of the water resources within a catchment results in an overall condition of that water resource that is significantly altered from its pre-development condition.

The procedure to determine the different classes of water resources must comprise of the following seven steps:

- a) **Step 1:** Delineate the units of analysis and describe the *status quo* of the water resource or water resources.
- b) **Step 2:** Link the socio-economic and ecological value and condition of the water resource or water resources.
- c) **Step 3:** Quantify the ecological water requirements and changes in non-water quality ecosystem goods, services and attributes.
- d) **Step 4:** Determine an ecologically sustainable base configuration scenario.
- e) **Step 5:** Evaluate scenarios within the integrated water resource management process.
- f) **Step 6:** Evaluate the scenarios with stakeholders.
- g) **Step 7:** Gazette and implement the class configuration.

1.3.2 Procedure for determining the Reserve

For each water resource class, the procedure for the determination of the Reserve must comprise of the following eight steps:

- a) **Step 1:** Initiate the basic human needs and ecological water requirements assessment.
- b) **Step 2:** Determine eco-regions, delineate resource units, select study sites and, where appropriate, align with Step 1 of the water resource classification procedure set out in Regulation 2(4).
- c) **Step 3:** Determine the reference conditions, present ecological status and the ecological importance and sensitivity of each of the selected study sites.
- d) **Step 4:** Determine the basic human needs and ecological water requirements for each of the selected study sites and, where appropriate, align with Step 3 of the water resource classification procedure set out in Regulation 2(4).
- e) **Step 5:** Determine operational scenarios and its socio-economic and ecological consequences.
- f) **Step 6:** Evaluate the scenarios with stakeholders and align with Step 6 of the water resource classification procedure set out in Regulation 2(4).
- g) **Step 7:** Design an appropriate monitoring programme.
- h) **Step 8:** Gazette and implement the Reserve.

1.3.3 Procedure for determining Resource Quality Objectives

For each water resource class, the procedure for establishing resource quality objectives must comprise of the following six steps:

- a) **Step 1:** Identify water users within each water resource management unit, and where appropriate, align with Step 1 of the water resource classification procedure set out in Regulation 2(4).
- b) **Step 2:** Determine the present state per water user and, where appropriate, align with Step 5 of the water resource classification procedure set out in Regulation 2(4).
- c) **Step 3:** Determine the desired water quality per user and, where appropriate, align with Step 6 of the water resource classification procedure set out in Regulation 2(4).
- d) **Step 4:** Determine water user specifications and, where appropriate, align with Step 6 of the water resource classification procedure set out in Regulation 2(4).
- e) **Step 5:** Determine water quality requirements of water uses and, where appropriate, align with Step 6 of the water resource classification procedure set out in Regulation 2(4).
- f) **Step 6:** Gazette and implement the resource quality objectives.

1.4 Project Implementation (Phases)

To date the most commonly applied manual to address the methods and procedures needed to implement the Groundwater Resource Directed Measures (GRDM) was based on Parsons and Wentzel (2007). This manual was updated in 2011 by the Institute for Groundwater Studies, University of the Free State, which included some new methods which can be applied to assess Groundwater Resource Directed Measures. More importantly the GRDM manual is an attempt to align to that of the

gazetted Regulations for the Establishment of the Classification System (2010) (as described in the previous section).

In view of the above, it was important to incorporate the updated methodology (and more specifically the new categorisation of groundwater resources) as outlined by the 2011 manual (Dennis, 2011). The GRDM assessment consisted of the following phases:

- **Phase 1: Inception**
 - Literature Review (identify and review all relevant information).
 - Identification of role players who can provide expert knowledge of the area
 - Project Plan (scheduled tasks and activities required)
 - Database (containing all collected geohydrological and related data)
 - Inception report
- **Phase 2: Study Implementation**
 - Description of the study area (including field verification process)
 - Delineation of groundwater resource units
 - Preliminary water resource categorisation
 - The quantification/determination of the groundwater Reserve
 - Setting of preliminary Resource Quality Objectives (RQO's)
 - Recommendations for a Groundwater monitoring programme to support the RQO's
- **Phase 3: Project Termination**
 - Once all the objectives have been achieved the client will terminate the project. The project team, and in particular the project manager, will then:
 - Supply delivery dates of final documents and products
 - Close all contracts
 - Complete and submit all reports
 - Submit final accounts and financial report

1.5 Assumptions related to GRDM

To be able to undertake GRDM assessments and quantify the volume of groundwater required to meet Classification requirements and sustain the Reserve, a number of assumptions are made:

- Groundwater systems are generally resilient and can normally recover from most perturbations. However, it is accepted that groundwater contamination can persist over decades and centuries.
- Groundwater resources can be developed and used up to a point without significantly impacting the ability of groundwater resources to sustain the Reserve or meet the RQOs.

- The ability of a geohydrological system to satisfy basic human needs, RQOs and the ecological Reserve is not impacted if regional groundwater levels do not decline significantly over the long term, and ambient groundwater quality remains within natural limits.
- The sustainable rate at which groundwater can be abstracted is a function of the average long-term annual recharge, while the volume of groundwater held in storage acts as a buffer during dry periods.
- It is assumed that recharge and groundwater abstraction are distributed relatively evenly throughout significant water resources.
- The validity of each GRDM assessment will be reviewed at least every five years using monitored data from the study area.

1.6 Sources of Information

The following sources of information were accessed during this study:

- 1:250 000 geological map sheets
- 1:500 000 hydrogeological map sheets
- Geohydrological reports obtained from consultants and DWA officials
- National Groundwater Archive (NGA)
- Groundwater Resource Information Project (GRIP) from DWA, Polokwane (Regional office)
- WARMS database from DWA, Polokwane
 - Preliminary validation results for the eastern and western sector of the Limpopo WMA¹.
- Local monitoring data from DWA, Polokwane
- Local and regional municipalities
- Field investigations (hydrocensus data)

¹ E-mail correspondence with Mr. F. Joubert (Schoeman and Partners) and Mr. C. Stopforth (Invirocon).

2 DESCRIPTION OF STUDY AREA

2.1 Location and Drainage Regions

The Limpopo WMA occupies the north-western part of the Limpopo Province. The Limpopo River watercourse forms the northern boundary of the WMA, and indeed of the country (DWAF, 2003a). The major tributaries, from the upstream end, are the Matlabas River, Mokolo River, Lephhalala River, Mogalakwena River, Sand River and the Nzhelele and Nwanedzi Rivers (refer to Figure 1-1). All of these rivers flow towards the Limpopo River in the north. The Limpopo River flows eastwards and eventually mouths in the Indian Ocean in Mozambique. The WMA does not include the total catchment area of the Limpopo River, since the upper tributaries (the Marico and Crocodile Rivers) are included in the Crocodile West and Marico WMA, and the downstream tributaries (Luvuvhu and Mutale Rivers) are included in the Luvuvhu and Letaba WMA. The Limpopo WMA includes a total of 68 quaternary catchments. Table 1 lists the sub-areas (secondary drainage area) tertiary drainages, quaternary catchments together with the main tributaries for the Limpopo WMA.

Table 1. Drainage description of the Limpopo WMA.

WMA	Sub-Area	Tertiary Drainage	Quaternary Catchments	Description
Limpopo	<i>Matlabas/Mokolo (A4)</i>	A41	A41A,B,C,D	Matlabas
			A41E	Steenbokpan
		A42	A42A,B,C,D,E,F	Mokolo (Upper)
			A42G, H, J	Mokolo (Lower)
	<i>Lephhalala (A5)</i>	A50	A50A,B,C,D,E,F	Lephhalala (Upper)
			A50G,H	Lephhalala (Lower)
			A50J	Soutkloof
	<i>Mogalakwena (A6)</i>	A61	A61A,B,C	Nyl (Upper)
			A61D,E	Nyl (Middle)
			A61F,G	Mogalakwena (Upper)
			A61H,J	Sterk
		A62	A62A,B,C,D,E,F,G,H,J	Mogalakwena (Middle)
		A63	A63C	Doringfontejiespruit
	A63A,B,D		Mogalakwena (Lower)	
	A63E		Kolope	
	<i>Sand (A7)</i>	A71	A71A,B,C,D	Sand (Upper)
			A71E,F,G	Hout
			A71H,J,K	Sand (Lower)
			A71L	Kongoloops/Soutsloot
		A72	A72A,B	Brak
<i>Nzhelele/Nwanedzi (A8)</i>	A80	A80A,B,C	Nzhelele (Upper)	
		A80D,E,F,G	Nzhelele (Lower)	
		A80H,J	Nwanedzi	

2.2 Topography

The topography is generally flat to rolling, with the Waterberg in the south and Soutpansberg in the north-east as main topographic features. The average altitude in the central part of the Limpopo WMA project area is between 400 and 800 m and between 1 200 and 2 000 m along the Soutpansberg, Blouberg and Waterberg mountain ranges (Figure 1-1) (Photo 1).



Photo 1. The Waterberg formation forms part of the Blouberg Mountain Range (Photo taken by Theo Rossouw).

2.3 Climate

In terms of climate, the Limpopo WMA is characterised by semi-arid temperatures in the south becoming arid in the northern portions. The mean annual temperature ranges between 16°C in the south to more than 22°C in the north with an average of 20°C for the catchment as a whole. Seasonal rainfall is characteristic of the area with mean annual rainfall of 300 mm to 700 mm per annum (DWAF, 2003b), occurring mainly in the summer months (e.g. October to March). In general, the rainfall decreases from the southern part of the WMA (average about 650 mm) to the drier northern parts, where the lowest MAP of about 350 mm occurs along the lower part of the Limpopo River valley. For a small portion in the Soutpansberg the MAP is 1 000 mm and higher (Figure 2-1).



Figure 2-1. Rainfall distribution map of the Limpopo Water Management Area.

Annual evaporation ranges from 1 500 mm in the northeast around the Soutpansberg region to more than 2500 in the west, with an average of 1 800 mm. As a result the average annual potential evaporation in the Limpopo WMA is higher than the rainfall in almost all areas which appreciably affects surface runoff from rainfall and causes high evaporation losses of water from storage dams. In addition, the low and variable rainfall together with high evaporation rates considerably exceeding rainfall result in a low expectation of natural recharge to groundwater.

2.4 Regional Geology

Towards the northeast the Limpopo WMA is underlain by the mega shear zone known as the Limpopo Mobile Belt, which strikes east to northeast and separates the Kaapvaal Craton from the Zimbabwean Craton (Figure 2-2). The resulting Limpopo Mobile Belt consists of three main crustal zones, namely the Northern Marginal Zone, the Central Zone and the Southern Marginal Zone, which lie parallel to one another in an ENE direction (Figure 2-2).

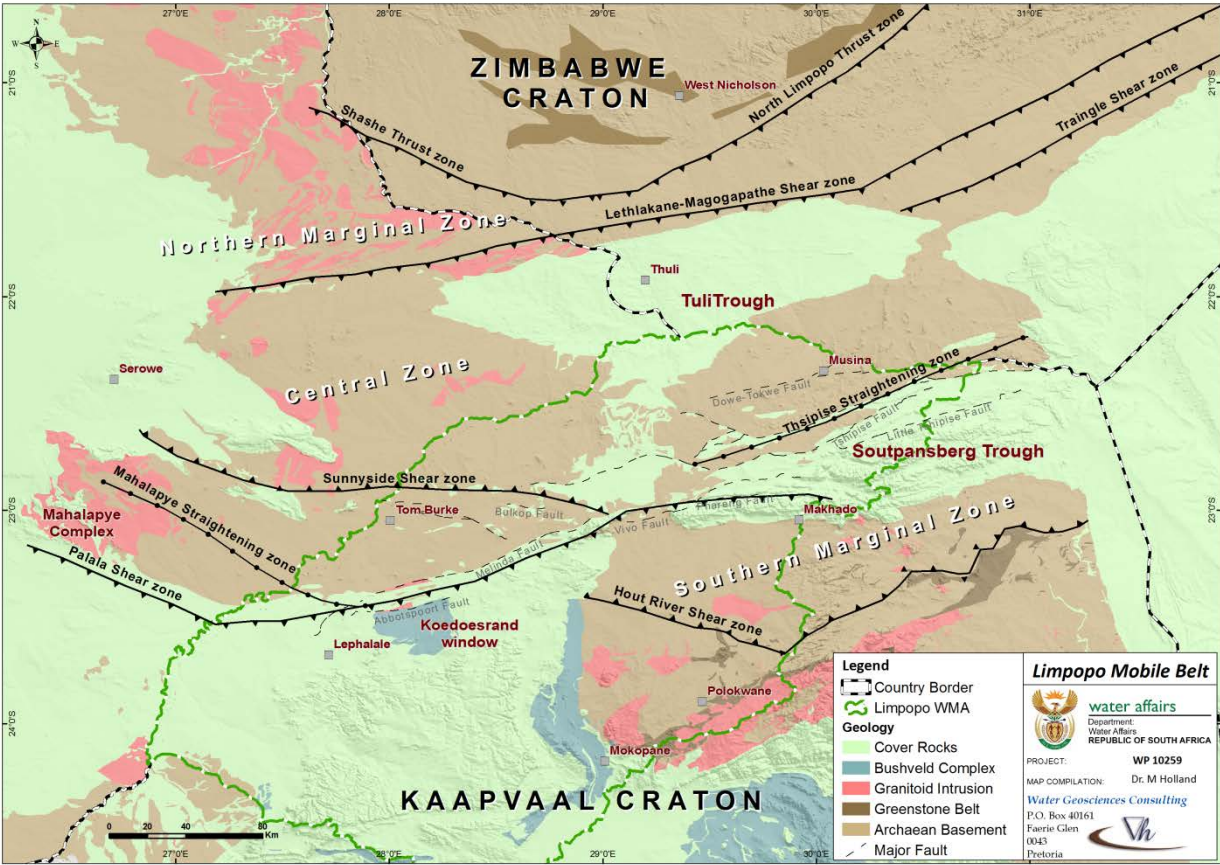


Figure 2-2. Generalised map of the Limpopo Mobile Belt showing the main features and subdivisions.

The Southern Marginal Zone is bounded by down faulted basins containing upper Karoo strata and the Soutpansberg Mountains consisting of Soutpansberg Group rocks, while to the south the northward dipping Hout River Shear Zone forms the boundary of the Limpopo Mobile Belt. To the

southwest the Limpopo Mobile belt is truncated by large E-W trending faults with younger Waterberg Group strata and the northern lobe of the Bushveld Complex on the down faulted side of the faults (e.g. Melinda Fault). The associated Palala Shear zone is regarded as the southern boundary of the Central zone of the Limpopo Mobile Belt.

2.4.1 Limpopo Mobile Belt

The LMB consists of gneissic, granites, granulites, serpentinites, metapelites and hornblende gneisses with infolded supra crustal rocks such as the Houtriver-Goudplaats gneisses and the Beit Bridge Complex (Figure 2-3), which have undergone high grade granulite metamorphism. The Beit Bridge Complex consists of metaquartzites, calcsilicates, amphibolite, meta-pelites and pink hornblende gneisses. The Bandelierskop Complex is infolded into the basement of the Houtriver-Goudplaats gneisses and consists of ultramafic peridotite, pyroxenite lavas, mafic granulite, amphibolite, metapelite, pelitic gneisses, magnetite, quartzite and meta quartzite). A number of massive, unfoliated granite intrusions occur as batholiths, plutons and stocks in the study area. These granitic intrusions form prominent topographical features that can be seen north of Polokwane (Photo 2). The Rhenosterkoppies and Pietersburg Greenstone Belts occur towards the southwest and north of Polokwane. They are composed largely of extrusive mafic and, to lesser extents, ultramafic and felsic rock. These Greenstone Belts are infolded mainly into grey granitic gneisses which dominate the early Archaean terranes (Brandl et al., 2006) (Figure 2-3).

2.4.2 Younger rocks of significance

The geology of the Limpopo WMA is summarized in this section from the Limpopo Water Resources Situation Assessment Report (DWAF, 2003a) and the Limpopo WMA Internal Strategic Perspective (ISP) (DWAF, 2004). To the south of the Limpopo Mobile Belt the Limpopo WMA is underlain by a wide variety of different lithologies. The south western quadrant of the study area is dominated by the northern lobe of the Bushveld Complex, which is intrusive into Transvaal Super Group strata and overlain by Waterberg Group sandstones which covers most of the quadrant (Figure 2-3). Transvaal Super Group rocks occur in the south central part of the study area with the strata dipping towards the Bushveld Complex. The most significant lithology in terms of groundwater potential is the Chuniespoort Group consisting of cherts, dolomites and subordinate limestone. Karoo Super Group rocks consisting of shale, shaley sandstone conglomerate with coal in places, occur in several localities throughout the Limpopo WMA but are prominent west of Lephalale and north of Alldays (Figure 2-3). The Soutpansberg Group rocks formed by the Blouberg and Soutpansberg mountain range have suffered rift type faulting and generally dip northwards.

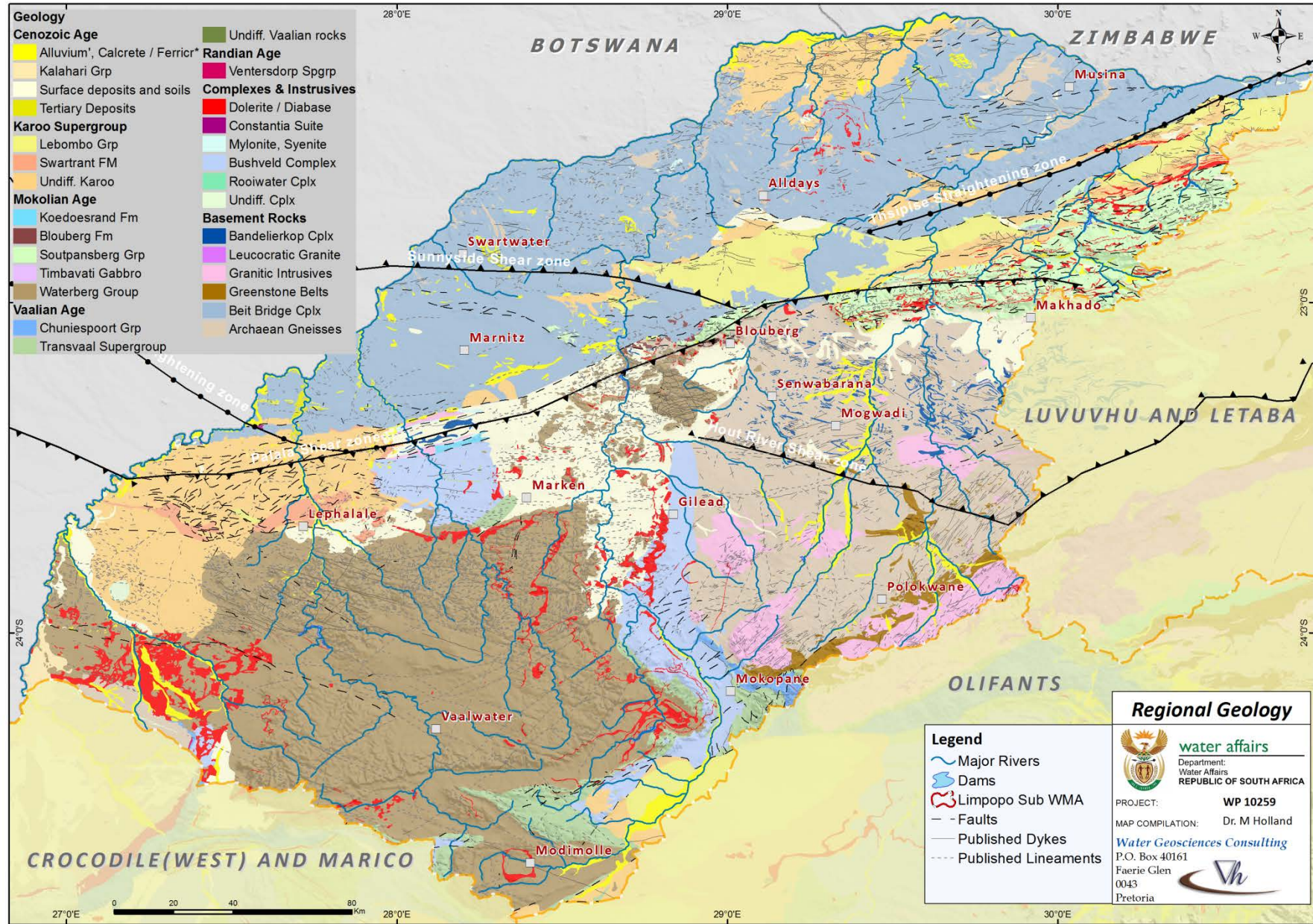


Figure 2-3. Geology of the Limpopo WMA.



Photo 2. Granitic batholith forming a distinct inselburg northwest of Polokwane (Photo taken by Martin Holland).

2.5 Soils

The soils in the Limpopo WMA can be summarised as deep sandy soil in the north, moderate to deep sandy loam in the central regions, and a mixture of sandy loam and clayey soil in the south. In the Soutpansberg area, the soil type is clayey loam. The deep soils of the Limpopo WMA are generally well-suited to agriculture, but the lack of surface runoff has been the limiting factor in agricultural development.

2.6 Land Use and Land Cover

Parts of the Limpopo WMA are heavily populated and widespread rural communities are a feature of the area which includes the old Lebowa and part of the old Venda. Hunters and cattle herders lived in the region since early times and these activities still thrive in the area today. Recent developments include large expansions in mining activities with respect to the platinum group metals and coal basins, mainly in the vicinity of the Bushveld Igneous Complex and the Karoo Super Group. Small areas of commercial forest are found in the high rainfall parts of the Soutpansberg near Makhado. Most of the WMA remains under natural vegetation, however, with livestock and game farming as main activities. Irrigation developments occur at various locations in the WMA, such as the Waterberg area, the Sand River catchment and along the Limpopo River, with much of the water being supplied from farm dams and groundwater.

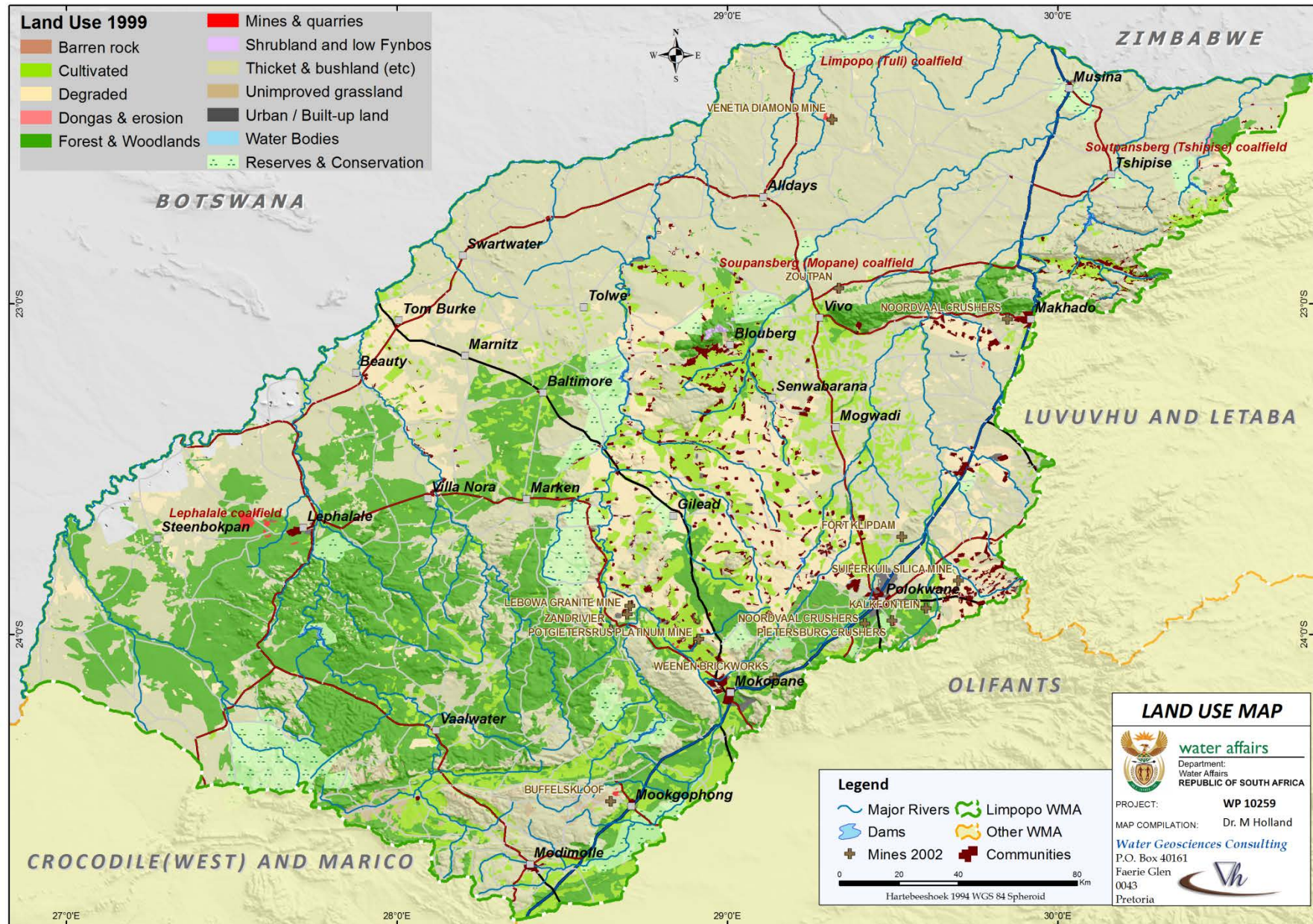


Figure 2-4. General land use map of the Limpopo WMA.

Approximately 700 rural villages are scattered throughout the WMA, more notably in the central parts, with little local economic activity to support these population concentrations (Figure 2-4). Polokwane is the largest urban centre in the WMA, and Musina, Makhado, Mokopane, Mookgopong, Lephallale and Modimolle as main towns. According to the latest demographic data from the Department of Water Affairs 1.7 million people live in the Limpopo WMA. Table 2 provides a summary of the major water user's and potential water supply issues within each sub-area of the Limpopo WMA. The Waterberg (Lephallale) coalfield has become the focus of numerous exploration efforts and is becoming a major coal mining center. However, the region is subject to infrastructure and water constraints. Other coalfields (e.g. Tuli Block and Soutpansberg Coalfields) in the Limpopo Province are also being explored, with a focus on coking coal. Other larger mining operations in the WMA include the Venetia diamond mine, the Grootegeluk collieries, the Potgietersrust and Messina platinum mines.

Table 2. Summary of major land use activities according to secondary drainage.

Sub-Area	Tertiary Drainage	Major Water Users	Comment (ISP) (DWAF, 2004)
<i>Matlabas</i>	A41	Irrigation	Largely undeveloped
<i>Mokolo</i>	A42	Lephallale Town	Mokolo Area is approximately in balance. (Additional water requirements from groundwater). The quality of the water resource could be affected by the various land uses. New open cast coal mining activities near the town of Lephallale.
		Rural Settlements	
		Grootegeluk Colliery	
		Matimba Power Station	
		Irrigation	
<i>Lephallala</i>	A50	Large Scale Irrigation	The Lephallala Area is stressed. Groundwater will be the primary source of water for the scattered rural settlements. No mining or industrial activities in this area.
		Rural Settlements	
<i>Mogalakwena</i>	A61/A62 /A63	Irrigation	Mining activities could pose serious pollution risks, more especially to groundwater. Groundwater use in the Area is large. In sourcing additional groundwater, care must be taken not to over-exploit the resource on a local scale.
		Mining/Industrial	
		Urban	
		Rural Settlements	
<i>Sand</i>	A71/A72	Irrigation	The surface water resource of the Area is very limited, urban requirements are supplied mostly from transfers into the Area. Large irrigation requirement is supplied mostly from groundwater (sustainability of the resource have been raised). Groundwater pollution in this area is widespread (more specifically nitrate).
		Mining/Industrial	
		Urban	
		Rural Settlements	
<i>Nzhelele</i>	A80	Irrigation	Increased rural requirements should be sourced from groundwater. No new allocations are possible to the irrigation. Groundwater quality might be impacted from agricultural activities in areas where application of fertilizers is poorly managed.
		Rural Settlements	
		Holiday Resort	
		Forestation	
<i>Nwanedi</i>	A80	Irrigation	There is extensive use of groundwater but still potential for further use. The risks of groundwater pollution by mining effluent and acid mine drainage must be understood. Prevention measures must be put in place, and monitoring programmes be established and maintained
		Mining (small scale)	
		Rural Settlements	

2.6.1 Vegetation

Grassland, and sparse Bushveld shrubbery and trees (Tropical Bush and Savanna) cover most of the terrain, which is also known for its splendid Boabab trees (DWAF, 2003b). Tropical Forest and woodlands occurs in the southern regions at altitudes ranging from 1 450 -1 750 m above sea level and rainfall from 700-750 mm per annum.

2.7 Hydrogeology

Some of the greatest groundwater needs in South Africa occur in the Limpopo WMA and groundwater is the only dependable source of water for many users. Groundwater is available and widely used throughout the WMA, but in varying quantities depending upon the hydrogeological characteristics of the underlying aquifer. The WMA is dominated by Intergranular and fractured aquifer systems with borehole yields between 0.1 and > 5 l/s (Figure 2-5) (Du Toit, 2003). The dominant rock types in the study area are the Goudplaats-, Hout River-, Alldays- and Sand River Gneiss as well as the Beit Bridge complex including the number of granitic intrusions. These rocks form the major subgroups of the Basement Crystalline Complex as they form part of the Achaean eon 3.1 to 2.5 Ga (Petzer, 2009). Aquifers are developed within the weathered overburden and fractured bedrock of these hard crystalline or re-crystallised rocks of igneous or metamorphic origin. Crystalline rocks are characterised by very low primary porosity (fresh or unweathered crystalline rocks contain virtually no water), and almost all groundwater movement and storage in these rocks takes place via fractures, faults, weathered zones and other secondary features that enhance the aquifer potential only locally (Lloyd, 1999). Intrusive batholiths and fractured contact zones can displace the host rocks during intrusion in order to create space for the ascending magma. These 10 to 100 metres wide zones are highly productive and can yield in boreholes in excess of 30 l/s (Du Toit, 2001).

A number of exceptionally high yielding areas not known anywhere else in Africa within the crystalline basement aquifer system occur in the Dendron (Mogwadi), Vivo, Baltimore and Tolwe regions (Figure 2-5). These aquifers have sustained (supposedly sustainable) large scale irrigation for the last few decades, suggesting high storage potential, high permeabilities and an interconnected fracture network (Photo 3). However, seeing that abstraction rates far exceed vertical recharge rates which amount to a few millimetre of the 400 mm annual rainfall, the sustainability of large scale abstraction from this groundwater resource is questionable, especially in the absence of a major recharge source. Since the early 1980s concern was expressed by Department of Water Affairs that increased groundwater abstraction may lead to failure of groundwater resources and a regional drop in water levels (Bush, 1987, Blecher, 1993; Jolly, 1986). Although evidence of over-abstraction is aggravated by below average rainfall, the groundwater level declined by 6 m since the early 1970s at the single DWA monitoring stations near Dendron (Holland, 2011). According to Masiyandima (2009) certain management interventions were implemented in the 1990s which together with an above average

rainfall for 2000 lead to a recovery of groundwater levels in 2001/2002. Continued decline of the groundwater level suggest that management interventions were not effective in controlling over abstraction. For decades the Mogwadi and Vivo area (Houdenbrak) has been a government controlled subterranean groundwater area managed by an Irrigation Board. However, failure to transform into a Water User Association with strong management measures is perhaps the biggest reason for the over-exploitation of the Houdenbrak basement aquifers.



Photo 3. Borehole with blow yield in excess of 40 l/s drilled on the Farm Brilliant south of Senwabarwana (Photo taken by Martin Holland).

The southwest of the Limpopo WMA is dominated by the Waterberg Group sandstones and the Karoo Super Group rocks which are classified as a fractured aquifer with expected borehole yields between 0.1 and > 2 l/s (Figure 2-5). Primary aquifers (or intergranular aquifers) occur throughout the WMA and exist in the vicinity of drainage channels where alluvial material overlies or replaces the weathered overburden creating a distinct intergranular aquifer type. The elongated alluvial aquifers follow rivers (so called valley trains), sand rivers or drainage lines with limited width and depth, which typically vary according to the topography and climate.

The mountainous area east of Mokopane are also of special interest as far groundwater is concerned as this area consists primarily of dolomite and has considerable groundwater resources. The karst aquifer with expected yields of more than > 5l/s is however heavily exploited, within quaternary catchment A61F (DWAF, 2004).

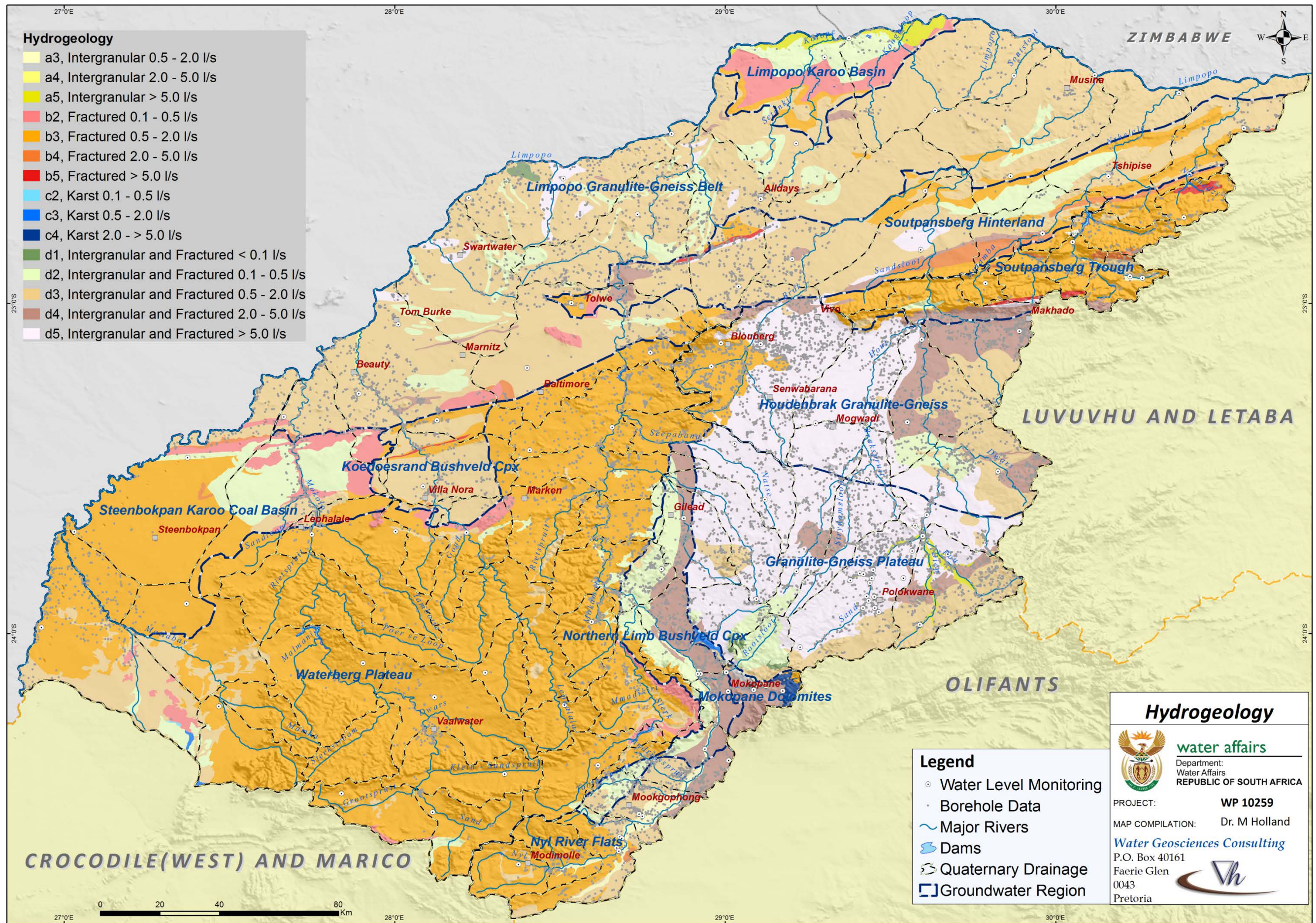


Figure 2-5. Hydrogeological map (Based on the 1:500 000 Pietersburg map) including borehole distribution and groundwater regions adapted from Vegter (2000).

2.7.1 Groundwater regions

The groundwater divisions as proposed by Vegter (2000) are primarily based on geology and not hydraulic units as such. As a result the delineated regions group similar geological rocks that has uniform water bearing properties. A comparison of the borehole information of the 12 groundwater regions within the Limpopo WMA adapted from Vegter (2000) is provided in Table 3 and spatially illustrated in Figure 2-5. From the results, the variability between delineated groundwater regions is clear. As expected the Mokopane dolomite region have above average transmissivity and yields, while lower transmissivities and yields are associated with the Karoo- and Soutpansberg Strata. The variability in groundwater potential is also evident between the crystalline basement complexes, where the Houdenbrak Granulite-Gneiss has higher average yields compared to the Limpopo Granulite-Gneiss Belt.

Table 3. Comparison of hydrogeological parameters for each groundwater region.

Hydrogeological Region	Info	BH Depth (mbgl)	Water Level (mbgl)	Transmissivity (m ² /day)	Rec. Yield (l/s for 24hrs)	Airlift Yield (l/s)	% of BH's within 150 m of Major River
All	Mean	65	19.5	44.5	1.2	5.9	9%
	N	10612	6652	1603	2538	2502	
Granulite-Gneiss Plateau	Mean	64	15.0	40.0	1.3	5.6	14%
	N	1964	1149	309	746	119	
Houdenbrak Granulite-Gneiss	Mean	67	27.5	47.9	1.6	10.9	6%
	N	2167	1237	390	537	790	
Koedoesrand Bushveld Cpx	Mean	53	9.8	52.5	1.1	-	9%
	N	142	114	61	85	-	
Limpopo Granulite-Gneiss Belt	Mean	57	22.9	38.7	1.1	2.4	5%
	N	2135	1393	128	162	673	
Limpopo Karoo Basin	Mean	33	12.4	12.4	0.8	3.7	22%
	N	99	86	1	1	28	
Mokopane Dolomites	Mean	69	21.5	112.3	1.6	7.8	18%
	N	124	92	22	30	15	
Northern Limb Bushveld Cpx	Mean	59	14.3	53.1	1.1	4.2	12%
	N	615	397	188	230	107	
Nyl River Flats	Mean	57	14.7	24.1	1.5	4.5	2%
	N	574	229	15	15	433	
Soutpansberg Hinterland	Mean	64	19.3	77.8	1.4	3.9	3%
	N	726	473	97	156	293	
Soutpansberg Trough	Mean	63	11.8	16.0	0.7	2.6	22%
	N	324	244	139	189	14	
Steenbokpan Karoo Coal Basin	Mean	91	21.2	7.5	1.5	1.6	6%
	N	269	220	8	12	13	
Waterberg Plateau	Mean	77	16.3	39.1	0.8	5.0	15%
	N	1473	1018	245	375	17	

N = Number of boreholes

Average water levels for the Limpopo WMA are 19 metres below groundwater level (mbgl). Deep water levels may be attributed to deeper water strikes, topography and groundwater potential. Shallow water levels are associated with the Koedoesrand Bushveld Complex which straddles the Lephalala River. This region is also characterised by the least average borehole depth typifying the occurrence of shallow water strikes. On the other hand the Steenbokpan Karoo Coal Basin has the deepest boreholes and may be as a result of deep drilling into the underlying confined Waterberg Group strata. Groundwater exploration in the Lephalala area by the Department of Water Affairs found the main water strikes in the Waterberg Group to be between 120 - 270 mbgl, with blow yields ranging from 0.2 – > 20 l/s (Veltman et al., 2009). Boreholes drilled into the shallow alluvial aquifer obtained blow yields of 0.7 – 10 l/s, while the Karoo rocks yielded minor water strikes 0.05 – 0.1 l/s. The study concluded that the Karoo rocks were not considered as a potential groundwater resource for the area's increasing water demands.

Remarkably 9 % of all boreholes are located along the major perennial drainage channels. Apart from the primary alluvial aquifers associated with these rivers, host rocks in the vicinity of rivers might be more intensely fractured, jointed and/or weathered. Drainage channels tend to follow zones of structural weaknesses (i.e. lineaments) in the near surface; therefore higher borehole yields are often experienced along these zones. The distribution of boreholes obtained from the National groundwater Archive (NGA) and the Limpopo Groundwater Resources Information Project (GRIP) is illustrated in Figure 2-5. It is noted that the accuracy and reliability of the relatively old NGA data is questionable but nevertheless provides baseline data on which the GRDM assessment can be based.

2.7.2 Groundwater use and availability

According to the Limpopo WMA Water Resources Situation Assessment in 2003 (DWAF, 2003b) nearly 40% of the yield from local water resources in the water management area is from groundwater. This amounts to approximately 99 million m³/a (Baron and Seward, 2000). More recent estimates from the GRA II dataset is substantially more than previous result show and amounts to 196 million m³/a. According to the Limpopo WMA ISP (DWAF, 2004), groundwater use amount to 310 million m³/a of which 85 % is utilised by the agriculture sector (Figure 2-6). This volume of total groundwater use for the Limpopo WMA was based on the Water Resource Management Services Database (WARMS) and the National Water Resource Strategy. This estimate relates to:

- 35 % of the utilisable groundwater exploitation potential of 540 million m³/a,
- and 90 % of the utilisable potable groundwater exploitation potential of 333 million m³/a for the Limpopo WMA.

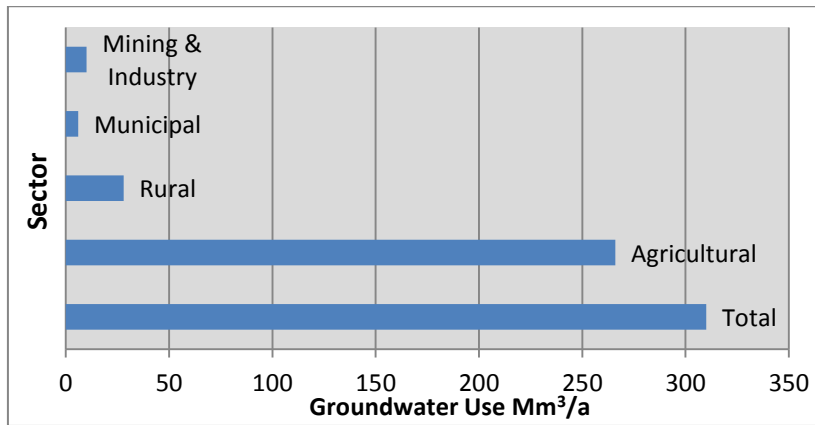


Figure 2-6. Groundwater use per sector (DWAF, 2004).

Groundwater Availability (DWAF, 2004b GRA II)

The volume of water that may be abstracted from a groundwater resource may ultimately be limited by anthropogenic, ecological and/or legislative considerations, which ultimately is a management decision that will reduce the total volume of groundwater available for development – referred to as the **Utilisable Groundwater Exploitation Potential (UGEP)**. It is likely that, with an adequate and even distribution of production boreholes in accessible portions of most catchments or aquifer systems, these volumes of groundwater may be annually abstracted on a sustainable basis. The UGEP under normal rainfall conditions for the county is estimated at $10.3 \times 10^9 \text{ m}^3/\text{a}$.

Groundwater quality is one of the main factors restricting the development of available groundwater resources. The **Utilisable Potable Groundwater Exploitation Potential (UPGEP)** represents an approximate 30 % reduction in the annual volumes of available groundwater for domestic supply due to water quality constraints.

The **Groundwater Harvest Potential** is aimed at providing preliminary estimates on a national scale of the annual maximum volume of groundwater that can be abstracted from a unit area on a sustainable basis. The HP for South Africa was estimated at $19.1 \times 10^9 \text{ m}^3/\text{a}$.

It must be emphasised that the volumes of groundwater estimated under the various exploitation scenarios are for planning purposes only. They give an indication of the availability and distribution of groundwater resources. Detailed studies are still required to quantify, develop and exploit individual groundwater abstraction schemes.

2.7.3 Groundwater recharge

The distribution of recharge based on the GRA II dataset is presented in Figure 2-7. Overall groundwater recharge is approximately 702 million m^3/a assuming recharge being 2% of mean annual precipitation (DWAF, 2004). As a result, the estimated groundwater use of 310 million m^3/a is theoretically 42 % of the annual recharge in the Limpopo WMA. However, while abstractions of groundwater for large scale irrigation from may lead to over-exploitation, in many other areas,

groundwater is the only remaining water resource which is not fully utilised and is generally under-utilised.

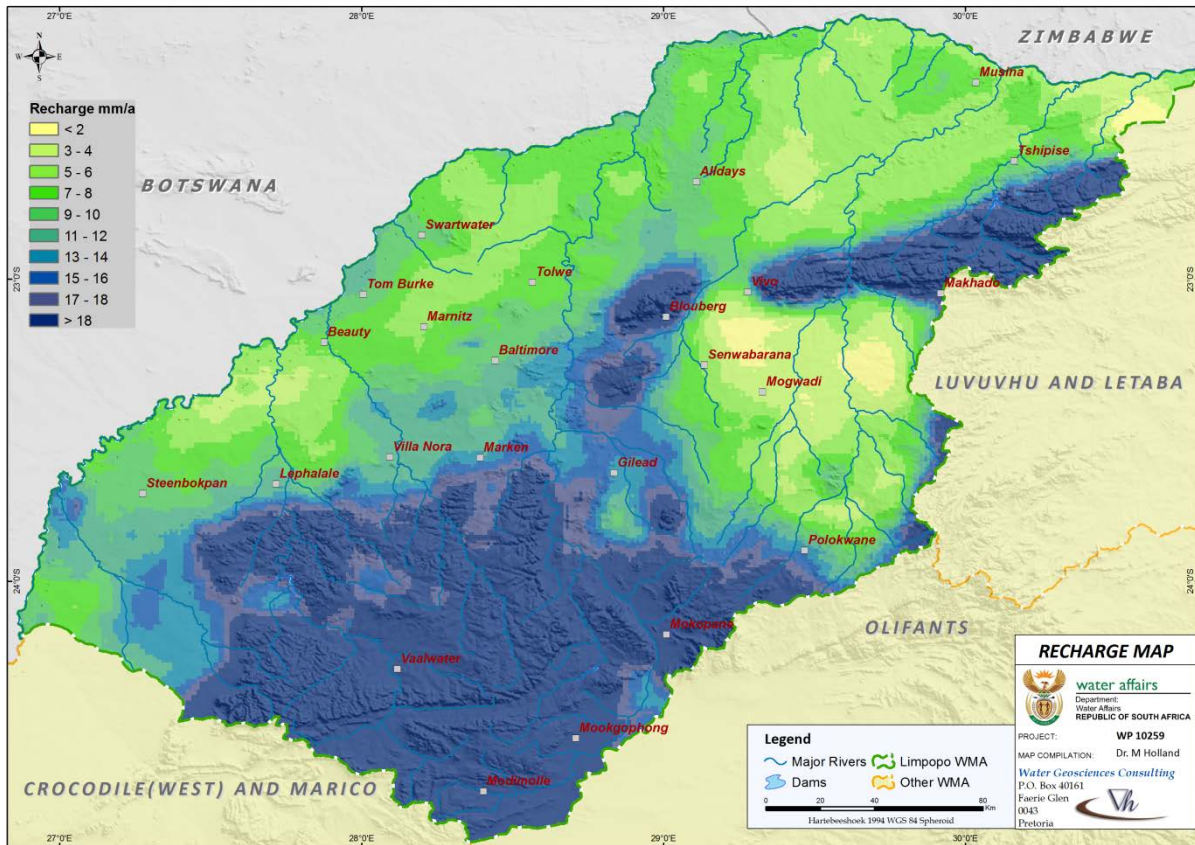


Figure 2-7. Recharge map based on values obtained from the GRA II dataset.

2.7.4 Groundwater quality

Even though the groundwater quality will be discussed in more detail in the following sections, a short discussion is provided here. Approximately 3 700 groundwater quality samples were collated from the NGA and GRIP Limpopo databases. Major elements (pH, EC, Ca, Mg, Na, K, SO₄, Cl, NO₃ as N and F) were compared to the water quality guidelines for acceptable drinking water specified by the South African National Standard (SANS 241:2006) (Table 4). It describes two classes of drinking water:

- Class I; is considered to be acceptable for lifetime consumption, and is the recommended compliance limit.
- Class II; is considered to represent drinking water for consumption for a limited period. This class specifies a water quality range that poses an increasing risk to consumer's dependent on the concentration of the determinant within the specified range.

Table 4. Average concentrations of major ions for groundwater samples in the Limpopo WMA (EC in mS/m, all other in mg/l).

Parameter	pH	EC	Ca	Mg	Na	K	SO ₄	Cl	NO ₃ as N	F
Nr. of samples	3789	3781	3575	3573	3564	3543	3622	3754	3651	3709
Minimum	3.55	0.40	0.36	0.03	2.00	0.01	0.05	0.20	0.10	0.10
Mean value	8.0	147.8	70.7	60.0	138.9	7.9	64.1	217.4	16.0	0.8
Maximum	10.1	2660.0	955.3	793.2	1972.6	203.0	2692.0	3593.1	239.1	13.5
Std. Deviation	0.5	165.2	70.4	57.0	147.7	10.5	176.3	349.6	23.0	1.2
Recommended drinking water quality limits (SANS:241, 2006)										
Class I: (Recommended operational limit)	5.0- 9.5	< 150	< 150	< 70	< 200	< 50	< 400	< 200	< 10	< 1
Class II: (Max. allowable)	4.0-10	150-370	150- 300	70- 100	200-400	50- 100	400-600	200-600	10-20	1-1.5
Class II: (Consumption period, max.)	No limit	7 years	7 years	7 years	7 years	7 years	7 years	7 years	7 years	1 year

Approximately 40 % of all groundwater samples in the Limpopo WMA exceed the recommended drinking limit. The most noticeable elements of concern for water consumption are nitrate (measured as nitrogen (N)) and chloride. According to Marais (1999), the single most important reason for groundwater sources in South Africa being declared unfit for drinking is nitrate levels exceeding 10 mg/l (as N). The main inputs of nitrate to groundwater in rural environments are derived from anthropogenic activities such as inappropriate on-site sanitation and wastewater treatment, improper sewage sludge, drying and disposal, and livestock concentration at watering points near boreholes. However, the extensive occurrence of nitrate in groundwater in uninhabited regions (Figure 2-8) suggest non-anthropogenic sources possibly related to evaporative enrichment of dry and wet deposition, biogenic point sources through N-fixing organisms, or to a geogenic origin (Tredoux and Talma, 2006). Several samples show major ion concentrations (i.e. Mg, Na, Cl, and F) and subsequently electric conductivities beyond acceptable limits. This can mostly be related to evaporative concentration of elements in discharge areas or due to low recharge values as well as long residence times for selected samples. The occurrence of fluoride is primarily controlled by geology and climate. Therefore, there are no preventative measures under the given spatial limits of water supply to avoid contamination.

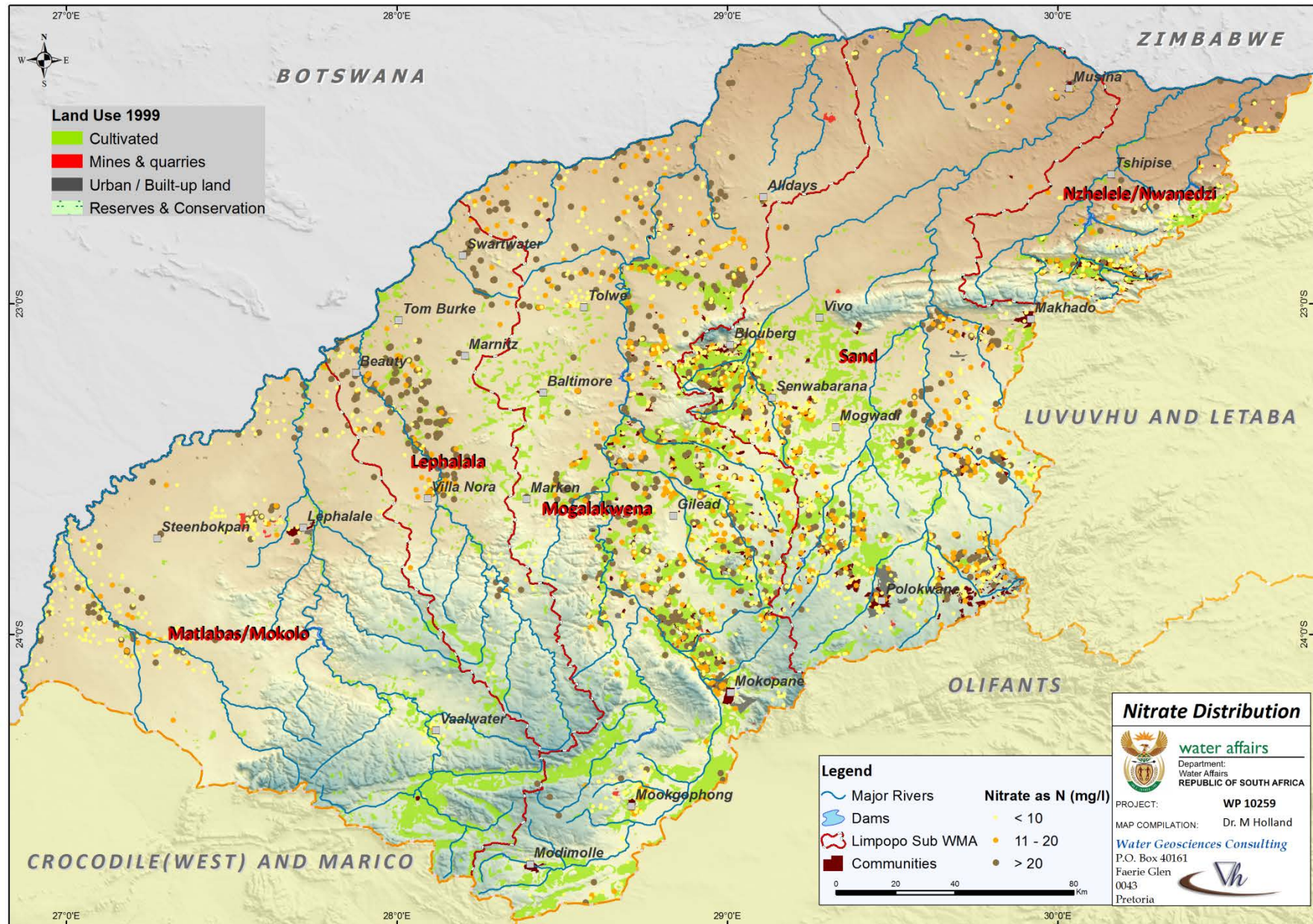


Figure 2-8. Nitrate (as N) concentration distribution map of the Limpopo WMA.

The quality of groundwater in the Limpopo WMA is of great concern especially taking cognisance of the fact that the Limpopo WMA is characterised by high rainfall variability, low recharge and limited groundwater quantities. The presence of undesirable natural hydrogeochemicals or by introduced contaminants reduces the exploitation value even further. In summary the groundwater quality in the Limpopo WMA is affected by:

- Pollution from urban areas and informal settlements surrounding urban centres,
- Contamination of groundwater as a result of high concentration of pit latrines in many rural villages,
- Impact of mining and industrial activities, and
- Diffuse pollution as a result of agricultural activities.

Microbiological quality hazards

Groundwater samples with microbiological results show a significantly increased risk for infectious disease transmission according to the total coliform bacterial range and samples obtained from numerous hospitals in the WMA indicates a risk for faecal coliform and E.Coli (Table 5).

Table 5. Microbiological results for all samples collated in the Limpopo WMA.

		Allowable compliance contribution (DWAF, 1996)*			
95% min.		100	Not detected	Not detected	Not detected
4% min.		1 000	10	1	Not detected
1% min.		10 000	100	10	1
Sample	Heterotrophic count/ml	Total Coliform count/100ml	Faecal Coliforms count/100ml	E.Coli count/100ml	
UP Samples 2009 (Holland, 2011)	Nr of Samples	12	12	12	-
	Compliance 95%	0	8	12	-
	Compliance 4%	8	0	0	-
	Compliance 1%	4	4	0	-
Rep7249 (Mokolo river and sewage works)	Nr of Samples	-		0	0
	Compliance 95%	-		0	0
	Compliance 4%	-		0	-
	Compliance 1%	-	7	7	7
Hospital Project (VSA Leboa) 38 groundwater samples	Nr of Samples	38	38	38	38
	Compliance 95%	13	15	29	29
	Compliance 4%	24	10	3	-
	Compliance 1%	1	13	6	9

* The allowable compliance contribution shall be at least 95% to the limits indicated with a maximum of 4% and 1% respectively.

Heterotrophic bacterial counts are used to indicate the general microbiological quality of water, i.e. the amount of bacteria present in the water. The total coliform bacteria count, which includes bacteria from the faecal group, is an indicator of the general sanitary quality of the groundwater, with many of these bacterial colonies originating potentially from an aquatic environment. The total faecal coliform

bacteria count, which is related to human or animal faecal pollution, refers to probable faecal pollution of water. The presence of coliform bacteria implies the potential presence of waterborne pathogens (DWAF, 1996). According to the Department of Water Affairs' water quality guidelines (DWAF, 1996) for domestic use, the total heterotrophic bacterial plate count of all groundwater samples from both areas indicates a slight or increased risk of bacterial infection and infectious disease transmission.

2.7.5 Groundwater – Surface water interaction

The interaction of groundwater with surface water depends on the physiographic and climatic setting of the landscape. Theoretical studies of two-dimensional groundwater flow in vertical sections by Tóth (1963) indicated that local, intermediate, and regional flow systems could be superimposed on one another within a groundwater basin. Regional flow occurs within the major interconnected fracture systems, while the main groundwater flow systems are relatively localised to the zones between recharge on watersheds to discharge by run-off or evaporation at valley bottoms (Figure 2-9).

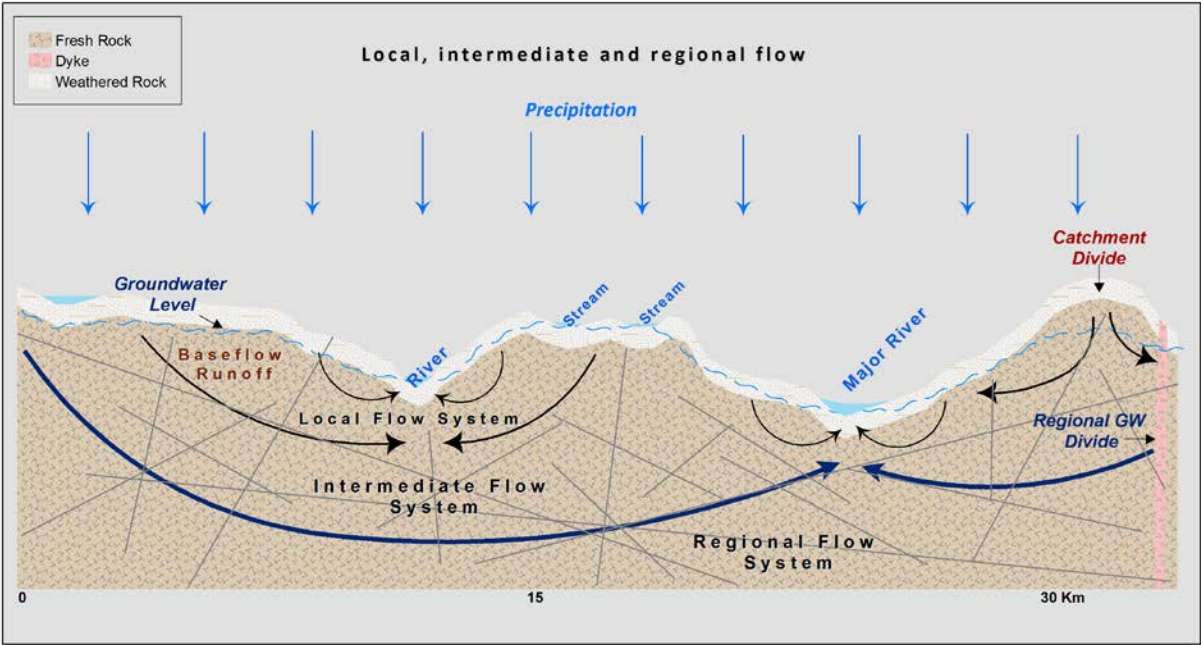


Figure 2-9. Simplified flow system.

A schematic representation of various linkages of groundwater and surface water is provided in (Figure 2-10). The interaction of groundwater and surface water in river valleys are affected by the interchange of local and regional groundwater flow systems with the rivers and by flooding and evapotranspiration.

- Small streams receive groundwater inflow primarily from local flow systems, which usually have limited extent and are highly variable seasonally. Therefore, it is not unusual for small streams to have gaining or losing reaches that change seasonally.

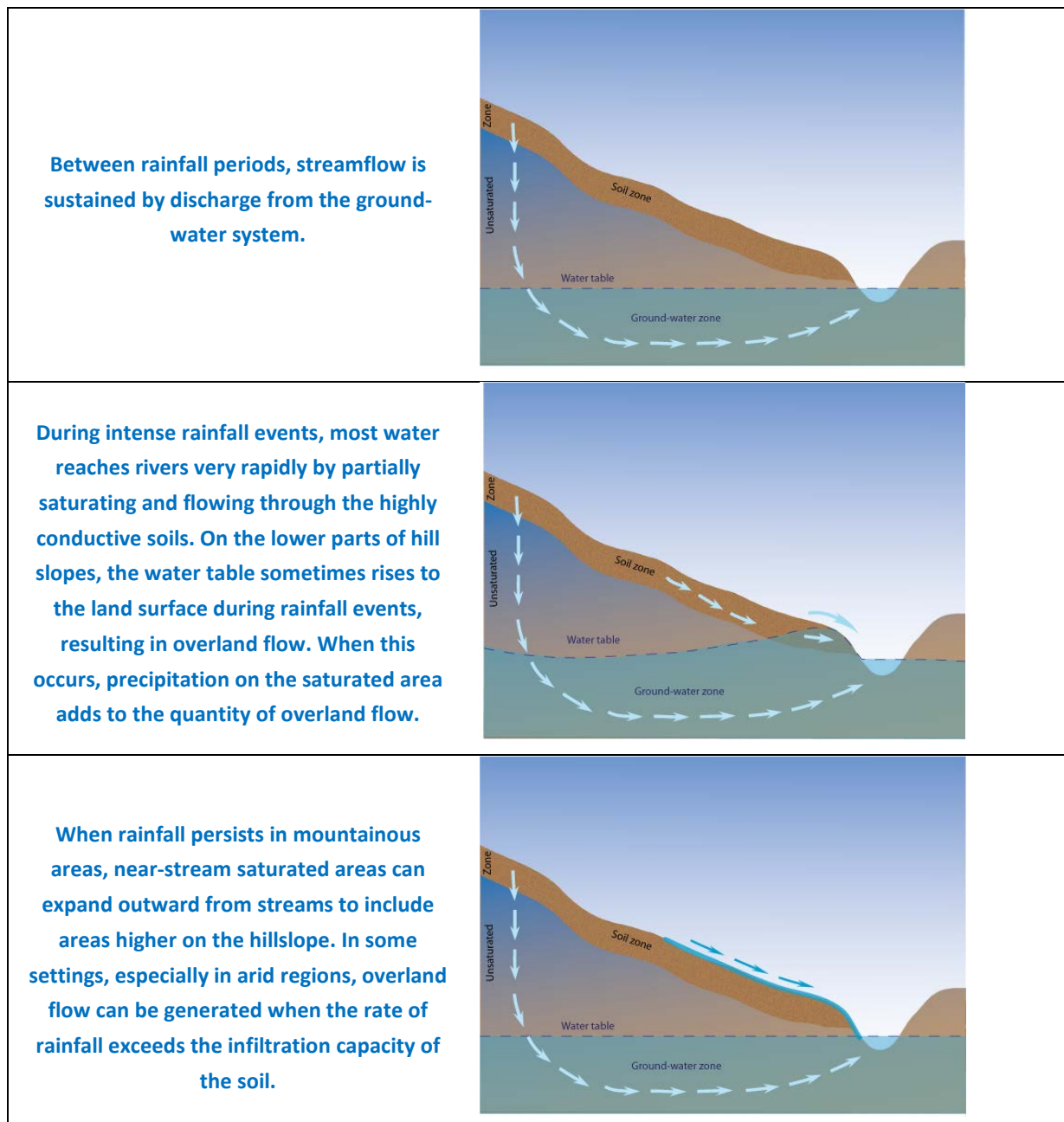


Figure 2-10. Interaction of groundwater with surface water (Dennis, 2011).

- For larger rivers that flow in alluvial valleys, the interaction of groundwater and surface water usually is more spatially diverse. Groundwater from regional flow systems discharges to the river as well as at various places across the flood plain.
 - At times of high river flows, water moves into the groundwater system as bank storage. The flow paths can be as lateral flow through the riverbank or, during flooding, as vertical seepage over the flood plain. The water table generally is not far below the land surface in alluvial valleys and plants can transpire water directly from groundwater.

- The hydrology of mountainous terrain is characterised by highly variable precipitation and water movement over and through steep land slopes. Some rock types underlying soils may be highly weathered or fractured and may transmit significant additional amounts of flow through the subsurface.
 - Near the base of some mountainsides, the water table intersects the steep valley wall some distance up from the base of the slope. This results in perennial discharge of groundwater and, in many cases, the presence of wetlands.

A river hydrograph consists of three components: direct runoff, interflow through the unsaturated zone and groundwater discharge from the saturated zone (Figure 2-11). Although a baseflow is often defined as the groundwater discharge from the saturated zone in classic hydrogeological textbooks the word baseflow is generally known to many hydrologists as delayed flow components (mainly groundwater), as opposed to a quick, direct runoff. Thus, baseflow itself is not indicative of origins of water sources. The baseflow is normally separated by removing the direct runoff from a hydrograph. As a result, such a baseflow component may still contain some interflow component.

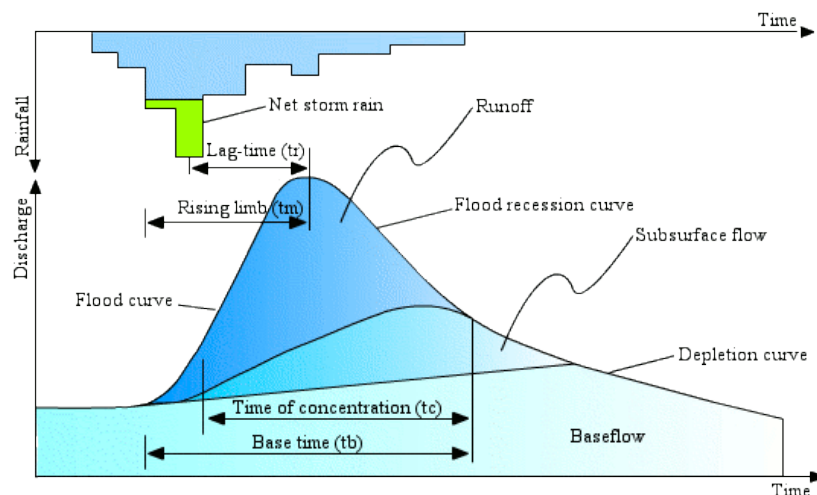


Figure 2-11. The flood hydrograph from a rainfall event (Musy, 2001).

Baseflow in the Limpopo WMA

Figure 2-12 illustrates whether the baseflow in a river is likely to be fed by groundwater. The Waterberg and Soutpansberg Mountains are an important recharge area and groundwater provides important baseflow to surface drainage. The lower reaches of the Limpopo WMA generally lacks baseflow and many major rivers has a low probability of being groundwater-fed.

Various methods with which the groundwater contribution to baseflow can be calculated are provided in Parsons and Wentzel (2007) and Dennis (2011). One of the most common methods to determine baseflow is through river hydrograph separation and recession curves. The spatial distribution of active flow gauging stations is illustrated in Figure 2-12. Many of the gauging stations in the lower catchments have been destroyed in the floods of 1990s resulting in limited data. Data permitting,

recession analysis was used to assist with the quantification of the groundwater contribution to baseflow. However, for the purpose of this Intermediate Reserve Assessment the baseflow estimates were primarily based on:

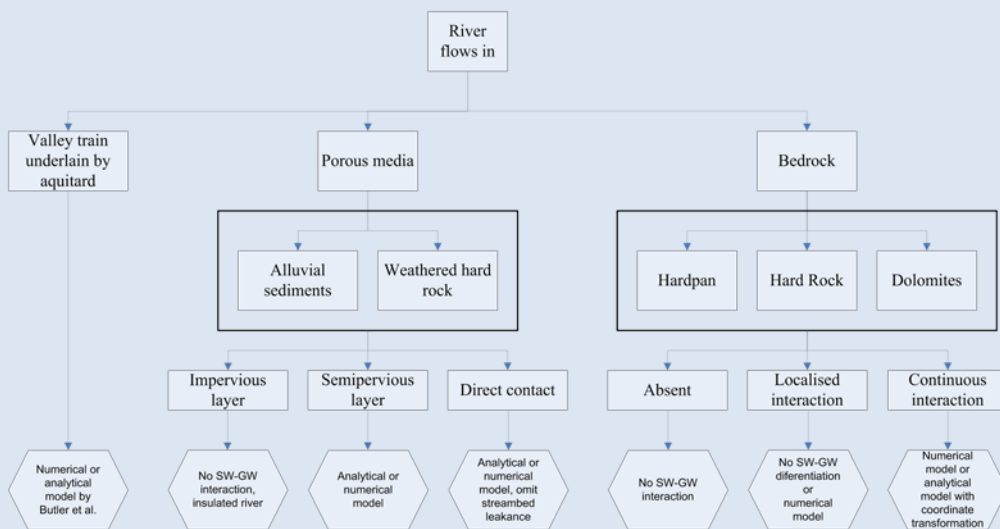
- Existing datasets (e.g. Hughes, Vegter & Schulze, Pitman, and van Tonder) on quaternary catchment scale.
- In-stream Flow Requirements (IFR) maintenance low flows based on the SPATSIM (Spatial and Time Series Information Modelling) flow modelling system (Hughes and Palmer, 2005) simulation runs conducted during this study (based on the PESC).
- Estimates of low flow scenarios done for the surface water reserve determination (if available).
- Specialist reports (or local knowledge).

As a result, while comparative estimates were shown in the assessment, the final groundwater contribution to baseflow estimate was based on the average of known datasets in addition to specialist reports, IFR low maintenance flows and data permitting a recession analysis estimate.

The groundwater contribution to flow in a river can be estimated using Darcy's Law, which states that the rate of flow through a porous medium is proportional to the loss of head, and inversely proportional to the length of the flow path (Parsons and Wentzel, 2007). However, to be able to calculate the volume of groundwater discharged into a river, an estimate of transmissivity, the hydraulic gradient and the length of river into which the groundwater is discharged are required. Although the Darcian approach, provide a simplistic assessment against which the results obtained from baseflow separation can be compared, it does not take into account the heterogeneous nature of most aquifer systems and localised variations in hydraulic properties. In addition the approximation of the transmissivity along the length of a river is difficult without adequate data. Furthermore, estimating the length of the river into which groundwater is discharged is no easy task, as it is unlikely that the entire length of a river is effluent in character and varies seasonally. Due to the data requirements needed on a local (smaller) scale the approach was not implemented. Focus was therefore largely on the groundwater – surface water classification with the aim to recommend the applicable assessment method for each groundwater unit within the Limpopo WMA.

Groundwater – surface water interaction - classification.

A simple two tier classification scheme, with a geological classification of the river-aquifer setting followed by a brief hydraulic classification of the interaction is proposed. The primary geological classification differentiates between rivers flowing in porous media or over bedrock. A third class accounts for valley trains underlain by aquitards, a typical situation of an alluvial aquifer along a river stretch underlain by impervious hard rocks.



Following the conceptualisation of the geological setting the type of surface-groundwater interaction is classified based on the prevailing hydraulic gradient.

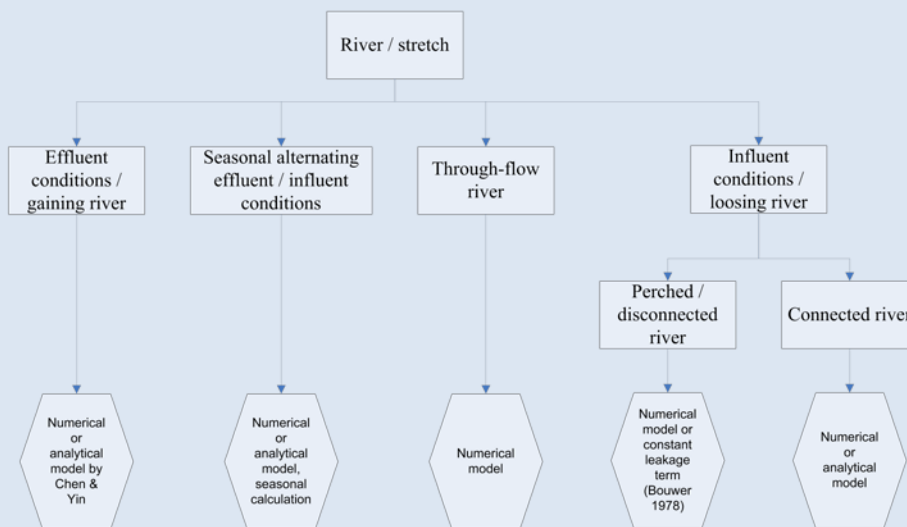




Figure 2-12. The relative probability of groundwater contributing to baseflow and the distribution of active flow gauging stations.

3 RESOURCE DELINEATION

3.1 Approach

Due to the size of the Limpopo WMA, it is not feasible to determine a Groundwater Reserve for the entire area. In addition, the first step in the RDM Classification process as outlined under Chapter 3 of the NWA, is the demarcation of the units of analysis (UA), of which is to be classified, a Reserve assessment undertaken and Resource Quality Objectives (RQOs) set.

Groundwater Units of Analysis (GUA)

By definition, quaternary catchments are used as the primary delineation of water resource units in RDM assessments. When delineating a groundwater unit, it is worth remembering that a Class, Reserve and RQOs have to be set for each unit; linkages with other components have to be considered; and each unit will have to be managed. As a result setting resource unit boundaries will probably be an iterative process requiring modification until all component requirements have been accommodated. However, due to the nature of groundwater the resource units are often completely different to that of surface water systems. In addition many GRDM assessments precede surface water RDM assessments. In this regard the delineation of groundwater is preliminary and provides valuable input towards the final classification of the integrated water resource. Accordingly to align more closely to the gazette approach for classifying water resources, the term Groundwater Unit of Analysis (GUA) will be used. Similarly to Groundwater Resource Units (GRUs) the GUAs are decided based on geohydrological, hydrological and ecological criteria, while taking into consideration the significance of groundwater (Dennis, 2011). In most instances, it is assumed that the GUA is the quaternary catchment; however, this might not always be the case. In this case a second level of delineation is based on aquifer (e.g. primary aquifer, secondary aquifer, dolomitic aquifer). Though these aquifers may be linked, the nature of subsurface flow in them is so different that they warrant obvious delineation. In some cases, it may be desirable to regroup these aquifer types into a single GUA. This is considered and motivated during the third level of delineation. Although no formal methodology exists for delineating groundwater resource units beyond the second level of delineation, three criteria namely physical, management and functional, could be used as the basis for delineation.

In this study the quaternary catchments were used as the primary delineation, while the GUAs were based on a single or a combination of quaternary catchments. The following aspects were considered:

- Although surface water and groundwater divides do not always correspond, groundwater must be considered in terms of an integrated water resource.
 - The Limpopo WMA is drained by 7 major rivers flowing into the Limpopo River. As a result the WMA is easily divided into 7 sub-catchments. Considering that the

ecological groundwater Reserve is determined by calculating the groundwater contribution to baseflow it makes sense to follow the hydrological approach.

- Regionally the groundwater mimics the topography. Figure 3-1 shows the very good correlation ($R^2=0.99$) between absolute surface and groundwater table elevations in metres above mean sea level (mamsl) for the Limpopo WMA.
 - The data presented in Figure 3-1 is based on 9000 water levels obtained from the GRIP and NGDB dataset and covers the entire Limpopo WMA.
- In addition, where the surface water Reserve has already been completed (e.g, the Mokolo catchment), the delineated surface water resources should be considered when establishing groundwater resource units.
- Identification and recognition of aquifer type and groundwater regimes within each sub-catchment (see Figure 2-5).
- Other components of the water cycle, such as wetlands, dams and smaller tributaries were also considered.

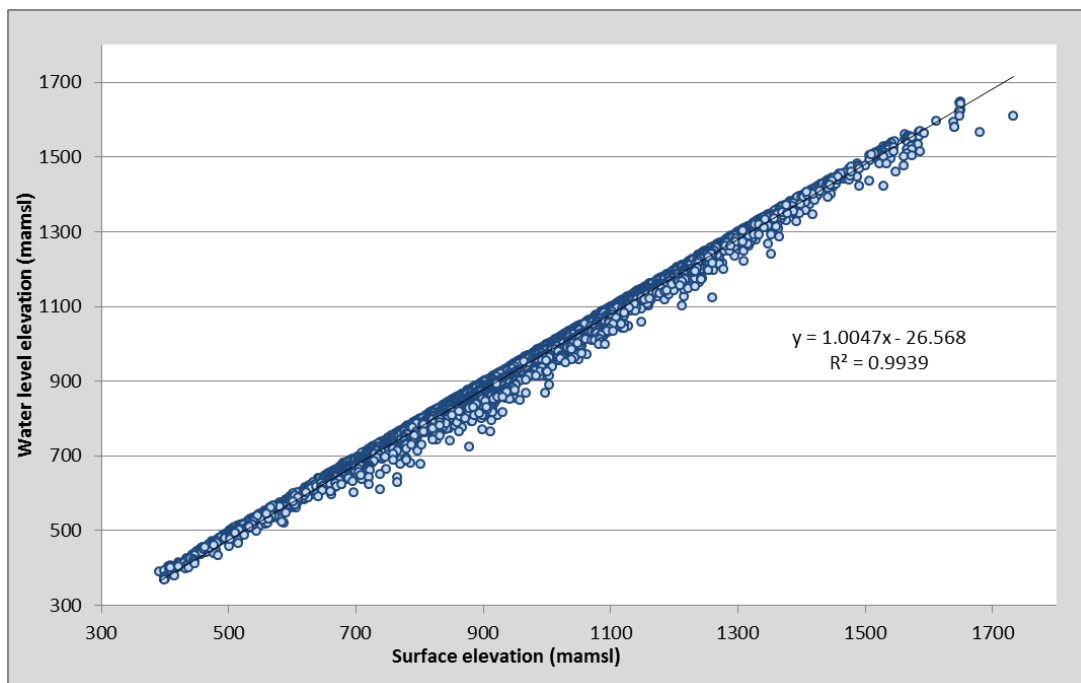


Figure 3-1. Correlation between surface topography and groundwater elevations for the Limpopo WMA.

3.2 Delineation

As already mentioned, there are 68 quaternary catchments within the Limpopo WMA, making delineation a complex process. Therefore the approach was to use the major drainage regions as the basis of the assessment. Within each sub-catchment GUAs were delineated. As discussed in the previous section a GUA may consist of one or many quaternary catchments. A summary of the delineated GUA within each sub-catchment is provided in Table 6. All GUAs coincide with the sub-

catchments except for A6/A7-3, which straddle the Mogalakwena- and Sand River sub-catchments. The tributaries draining the associated quaternary catchments drain directly into the Limpopo River. These catchments also straddle the Limpopo Karoo Basin, so as a result they were delineated as a single GUA (see Figure 2-5 and Figure 3-2). The final 28 groundwater units of analysis are presented as Figure 3-2 and include the surface drainage features and the intercepted quaternary catchments.

Table 6. Description of delineated groundwater units of analysis in the Limpopo WMA.

Drainage system	GUA	Nr of Quats.	Description	Geology
Matlabas	A41-1	2	Upper Matlabas	Waterberg Group
	A41-2	2	Lower Matlabas	Waterberg Group/Karoo Super Group
	A41-3	1	Steenbokpan	Karoo Super Group
Mokolo	A42-1	2	Upper Mokolo	Waterberg Group
	A42-2	4		Waterberg Group
	A42-3	2	Middle Mokolo	Waterberg Group
	A42-4	1	Lower Mokolo	Karoo Super Group
Lephalala	A50-1	6	Upper Lephalala	Waterberg Group
	A50-2	1	Middle Lephalala	Bushveld Complex
	A50-3	1	Lower Lephalala	Basement Complex
	A50-4	1	Limpopo Stem (Lephalala)	Basement Complex
Upper Mogalakwena	A61-1	5	Nyl River Valley	Bushveld Complex, Lebombo Group
	A61-2	2	Upper Mogalakwena west	Bushveld Complex, Waterberg Group
	A61-3	3	Upper Mogalakwena east	Bushveld- and Basement Complex, Dolomites
Middle- and Lower Mogalakwena	A62-1	3	Middle Mogalakwena	Bushveld Complex, Waterberg Group
	A62-2	2		Bushveld- and Basement Complex,
	A62-3	3		Waterberg Group
	A63-1	3	Lower Mogalakwena	Basement Complex, Karoo Super Group, Lebombo Group
	A63-2	1	Limpopo Stem (Mogalakwena)	Basement Complex
Upper Sand	A7-1	2	Upper Sand	Basement Complex, Alluvium
	A7-2	3	Middle Sand	Basement Complex
	A7-3	4	Hout en Brak	Basement Complex
Lower Sand	A7-4	2	Lower Sand	Basement Complex, Karoo Super Group, Lebombo Group
	A7-5	1		Basement Complex, Karoo Super Group
Limpopo Tributaries	A6/7-3	2	Separated from Mogalakwena and Sand sub-catchments	Basement Complex, Karoo super Group
Nzhelele	A8-1	6	Upper Nzhelele	Soutpansberg Group, Karoo Super Group, Lebombo Group, Basement Complex
	A8-2	1	Lower Nzhelele	Soutpansberg Group, Karoo Super Group, Basement Complex
Nwanedzi	A8-3	2	Nwanedzi	Soutpansberg Group, Karoo Super Group, Basement Complex

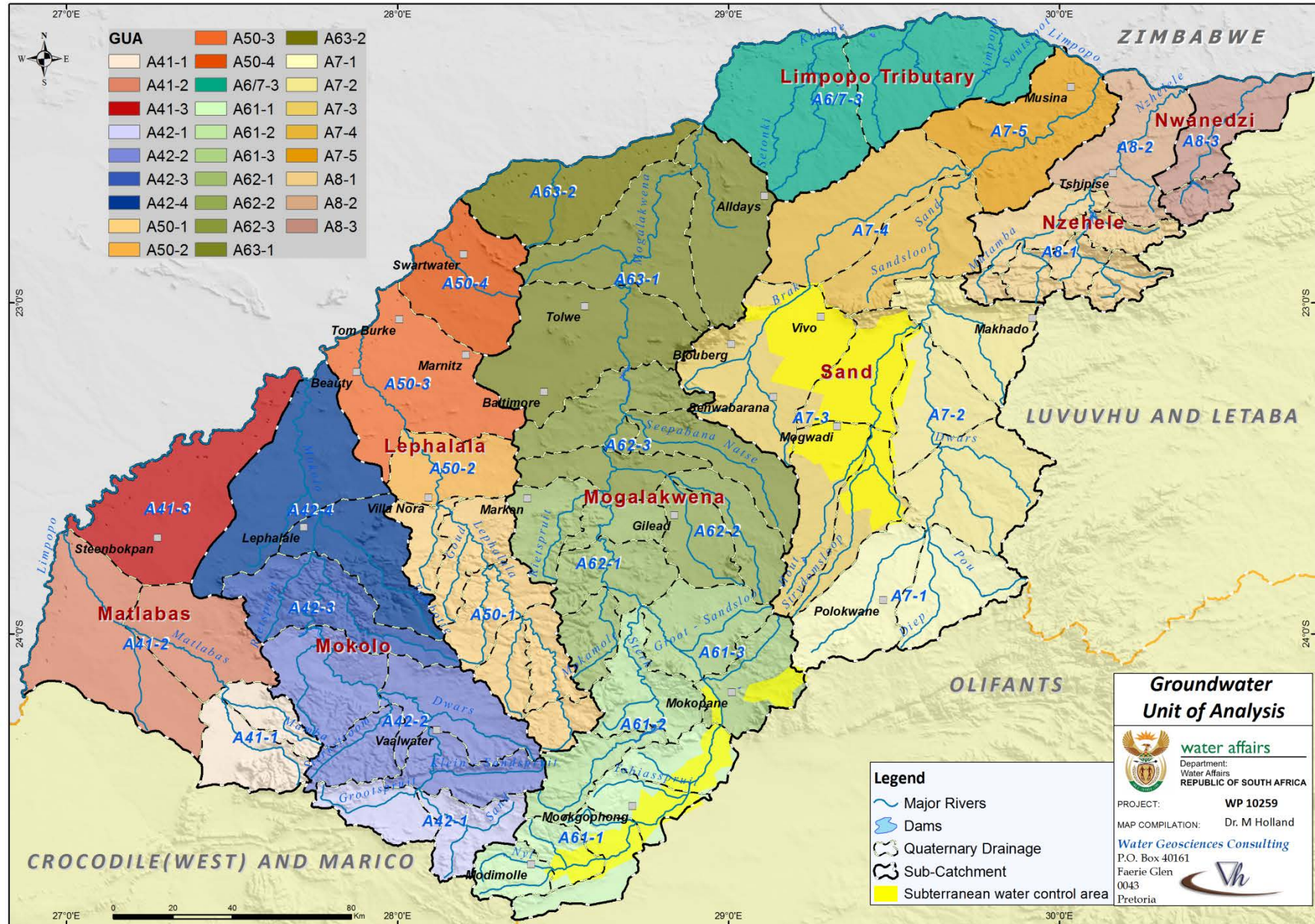
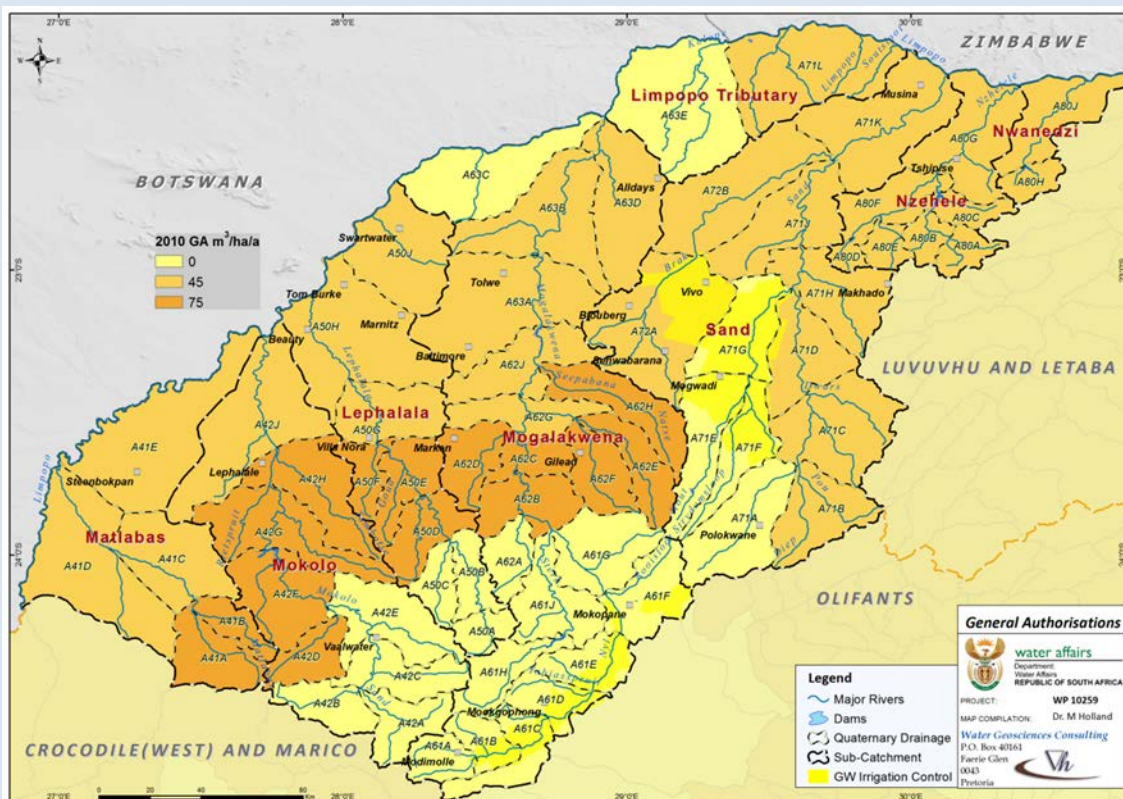


Figure 3-2. Map of the delineated GUAs for the Limpopo WMA.

General Authorisations (GA)

General Authorisations allow the Department of Water Affairs to authorise large numbers of people to take up water without the need for a license. The GA is one of the routes through which water is made accessible to the broader public, particularly small scale users. GAs will therefore be used to support the Water Allocation Reform process, both within compulsory licensing and in other areas, to make it easier for the rural poor to take up water. The suggested general authorisation per quaternary catchment for the Limpopo WMA is illustrated below. The GA is based on a fraction of the difference between the Harvest Potential, the existing groundwater use and a portion of the baseflow.



The newly proposed GAs in 2010 has increased in 34 quaternary catchments, while decreasing in 13 catchments to 0 m³/ha/a. The latter decrease in GAs pertains mostly to the upper Waterberg area and the subterranean water control areas. The increase in the GAs promotes the uptake of smaller amounts of groundwater by rural communities in the Limpopo WMA.

The Subterranean government water control areas are listed in Table 7 and illustrated spatially in Figure 3-2. These control areas are excluded from General Authorisations for groundwater abstraction (Government Gazette, 2004). These water control areas should be transformed into water user associations (WUA); however, the transformation process requires considerable stakeholder engagement, focused change management and a process of rigorous evaluation of the proposed documents for the WUA establishment.

Table 7. Subterranean government water control areas excluded from General Authorisation for groundwater abstraction.

Tertiary/ Quaternary drainage region	Description of subterranean government water control area	Government Notice No.	Government Gazette Date
A60,B50,B31	Nyl River Valley	56	1971-03-26
A70	Dendron-Vivo (Houdenbrak)	813	1994-04-29
A60	Dorpsrivier	312	1990-02-16

Irrigation Boards concerned about protection of existing interests and assets (irrigation infrastructure) owned by the Boards (fear of loss of control and ownership in future) influences the reluctance to form fully fledged WUAs. In addition, WUAs requires management strategies specifically towards desired status category and management option. For this study it was therefore important to take recognition of these water control areas in the delineation process.

4 RESERVE DETERMINATION AND CATEGORISATION

4.1 Matlabas Drainage System

The Matlabas River drains the most western area of the Limpopo WMA. The altitude in the Waterberg mountain range where the Matlabas River originates is in the order of 1 400 m and the altitude decreases to approximately 840 m where it flows into the Limpopo River (Figure 4-1). The Matlabas catchment is a largely undeveloped catchment with limited water resources and limited water use. There are no significant dams in this catchment and a significant portion of the water use is from groundwater due to the non-perennial flow of the Matlabas River and hence no sustainable yield from surface water. Current and future developments around the available coal reserves in the Steenbokpan area will require adequate planning for future water needs. Three GUAs have been delineated for the Matlabas area, namely A41-1, A41-2 and A41-3 (Figure 4-1). A summary of the borehole information for the region is shown in Table 8. Limited pumping test data is available for the region.

Table 8. Borehole information for the Matlabas drainage region.

Description	UA	Geology	Info	BH Depth (mbgl)	Water Level (mbgl)	T-value (m ² /day)	Rec. Yield (l/s for 24hrs)	Airlift Yield (l/s)
Upper Matlabas	A41-1	Waterberg Group	N	40	40			-
			Mean	94	27.6			-
Middle Matlabas	A41-2	Karoo Super Group/ Waterberg Group	N	485	428		32	-
			Mean	86	27.0		0.93	-
Steenbokpan	A41-3	Karoo Super Group	N	91	385	2	2	-
			Mean	69	29.6	9	0.67	-

N = Number of boreholes

The potential of individual boreholes in this area is generally low and hence development of the groundwater resource would probably be for small-scale irrigation. Borehole yields generally range between 0.1 – 2 l/s. The main aquifer types include:

- Fractured Karoo Super Group and Waterberg Group aquifers (Predominately)
 - The Waterberg formation is associated with steep topography and shows generally poor capability to produce huge amounts of groundwater. Recharge to the aquifer, often discharged on the steep slopes, provides baseflow to the rivers. A weathered zone aquifer is found only where deep weathering occurs and provides groundwater storage that feeds the underlying fractured aquifer.
 - The Karoo aquifer shows similar aquifer properties as the Waterberg aquifer comprising of fractured rocks with a porous matrix. However, groundwater resources and especially the development thereof, are limited due to the low recharge to these aquifers.

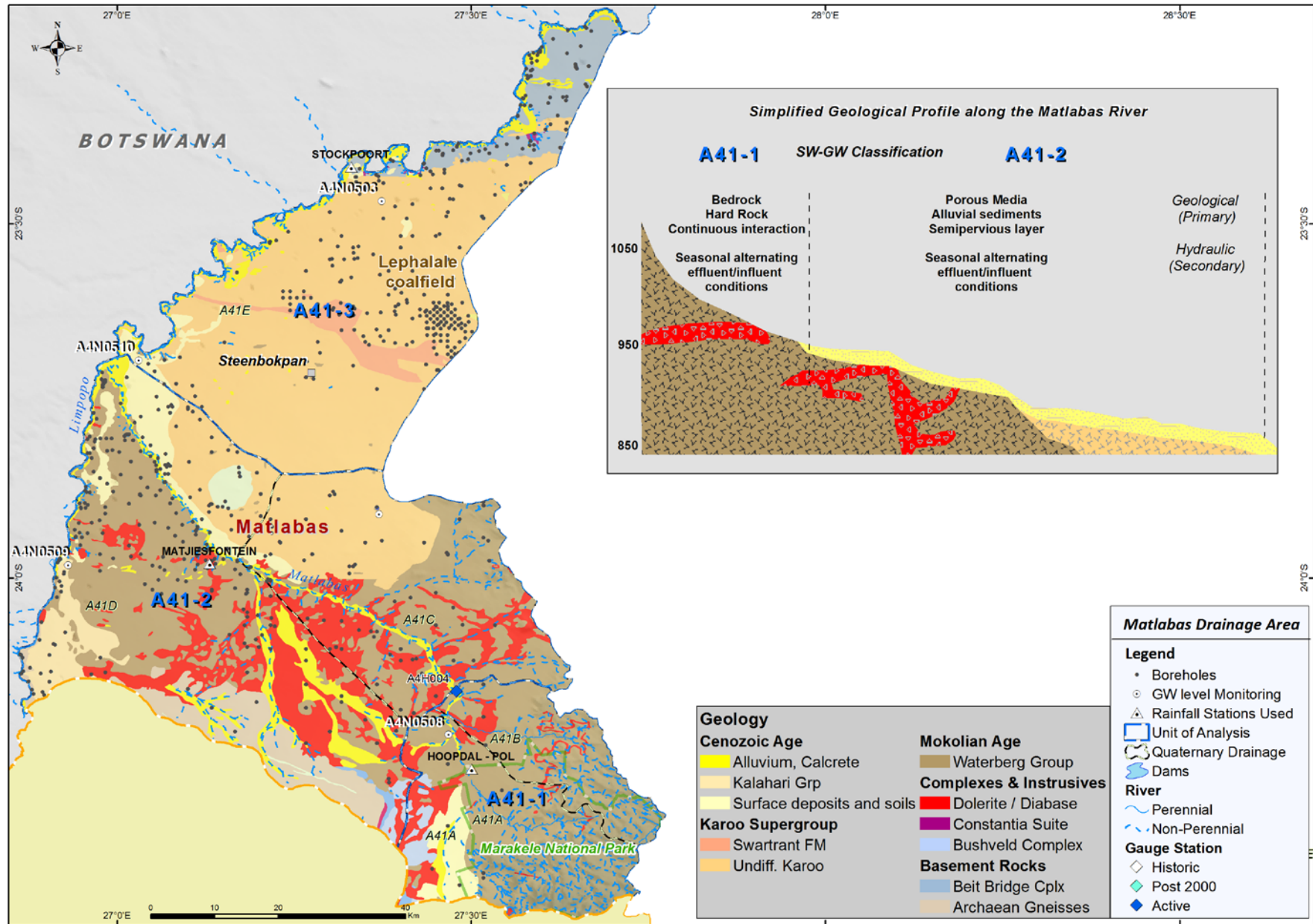


Figure 4-1. Geology, GUAs and SW-GW classification of the Matlabas drainage region.

- Intergranular Alluvial aquifers (Limited to the main river stems)
 - It is an important local, major aquifer and exists in equilibrium with surface water, adjacent groundwater systems and ecosystems along the rivers.
- Intergranular and fractured (southern boundary of GUA A41-2)
 - The Achaean age basement gneisses comprise of deeper fractured (i.e. secondary) aquifers overlain by a weathered horizon of variable thickness.

4.1.1 Groundwater recharge

Mean annual precipitation is approximately 400 to 500 mm per annum over most of the Matlabas drainage region. The low and variable rainfall together with evaporation rates considerably exceeding rainfall result in a low expectation of natural recharge to groundwater over most of the area (Figure 2-1). Recharge vary spatially from as high as 18 mm/a in the higher lying areas to less than 2 mm/a in the lower parts of the catchment (see Figure 2-7).

Table 9. Rainfall Data for selected stations in the Matlabas region.

Station*	Start Date	MAP (mm)	Elevation (mamsl)
Hoopdal	1969	485	971
Stockpoort	1965	400	818
Majtiesfontein#	1960	443	898

*- South African Weathers Services.

- Closed in 2004.

Recharge

Recharge is defined as the addition of water to the zone of saturation. Usually the method used to quantify recharge is dependent on the data available on which to base the assessment. For this assessment existing datasets will be used e.g. Vegter's (1995) recharge map and GRA II data. The recharge from rainfall was also estimated using the Chloride Mass Balance (CMB) method for each UA. It is expressed as a percentage of the Mean Annual Precipitation (MAP) and is based on the following equation:

$$\% \text{ Recharge} = \frac{\text{Chloride concentration in rainfall}}{\text{Chloride concentration in groundwater}} * 100$$

The Chloride Mass Balance (CMB) method has been suggested as the most reliable technique for determining recharge rates to fractured rock aquifers systems (Cook, 2003).

A review of previous work done on the GRA II project, Vegter's (1995) estimates and recharge estimates based on specialist reports were made. These values were calculated for each of the quaternaries constituting the groundwater unit of analysis and are summarised as Table 10.

Table 10. Recharge estimation (Matlabas).

Description	GUA	Quat	MAP (mm)	Area (km ²)	GRA II		Vegter (1995)	Specialist report Mm ³	Used Mm ³	Recharge %
					(Wet) Mm ³	(Dry) Mm ³	Mean Mm ³			
Upper Matlabas	A41-1	A41A	625.3	692	19.85	14.33	18.81	-	17.66	4.1
		A41B	586.6	358	8.60	6.14	8.85	-	7.86	3.7
Lower Matlabas	A41-2	A41C	511.7	1111	16.41	11.44	11.84	-	13.23	2.3
		A41D	491.6	1913	20.51	14.12	15.51	-	16.71	1.8
Steenbokpan	A41-3	A41E	438.2	1940	14.99	9.96	12.80	11.9	12.41	1.5

Water level trends

A summary of the short term water level data obtained from selected monitoring boreholes within the region is presented in Table 11 and illustrated spatially in Figure 4-1. For comparative purposes all hydrographs were based on a four year period (January 2007 to January 2011). Generally, groundwater levels fluctuate according to the characteristics of precipitation events (i.e. amount, duration, and intensity) and various hydrogeological variables (i.e. topography, thickness of the unsaturated zone, and matrix composition of saturated and unsaturated materials). Groundwater level fluctuations from the observed hydrographs vary between 0.4 and 1.5 m. Only a subtle response in water levels as a result of rainfall is observed for most boreholes. However, a well-identified seasonal water-level fluctuation is observed for station A4N0508. No declining trend due to over abstraction is observed from the hydrographs.

Table 11. Water level trends for selected monitoring stations in the Matlabas region.

<p>A41-1 A4N0508</p> <p>Date WL (mbgl)</p> <p>Oct-08 12.02</p> <p>Nov-10 11.04</p> <p>Difference (m) 1.48</p> <p>Rainfall Data Hoopdal (Jan-07 to June-10)</p>	
<p>A41-2 A4N0509</p> <p>Date WL (mbgl)</p> <p>Oct-08 21.63</p> <p>Nov-10 21.67</p> <p>Difference (m) -0.04</p> <p>Rainfall Data Hoopdal (Jan-07 to June-10)</p>	
<p>A41-3 A4N0503 (red)</p> <p>Date WL (mbgl)</p> <p>Aug-08 14.57</p> <p>Nov-10 14.73</p> <p>Difference (m) -0.14</p> <p>A4N0510 (blue)</p> <p>Oct-08 20.82</p> <p>Nov-10 20.70</p> <p>Difference (m) 0.12</p> <p>Rainfall Data Stockpoort (Jan-07 to June-10)</p>	

4.1.2 Groundwater contribution to baseflow

Based on the groundwater-surface water classification described in section 2.7.5 the Matlabas River stretch can be classified into a continuous interaction bedrock system (Waterberg Group) in the upper reaches, while the low reaches can be classified as a porous media (alluvial sediments) underlain by a semi-pervious layer (Figure 4-1). In both cases seasonal alternating effluent / influent conditions can

be experienced. Both analytical and numerical models could be applied to evaluate groundwater-surface water interaction of the Matlabas River. Comparison of groundwater contribution to baseflow estimates for the Matlabas drainage region are summarised in Table 12. The hydrograph separation curve for station A4H004 is shown in Figure 4-2.

Table 12. Groundwater contribution to baseflow estimates.

Description	GRU	Quat	Hughes Mm ³	Shultz Mm ³	Pitmann Mm ³	GRA II (WR2005) Mm ³	Maint. Low flow	Specialist*/Hydrograph# Mm ³	Average Mm ³
Upper Matlabas	A41-1	A41A	7.01	0.57	3.46	4.82	3.18	8.89#	4.65
		A41B	2.97	0.30	1.68	2.21	0.75		1.58
Lower Matlabas	A41-2	A41C					0.39	0.85*	0.62
		A41D					0.54		0.54
Steenbokpan	A41-3	A41E	0.17				0.53		0.35

Baseflow

The Schultz figures consider baseflow to be the portion of ground water which contributes to the low flow of streams originating from the regional groundwater body. The Herold and Hughes interpretations of baseflow include all water which migrates through the subsurface, hence it includes seepage from perched aquifers, high lying springs and interflow. A large fraction of this water never reaches the regional aquifer, hence does not form part of the available groundwater resources. To determine potential baseflow depletion resulting from pumping the regional aquifer the Schultz figures may be more appropriate. To determine the potential impact of induced recharge, or to set subsurface water contribution to the ecological reserve, the Hughes figure and the hydrograph separation method provides a volumetric total of available baseflow.

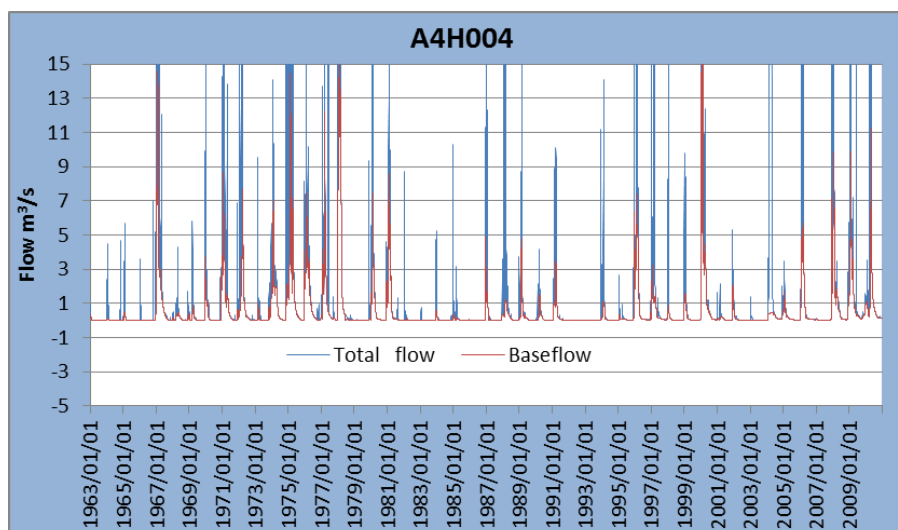


Figure 4-2. Baseflow separation for A4H004 (A41A).

Reserve determination

The groundwater component of the Reserve is the part of the groundwater resource that sustains basic human needs and in some instances contributes to EWR. To be able to quantify the groundwater component of the Reserve, the volume of groundwater needed for BHN and contributing to EWR needs to be quantified. The EWRs of the Resource in question must consider the following:

- Groundwater contribution to baseflow in rivers.
- Groundwater contribution to wetlands.
- Groundwater contribution to springs and other Groundwater Dependant Ecosystems.

The groundwater component of the Reserve is defined by the following relationship:

$$Reserve(\%) = \frac{EWR_{gw} + BHN_{gw}}{Re} \times 100$$

Where:

- Re = recharge
BHN_{gw} = basic human needs derived from groundwater
EWR_{gw} = groundwater contribution to EWR

Groundwater should only be allocated to users and potential users once the volume of groundwater that contributes to sustaining the Reserve has been quantified and RQOs have been met.

Due to the scale of this assessment in addition to the difficulty in quantifying groundwater contributions to wetlands, springs and GDEs, the EWR_{gw} is mainly based on the groundwater contribution to baseflow. However, mentioning of potential GDEs, wetlands and springs occurring within each GUA will allow the RDM office to initiate more detailed studies to account for these contributions to the Reserve.

4.1.3 Basic Human Needs (BHN)

Currently, basic human needs (BHN) are set at 25 ℓ/p/d. Although normally quite small in comparison to other uses, it must be borne in mind that this is a right to water and must be legally protected. Numerous sources of population data are available for the Limpopo WMA. Population estimates is provided in the Water Resources Situation Assessment for the Limpopo WMA (DWAF, 2003a), the overview of water resources availability and utilisation of the Limpopo WMA (2003b) and the Limpopo Internal Strategic Perspective (ISP) (DWAF, 2004).

Table 13. Basic human needs estimates.

Description	GRU	Quat	Population*	BHN Estimate Mm ³
Upper Matlabas	A41-1	A41A	6785	0.062
		A41B	5175	0.047
Lower Matlabas	A41-2	A41C	7749	0.071
		A41D	5483	0.050
Steenbokpan	A41-3	A41E	7886	0.072

* - Based on 2001 statistics and the Limpopo ISP (DWA, 2004b)

4.1.4 Reserve determination summary

The Reserve assessment is firstly provided on a groundwater resource unit level in Table 14 and summarized for the Limpopo WMA on a quaternary level in Appendix A.

Table 14. Groundwater Reserve summary (Matlabas region).

Description	GUA	Area (Km ²)	Recharge Mm ³	GW to Baseflow Mm ³	BHN Mm ³	Reserve Mm ³	Reserve as % of Recharge
Upper Matlabas	A41-1	1050	25.53	6.33	0.11	6.44	25%
Lower Matlabas	A41-2	3024	29.95	1.16	0.12	1.28	4%
Steenbokpan	A41-3	1940	12.41	0.35	0.07	0.42	3%

4.1.5 Groundwater use and availability

Defining stress

The concept of stressed water resources is addressed by the NWA, but is not defined. Part 8 of the Act gives some guidance by providing the following qualitative examples of 'water stress':

- Where demands for water are approaching or exceed the available supply.
- Where water quality problems are imminent or already exist.
- Where water resource quality is under threat.

The groundwater stress index reflects water availability versus water used. Groundwater use should include water utilised by current water users, water required to sustain the Reserve as well as for BHN. The Stress Index for an assessment area is defined as follows:

$$SI(\%) = \frac{gwUse}{Recharge} \times 100$$

Where:

gwUse = Current groundwater use

Recharge = Recharge (as a volume)

In calculating the Stress Index, the variability of annual recharge is taken into account in the sense that not more than 65% of average annual recharge can be allocated on a catchment scale).

PRESENT CATEGORY	DESCRIPTION	COMPLIANCE (SPATIAL/TEMPORAL)
I	Minimally used	≤20%
II	Moderately used	20% – 65%
III	Heavily used	> 65%

A guide for quantifying groundwater use is documented below.

ACTIVITY	PERCENTAGE OF RECHARGE
Stock watering, farm domestic water supply, rural water supply	Use ranges between 5% and 20% of recharge
Small-scale irrigation, rural water supply, water supply for villages and small towns	Use ranges between 20% and 40% of recharge
Water supply for large rural communities, medium to large towns, large-scale irrigation	Use ranges between 40% and 65% of recharge

Calculating groundwater use

WARMS (Water Use Authorisation & Registration Management System)

The NWA makes registration with the National Register of Water Users mandatory. All water users, who do not receive their water from a service provider, local authority, water board, irrigation board, government water scheme or other bulk supplier need to register. This is with the exception of Schedule 1 users. It is important to note that the lawfulness of the registered water use still needs to be determined by the Department of Water Affairs. Validated data is available on quaternary catchment scale for the Limpopo WMA. WARMS is one of the only sources of data available that is based on actual current reporting. There are issues with under and over registration, but when these have been corrected it will be a fundamental functional dataset for the DWAF with a potentially long lifetime.

The approach adopted for this study was to compare abstraction rates from specialist reports with the WARMS database and the existing use figures available in the GRA II. A final estimate is based on the most probable value taking into consideration the range of estimates and local knowledge of the region, in addition to local datasets such as the Limpopo GRIP.

Groundwater use estimates vary significantly between the GRA II dataset and the recently validated WARMS dataset (Table 15). However, even with the utilisation of the upper limit for the assessment it appears that groundwater is underutilised in the region. As a result groundwater abstraction amounts to a small component of the harvest potential. It is important to note that the UGEP (for the lower catchments) is an overestimate of available groundwater resources which is estimated at almost twice the HP volumes (Table 15). It is likely that, with an adequate and even distribution of production boreholes in accessible portions of most catchments or aquifer systems, that the HP volumes or where abstraction exceeds the HP, up to 65 % of Recharge may be annually abstracted on a sustainable basis.

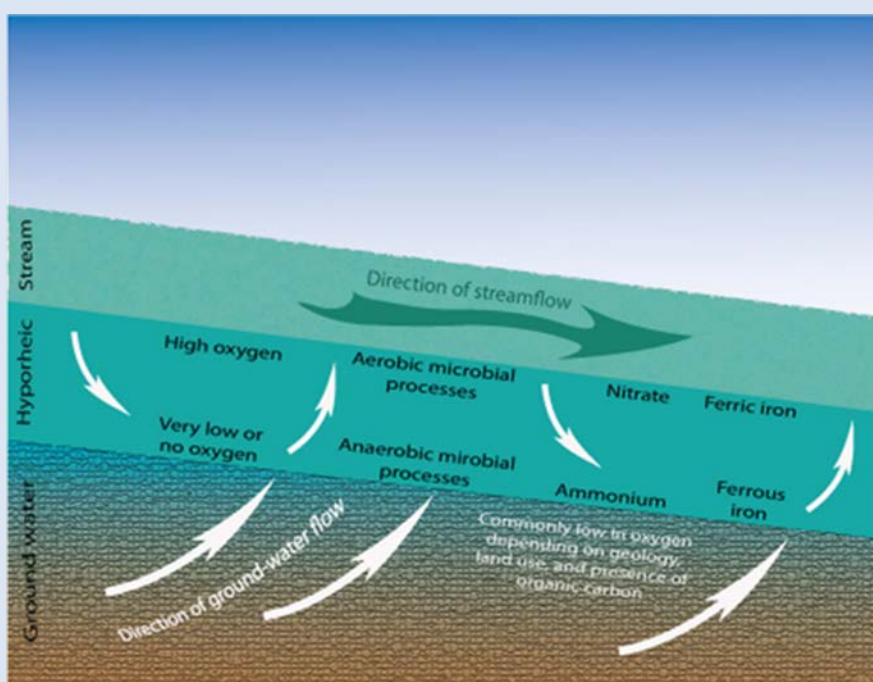
Table 15. Groundwater availability and stress index (Matlabas region).

Description	GUA	Quat	RE Mm ³	Groundwater availability Mm ³ /a		Groundwater Use Mm ³ /a			GW Use as % of HP	Stress Index (GW Use as % of Recharge)
				HP	UGEP	GRA II Mm ³	WARMS (*validated)	Final Estimate		
Upper Matlabas	A41-1	A41A	17.66	8.75	5.17	1.22	0.21*	1.22	14%	7%
		A41B	7.86	4.43	2.45	0.01	0.15	0.15	3%	2%
Lower Matlabas	A41-2	A41C	13.23	9.72	37.65#	0.25	0.11	0.25	3%	2%
		A41D	16.71	14.93	35.26#	2.76	0.89*	2.76	18%	16%
Steenbokpan	A41-3	A41E	12.41	12.73	29.92#	1.79	0.30*	1.79	14%	14%

- This may be an over estimate of available groundwater resource considering the HP estimates.

Groundwater quality

Domestic use (human consumption) is considered by the authors as the highest beneficial use, with the supposedly most stringent quality requirements. It is assumed that any water resource, which is deemed fit for human consumption, also meets the requirements of aquatic ecosystems. While the water quality requirements of aquatic ecosystems might differ and are in fact for several elements even more stringent than for domestic use (e.g. Cd), the chosen approach avoids the pitfall of equating groundwater quality in the sub-surface to water quality discharging into a surface water body. In other words, the methodology recognizes the processes occurring in discharge areas in general (e.g. evapotranspiration) and the enhanced microbiological and chemical reactions (e.g. Redox or cation exchange reactions) in the hyporheic zone specifically (Figure below), without trying to quantify them by setting only domestic use requirements for the groundwater resource itself.



It is therefore recommended to use the South African Water Quality Guidelines Vol. 1 – Domestic use (DWA, 1996), or the national drinking water standard (SANS 241: 2006) for the present status category assessment of a water resource.

PRESENT CATEGORY	DESCRIPTION	COMPLIANCE (SPATIAL/TEMPORAL)
I	DWA class 0 or 1 or natural background	95 %
II	DWA class 2 (95 % compliance) or natural background (75 % compliance)	75 %
III	DWA class 3 or 4 or natural background (<75 % compliance)	<75 %

Groundwater Quality

The groundwater samples indicate a variety of water types mainly Ca/Mg-HCO₃, Na-HCO₃ and Na-Cl (Figure 4-3). A high percentage of samples relate to a fresh recharge type (Ca/Mg-HCO₃) water, while cation and anion exchange process may be occurring within the strata hence Na-Cl and Ca/Mg-Cl type water present. However, some impacts of anthropogenic activity may be present in the more Ca-Mg-Cl-SO₄ type compositions.

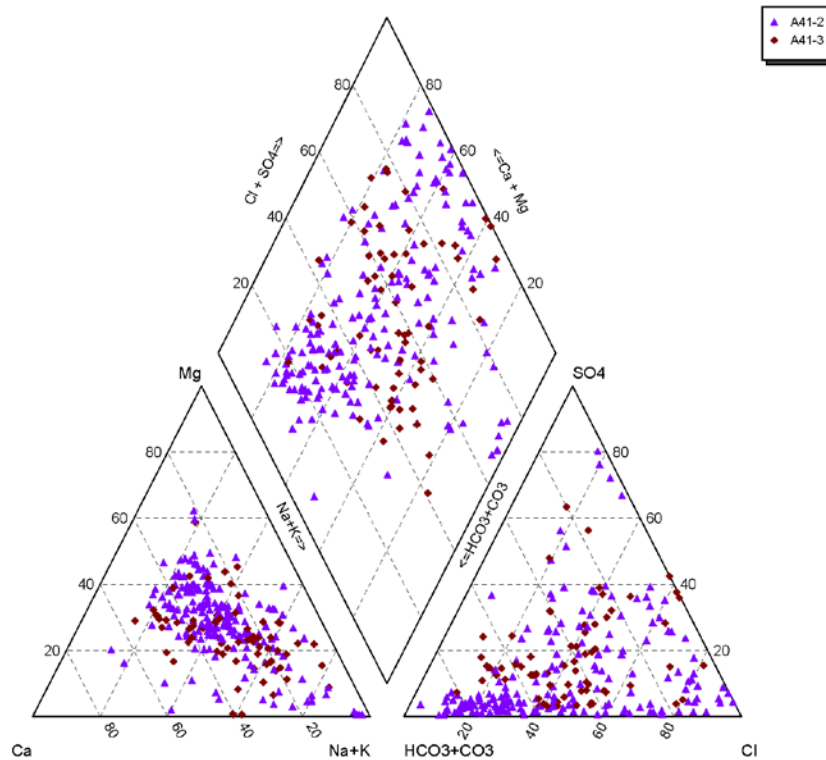


Figure 4-3. Piper diagram for the Matlabas drainage region.

Overall groundwater quality in the Matlabas region is considered to be marginal to poor with only a third of groundwater samples being within the recommended drinking limit as specified by SANS (2006). The most notable elements of concern include NO₃ as N and F with average concentrations above the recommended drinking limit (Table 16). In addition, several samples show major ion concentrations (e.g. Mg, Na, Cl) and subsequently electric conductivities (EC) beyond acceptable limits. This can mostly be related to evaporative concentration of elements in discharge areas or due to low recharge values as well as long residence times for selected samples.

Table 16. Groundwater quality for the Matlabas region (All units in mg/l, EC in mS/m).

GUA	Parameter	pH	EC	Ca	Mg	Na	K	SO ₄	Cl	NO ₃ as N	F	Compliance (% of samples within Class I)	Present Category
A41-1	Nr	-	-	-	-	-	-	-	-	-	-		-
	Mean	-	-	-	-	-	-	-	-	-	-		
A41-2	Nr	190	190	189	189	189	189	189	189	187	189	31 %	III
	Mean	7.5	214.5	125.9	79.5	202.7	7.4	126.7	439.4	10.5	1.6		
A41-3	Nr	81	82	78	78	78	69	78	78	54	78	32 %	II*
	Mean	7.6	221.9	91.6	52.6	200.7	13.0	150.8	298.9	9.0	1.2		

Class I

Class II

Exceed Class II

* - Natural high sodium and chloride concentrations (reduced to Present Category II).

4.1.6 Final Categorisation

Baseline class

Defining the point at which a resource is no longer being used in a sustainable manner is generally very difficult. The level of sustainability probably fluctuates through time, and impacts from over-use could manifest themselves sometime after the impact was caused. The change from sustainable use to over-use is gradational, and not necessarily marked by some distinct change.

Indicators of quantitative unsustainable groundwater use include:

- Land subsidence or sinkhole formation.
- Long-term declining water levels on a regional level.
- Long-term declining water quality levels.

A guide for assessing the status of groundwater units based on observed impacts resulting from groundwater abstraction is presented below.

PRESENT CATEGORY	GENERIC DESCRIPTION	AFFECTED ENVIRONMENT
Minimally used (I)	The water resource is minimally altered from its pre-development condition	No sign of significant impacts observed
Moderately used (II)	Localised low level impacts, but no negative effects apparent	Temporal, but not long-term significant impact to: – spring flow – river flow – vegetation – land subsidence – sinkhole formation – groundwater quality
Heavily used (III)	The water resource is significantly altered from its pre-development condition	Moderate to significant impacts to: – spring flow – river flow – vegetation – land subsidence – sinkhole formation – groundwater quality

A summary of the final categorisation for the Matlabas region is shown in Table 17.

Table 17. Final groundwater categorisation for each GUA (Matlabas region).

GMA	GUA	Area (Km ²)	Recharge Mm ³	Groundwater Use Mm ³ /a	Stress Index (SI)	Present Category (SI)	Present Category (Impact)	Present Category (Quality)
Upper Matlabas	A41-1	1050	25.53	1.37	5%	I	I	-
Lower Matlabas	A41-2	3024	29.95	3.00	10%	I	I	III
Steenbokpan	A41-3	1940	12.41	1.79	14%	I	I	II

4.2 Mokolo Drainage System

The Mokolo River has various tributaries. Of these tributaries, namely the Sand River and the Grootspuit, originate in the Waterberge mountain range and flow into the Mokolo River upstream of the Mokolo Dam. Other tributaries are Tambotie River, Poer se Loop and Rietspruit River that join the Mokolo River downstream of the Mokolo Dam. The altitude varies from 1 700 m to 790 m at the confluence with the Limpopo River.

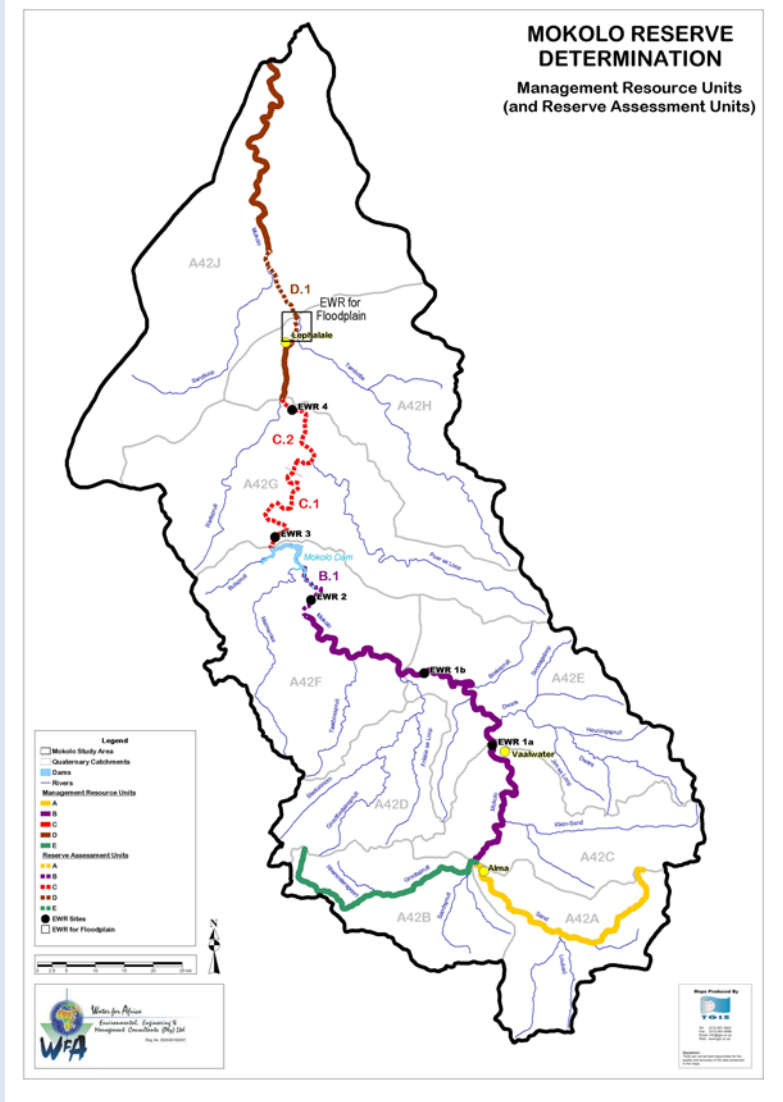
According to the Limpopo ISP (DWA, 2004b) the Mokolo drainage system has more surface water available than any other of the drainage systems in the WMA. Catchments such as the Mokolo, which have large areas situated in the mountainous areas of the Waterberg therefore have much higher unit runoffs than catchments such as the Sand and Matlabas which are situated in predominantly flat areas of the WMA. The large Mokolo Dam is situated in this drainage system, which provides water for a multitude of uses, the most important being the supply to the Matimba Power Station and Grootgeluk coal mine near Lephalale. The Lephalale coalfield have approximately 40% of South Africa's remaining coal reserves and the development of new power stations in this area is inevitable as coal reserves on the Mpumalanga Highveld become depleted (DWA, 2004b). Irrigation, which is by far the largest user of the Mokolo drainage system, takes place mostly upstream of the Mokolo Dam, with water sourced from farm dams and run-of-river.

The Mokolo River catchment was identified as a priority area in which a preliminary high confidence Reserve was required, due to proposed developments (particularly in the mining and power generation sectors) and the associated increased water demands in the catchment. A summary of the Surface Water Reserve is provided in the box below. In this assessment four GUAs have been delineated for the Mokolo area, namely A42-1, A42-2, A41-3 and A42-4 (Figure 4-4) to align more closely to the delineated Surface Water MRUs.

Mokolo Surface Water Reserve

The delineated Management Resource Units (MRUs) are summarized in the table and figure.

MRU	Delineation	Quat
MRU Mokolo A	Source of Sand River to confluence with the Grootspuit.	A42A
MRU Mokolo B	Confluence of Grootspuit and Sand River to end of inundation of Mokolo Dam.	A42D, A42E, 42F
RAU Mokolo B.1	Road bridge to start of inundation of the dam.	A42F
MRU Mokolo C	Dam wall to Rietspruit confluence (end of 6.01 EcoRegion).	A42G
RAU C.1	Dam Wall to end of gorge (upstream of Poer se Loop confluence)	A42G
RAU C.2	End of RAU C.1 to the Rietspruit confluence.	A42G
MRU Mokolo D	Rietspruit confluence to Limpopo confluence.	A42H, A42J
RAU D.1	From the road bridge (R33) upstream of Tamboti-Mokolo confluence to a point downstream of Tamboti-Mokolo confluence.	A42J
MRU E	Source of Grootspuit to confluence with the Sand River.	A42B



Mokolo Surface Water Reserve (continued...)

Five EWR (Ecological Water Requirements) sites were selected in the Mokolo River Catchment. The final flow requirements are expressed as a percentage of the natural MAR (see table below).

EWR scenario results as a percentage of the nMAR

EWR site	EC¹	Maintenance low flows (%nMAR)	Drought low flows (%nMAR)	High flows (%nMAR)	Long term mean (% nMAR)
EWR 1A nMAR: 84.84 pMAR: 68.89	C/D PES	12.8	0.9	4.0	16.7
	B/C REC	24.6	0.9	4.0	22.6
	D AEC	8.5	0.9	3.4	13.6
EWR 1B nMAR: 135.03 pMAR: 109.02	B/C PES	12.3	0.7	4.5	13.6
	B REC	18.2	0.7	4.5	17.6
	C/D AEC	5.9	0.7	4	9.7
EWR 2 nMAR: 196.2 pMAR: 163.16	B/C PES	8.5	2.5	3.9	11.7
	B REC	17.6	3.0	4.7	19.8
	C AEC	5.5	2.5	3.9	9.1
EWR 3 nMAR: 214.5 pMAR: 156.46	B/C PES	6.5	0.14	2.1	8.9
	B REC	9.3	2.4	3.3	12.5
	C/D AEC	3.2	0.14	1.9	7.2
EWR 4 nMAR: 253.3 pMAR: 190.1	C PES	7.3	0	4.7	12.3
	B REC	13.5	4.5	4.7	16.5
	C/D AEC	3.5	0	3.4	8

1 - Refer to Report 26/8/3/10/14/008 (DWAF, 2008).

The purpose of the Surface Water EWR report is to determine the low as well as high flows that are required to maintain the current state of ecological health (PES) at each EWR Site. This requires the specialists to determine the flows that would be required to either improve the ecological health of the specific River (the REC) or to maintain the river in a lower health status than its current situation (the AEC). The current state as well as feasible alternatives (REC, AEC) to the current state for the Mokolo catchment was described as part of the EcoClassification Task (Report 26/8/3/10/14/009; DWAF, 2008b). This report subsequently provides the low and high flows that are required to achieve each of these ecological categories, where the results are referred to as EWR scenarios.

An intermediate assessment on the groundwater component of the Reserve determined that the groundwater contribution to baseflow is much higher for the southern, higher lying parts of the Mokolo catchment (delineated as Waterberg recharge unit) compared to the middle, lower lying parts of the Mokolo catchment (delineated as Waterberg discharge unit). The groundwater contribution to base flow in the northern parts (i.e. Karoo/Basement resource unit) is significantly lower compared to the southern and middle sections of the Mokolo catchment.

A review of the preliminary groundwater Reserve determination together with the results of the Surface Water Reserve was considered in this assessment.

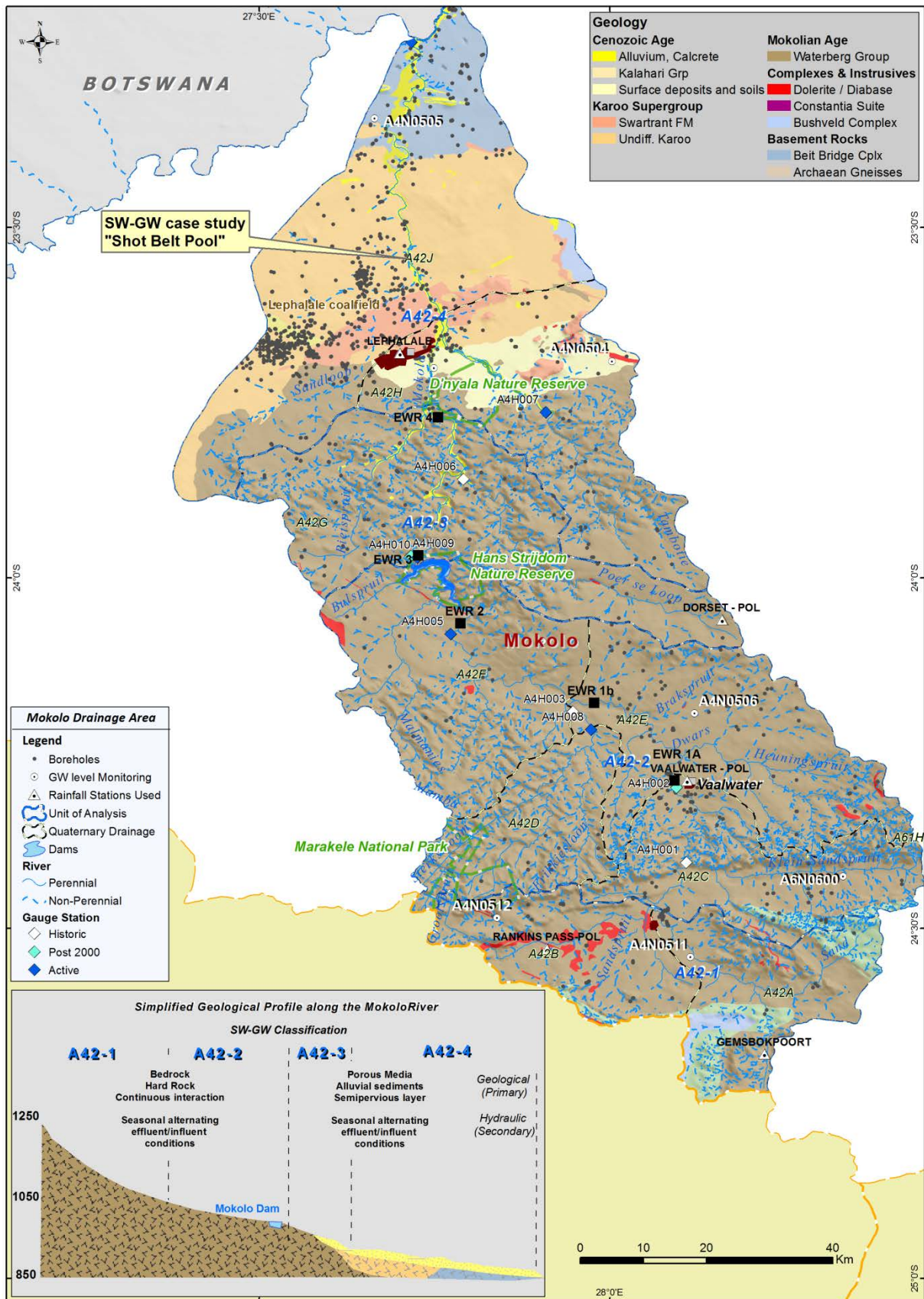


Figure 4-4. Geology, GUAs and SW-GW classification of the Mokolo drainage region.

The main aquifer types include:

- Fractured Karoo Super Group and Waterberg Group aquifers (Predominately)
 - The Waterberg aquifer is predominantly of a fractured and weathered type potentially connected to alluvial deposits occurring along the Mokolo River. The main groundwater targets are associated with fractured dyke contacts and fault zones. The Waterberg formation is associated with steep topography and shows generally poor capability to produce huge amounts of groundwater. Recharge to the aquifer, often discharged on the steep slopes, provides baseflow to the rivers. A weathered zone aquifer is found only where deep weathering occurs and provides groundwater storage that feeds the underlying fractured aquifer.
 - The Karoo aquifer shows similar aquifer properties as the Waterberg aquifer comprising of fractured rocks with a porous matrix. However, groundwater resources and especially the development thereof, are limited due to the low recharge to these aquifers.
- Intergranular Alluvial aquifers (Limited to the main river stems)
 - Alluvial aquifers are recharged during periods of high stream-flows and discharge events (from the Mokolo dam) as well as during the rainfall season. It is an important local, major aquifer and exists in equilibrium with surface water, adjacent groundwater systems and ecosystems along the rivers.
- Intergranular and fractured (near the confluence of the Limpopo River)
 - The northern region of the Mokolo drainage area is underlain by basement aquifers that comprise of deeper fractured (i.e. secondary) aquifers overlain by a weathered horizon of variable thickness. Thick, weathered aquifer zones are expected in areas where the bedrock has been subjected to intense fracturing. The existence of diabase and dolerite dykes forms poor groundwater targets due to the lack of weathering on the margins of these dykes with the basement rocks (gneiss), especially below the static water level. The most noticeable aquifer within the basement rocks are the ENE trending zones of shearing, faulting and brecciation and are usually covered with Quaternary deposits contributing to the aquifer's storage potential

Borehole yields generally range between 0.1 – 2 l/s. However, recent groundwater exploration investigations in the Lephale area yielded boreholes of more than 20 l/s within the confined Waterberg Group (underlying the Karoo aquifer) and more than 10 l/s within the alluvium aquifer.

A summary of the borehole information for the region is shown in Table 18. According to the pumping tests conducted in the Mokolo drainage area, there are vast differences in the transmissivities of the GUAs.

Table 18. Borehole information for the Mokolo drainage region.

Description	UA	Info	BH Depth (mbgl)	Water Level (mbgl)	Transmissivity (m ² /day)	Rec. Yield (l/s for 24hrs)	Airlift Yield (l/s)
Upper Mokolo	A42-1	N	142	128	5	8	-
		Mean	85	19.6	5.56	0.70	-
	A42-2	N	323	298	23	27	-
		Mean	92	21.3	20.37	1.43	-
Middle Mokolo	A42-3	N	127	126	2	2	-
		Mean	118	22.4	17.0	0.81	-
Lower Mokolo	A42-4	N	318	840	10	13	64
		Mean	109	30.7	17	0.94	5.1

N = Number of boreholes

4.2.1 Groundwater recharge

The characteristics of the catchment indicate that there are three climatic zones with the following MAP. In the upper catchments the precipitation is between 600 and 700 mm per annum. In the middle portion of the catchment the precipitation ranges between 500 and 600 mm per annum, while in the lower catchment downstream of the Mokolo Dam the MAP ranges between 400 mm and 500 mm per annum (Table 19). The low and variable rainfall together with evaporation rates considerably exceeding rainfall in the lower Mokolo catchment result in a low expectation of natural recharge to groundwater over most of the area. As a result the recharge vary spatially from as high as 22 mm/a in the higher lying areas to less than 2 mm/a in the lower parts of the catchment (see Figure 2-7).

Table 19. Rainfall Data for selected stations in the Mokolo region.

Station*	Start Date	MAP (mm)	Elevation (mamsl)
Gemsbokpoort [#]	1987	627	1 438
Vaalwater	1965	570	1 139
Lephalale [#]	1993	384	839

*- South African Weathers Services.

[#] - Closed in 2008.

A review of previous work done on the GRA II project, Vegter's (1995) estimates and recharge estimates based on specialist reports were made. These values were calculated for each of the quaternaries constituting the unit of analysis and are summarised as Table 20.

Table 20. Recharge estimation (Mokolo).

GMA	UA	Quat	MAP (mm)	Area (km ²)	GRA II		Vegter (1995)	Specialist report Mm ³	Used Mm ³	Recharge %
					(Wet) Mm ³	(Dry) Mm ³	Mean Mm ³			
Upper Mokolo	A42-1	A42A	639.9	573	15.96	11.60	27.00		18.19	5.0
		A42B	659.9	522	16.58	12.11	18.63		15.77	4.6
	A42-2	A42C	655.5	698	21.91	15.99	43.18		27.02	5.9
		A42D	667.3	497	19.57	14.35	16.67		16.86	5.1
		A42E	604.7	1007	30.11	21.62	47.22		32.98	5.4
		A42F	577.0	1022	22.87	16.29	28.21		22.46	3.8
Middle Mokolo	A42-3	A42G	550.8	1207	25.80	18.25	35.15		26.40	4.0
Lower Mokolo	A42-4	A42H	517.6	1057	15.85	11.05	27.53		18.15	3.3
		A42J	428.3	1812	13.53	9.18	16.18	12.34	12.81	1.7

Water level trends

A summary of the short term water level data obtained from selected monitoring boreholes within the region is presented in Table 21 and illustrated spatially in Figure 4-4. For comparative purposes all hydrographs were based on a four year period (January 2007 to January 2011). Groundwater level fluctuations from the observed hydrographs vary between 0.2 and 2.4 m. A significant response in water levels as a result of rainfall is observed for boreholes in the upper Mokolo catchment (A42-1 and A42-2), while a more subtle response is observed at station A4H0506. A declining water level trend is observed at station A4H0505 in the lower Mokolo catchment and may be attributed to over-abstraction in addition to prolonged periods of low rainfall.

Table 21. Water level trends for selected monitoring stations in the Mokolo region.

<p>A42-1 <i>A4N0511 (red)</i> Date WL (mbgl) Sep-09 5.74 Nov-10 5.82 Difference (m) -0.08 <i>A4N0512 (blue)</i> Apr-09 10.48 Nov-10 10.45 Difference (m) 0.03 Rainfall Data Rankins (Jan-07 to June-10)</p>	
<p>A42-2 <i>A4N0506 (red)</i> Date WL (mbgl) Apr-09 22.04 Nov-10 20.13 Difference (m) -1.41 <i>A6N0600 (blue)</i> Apr-09 13.12 Nov-10 10.65 Difference (m) 2.72 Rainfall Data Vaalwater (Jan-07 to June-10)</p>	
<p>A42-4 <i>A4N0505</i> Date WL (mbgl) Oct-08 33.39 Nov-10 33.83 Difference (m) -0.44 Rainfall Data Lephalale (Jan-07 to June-10)</p>	

4.2.2 Groundwater contribution to baseflow (Ecological Water Requirements)

Based on the groundwater-surface water classification described in section 2.7.5 the Mokolo River stretch can be classified into a continuous interaction bedrock system (Waterberg Group) in the upper reaches, while the low reaches can be classified as a porous media (alluvial sediments) (Figure 4-4). In both cases seasonal alternating effluent / influent conditions can be experienced. Both analytical

and numerical models could be applied to evaluate groundwater-surface water interaction of the Mokolo River.

Based on detailed field work to classify the groundwater-surface water interaction of the Mokolo River as part of the groundwater Reserve determination study for the Mokolo catchment the following conceptual aquifer model is proposed:

- The alluvial aquifer associated with the Mokolo River is in direct contact with the river.
- The alluvial aquifer is generally unconfined.
- The regional aquifers show marginal gradients towards the Mokolo River course and exchange water with the river only indirectly via the alluvial deposits.
- The surface-groundwater exchange between the alluvium and the Mokolo River occurs on a far shorter time scale in comparison to the interaction between the regional and alluvial aquifers.

Comparison of groundwater contribution to baseflow estimates for the Mokolo drainage region are summarised in Table 22. The hydrograph separation curve for station A4H002 and A4H005 is shown in Figure 4-5.

Table 22. Groundwater contribution to baseflow estimates.

GMA	GRU	Quat	Hughes Mm ³ /a	Shultz Mm ³ /a	Pitmann Mm ³ /a	GRA II (WR2005) Mm ³ /a	Maint. Low flow Mm ³ /a	Specialist*/ Hydrograph# Mm ³ /a	² Average Mm ³	EWR Site	¹ Maint. low flows Mm ³
Upper Mokolo	A42-1	A42A	15.62	9.60	17.99	9.32	4.07		7.66		
		A42B	15.39	9.27	16.86	8.59	4.05		7.31		
	A42-2	A42C	20.26	12.21	22.41	11.46	2.83	11.01*	9.38	1A	10.8
		A42D	19.10	5.92	15.26	7.07	9.19		7.39		
		A42E	29.89	10.02	26.79	13.72	8.18		10.64	1B	16.6
		A42F	10.51	0.63	4.70	4.23	2.48	7.84*	3.79	2	16.7
Middle Mokolo	A42-3	A42G	11.33	0.66	5.31	4.41	2.70		2.59	3	13.9
										4	18.5
Lower Mokolo	A42-4	A42H	7.93	0.54	4.33	3.50	0.63		1.56		
		A42J	0.09				0.36	0.74#	0.55		

1 – Adapted from the Preliminary Surface Water Reserve for the Mokolo (DWAF, 2008). Flow volume required at each EWR site based on a percentage of run-off and PES.

2 – Excludes Hughes and Pitmann as it may overestimate the groundwater component to baseflow.

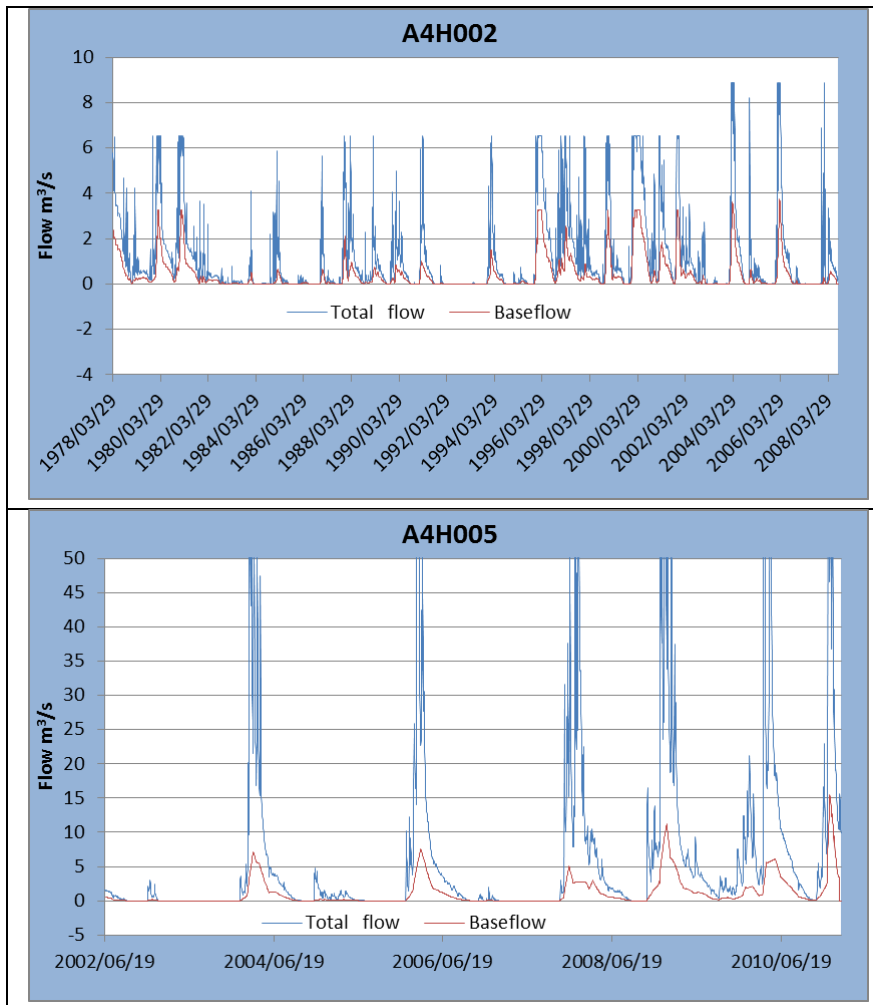


Figure 4-5. Baseflow separation for A4H002 (A41C) and A4H005 (A42F).

4.2.3 Basic Human Needs (BHN)

Table 23. Basic human needs estimates.

GMA	GRU	Quat	Population*	BHN Estimate Mm ³
Upper Mokolo	A42-1	A42A	1755	0.016
		A42B	1751	0.016
	A42-2	A42C	2809	0.026
		A42D	1326	0.012
		A42E	7054	0.064
		A42F	1253	0.011
Middle Mokolo	A42-3	A42G	1014	0.009
Lower Mokolo	A42-4	A42H	8715	0.080
		A42J	6353	0.058

* - Based on population not dependent on run of river (DWAF, 2008).

4.2.4 Reserve determination summary

The Reserve assessment is firstly provided on a groundwater resource unit level in Table 24 and summarized for the Limpopo WMA on a quaternary level in Appendix A.

Table 24. Groundwater Reserve summary (Mokolo region).

GMA	GUA	Area (Km ²)	Recharge Mm ³	GW to Baseflow Mm ³	BHN Mm ³	Reserve Mm ³	Reserve as % of Recharge
Upper Mokolo	A42-1	1095	33.96	14.97	0.05	15.02	44%
	A42-2	3224	99.33	31.20	0.22	31.42	32%
Middle Mokolo	A42-3	1207	26.40	2.59	0.02	2.61	10%
Lower Mokolo	A42-4	2869	30.95	2.11	0.18	2.29	7%

4.2.5 Groundwater use and availability

Groundwater use estimates vary significantly between the GRA II dataset and the recently validated WARMS dataset (Table 25). Despite the extensive use of groundwater especially in the upper Mokolo it appears that groundwater is underutilised in the region. It is important to note that the UGEP (for the lower catchments) is an overestimate of available groundwater resources which is estimated at almost twice the HP volumes (Table 25).

Table 25. Groundwater availability and stress index (Mokolo region).

GMA	GUA	Quat	RE Mm ³	Groundwater availability Mm ³ /a		Groundwater Use Mm ³ /a			GW Use as % of HP	Stress Index (GW Use as % of Recharge)
				HP	UGEP	GRA II Mm ³	¹ WARMS	Final Estimate		
Upper Mokolo	A42-1	A42A	18.19	9.57	2.43	4.56	1.33	4.56	48%	25%
		A42B	15.77	5.73	2.78	4.47	2.47	4.47	78%	28%
	A42-2	A42C	27.02	9.75	3.92	5.51	3.27	5.51	57%	20%
		A42D	16.86	6.25	5.72	2.93	0.11	2.93	47%	17%
		A42E	32.98	12.79	35.15#	8.10	1.51	8.10	63%	25%
		A42F	22.46	12.78	21.07#	2.66	0.86	2.66	21%	12%
Middle Mokolo	A42-3	A42G	26.40	12.82	41.31#	0.07	0.13	0.13	1%	1%
Lower Mokolo	A42-4	A42H	18.15	10.43	24.27#	0.06	0.09	0.09	1%	< 1%
		A42J	12.81	13.42	29.31#	0.22	2.12	2.12	16%	17%

- This may be an over estimate of available groundwater resource considering the HP estimates.

1 – Registered use as per Mokolo validation report (Total of 10.4 Mm³/a).

4.2.6 Groundwater quality

Similar to the Matlabas region groundwater samples in the Mokolo drainage region indicate a variety of water types (e.g. Ca/Mg-HCO₃, Na-HCO₃ and Na-Cl) (Figure 4-6). A high percentage of samples relate to a fresh recharge type (Ca/Mg-HCO₃) water (e.g. A42-2); while cation and anion exchange process may be occurring within the strata hence Na-Cl and Ca/Mg-Cl type water present. However, some impacts of anthropogenic activity may be present in the more Ca-Mg-Cl-SO₄ type compositions, especially in A42-4.

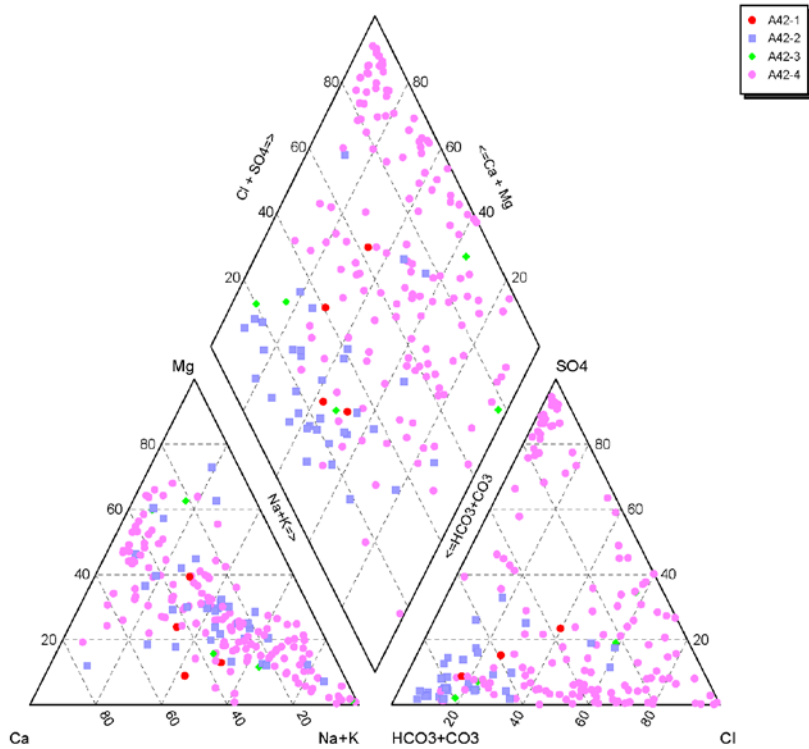


Figure 4-6. Piper diagram for the Mokolo drainage region.

Groundwater quality in the Upper Mokolo region is considered to be marginal with more than 75 % of samples within the recommended drinking limit as specified by SANS (2006). However, in the Middle- and Lower Mokolo less than 30 % comply with the specified drinking water quality standard. The most notable elements of concern include NO₃ as N and F with average concentrations above the recommended drinking limit (Table 26). In addition, several samples show major ion concentrations (e.g. Mg, and Cl) and subsequently electric conductivities (EC) beyond acceptable limits. This can mostly be related to evaporative concentration of elements in discharge areas or due to low recharge values as well as long residence times for selected samples. Elevated SO₄ concentrations may be attributed directly to the mining activities in the A42-4 GUA.

Table 26. Groundwater quality for the Mokolo region (All units in mg/l, EC in mS/m).

GUA	Parameter	pH	EC	Ca	Mg	Na	K	SO ₄	Cl	NO ₃ as N	F	Compliance (% of samples within Class I)	Present Category
A42-1	Nr	8	8	8	8	8	7	8	8	1	8	65 %	II
	Mean	7.6	16.9	14.0	3.3	18.3	1.7	6.5	10.4	1.0	0.8		
A42-2	Nr	55	55	50	51	51	43	51	54	36	55	87 %	II
	Mean	7.5	39.1	25.7	16.5	35.4	1.9	14.3	29.4	3.4	0.4		
A42-3	Nr	6	6	6	6	6	6	6	6	4	6	33 %	III
	Mean	7.8	121.7	52.0	32.0	159.0	3.6	126.4	195.9	1.6	1.0		
A42-4	Nr	222	216	206	203	206	195	205	204	98	204	20 %	III
	Mean	7.4	266.2	134.5	78.2	190.7	10.2	411.8	301.9	15.6	1.8		

Class I

Class II

Exceed Class II

4.2.7 Summary of field verification

Groundwater level fluctuations were measured continuously from 21 October 2009 to 21 February 2011 in five of the boreholes. One borehole targeting the host rock (Karoo Supergroup) four in the alluvial aquifer and one within monitoring the water level of the 'Shot belt' Pool (Figure 4-8). From the analysis, the groundwater flow is generally away from the 'Shot Belt' Pool westwards and eastwards towards the alluvial aquifer and Mokolo River. The groundwater flow indicates influent conditions with respect to the 'Shot Belt' Pool and Mokolo River. Rainfall and corresponding changes in weir flow data (i.e. probably related to spills or scheduled releases from the Mokolo Dam) correlate generally very well. An overall decrease in weir flows, over the specified period, correlates well with a similar decrease in rainfall.

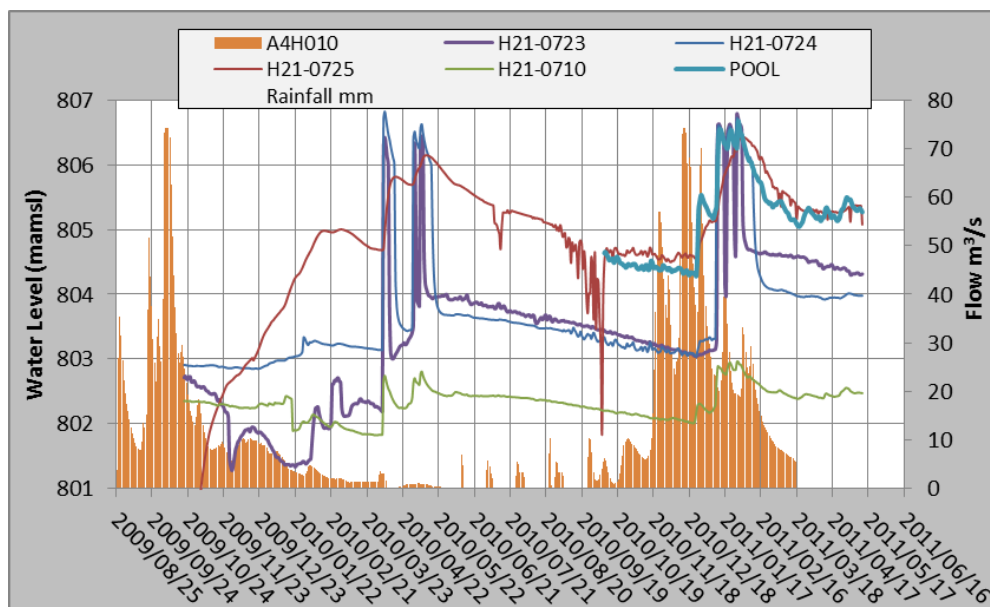


Figure 4-7. Groundwater level fluctuation presented with the Mokolo Dam weir (A4H010).

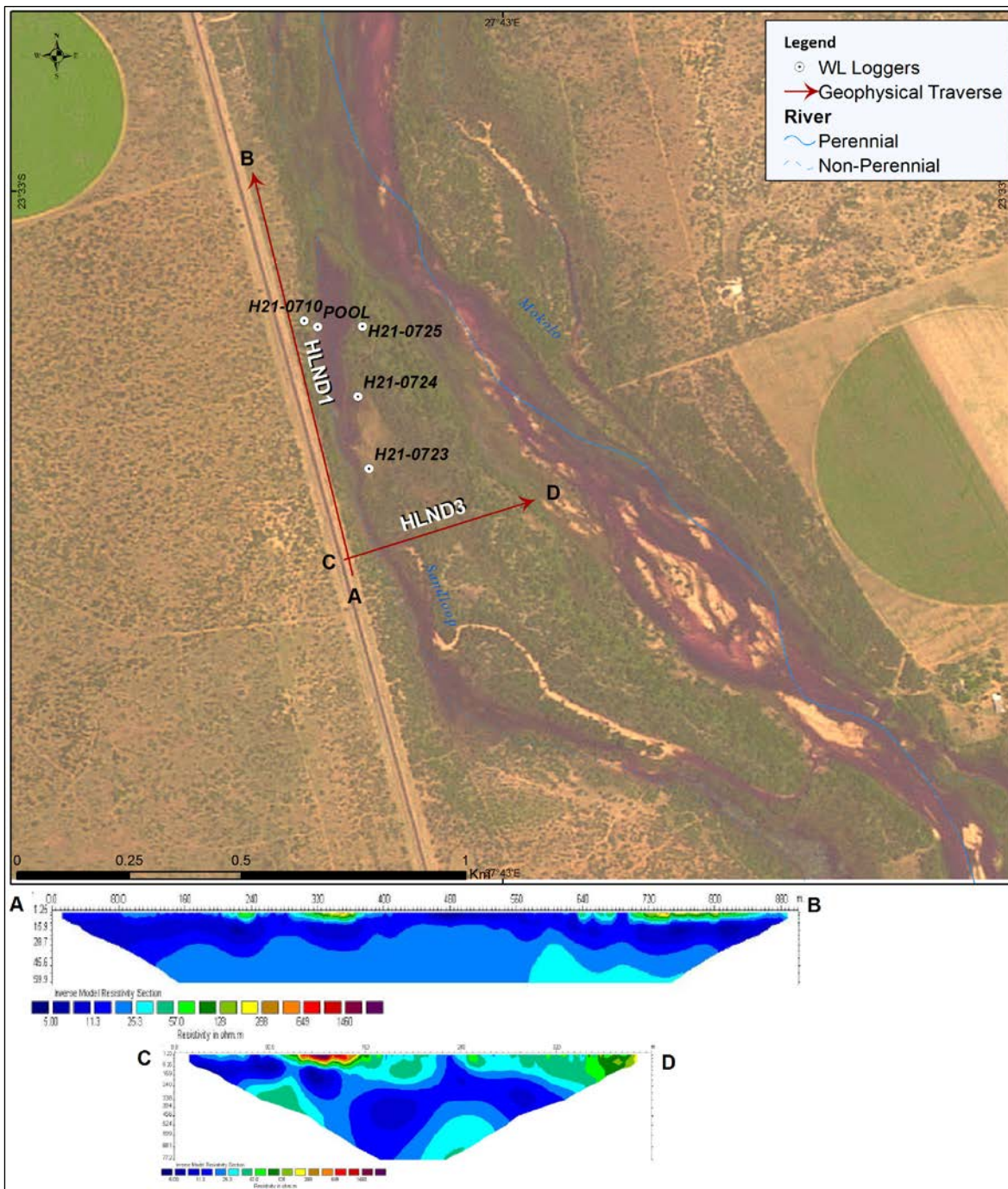


Figure 4-8. Mokolo geophysical traverses and monitoring boreholes.

Historical reports indicate that water released from the Mokolo Dam is of utmost importance to irrigation projects and probably also to the ecological functioning of the Mokolo River. All water users, especially for irrigation, rely heavily on the releases from the Mokolo Dam indicating that most water from the Mokolo River is driven by surface water and to a small extent groundwater recharge. Hence the surface-groundwater interaction is driven by the release of surface water from the Mokolo Dam as seen with the groundwater fluctuation in the monitored boreholes next to the 'Shot Belt' Pool (Photo 4).



Photo 4. Shot Belt Pool flooded in January 2011 (Photo taken by Martin Holland).

4.2.8 Final Categorisation

A summary of the categorisation for the Mokolo region is shown in Table 27.

Table 27. Final groundwater categorisation for each GUA (Mokolo region).

GMA	GUA	Area (Km ²)	Recharge Mm ³	Groundwater Use Mm ³ /a	Stress Index (SI)	Present Category (SI)	Present Category (Impact)	Present Category (Quality)
Upper Mokolo	A42-1	1095	33.96	9.02	27%	II	I	II
	A42-2	3224	99.33	19.20	19%	I	I	II
Middle Mokolo	A42-3	1207	26.40	0.13	1%	I	I	III
Lower Mokolo	A42-4	2869	30.95	2.21	7%	I	II	III

4.3 Lephhalala Drainage System

The Lephhalala River originates in the Sandrivier Mountains that forms part of the Waterberge. The altitude varies from 1 700 m to 780 m (DWA, 2003a). The upper Lephhalala River is relatively undeveloped and traverses large wilderness areas. The runoff originates in the upper reaches, and most of the surface water use is found in these upper catchments, where the large number of farm dams supports a significant amount of irrigation. Lower down in the catchment irrigators make use of water from alluvial aquifers. Individual irrigators developed irrigation schemes where water is obtained mainly from more than 530 farm dams having a combined capacity of about 9.5 Mm³ (DWA, 2003a). The only other significant water use is the rural water use and it is assumed that this is sourced from

groundwater. Communities in the catchment are located in the lower reaches and they rely mainly on the groundwater resource. The upper Lephhalala River has significant potential for surface water development and a number of dam sites have been investigated (DWA, 2003a). However, it is unlikely that the construction of a major dam on the Lephhalala River will be environmentally acceptable (DWA, 2003b). Allocations in the Lephhalala catchment seem to exceed the available yield and according to the Limpopo ISP (DWA, 2004) the catchment appears to be stressed. As a result additional water for development purposes should be sourced from groundwater.

Recognising the important wilderness areas in the catchment, it may be set as an objective for the Lephhalala River to be managed in a close to natural state, at least upstream of current conservation areas in the catchment (DWA, 2003b). Several red data pool dependant species occur in this catchment due to wetlands and the nature of the river, particularly in the upper parts of the catchment.

In this assessment four GUAs have been delineated for the Lephhalala drainage area, namely A50-1, A50-2, A50-3 and A50-4 (Figure 4-9). A summary of the borehole information for the region is shown in Table 28.

Table 28. Borehole information for the Mokolo drainage region.

Description	GUA	Info	BH Depth (mbgl)	Water Level (mbgl)	Transmissivity (m ² /day)	Rec. Yield (l/s for 24hrs)	Airlift Yield (l/s)
Upper Lephhalala	A50-1	N	185	156		2	-
		Mean	77	20.1		0.81	-
Middle Lephhalala	A50-2	N	121	89	44	66	-
		Mean	52	11.0	61.62	0.97	-
Lower Lephhalala	A50-3	N	395	294	80	101	10
		Mean	65	17.5	41.35	1.16	2.5
Limpopo Stem	A50-4	N	287	210	1	1	103
		Mean	50	27.3	14.70	0.40	2.9

N = Number of boreholes

Borehole yields generally range between 0.1 – 2 l/s. Hydrogeological findings by Bush (1989) in the Swartwater area revealed that 66 % of boreholes surveyed had yields below 1 l/s. Vegter (2000) indicated that only 19 % of boreholes recorded yielded more than 1 l/s in an area east of Beauty. However significant higher borehole yields are obtained along the middle reaches of the Lephhalala River within the Bushveld Complex.

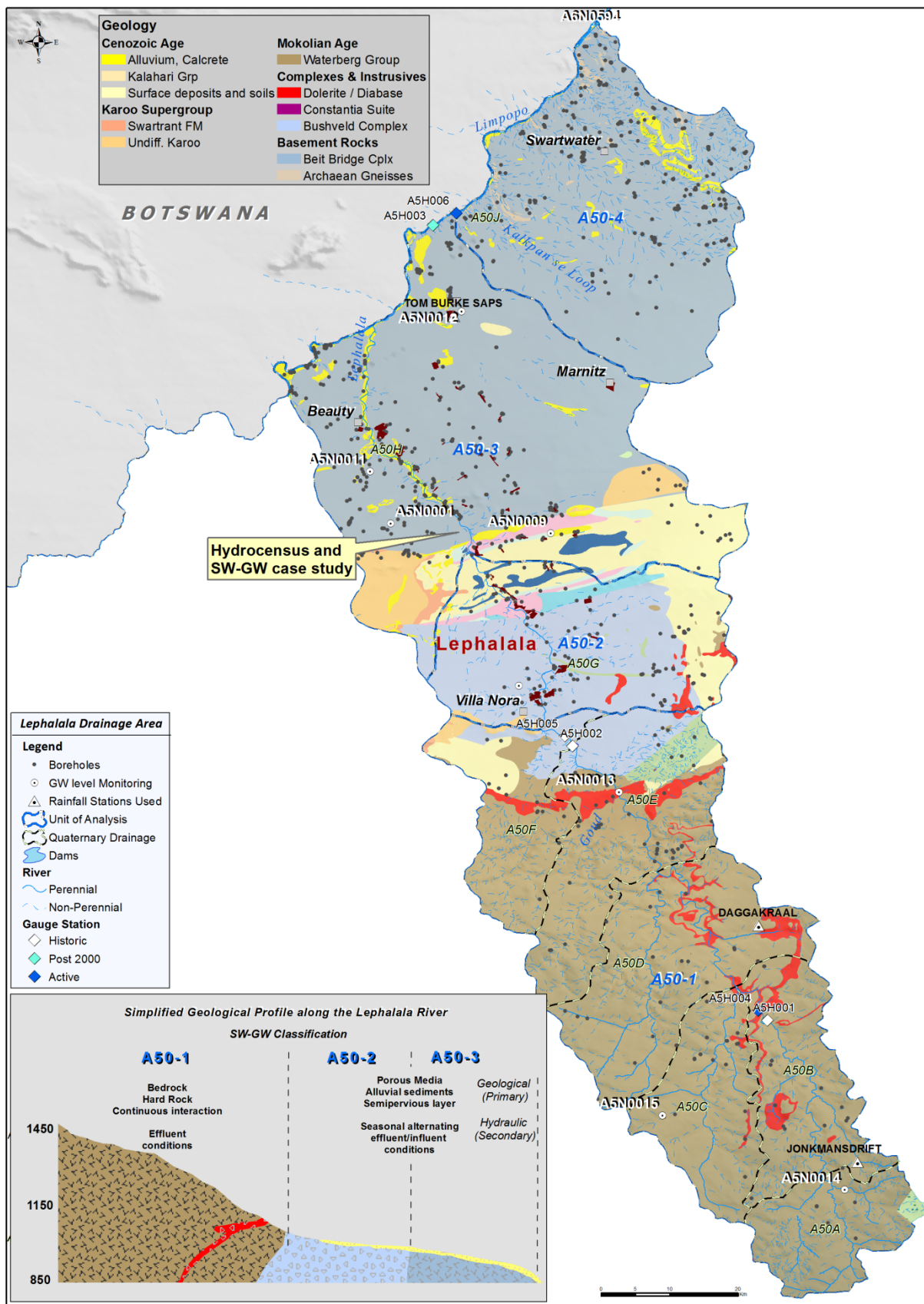


Figure 4-9. Geology, GUAs and SW-GW classification of the Lephhalala drainage region.

The main aquifer types include:

- Fractured Waterberg Group aquifers (Predominately)
 - The Waterberg formation is associated with steep topography and shows generally poor capability to produce huge amounts of groundwater. Recharge to the aquifer, often discharged on the steep slopes, provides baseflow to the rivers. A weathered zone aquifer is found only where deep weathering occurs and provides groundwater storage that feeds the underlying fractured aquifer.
- Intergranular Alluvial aquifers (Limited to the main river stems)
 - Alluvial aquifers are recharged during periods of high stream-flows as well as during the rainfall season. It is an important local, major aquifer and exists in equilibrium with surface water, adjacent groundwater systems and ecosystems along the rivers. The alluvium appears to be better developed along the lower reaches of the Lephala River with a thickness of approximately 5 m.
- Intergranular and fractured (Bushveld And Basement Complex)
 - The middle and lower reaches of the Lephala drainage area is underlain by basement aquifers that comprise of deeper fractured (i.e. secondary) aquifers overlain by a weathered horizon of variable thickness. Thick, weathered aquifer zones are expected in areas where the bedrock has been subjected to intense fracturing.

4.3.1 Groundwater recharge

Mean annual precipitation varies from between 400 mm in the vicinity of Beauty in the west to about 600 mm in the southeast (Table 29). The low and variable rainfall together with evaporation rates considerably exceeding rainfall result in a low expectation of natural recharge to groundwater over most of the area. As a result the recharge vary spatially from as high as 18 mm/a in the higher lying areas to less than 2 mm/a in the lower parts of the catchment (see Figure 2-7).

Table 29. Rainfall Data for selected stations in the Lephala region.

Station*	Start Date	MAP (mm)	Elevation (mamsl)
Jonkmansdrift	1984	604	1 400
Daggakraal [#]	1965	570	1 150
Tom Burke	1960	406	807

*- South African Weathers Services.

[#] - Closed in 2002.

A review of previous work done on the GRA II project, Vegter's (1995) estimates and recharge estimates based on specialist reports were made. These values were calculated for each of the quaternaries constituting the unit of analysis and are summarised as Table 30.

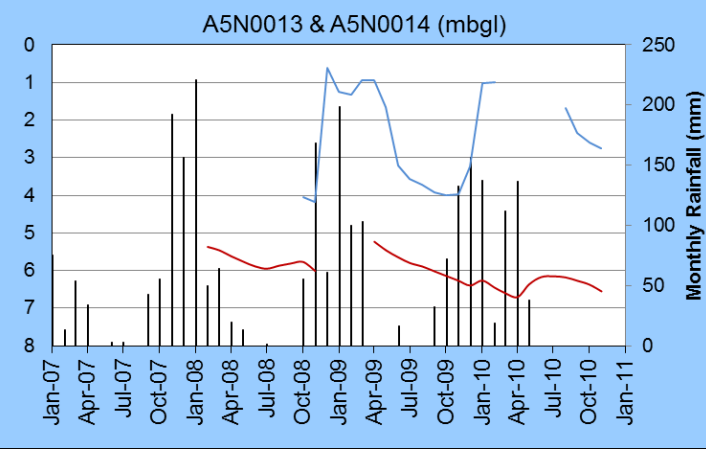
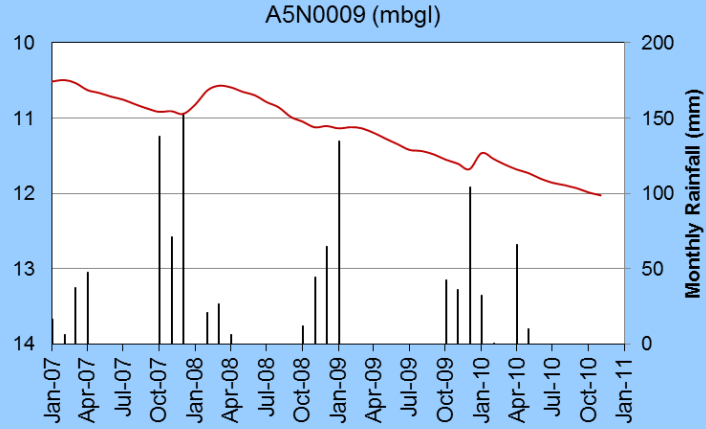
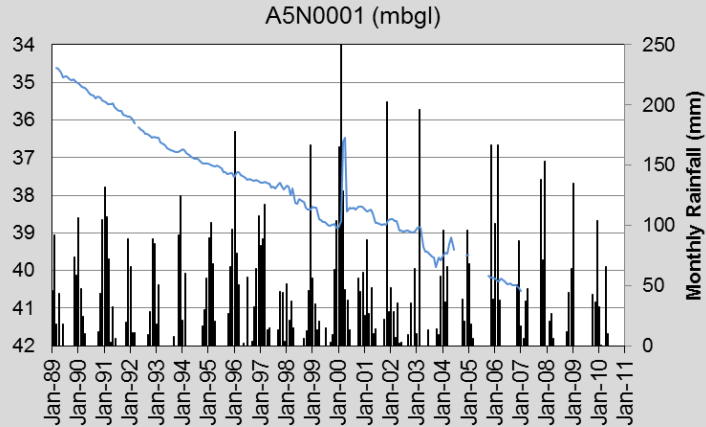
Table 30. Recharge estimation (Lephalala).

Description	GUA	Quat	MAP (mm)	Area (km ²)	GRA II		Vegter (1995)	Specialist report Mm ³	Used Mm ³	Recharge %
					(Wet) Mm ³	(Dry) Mm ³	Mean Mm ³			
Upper Lephalala	A50-1	A50A	654.1	298	11.35	8.28	19.21		10.49	5.4
		A50B	599.0	406	12.05	8.64	19.87		11.10	4.6
		A50C	593.0	362	10.36	7.40	15.24		9.10	4.2
		A50D	558.2	637	12.57	8.89	20.38		11.88	3.3
		A50E	517.0	629	10.95	7.63	16.56		10.08	3.1
		A50F	495.8	372	5.35	3.70	9.39		5.34	2.9
Middle Lephalala	A50-2	A50G	435.3	821	9.20	6.26	6.02		6.79	1.9
Lower Lephalala	A50-3	A50H	407.2	1945	15.11	9.91	12.25	8.71	12.46	1.6
Limpopo Stem	A50-4	A50J	391.1	1255	8.84	5.91	13.12		8.92	1.8

Water level trends

A summary of the short term water level data obtained from selected monitoring boreholes within the region is presented in Table 31 and illustrated spatially in Figure 4-9. For comparative purposes the short term water level were based on a four year period (January 2007 to January 2011), while the long term water level data extends back to the late 1980s. Groundwater level fluctuations from the observed hydrographs vary between 1 and 7 m. A significant response in water levels as a result of rainfall is observed for boreholes in the upper Lephalala catchment (A50-1), while a more subtle response is observed at stations lower down the catchment (e.g. A5N0009).

Table 31. Water level trends for selected monitoring stations in the Lephalala region.

<p>A50-1 <i>A5N0513 (red)</i> Date WL (mbgl) Feb-08 5.37 Nov-10 6.55 Difference (m) -1.18 <i>A5N0514 (blue)</i> Oct-08 4.06 Nov-10 2.75 Difference (m) 1.31 Rainfall Data Jonkmansdrift (Jan-07 to June-10)</p>	
<p>A50-3 <i>A5N0009</i> Date WL (mbgl) Oct-06 10.46 Nov-10 12.03 Difference (m) -1.57 Rainfall Data Tom Burke (Jan-07 to June-10)</p>	
<p>A50-3 <i>A5N0001</i> Date WL (mbgl) Oct-1988 34.6 Feb-08 41.7 Difference (m) -7.1 Rainfall Data Tom Burke (Jan-07 to June-10)</p>	

A well-identified seasonal water-level fluctuation is observed over most stations. Rapid increases in water levels are associated with extreme single rainfall events, while progressive increases are related to long periods of low intensity rainfall events. However, below average rainfall periods result in a recession period that may continue throughout the season with little or no recharge at all. According to Vegter (2000) the requirements to qualify as a major recharge season, is a seasonal rainfall of greater

than 500 mm of which at least 300 mm must fall within a period of 2 months or 400 mm within 4 months.

Although a decrease in water levels is expected due to below average rainfall over the last decade, a decrease in water levels of 7 m at the long term A5N0001 monitoring station suggest the potential impacts of over-abstraction for irrigation purposes. Throughout the last few decades concern was expressed by farmers in the Swartwater – Marnitz area that increased groundwater abstraction for irrigation purposes may relate to a regional drop in water levels. A study by Blecher (1993) attributed a drop in water levels of up to 20 m, to severe drought conditions, low storage capacity and limited recharge. According to the author the effects of abstraction for irrigation appeared to be localised and limited to the farms concerned. Similarly, Bush (1987) concluded that declining water levels and yields for particular boreholes was an indication of site-specific dewatering due to the limited extent of the aquifers and their poor storage capabilities, and not a regional lowering of the water table.

4.3.2 Groundwater contribution to baseflow

Based on the groundwater-surface water classification described in section 2.7.5 the Lephhalala River stretch can be classified into a continuous interaction bedrock system (Waterberg Group) in the upper reaches, while the low reaches can be classified as a porous media (alluvial sediments) (Figure 4-9). Effluent conditions are expected in the upper reaches while seasonal alternating effluent / influent conditions can occur along the lower reaches of the Lephhalala River. Both analytical and numerical models could be applied to evaluate groundwater-surface water interaction of the Lephhalala River.

Similar to the Mokolo River, the surface-groundwater exchange between the alluvium and the Lephhalala River occurs on a far shorter time scale in comparison to the interaction between the regional and alluvial aquifers. Regional aquifers of the lower catchment show marginal gradients towards the Lephhalala River course and exchange water with the river only indirectly via the alluvial deposits. However, in the upper reaches of the catchment a higher gradient towards the River course is observed and where the alluvium is lacking the surface-groundwater exchange is directly from the regional aquifer to the River.

Comparison of groundwater contribution to baseflow estimates for the Lephhalala drainage region are summarised in Table 32. The hydrograph separation curve for station A5H004 is shown in Figure 4-10.

Table 32. Groundwater contribution to baseflow estimates.

GMA	GRU	Quat	Hughes Mm ³ /a	Shultz Mm ³ /a	Pitmann Mm ³ /a	GRA II (WR2005) Mm ³ /a	Maint. Low flow Mm ³ /a	Specialist*/ Hydrograph# Mm ³ /a	Average Mm ³
Upper Lephala	A50-1	A50A	11.19	3.48	8.97	4.22	3.01		3.57
		A50B	11.81	3.87	10.72	5.44	3.07	7.80#	5.04
		A50C	10.27	3.42	9.45	4.82	1.25		3.16
		A50D	6.71	0.36	2.87	2.12	2.98		1.82
		A50E	4.86	0.33	2.58	1.88	0.42		0.88
		A50F	2.39	0.18	1.49	1.04	0.23		0.48
Middle Lephala	A50-2	A50G					0.02	0.47*	0.25
Lower Lephala	A50-3	A50H					0.04	0.88*	0.46
Limpopo Stem	A50-4	A50J					0.72	0.50*	0.61

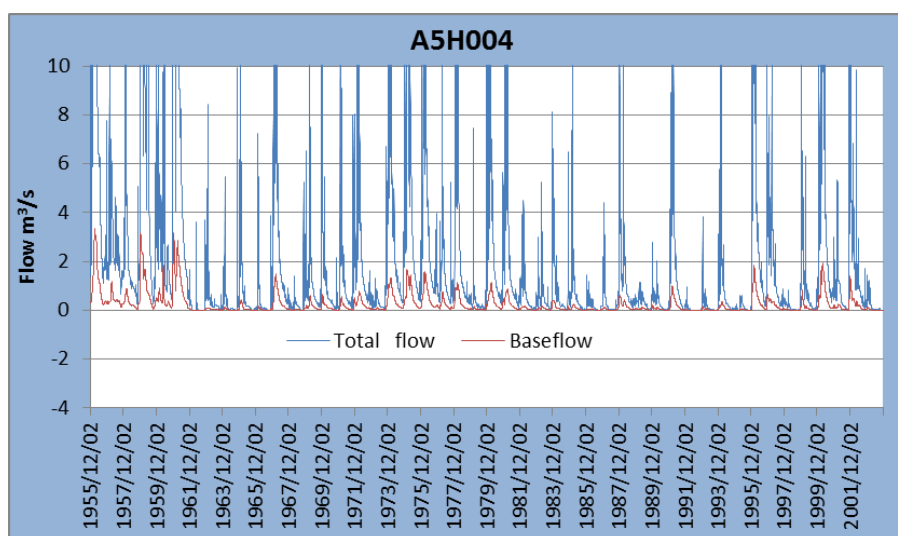


Figure 4-10. Baseflow separation for A5H004 (A50B).

4.3.3 Basic Human Needs (BHN)

Table 33. Basic human needs estimates.

Description	GRU	Quat	Population*	BHN Estimate Mm ³
Upper Lephala	A50-1	A50A	826	0.008
		A50B	664	0.006
		A50C	1105	0.010
		A50D	689	0.006
		A50E	555	0.005
		A50F	416	0.004
Middle Lephala	A50-2	A50G	33390	0.305
Lower Lephala	A50-3	A50H	36330	0.332
Limpopo Stem	A50-4	A50J	2622	0.024

* - Based on 2001 statistics and the Limpopo ISP (DWA, 2004b).

4.3.4 Reserve determination summary

The Reserve assessment is firstly provided on a groundwater resource unit level in Table 34 and summarized for the Limpopo WMA on a quaternary level in Appendix A.

Table 34. Groundwater Reserve summary (Lephalala region).

Description	GUA	Area (Km ²)	Recharge Mm ³	GW to Baseflow Mm ³	BHN Mm ³	Reserve Mm ³	Reserve as % of Recharge
Upper Lephalala	A50-1	2704	69.27	14.95	0.04	14.99	22%
Middle Lephalala	A50-2	821	7.16	0.25	0.30	0.55	8%
Lower Lephalala	A50-3	1945	11.49	0.46	0.33	0.80	7%
Limpopo Stem	A50-4	1255	9.29	0.61	0.02	0.63	7%

4.3.5 Groundwater use and availability

Groundwater in the upper Lephalala region appears to be underutilised while groundwater resources in the lower reaches of the Lephalala drainage system (A50-3 and A50-4) are used extensively. As a result large portion of the natural recharge and harvest potential are already being exploited (Table 35).

Table 35. Groundwater availability and stress index (Lephalala region).

GMA	GUA	Quat	RE Mm ³	Groundwater availability Mm ³ /a		Groundwater Use Mm ³ /a			GW Use as % of HP	Stress Index (GW Use as % of Recharge)
				HP	UGEP	GRA II Mm ³	WARMS (*validated)	Final Estimate		
Upper Lephalala	A50-1	A50A	12.95	3.71	10.38#	2.73	0.01*	2.73	13%	4%
		A50B	13.52	5.12	4.70	0.79	0.80	0.80	16%	6%
		A50C	11.00	4.61	2.85	1.22	1.20	1.22	26%	11%
		A50D	13.95	8.17	8.57	0.17	0.09*	0.17	2%	1%
		A50E	11.71	8.63	3.92	0.37	0.02*	0.37	4%	3%
		A50F	6.14	4.12	7.06#	0.06	0.14	0.14	3%	2%
Middle Lephalala	A50-2	A50G	7.16	5.82	5.55	0.67	0.56*	0.67	12%	9%
Lower Lephalala	A50-3	A50H	11.49	12.17	9.38	1.10	8.44*	8.44	69%	73%
Limpopo Stem	A50-4	A50J	9.29	13.04	6.91	1.19	3.83*	3.83	29%	41%

- This may be an over estimate of available groundwater resource considering the HP estimates.

4.3.6 Groundwater quality

Groundwater samples in the Lephalala drainage region indicate a variety of water types (e.g. Ca/Mg-HCO₃, Na-HCO₃ and Na-Cl) (Figure 4-6). A high percentage of samples relate to a fresh recharge

type (Ca/Mg-HCO₃) water, while cation and anion exchange process may be occurring within the strata hence Na-Cl and Ca/Mg-Cl type water is present.

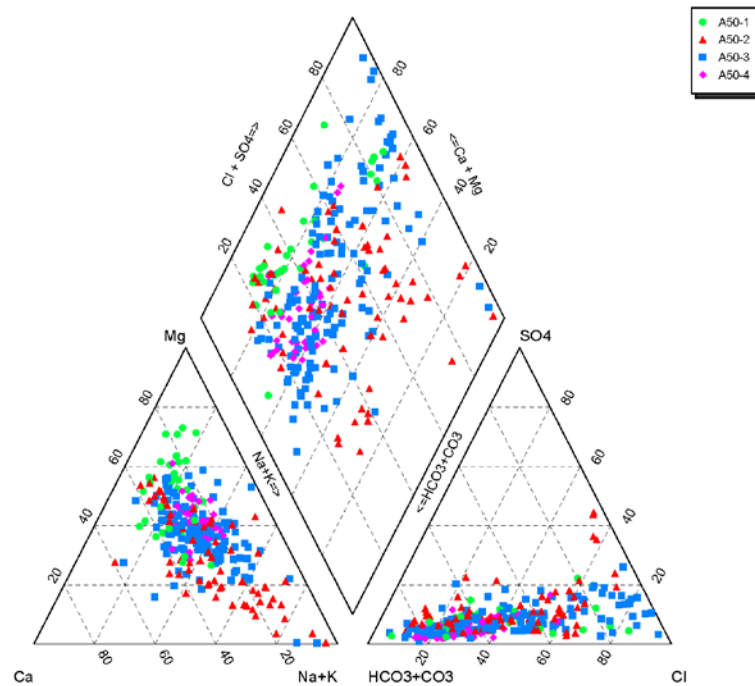


Figure 4-11. Piper diagram for the Lephalala drainage region.

Groundwater quality in the Lephalala region is considered to be marginal to poor with only 48 % of samples in the Upper reaches within the recommended drinking limit while less than 11 % of samples in the lower Lephalala reaches comply with the drinking water quality standard. The most notable elements of concern include NO₃ as N with average concentrations above the maximum allowable recommended drinking limit (Table 36). In addition, several samples show major ion concentrations (e.g. Mg, and Cl) and subsequently electric conductivities (EC) beyond acceptable limits. This can mostly be related to evaporative concentration of elements in discharge areas or due to low recharge values as well as long residence times for selected samples.

Table 36. Groundwater quality for the Lephalala region (All units in mg/l, EC in mS/m).

GUA	Parameter	pH	EC	Ca	Mg	Na	K	SO ₄	Cl	NO ₃ as N	F	Compliance (% of samples within Class I)	Present Category
A50-1	Nr	33	33	33	33	33	33	33	33	31	33	48 %	II*
	Mean	7.9	130.9	66.3	68.3	65.0	7.7	43.1	182.1	16.1	0.5		
A50-2	Nr	102	102	96	96	95	90	96	102	91	99	9 %	III
	Mean	7.9	169.8	86.8	54.9	169.1	4.1	94.6	251.3	31.4	1.9		
A50-3	Nr	216	216	185	187	186	185	186	216	203	210	11 %	III
	Mean	7.9	197.0	111.8	94.9	147.9	10.8	73.9	313.4	44.6	1.1		
A50-4	Nr	37	37	37	37	37	37	37	37	37	37	5 %	III
	Mean	7.9	130.2	78.2	76.8	98.6	13.3	34.0	141.9	29.6	0.7		

Class I

Class II

Exceed Class II

4.3.7 Summary of field verification

To further the understanding of the groundwater-surface water interaction in the Middle Lephalala region some field investigation were conducted as part of the field verification component of the Limpopo Reserve assessment. This included limited ground geophysics, a hydrocensus and installation of 4 continuous water level recorders on the banks of the River system and within the regional host rock. Resistivity profiles along and across the Lephalala River at Villa Nora are illustrated in Figure 4-12.

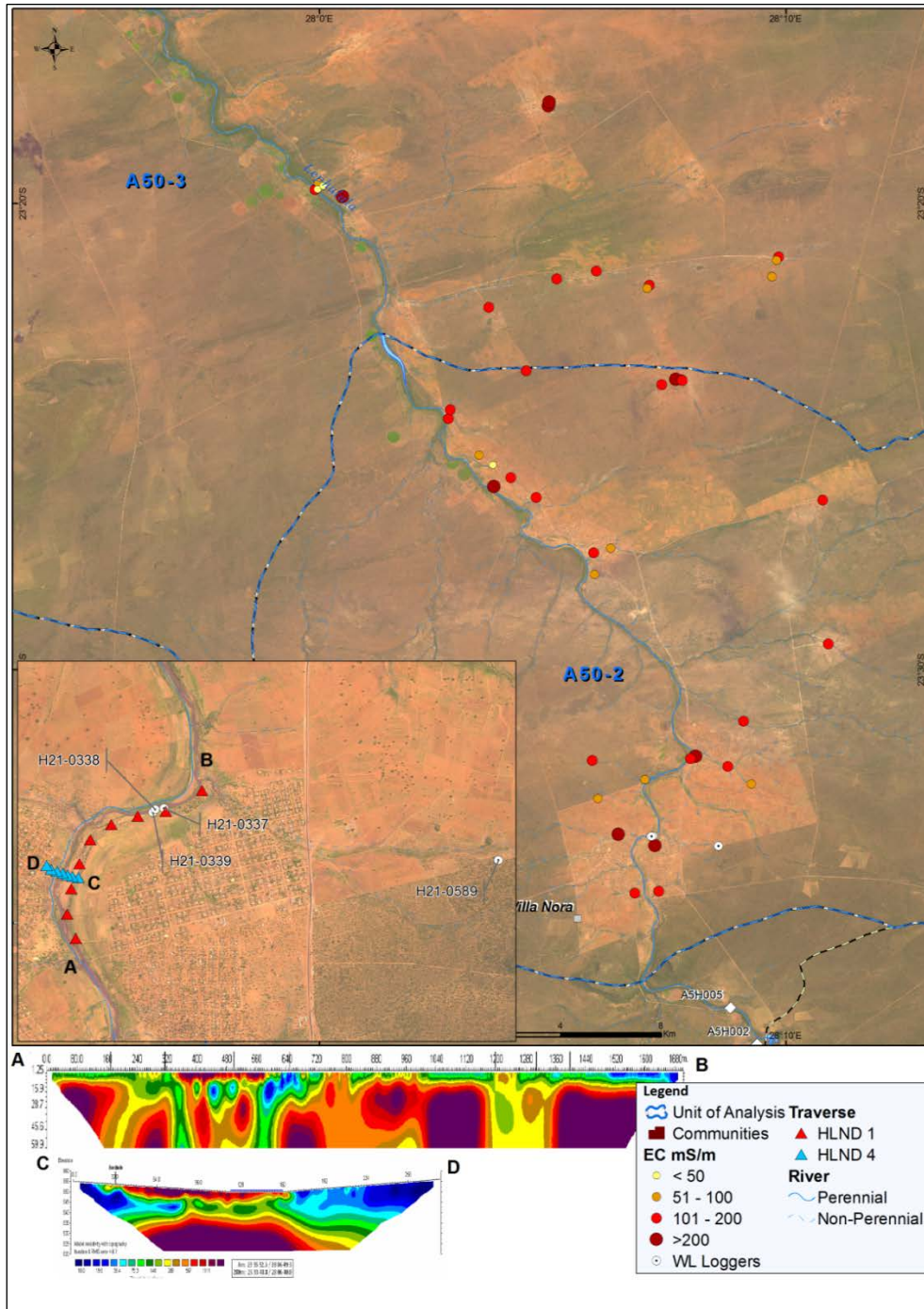


Figure 4-12. Villa Nora geophysical traverses and monitoring boreholes.

The relatively low resistivity are (< 110 Ωm) evident in the top layer in immediate connection with the main river channel. The thickness of the layer varies from a few metres to around 10 meters below the present river channel. In places the layer is interrupted by what may be interpreted as an intrusive dyke. Below the stream channel and inferred alluvium layer a high resistive indication is visible at depth. This may be interpreted as the Bushveld Complex bedrock. In some section along the River course the river channel incises into the bedrock with a thin or absent alluvium layer, and in other a weathered aquifer underlies the alluvium. The alluvial aquifers interact with the composite weathered aquifer as well as surface water, both interactions dependent amongst other factors, on prevailing groundwater gradients as well as the presence (or lack) of clogging layers in the streambed resulting in an imperfect hydraulic connection.

The 44 groundwater samples taken in March 2011 confirm the poor water quality observed from the regional datasets in the previous section. Based on the results average Nitrate values exceed the maximum recommended drinking water limits, while average fluoride concentrations is within the upper reaches of the maximum allowable limit. In summary more than 70 % of samples exceed Class II (maximum allowable limit). The elevated Nitrate concentrations in the groundwater could be directly related to anthropogenic activities such as inappropriate on-site sanitation (pit latrines) and livestock concentration at watering points near boreholes. The potential pollution of these sources is enhanced through the shallow water levels and high transmissivities observed in the area. The average depth to water, based on the 117 measurements, is 8.8 m. As a result the aquifer is highly vulnerable to pollution and may lead to widespread contamination of the groundwater resources (Figure 4-12.).

Table 37. Average concentrations of major ions for groundwater samples in the Limpopo WMA (EC in mS/m, all other in mg/l).

Parameter	pH	EC	Ca	Mg	Na	K	SO ₄	Cl	NO ₃ ^{as} N	F
Nr. of samples	44 samples									
Minimum	6.9	41.2	21.3	4.3	11.7	0.3	12.0	14.5	1.5	0.2
Mean value	7.4	141.1	80.6	57.2	123.8	5.8	48.8	163.8	28.8	1.5
Maximum	7.9	455.0	422.8	224.6	439.7	44.1	146.8	1186.4	122.0	7.1
Std. Deviation	0.3	81.9	73.1	40.2	86.9	7.7	31.4	221.4	26.4	1.5
Recommended drinking water quality limits (SANS:241, 2006)										
Class I: (Recommended operational limit)	5.0-9.5	< 150	< 150	< 70	< 200	< 50	< 400	< 200	< 10	< 1
Class II: (Max. allowable)	4.0-10	150-370	150-300	70-100	200-400	50-100	400-600	200-600	10-20	1-1.5
Class II: (Consumption period, max.)	No limit	7 years	7 years	7 years	7 years	7 years	7 years	7 years	7 years	1 year

Groundwater level fluctuations were measured continuously from 5 January 2011 to 13 May 2011 in one borehole targeting the Bushveld Igneous Complex, while the other three targeted the river banks of the Lephalala River (Photo 5).



Photo 5. Borehole equipped with water level logger along the banks of the Lephalala River near Villa Nora (Photo taken by Martin Holland).

The water table is generally unconfined and local groundwater flow follows the surface drainage towards the alluvial aquifer. Unfortunately no flow gauging stations were available at the 'Villa Nora' site; however an upstream gauging station on the Waterberg Formation was used for comparison purposes. It appears that the water levels in the boreholes is somewhat masked by the storm run-of event observed from the gauging station (Figure 4-13).

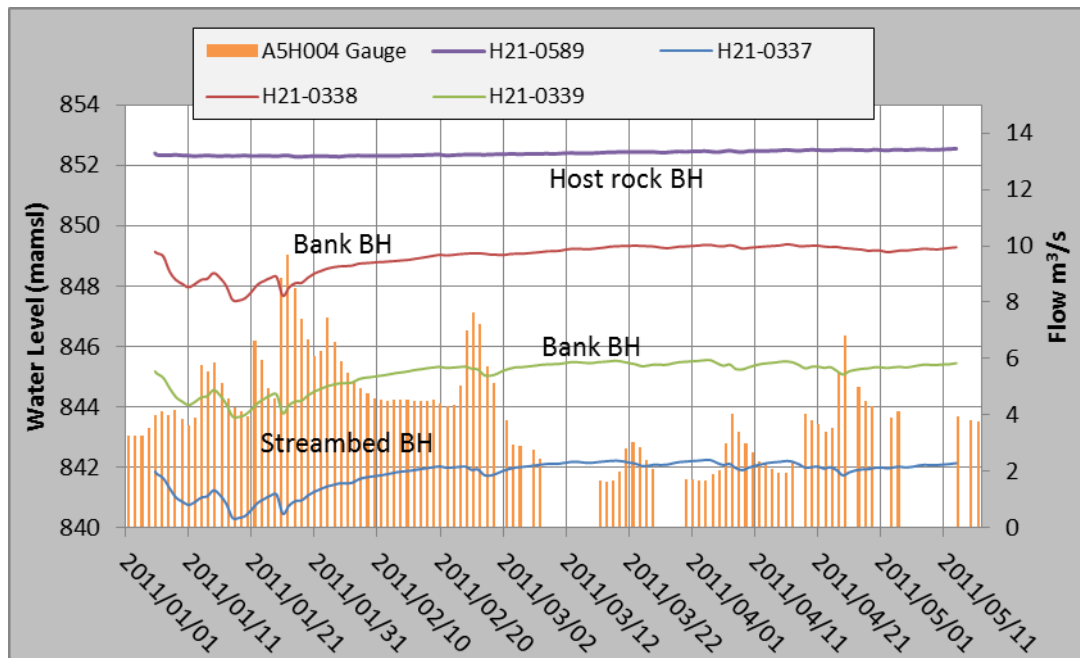


Figure 4-13. Groundwater level fluctuation for the Villa Nora case study (A4H010).

After the run-off event a slight dip in the groundwater level is observed before it recovers to pre-storm run-off events. It's clear that these events have an impact on water level along the banks of the Lephalala River and more importantly recharging of the alluvial system. The storm run-off events observed in January has increased water levels on the river banks with more than 1 m. The borehole within the host rock is much more subtle to changes in recharge events which in this case may be attributed to the low permeability of the host rock.

4.3.8 Final Categorisation

A summary of the categorisation for the Lephalala region is shown in Table 38.

Table 38. Groundwater categorisation for each GUA (Lephalala region).

Description	GUA	Area (Km ²)	Recharge Mm ³	Groundwater Use Mm ³ /a	Stress Index (SI)	Present Category (SI)	Present Category (Impact)	Present Category (Quality)
Upper Lephalala	A50-1	2704	69.27	5.43	8%	I	I	II
Middle Lephalala	A50-2	821	7.16	0.67	9%	I	I	III
Lower Lephalala	A50-3	1945	11.49	8.44	73%	III	III	III
Limpopo Stem	A50-4	1255	9.29	3.83	41%	II	I	III

4.4 (Upper) Mogalakwena Drainage System

The Mogalakwena River is known as the Nyl River in its upper reaches. The Nyl River originates north of Bela-Bela at an altitude of about 1 500 m. At Mokopane the name changes and it becomes the Mogalakwena River (DWA, 2003a). The river flows northwards and joins the Limpopo River at an altitude of about 625 m. The upper Mogalakwena catchment is densely populated. As a result groundwater resource development occurred mainly to allow irrigation and to meet domestic and urban water needs. Several small mines and one large mine (Impala Platinum Mine) were developed and utilise local groundwater resources and limited surface water resources. Numerous well-fields were developed to meet consumers' needs. Two Subterranean government water control areas occur within the upper Mogalakwena drainage region namely, Nyl River Valley and Dorpsrivier, and are illustrated in Figure 4-14. The groundwater resource had been and still is extensively utilised in the region for municipal, irrigation and mining purposes. The Nylsvley wetland in the upper reaches of the Mogalakwena River catchment is home to a large number of bird species and is a registered RAMSAR site. The 16,000-ha Nyl River Flood-plain that stretches over 70 km from Modimolle to Mokopane forms part of South Africa's largest flood-plain.

In this assessment three GUAs have been delineated for the Upper Mogalakwena drainage area, namely A61-1, A61-2 and A61-3 (Figure 4-14). A summary of the borehole information for the region is shown in Table 28. According to the pumping tests conducted in the Upper Mogalakwena, there are

vast differences in the transmissivities of the groundwater UA's. Most notably is the high transmissivities observed in the Dorps River Valley A61-3 GUA. A number of large yielding aquifers including the Chuniespoort Group dolomites occur within the Upper Mogalakwena drainage region.

Table 39. Borehole information for the Upper Mogalakwena drainage region.

Drainage system	UA	Info	BH Depth (mbgl)	Water Level (mbgl)	Transmissivity (m ² /day)	Rec. Yield (l/s for 24hrs)	Airlift Yield (l/s)
Nyl River Valley	A61-1	N	787	333	17	17	536
		Mean	56	14.6	22.21	1.41	4.5
Doorndraai	A61-2	N	159	127	4	5	-
		Mean	68	16.5	6.60	0.53	-
Dorps River Valley	A61-3	N	496	356	167	227	35
		Mean	68	15.1	65.85	1.19	5.2

N = Number of boreholes

Borehole yields generally range between 0.1 – > 5 l/s. The main aquifer types include:

- Fractured aquifers
 - The Waterberg formation (Upper Nyl River Valley) is associated with steep topography and shows generally poor capability to produce huge amounts of groundwater. A weathered zone aquifer is found only where deep weathering occurs and provides groundwater storage that feeds the underlying fractured aquifer.
 - Fractured rocks of the Pretoria Group, Granitic Intrusives and the Bushveld complex owe their groundwater potential largely to fracturing. Owing to its inaccessibility and limited and restricted occurrence the groundwater potential of the Black Reef quartzites is regarded insignificant whereas the water bearing properties of the quartzite and shale of the Pretoria Group are dependent on fracturing. The shale is in general far more favourable than the quartzites although the quartzites constitute good aquifers where fractured. Where the shales have been metamorphosed and converted to hornfels by the heat of the Bushveld Complex, its water bearing properties diminished. The hornfels are usually very hard rocks with few joints. The groundwater potential of the Pretoria Group is regarded to be low to moderate.
- Intergranular Alluvial aquifers (Limited to the main river stems)
 - Alluvial aquifers are recharged during periods of high stream-flows as well as during the rainfall season. It is an important local, major aquifer and exists in equilibrium with surface water, adjacent groundwater systems and ecosystems along the rivers. The total alluvial thickness varies from 10 to 24 m and is used in conjunction with the underlying weathered and fractured bedrock aquifers. Due to its limited extent and saturated thickness these aquifers are also vulnerable to over-abstraction during periods of drought when there is little or no recharge.

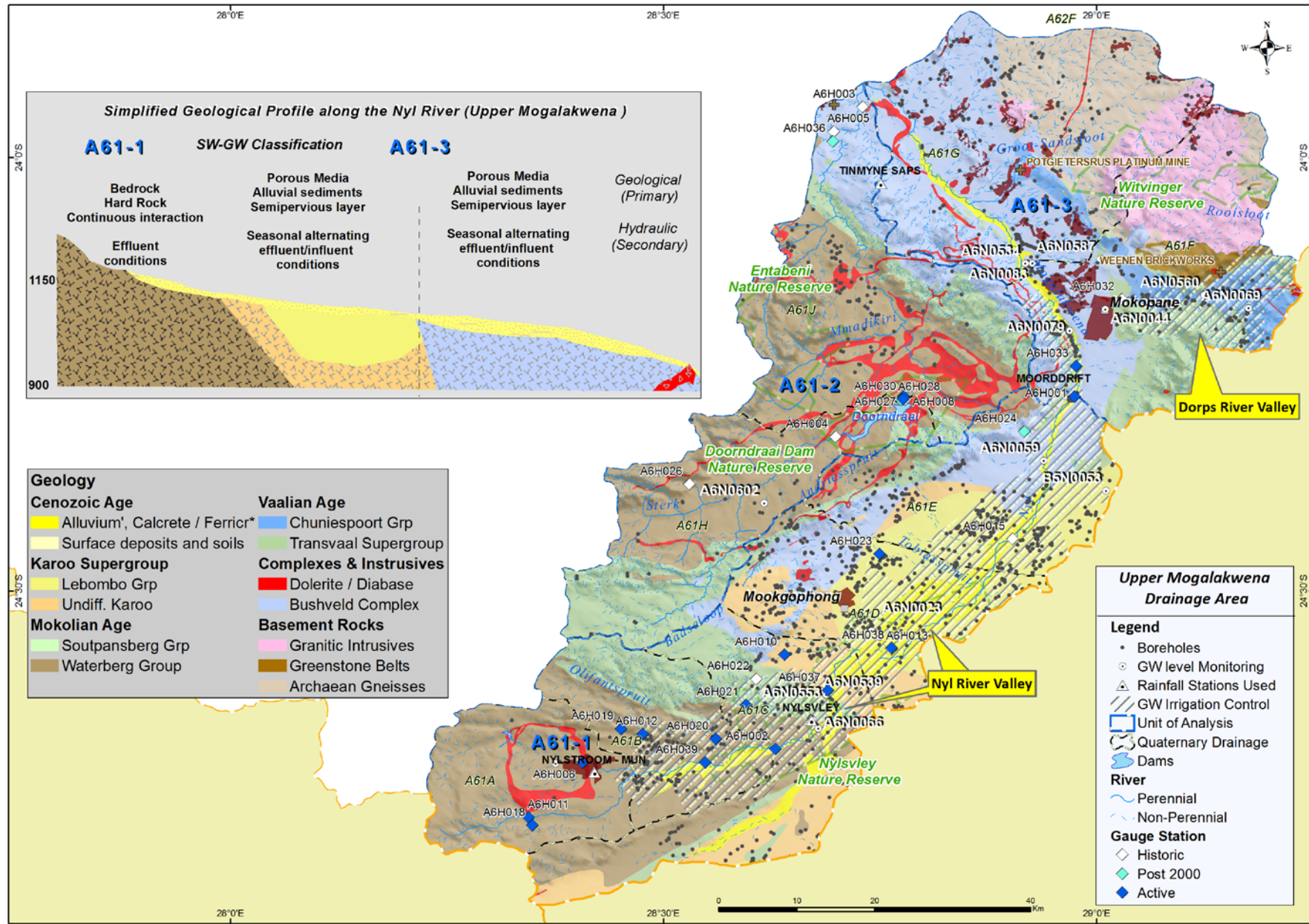


Figure 4-14. Geology, UAs and SW-GW classification of the Upper Mogalakwena drainage region.

- Intergranular and fractured (Basement Complex)
 - They are mostly restricted to the igneous and metamorphic rocks occurring in the study area especially the mafic rocks (gabbro, norite, etc.) of the Bushveld Complex and the Hout River Gneiss. Its groundwater potential is generally good with water occurring in deeply (up to 55m in places) weathered and fractured basins occurring in these mafic rocks.
- Kart aquifers
 - These aquifers mainly occur in the Chuniespoort Group dolomites, which is stratigraphically part of the Transvaal Sequence. Groundwater generally occurs along fault and shear zones associated with intense deformation resulting in the occurrence of fractures, joints and cavities subsequently enlarged by dissolution processes in the dolomites. Large quantities of groundwater can be stored in these dissolution channels and cavities. Borehole yields are generally moderate to high with an expected third of the boreholes yielding in excess 3 l/s.

4.4.1 Groundwater recharge

Mean annual precipitation varies from 600 mm in the Nyl River valley and Mokopane to about 450 mm north of Doorndraai dam (Table 40). Compared to other drainage areas the recharge rates of the Upper Mogalakwena ranges from 12 mm/a to more than 20 mm/a (see Figure 2-7).

Table 40. Rainfall Data for selected stations in the Upper Mogalakwena region.

Station*	<i>Start Date</i>	<i>MAP (mm)</i>	<i>Elevation (mamsl)</i>
Nylstroom	1960	605	1 151
Moorddrift	1985	558	1 075
Tinmyne	1981	482	1 178

*- South African Weathers Services.

A review of previous work done on the GRA II project, Vegter's (1995) estimates and recharge estimates based on specialist reports were made. These values were calculated for each of the quaternaries constituting the unit of analysis and are summarised as Table 41.

Table 41. Recharge estimation (Lephalala).

Description	GUA	Quat	MAP (mm)	Area (km ²)	GRA II		Vegter (1995)	Specialist report Mm ³	Used Mm ³	Recharge %
					(Wet) Mm ³	(Dry) Mm ³	Mean Mm ³			
Nyl River Valley	A61-1	A61A	629.1	381	11.86	8.57	16.81		12.41	5.2
		A61B	629.1	362	10.89	7.86	14.56		11.10	4.9
		A61C	632.7	587	16.44	11.83	17.93		15.40	4.1
		A61D	630.2	456	12.37	8.91	16.59		12.63	4.4
		A61E	624.6	547	10.57	7.57	18.22		12.12	3.5
Doorndraai	A61-2	A61H	636.0	585	18.94	13.74	27.28		19.99	5.4
		A61J	630.7	818	23.46	17.01	32.37		24.28	4.7
Dorps River Valley	A61-3	A61F	597.2	789	22.40	16.07	18.61	14.14	17.80	3.8
		A61G	584.8	927	20.80	14.82	22.62	18.97	19.31	3.6

Water level trends

A summary of the short term water level data obtained from selected monitoring boreholes within the region is presented in Table 42. Groundwater level fluctuations from the observed data vary between 1 and 40 m for the Nyl River Valley (A61-1) and between 4.5 and 31 m in the Dorps River Valley (A61-3). Compared to A61-1, A61-3 has deeper average water levels, higher fluctuations and a mean drop in groundwater levels of 0.9 m. There are two main interrelated factors which control the general trend of groundwater-level fluctuations in the area, namely recharge and abstraction. In prolonged periods of below average rainfall recharge of groundwater from rainfall is less and consequently more groundwater from storage is taken from the aquifer. For comparative purposes the long term water level data extends back to 1989 (Table 43 and Table 44). A well-identified seasonal water-level fluctuation is observed over most stations. Rapid increases in water levels are associated with extreme single rainfall events, while progressive increases are related to long periods of low intensity rainfall events.

Table 42. Summary of groundwater level data within the Upper Mogalakwena region.

GMA	ID	Start Date	End Date	Count	Min (mbgl)	Mean (mbgl)	Max (mbgl)	Fluctuation (Max-Min) (m)	Difference 1st and last (m)
A61-1	A6N0023	Jan-71	Nov-10	358	2.5	7.8	12.9	10.3	-3.15
	A6N0059	Sep-75	Nov-10	342	1.1	8.5	16.1	15.0	2.66
	A6N0066	Jan-75	Nov-10	404	5.1	18.2	48.0	42.9	0.27
	A6N0539	Oct-05	Nov-08	38	0.5	1.0	1.9	1.4	-0.08
	A6N0544	Dec-88	Nov-10	196	1.1	4.4	6.6	5.5	-0.87
	A6N0545	Nov-88	Nov-08	149	0.2	3.2	5.7	5.5	1.02
	A6N0546	Dec-88	Nov-10	179	0.7	3.9	6.6	5.9	-0.10
	A6N0547	Dec-88	Nov-10	177	0.6	3.9	6.6	6.0	-0.01
	A6N0550	Jan-89	Nov-10	203	2.3	9.2	15.1	12.8	1.09
	A6N0553	Jul-93	Jan-10	139	0.0	0.9	5.2	5.2	0.14
	A6N0585	Aug-07	Nov-10	40	18.1	18.8	19.6	1.5	0.43
				Mean	2.9	7.3	13.1	10.2	-0.1
A61-2	A6N0602	Oct-09	Nov-10	12	12.1	14.6	17.1	4.9	-0.58
A61-3	A6N0044	Jan-81	Nov-10	352	5.7	10.7	15.6	9.9	3.06
	A6N0069	Feb-77	Nov-10	393	22.8	40.4	54.3	31.6	6.83
	A6N0079	Mar-80	Nov-10	356	2.2	5.9	11.9	9.8	-0.98
	A6N0083	Jan-85	Nov-10	283	11.1	18.5	24.6	13.5	2.53
	A6N0534	Jan-77	Nov-10	378	2.2	9.8	19.4	17.1	2.86
	A6N0560	Feb-93	Nov-10	185	2.1	5.0	7.9	5.8	-3.35
	A6N0581	Oct-06	Nov-10	49	12.5	16.3	27.6	15.2	-0.54
	A6N0587	Oct-05	Nov-10	62	10.8	12.5	15.6	4.8	-3.17
				Mean	8.7	14.9	22.1	13.5	-0.9

Table 43. Water level trends for selected monitoring stations in the Nyl River Valley (A61-1).

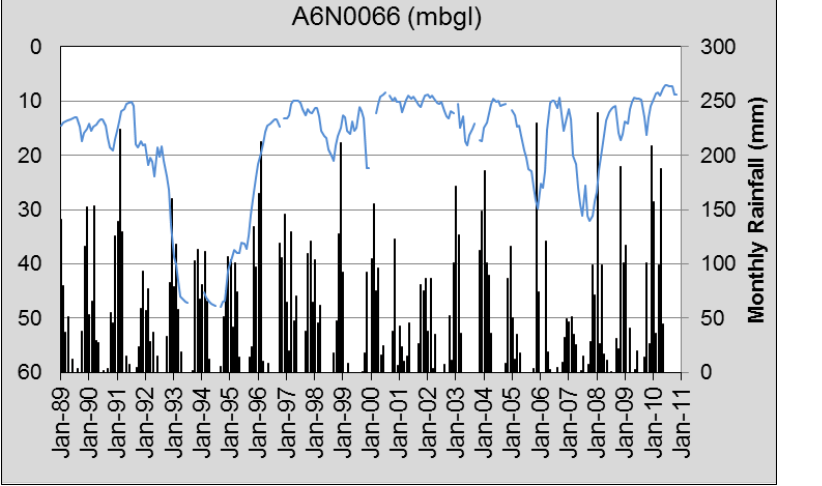
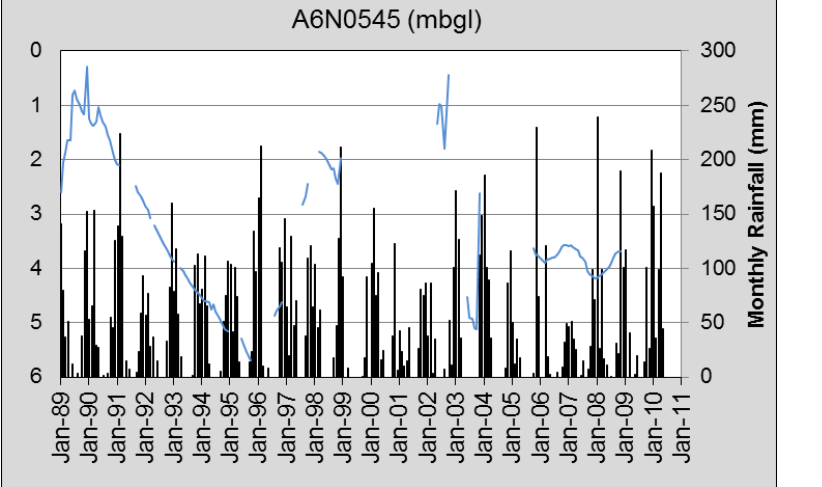
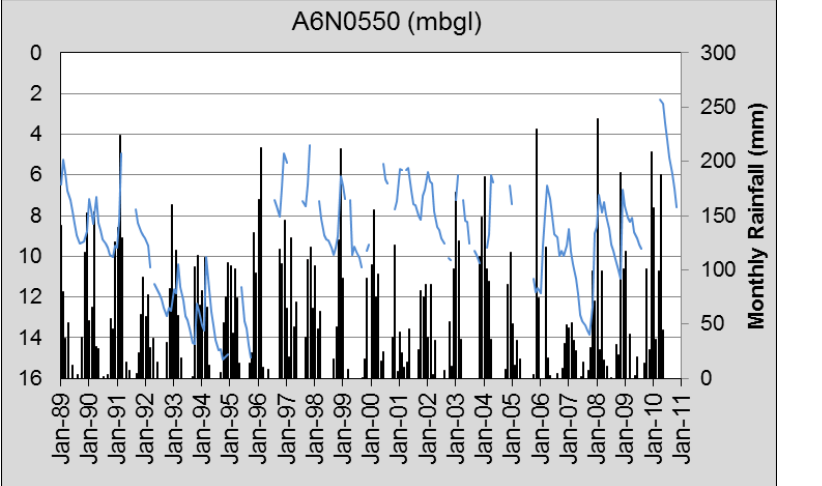
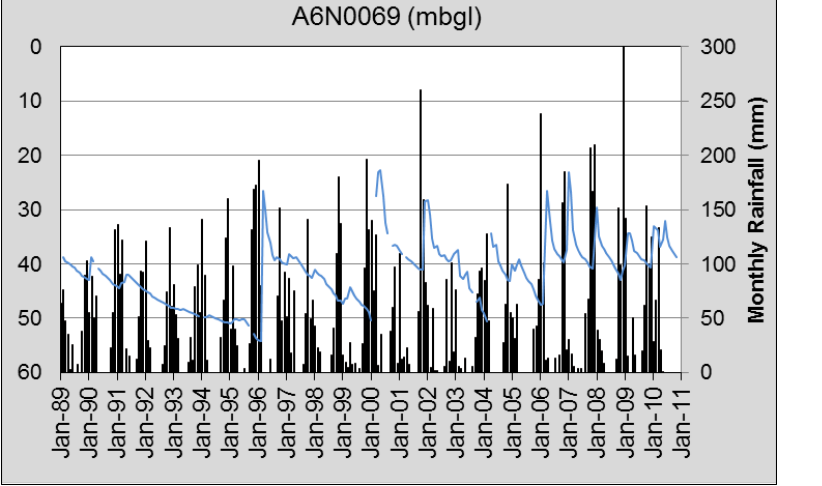
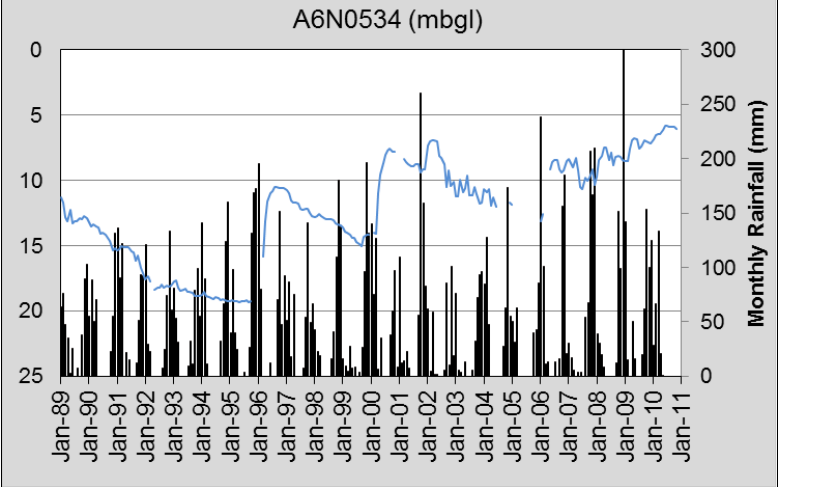
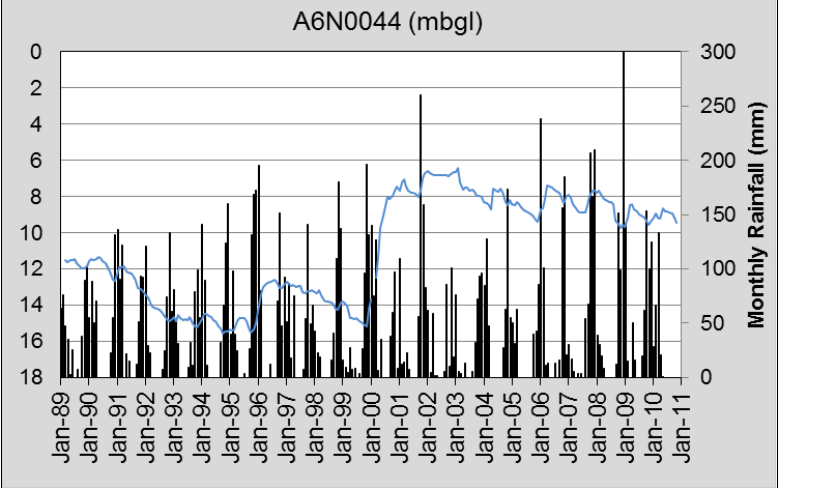
<p>A61-1 A6N0066 Date WL (mbgl) Jan-89 14.53 Nov-10 8.74 Difference (m) 5.79 Rainfall Data Nylsvlei (Jan-89 to June-10)</p>	
<p>A61-1 A6N0545 Date WL (mbgl) Jan-89 2.67 Nov-08 3.69 Difference (m) -1.09 Rainfall Data Nylsvlei (Jan-89 to June-10)</p>	
<p>A61-1 A6N0550 Date WL (mbgl) Jan-89 6.48 Nov-10 7.57 Difference (m) -1.09 Rainfall Data Nylsvlei (Jan-89 to June-10)</p>	

Table 44. Water level trends for selected monitoring stations in the Dorps River Valley (A61-3).

<p>A61-3 A6N0069 Date WL (mbgl) Jan-89 38.50 Nov-10 38.77 Difference (m) -0.27 Rainfall Data Nylsvlei (Jan-07 to June-10)</p>	 <p style="text-align: center;">A6N0069 (mbgl)</p>
<p>A61-3 A6N00534 Date WL (mbgl) Jan-89 11.34 Nov-10 6.06 Difference (m) 5.28 Rainfall Data Nylsvlei (Jan-07 to June-10)</p>	 <p style="text-align: center;">A6N00534 (mbgl)</p>
<p>A61-3 A6N0044 Date WL (mbgl) Jan-89 11.62 Nov-10 9.45 Difference (m) 2.17 Rainfall Data Nylsvlei (Jan-07 to June-10)</p>	 <p style="text-align: center;">A6N0044 (mbgl)</p>

4.4.2 Groundwater contribution to baseflow

Based on the groundwater-surface water classification described in section 2.7.5 the Upper Mogalakwena River stretch can be classified into a continuous interaction bedrock system (Waterberg Group) in the upper reaches, while the middle (Nyl River Valley) and low reaches (Dorps River Valley) can be classified as a porous media (alluvial sediments) (Figure 4-4). The Nyl river valley can be regarded as a gaining river while in the lower reaches seasonal alternating effluent / influent conditions can be experienced.

Apart from exceptionally wet periods, flow in the river is sustained mainly by groundwater. Groundwater is generally toward the main River channel; however, intermittency implies local inversions from effluent to influent conditions by secondary permeability variations in the underlying lithology. Numerous seasonal and some perennial springs occur in the dolomitic formations, which contribute significantly, to the baseflow component of the Dorps River (A61G). However, some springs occurring in the lower Dorps River catchment have been effected by the abstraction from boreholes.

Comparison of groundwater contribution to baseflow estimates for the Upper Mogalakwena drainage region are summarised in Table 45.

Table 45. Groundwater contribution to baseflow estimates.

GMA	GRU	Quat	Hughes Mm ³ /a	Shultz Mm ³ /a	Pitmann Mm ³ /a	GRA II (WR2005) Mm ³ /a	Maint. Lowflow Mm ³ /a	Specialist*/ Hydrograph# Mm ³ /a	Average Mm ³
Nyl River Valley	A61-1	A61A	6.98	1.80	6.48	3.77	0.89		2.15
		A61B	5.84	1.20	5.43	2.83	0.50		1.51
		A61C	8.31	1.11	7.63	3.37	0.54		1.67
		A61D	6.54	1.11	5.47	3.08	1.27		1.82
		A61E	7.30	1.11	6.56	3.25	0.61		1.66
Doorndraai	A61-2	A61H	11.99	6.12	10.76	6.83	1.72		4.89
		A61J	15.95	7.74	14.97	9.15	2.28		6.39
Dorps River Valley	A61-3	A61F	6.51	2.64	6.15	5.16	1.57		3.12
		A61G	7.17	2.97	7.05	4.87	1.69	3.92*	3.36

4.4.3 Basic Human Needs (BHN)

Table 46. Basic human needs estimates.

Description	GUA	Quat	Population*	BHN Estimate Mm ³
Nyl River Valley	A61-1	A61A	41455	0.378
		A61B	1998	0.018
		A61C	2116	0.019
		A61D	7882	0.072
		A61E	588	0.005
Doorndraai	A61-2	A61H	2010	0.018
		A61J	1205	0.011
Dorps River Valley	A61-3	A61F	110423	1.008
		A61G	102477	0.935

* - Based on 2001 statistics and the Limpopo ISP (DWA, 2004b).

4.4.4 Reserve determination summary

The Reserve assessment is firstly provided on a groundwater resource unit level in Table 47 and summarised for the Limpopo WMA on a quaternary level in Appendix A.

Table 47. Groundwater Reserve summary (Upper Mogalakwena region).

Description	GUA	Area (Km ²)	Recharge Mm ³	GW to Baseflow Mm ³	BHN Mm ³	Reserve Mm ³	Reserve as % of Recharge
Nyl River Valley	A61-1	2333	63.67	8.82	0.49	9.31	15%
Doorndraai	A61-2	1403	44.27	11.28	0.03	11.31	26%
Dorps River Valley	A61-3	1716	37.11	6.49	1.94	8.43	23%

4.4.5 Groundwater use and availability

Groundwater is used extensively throughout the Upper Mogalakwena and in some catchments large portions of the harvest potential and natural recharge are being abstracted. It is important to note that if one considers the exploitation potential (UGEP) in determining the groundwater availability, then the situation changes dramatically (Table 48). The total available exploitation potential for the Upper Mogalakwena has already been exceeded by an estimated 13 Mm³/a.

Table 48. Groundwater availability and stress index (Upper Mogalakwena region).

GMA	GUA	Quat	RE Mm ³	Groundwater availability Mm ³ /a		Groundwater Use Mm ³ /a			GW Use as % of HP	Stress Index (GW Use as % of Recharge)
				HP	UGEP	GRA II Mm ³	WARMS (*validated)	Final Estimate		
Nyl River Valley	A61-1	A61A	12.41	4.85	1.92	2.29	0.77*	2.29	47%	18%
		A61B	11.10	6.23	2.24	0.63	0.24*	0.63	10%	6%
		A61C	15.40	10.60	3.76	2.11	1.87*	2.11	20%	14%
		A61D	12.63	9.93	2.29	2.69	1.80*	2.69	27%	21%
		A61E	12.12	10.39	2.28	8.50	7.38*	8.50	82%	70%
Doorndraai	A61-2	A61H	19.99	10.17	3.19	6.26	0.86*	6.26	62%	31%
		A61J	24.28	10.20	3.62	7.96	1.13*	7.96	78%	33%
Dorps River Valley	A61-3	A61F	17.80	10.85	6.43	11.76	2.46*	11.76	108%	66%
		A61G	19.31	11.42	5.72	2.02	0.30*	4.97 [#]	44%	26%

- Specialist DWA report.

4.4.6 Groundwater quality

Regional water quality in the Upper Mogalakwena is subject to considerable variation due to the extensive use of groundwater, various lithologies and groundwater-surface water interaction. Groundwater samples indicate a variety of water types (e.g. Ca/Mg-HCO₃, Na-HCO₃ and Na-Cl) (Figure 4-15). A high percentage of samples relate to a fresh recharge type (Ca/Mg-HCO₃) water, while cation and anion exchange process may be occurring within the strata hence Na-Cl and Ca/Mg-Cl type water present.

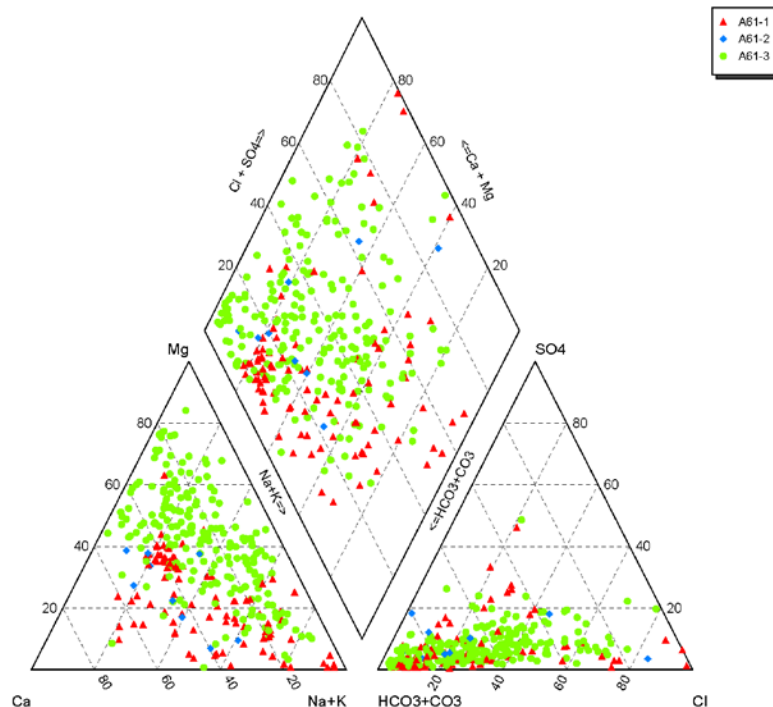


Figure 4-15. Piper diagram for the Upper Mogalakwena drainage region.

Groundwater quality in the Nyl River Valley is considered to be marginal with more than 44 % of samples within the recommended drinking limit as specified by SANS (2006). However, in the Dorps River Valley less than 25 % comply with the specified drinking water quality standard. The most notable elements of concern include NO₃ as N with average concentrations above the recommended drinking limit (Table 49). Apart from inappropriate on-site sanitation or poorly placed pit latrines high nitrate concentrations are often related to the application of nitrogenous fertilizers: removal of excess nitrates by percolates may be enhanced by the addition of irrigation water. Farm animals produce considerable amounts of nitrogenous organic waste that tends to concentrate where large numbers of animals are confined.

Table 49. Groundwater quality for the Upper Mogalakwena region (All units in mg/l, EC in mS/m)

GUA	Parameter	pH	EC	Ca	Mg	Na	K	SO ₄	Cl	NO ₃ as N	F	Compliance (% of samples within Class I)	Present Category
A61-1	Nr	108	108	108	107	108	106	108	108	93	108	44 %	II*
	Mean	7.4	52.0	39.2	16.1	45.0	3.3	12.1	54.2	6.6	1.9		
A61-2	Nr	9	9	9	9	9	9	9	9	7	9	23 %	III
	Mean	7.9	81.3	61.3	24.9	60.6	3.6	26.6	84.9	19.2	1.2		
A61-3	Nr	275	274	267	266	263	244	266	272	246	269	22 %	III
	Mean	8.0	126.3	65.9	70.7	107.3	3.8	46.3	143.0	20.0	0.8		

Class I

Class II

Exceed Class II

* - Natural high fluoride concentrations (reduced to Present Category II).

4.4.7 Final Categorisation

A summary of the categorisation for the Upper Mogalakwena region is shown in Table 50.

Table 50. Groundwater categorisation for each GUA (Upper Mogalakwena).

GMA	GUA	Area (Km ²)	Recharge Mm ³	Groundwater Use Mm ³ /a	Stress Index (SI)	Present Category (SI)	Present Category (Impact)	Present Category (Quality)
Nyl River Valley	A61-1	2333	63.67	16.23	25%	II	II	II
Doorndraai	A61-2	1403	44.27	14.22	32%	II	I	III
Dorps River Valley	A61-3	1716	37.11	16.73	45%	II	III	III

4.5 (Middle and Lower) Mogalakwena Drainage System

The Middle- and Lower Mogalakwena catchment have limited surface water resources but large groundwater resources which have already been extensively exploited by the irrigation sector. According to the Limpopo ISP (DWA, 2004) water yield and water allocations in the Mogalakwena catchment is currently in balance. High rural population densities occur in the middle part of the Mogalakwena catchment which should be able to source their water from groundwater while larger requirements may require transfers in from the Olifants WMA since there is little scope for further development of the local surface water resources. As a result of the low rainfall over this part of the country, relatively little surface runoff is generated. The runoff is highly seasonal and variable, with intermittent flow in many of the tributaries.

In this assessment five GUAs have been delineated for the Middle and Lower Mogalakwena drainage area, namely A62-1, A62-2, A62-3, A63-1 and A63-2 (Figure 4-16). According to the pumping tests conducted in the Middle- and Lower Mogalakwena, there are vast differences in the transmissivities of the GUA's (Table 51). Most notably is the high transmissivities observed in A62-2 and A63-1. The high yielding boreholes associated with A62-2 is located along the contact zones of the batholiths which intruded the older Hour River Gneiss. In GUA A63-1, Tolwe and Baltimore is known for its large scale irrigation from boreholes. However, the sustainability of large scale abstraction from this groundwater resource is questionable, especially in the absence of a major recharge source.

Table 51. Borehole information for the Middle and Lower Mogalakwena drainage region.

Drainage system	UA	Info	BH Depth (mbgl)	Water Level (mbgl)	Transmissivity (m ² /day)	Rec. Yield (l/s for 24hrs)	Airlift Yield (l/s)
Middle Mogalakwena	A62-1	N	464	274	112	160	1
		Mean	65	15.2	50.81	0.54	1.4
	A62-2	N	430	280	77	226	-
		Mean	65	13.9	76.79	1.45	-
	A62-3	N	461	322	91	230	-
		Mean	67	14.8	27.33	0.89	-
Lower Mogalakwena	A63-1	N	1283	834	169	201	431
		Mean	67	23.7	60.98	1.31	2.9
Limpopo Stem (Mogalakwena)	A63-2	N	420	264	-	-	170
		Mean	47	19.9	-	-	2.0

N = Number of boreholes

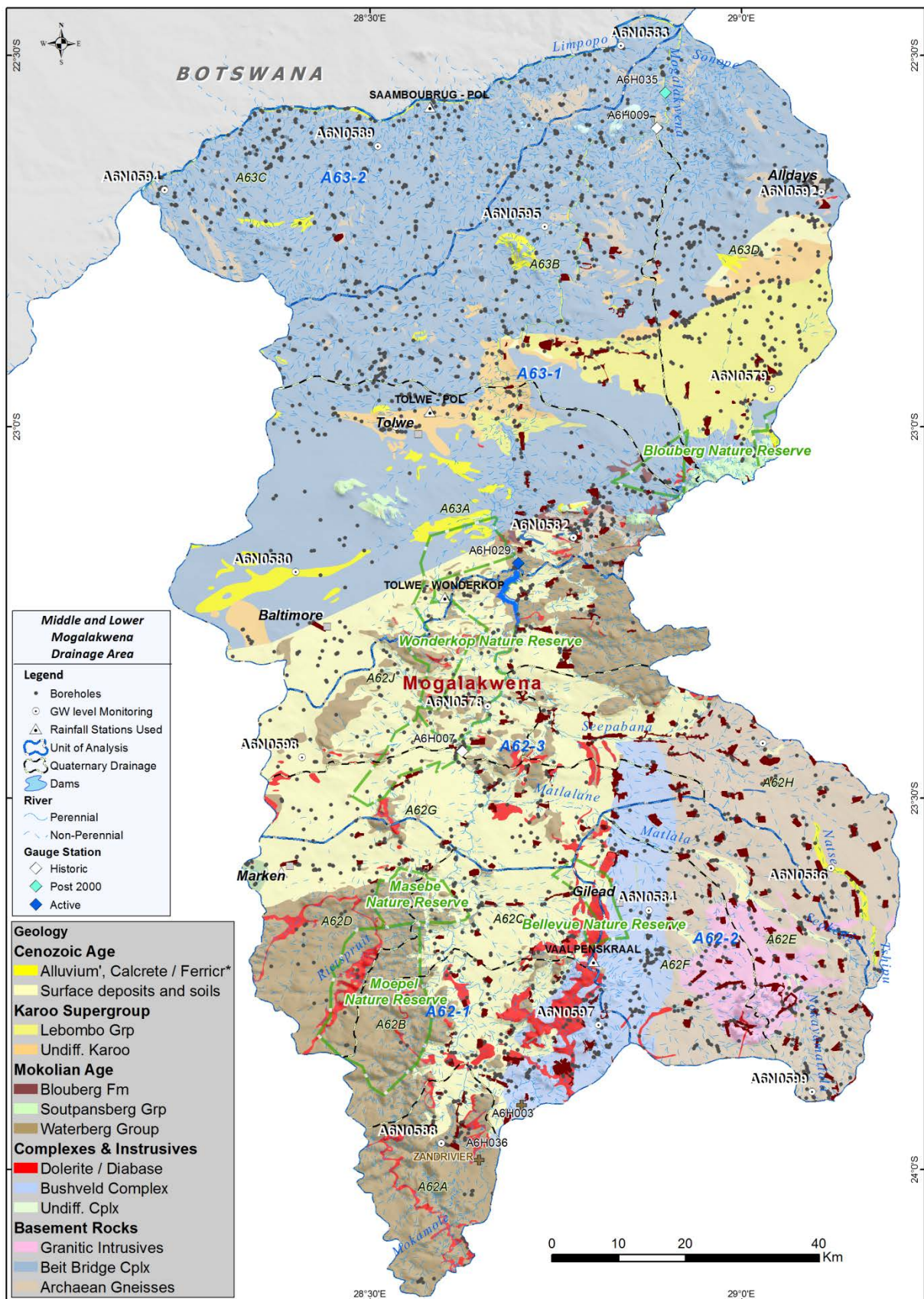


Figure 4-16. Geology, GUAs and SW-GW classification of the Middle- and Lower Mogalakwena drainage region.

Borehole yields generally range between 0.1 – 5 l/s. The main aquifer types include:

- Fractured aquifers (Waterberg Formation and Granitic Intrusives)
 - The Waterberg formation is associated with steep topography and shows generally poor capability to produce huge amounts of groundwater. Recharge to the aquifer, often discharged on the steep slopes, provides baseflow to the rivers. A weathered zone aquifer is found only where deep weathering occurs and provides groundwater storage that feeds the underlying fractured aquifer.
 - Karoo Aquifers occur in the eastern parts of the Lower Mogalakwena drainage region. The hydraulic characteristics of these Karoo Formations differ quite considerably. Secondary permeability created by fracturing and faulting of the basaltic formations is responsible for the high yields obtainable. Without this development no aquifer exists.
- Intergranular Alluvial aquifers (Limited to the main river stems)
 - Alluvial aquifers are recharged during periods of high stream-flows as well as during the rainfall season. It is an important local, major aquifer and exists in equilibrium with surface water, adjacent groundwater systems and ecosystems along the rivers. The alluvium appears to be better developed along the lower reaches of the Lephhalala River with a thickness of approximately 5 m.
- Intergranular and fractured (Beit Bridge Complex, Bushveld Complex and Achaean Gneiss)
 - The igneous and metamorphic rocks occurring in the eastern portions of the Middle Mogalakwena area especially the mafic rocks (gabbro, norite, etc.) of the Bushveld Complex and the Hout River Gneiss have good water bearing potential. Thick, weathered aquifer zones are expected in areas where the bedrock has been subjected to intense fracturing.
 - The Beit Bridge Complex is represented in the northern sector of the Mogalakwena drainage region. Ground water is entrapped in small relatively shallow, locally developed basins and troughs revealing that mechanical and chemical weathering appear to be associated with surface drainage channels.

4.5.1 Groundwater recharge

Mean annual precipitation varies from 600 mm in the south to less than 400 mm in the north (Table 52). In lower lying areas the low and variable rainfall together with evaporation rates (2 000 mm) considerably exceeding rainfall result in a low expectation of natural recharge to groundwater. Recharge vary spatially from as high as 18 mm/a in the Waterberg region to less than 3 mm/a at the confluence with the Limpopo River (see Figure 2-7).

Table 52. Rainfall Data for selected stations in the Middle- and Lower Mogalakwena region.

Station*	Start Date	MAP (mm)	Elevation (mamsl)
Vaalpenskraal	1960	490	1 150
Tolwe	1969	389	839
Saamboubrug	1963	341	693

*- South African Weathers Services.

A review of previous work done on the GRA II project, Vegter's (1995) estimates and recharge estimates based on specialist reports were made. These values were calculated for each of the quaternaries constituting the unit of analysis and are summarised as Table 53.

Table 53. Recharge estimation (Middle- and Lower Mogalakwena).

GMA	UA	Quat	MAP (mm)	Area (km ²)	GRA II		Vegter (1995)	Specialist report Mm ³	Used Mm ³	Recharge %
					(Wet) Mm ³	(Dry) Mm ³	Mean Mm ³			
Middle Mogalakwena	A62-1	A62A	610.2	428	11.07	7.98	17.44		12.16	4.7
		A62B	528.7	710	14.20	9.96	20.05		14.74	3.9
		A62C	478.3	385	6.53	4.50	9.10		6.71	3.6
		A62D	488.8	603	10.15	7.02	14.44		10.54	3.6
	A62-2	A62E	460.4	621	8.59	5.88	7.61	4.57	6.66	2.3
		A62F	478.1	620	9.18	6.33	8.54	4.45	7.12	2.4
	A62-3	A62G	437.3	627	8.25	5.63	6.59		6.83	2.5
		A62H	439.3	871	10.94	7.45	10.42	5.74	8.64	2.1
		A62J	450.1	930	12.44	8.50	7.42	8.37	9.18	2.2
Lower Mogalakwena	A63-1	A63A	433.1	1928	18.20	12.36	8.06	7.93	11.64	1.4
		A63B	393.9	1505	11.35	7.61	16.38	8.89	11.06	1.9
		A63D	412.3	1319	13.99	9.43	15.10	10.88	12.35	2.3
Limpopo Stem (Mogalkwena)	A63-2	A63C	377.7	1323	8.14	5.32	15.88	7.50	9.21	1.8

Water level trends

A summary of the short term water level data obtained from selected monitoring boreholes within the region is presented in Table 54 and Table 55. For comparative purposes all hydrographs were based on a four year period (January 2007 to January 2011). While the Middle Mogalakwena monitoring stations display a well-identified seasonal water-level fluctuation, the stations north of Baltimore (A6N0580) and the station south of Alldays (A6N0579) in the Lower Mogalakwena have been declining since 2007 with no or little recharge during the wet-seasons.

Table 54. Water level trends for selected monitoring stations in the Middle Mogalakwena region.

<p>A62-1 A6N00588</p> <p>Date WL (mbgl)</p> <p>Jun-07 4.24</p> <p>Nov-10 3.95</p> <p>Difference (m) 0.29</p> <p>Rainfall Data Tinmyne (Jan-07 to June-10)</p>	<p>A6N00588 (mbgl)</p>
<p>A62-2 A6N00584</p> <p>Date WL (mbgl)</p> <p>Jun-07 28.69</p> <p>Nov-10 28.92</p> <p>Difference (m) -0.23</p> <p>Rainfall Data Vaalpenskraal (Jan-07 to June-10)</p>	<p>A6N00584 (mbgl)</p>
<p>A62-3 A6N00578</p> <p>Date WL (mbgl)</p> <p>Jan-07 9.41</p> <p>Nov-10 9.64</p> <p>Difference (m) -0.22</p> <p>Rainfall Data Tolwe (Jan-07 to June-10)</p>	<p>A6N00578 (mbgl)</p>

Table 55. Water level trends for selected monitoring stations in the Lower Mogalakwena region (A61-3).

<p>A63-1 A6N0580</p> <p>Date WL (mbgl)</p> <p>Jun-07 23.94</p> <p>Nov-10 25.42</p> <p>Difference (m) -1.48</p> <p>Rainfall Data Tolwe (Jan-07 to June-10)</p>	<p>A6N0580 (mbgl)</p>
<p>A63-1 A6N0579</p> <p>Date WL (mbgl)</p> <p>Jan-07 51.70</p> <p>Nov-10 54.68</p> <p>Difference (m) -2.95</p> <p>Rainfall Data Mara (Jan-07 to June-10)</p>	<p>A6N0579 (mbgl)</p>
<p>A63-2 A6N0589</p> <p>Date WL (mbgl)</p> <p>Oct-07 11.53</p> <p>Feb-10 11.78</p> <p>Difference (m) -0.25</p> <p>Rainfall Data Saamboubrug (Jan-07 to June-10)</p>	<p>A6N0589 (mbgl)</p>

4.5.2 Groundwater contribution to baseflow

Based on the groundwater-surface water classification described in section 2.7.5 the Middle Mogalakwena River stretch can be classified into a localized interacting weathered hard rock system (Bushveld Complex) in the upper reaches, while the Waterberg Group will be in continues interaction with the river and probability of baseflow is regarded as high. In the lower reaches alluvium replaces the weathered material and can be classified as a porous media with a semi-pervious layer (Figure 4-16). In both cases seasonal alternating effluent / influent conditions can be experienced. Both analytical and numerical models could be applied to evaluate groundwater-surface water interaction of the Middle- and Lower Mogalakwena River.

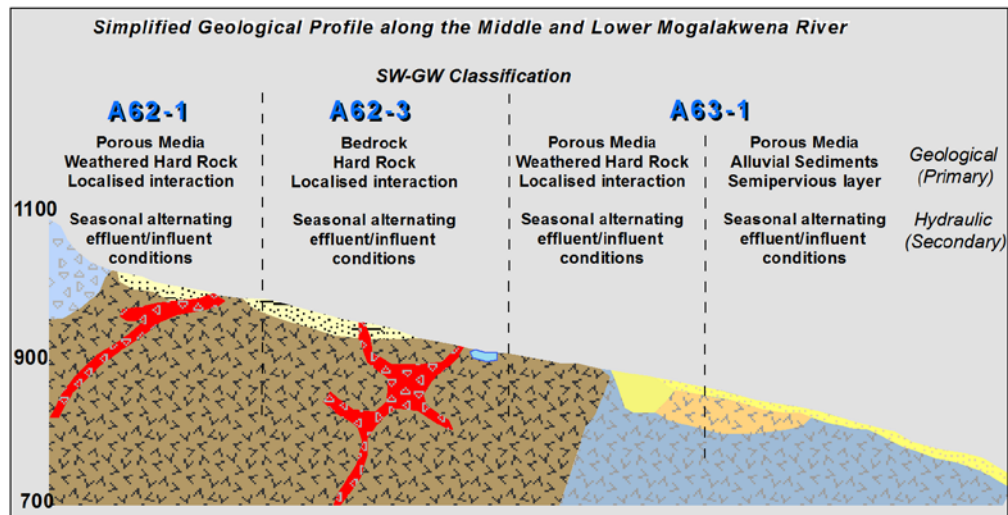


Figure 4-17. Simplified section of the Middle and Lower Mogalakwena region.

Due to the extreme periodicity and strong seasonal character of rainfall as well as the combined effects of very dense bush and high evapotranspiration losses, extremely erratic surface flow is known to occur. Surface flow in the lower Mogalakwena River is to a great extent controlled by releases from the Glen Alpine Scheme towards irrigation activities downstream.

Comparison of groundwater contribution to baseflow estimates for the Middle- and Lower Mogalakwena drainage region are summarised in Table 56. The hydrograph separation curve for station A6H029 is shown in Figure 4-18.

Table 56. Groundwater contribution to baseflow estimates.

Description	GRU	Quat	Hughes Mm ³ /a	Shultz Mm ³ /a	Pitmann Mm ³ /a	GRA II (WR2005) Mm ³ /a	Maint. Low flow Mm ³ /a	Specialist*/ Hydrograph# Mm ³ /a	Average Mm ³
Middle Mogalakwena	A62-1	A62A	8.24	3.72	7.58	4.52	3.46		3.90
		A62B	4.71	0.48	2.27	2.44	1.27		1.40
		A62C	1.82	0.27	1.12	1.11	0.49		0.62
		A62D	3.08	0.39	1.75	1.82	1.45		1.22
	A62-2	A62E					0.34		0.34
		A62F	0.02				0.41		0.41
	A62-3	A62G					0.14		0.14
		A62H	0.01				0.40		0.40
A62J		0.05				0.24	1.10#	0.67	
Lower Mogalakwena	A63-1	A63A	0.08				0.03		0.03
		A63B					0.02		0.02
		A63D					0.37		0.37
Limpopo Stem (Mogalkwena)	A63-2	A63C					0.84		0.84

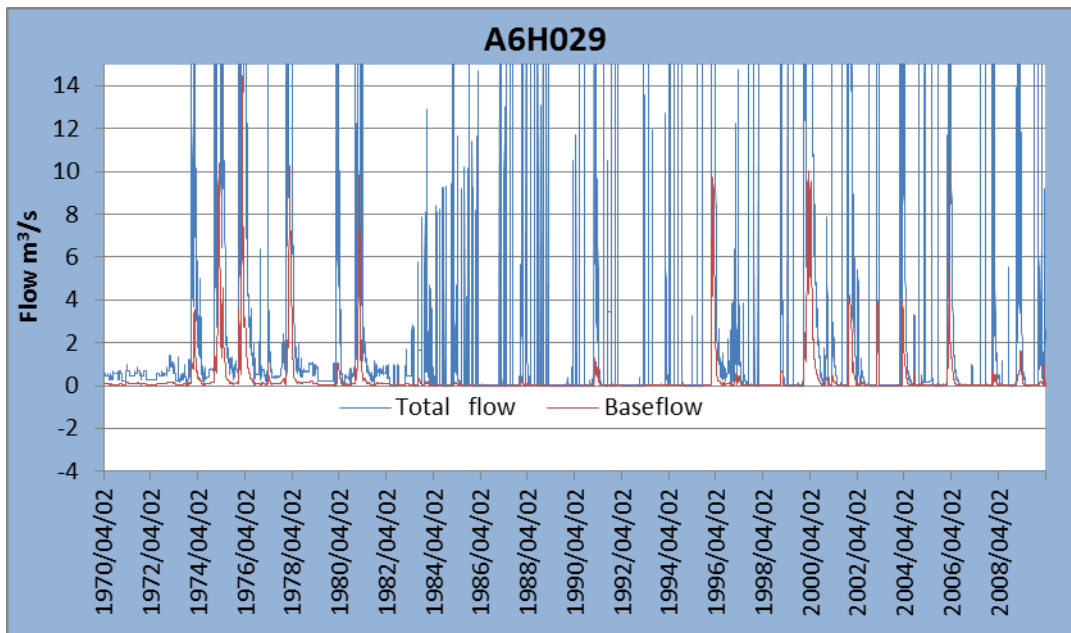


Figure 4-18. Baseflow separation for A6H029 (A62J).

4.5.3 Basic Human Needs (BHN)

Table 57. Basic human needs estimates.

Description	GUA	Quat	Population*	BHN Estimate Mm ³
Middle Mogalakwena	A62-1	A62A	14536	0.133
		A62B	56207	0.513
		A62C	22739	0.207
		A62D	10556	0.096
	A62-2	A62E	77374	0.706
		A62F	37709	0.344
	A62-3	A62G	22701	0.207
		A62H	46961	0.429
		A62J	16597	0.151
Lower Mogalakwena	A63-1	A63A	41959	0.383
		A63B	28036	0.256
		A63D	28684	0.262
Limpopo Stem (Mogalkwena)	A63-2	A63C	9775	0.089

* - Based on 2001 statistics and the Limpopo ISP (DWA, 2004b).

4.5.4 Reserve determination summary

The Reserve assessment is firstly provided on a groundwater resource unit level in Table 58 and summarized for the Limpopo WMA on a quaternary level in Appendix A.

Table 58. Groundwater Reserve summary (Middle- and Lower Mogalakwena region).

Description	GUA	Area (Km ²)	Recharge Mm ³	GW to Baseflow Mm ³	BHN Mm ³	Reserve Mm ³	Reserve as % of Recharge
Middle Mogalakwena	A62-1	2126	44.15	7.14	0.95	8.09	18%
	A62-2	1241	13.79	0.75	1.05	1.80	13%
	A62-3	2428	24.65	1.20	0.79	1.99	8%
Lower Mogalakwena	A63-1	4752	35.05	0.41	0.90	1.31	4%
Limpopo Stem (Mogalkwena)	A63-2	1323	9.21	0.84	0.09	0.93	10%

4.5.5 Groundwater use and availability

Groundwater use estimates vary significantly between the GRA II dataset and the recently validated WARMS dataset (Table 59). Groundwater is overexploited in the Lower Mogalakwena more specifically quaternary catchment A63A. Registered groundwater use far exceeds the harvest potential and equals the volume of natural recharge. Although groundwater is used extensively throughout the region groundwater in many catchments is underutilised. It is likely that, with an adequate and even distribution of production boreholes in accessible portions of most catchments or

aquifer systems, that the HP volumes or where abstraction exceeds the HP up to 65 % of Recharge may be annually abstracted on a sustainable basis.

Table 59. Groundwater availability and stress index (Middle- and Lower Mogalakwena region).

GMA	GUA	Quat	RE Mm ³	Groundwater availability Mm ³ /a		Groundwater Use Mm ³ /a			GW Use as % of HP	Stress Index (GW Use as % of Recharge)
				HP	UGEP	GRA II Mm ³	WARMS (*validated)	Final Estimate		
Middle Mogalakwena	A62-1	A62A	12.16	5.48	1.86	2.88	0.58*	2.88	52%	24%
		A62B	14.74	8.91	11.48	0.49	0.54	0.54	6%	4%
		A62C	6.71	4.58	6.03	0.13	0.10	0.13	3%	2%
		A62D	10.54	7.06	5.07	0.25	0.65*	0.65	9%	6%
	A62-2	A62E	6.66	7.32	7.58	0.79	0.32	0.79	11%	12%
		A62F	7.12	6.99	6.51	0.44	1.36*	1.36	20%	19%
	A62-3	A62G	6.83	5.42	17.88	0.28	0.03*	0.28	5%	4%
		A62H	8.64	9.65	15.03	0.48	0.03	0.48	5%	6%
		A62J	9.18	6.41	13.15	0.14	0.38*	0.38	6%	4%
Lower Mogalakwena	A63-1	A63A	11.64	7.96	10.04	0.84	10.97*	10.97	138%	94%
		A63B	11.06	15.53	9.89	1.31	1.35*	1.35	9%	12%
		A63D	12.35	13.98	11.53	1.00	2.02*	2.02	14%	16%
Limpopo Stem (Mogalkwena)	A63-2	A63C	9.21	14.75	7.90	0.11	1.76*	1.76	12%	19%

- Specialist DWA report.

4.5.6 Groundwater quality

Groundwater samples in the Middle and Lower Mogalakwena drainage region indicate a variety of water types (e.g. Ca/Mg-HCO₃, Na-HCO₃ and Na-Cl) (Figure 4-19). A high percentage of samples relate to a fresh recharge type (Ca/Mg-HCO₃) water, while cation and anion exchange process may be occurring within the strata hence Na-Cl and Ca/Mg-Cl type water present.

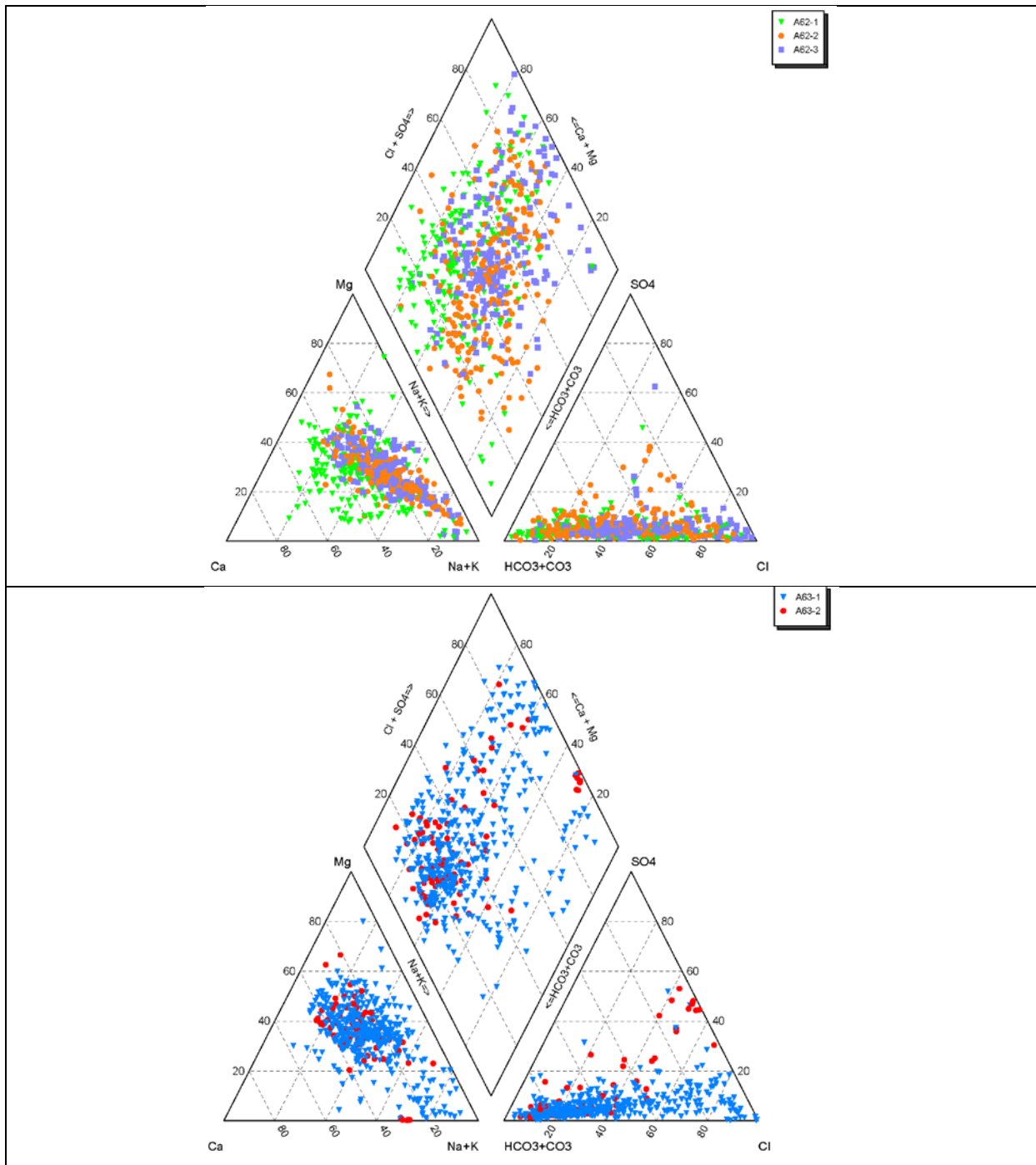


Figure 4-19. Piper diagram for the Middle- and Lower Mogalakwena drainage region.

Groundwater quality in the Middle- and Lower Mogalakwena region is considered to be poor with only a third of samples complying with the recommended drinking water quality standard. The most notable elements of concern include NO_3 as N with average concentrations above the maximum allowable recommended drinking limit (Table 60). In addition, several samples show major ion concentrations (e.g. Mg and Cl) and subsequently electric conductivities (EC) beyond acceptable

limits. This can mostly be related to evaporative concentration of elements in discharge areas or due to low recharge values as well as long residence times for selected samples. In contrast to nitrate, the occurrence of fluoride is primarily controlled by geology and climate. Therefore, there are no preventative measures under the given spatial limits of water supply to avoid contamination.

Table 60. Groundwater quality for the Middle- and Lower Mogalakwena region (All units in mg/l, EC in mS/m).

GUA	Parameter	pH	EC	Ca	Mg	Na	K	SO ₄	Cl	NO ₃ as N	F	Compliance (% of samples within Class I)	Present Category
A62-1	Nr	230	230	229	229	229	225	231	231	189	231	29 %	III
	Mean	7.9	138.2	83.8	48.9	120.2	4.5	21.1	222.8	20.8	1.2		
A62-2	Nr	270	270	253	253	251	252	259	270	253	263	26 %	III
	Mean	7.9	150.6	67.3	50.9	172.4	12.1	39.1	238.7	17.2	0.9		
A62-3	Nr	265	265	256	256	256	256	261	265	231	264	33 %	III
	Mean	7.9	179.0	78.5	63.3	193.5	10.9	38.4	349.9	17.7	0.7		
A63-1	Nr	480	480	452	452	452	442	459	474	437	475	23 %	III
	Mean	7.9	172.5	85.1	74.9	159.8	5.6	54.4	294.1	20.6	0.6		
A63-2	Nr	85	85	85	85	85	85	85	85	81	85	8 %	III
	Mean	7.8	141.0	89.2	60.7	134.2	3.8	104.9	153.1	18.0	1.8		

Class I

Class II

Exceed Class II

4.5.7 Final Categorisation

A summary of the categorisation for the Middle- and Lower Mogalakwena region is shown in Table 61.

Table 61. Groundwater category for each GUA (Middle- and Lower Mogalakwena).

GMA	GUA	Area (Km ²)	Recharge Mm ³	Groundwater Use Mm ³ /a	Stress Index (SI)	Present Category (SI)	Present Category (Impact)	Present Category (Quality)
Middle Mogalakwena	A62-1	2126	44.15	4.19	10%	I	I	III
	A62-2	1241	13.79	1.89	16%	I	I	III
	A62-3	2428	24.65	0.77	3%	I	I	III
Lower Mogalakwena	A63-1	4752	35.05	14.35	41%	II	II	III
Limpopo Stem (Mogalakwena)	A63-2	1323	9.21	1.76	19%	I	I	III

4.6 (Upper) Sand Drainage System

The Sand River originates south of Polokwane and drains the eastern part of the Limpopo WMA. The River traverses semi-arid terrain before passing through the gorge at the Soutpansberg mountains, has had little surface water resource development. However, it has exceptional groundwater reserves which have been fully and possibly over-exploited. The water requirements (including the Lower Sand) are large compared to the rest of the WMA, but again irrigation is the largest water user, with a requirement of 185 million m³/a. Urban requirements, estimated at 24 million m³/a, are supplied mostly from transfers in from other WMAs (DWA, 2004). In this assessment three groundwater UAs have been delineated for the Upper Sand drainage area, namely A7-1, A7-2 and (Figure 4-20). The area is characterised by high transmissivities and as a result has good groundwater potential (Table 62).

Table 62. Borehole information for the Upper Sand drainage region

Drainage system	UA	Info	BH Depth (mbgl)	Water Level (mbgl)	Transmissivity (m ² /day)	Rec. Yield (l/s for 24hrs)	Airlift Yield (l/s)
Upper Sand	A7-1	N	845	487	187	234	12
		Mean	60	16.6	32.75	1.42	8.0
Middle Sand	A7-2	N	844	522	202	216	73
		Mean	60	24.0	32.10	1.38	7.2
Hout en Brak	A7-3	N	1944	1025	262	521	865
		Mean	69	25.7	52.74	1.52	10.2

N = Number of boreholes

Borehole yields generally range between 0.1 – > 5 l/s. The main aquifer types include:

- Intergranular and fractured (Achaean gneiss, Granite intrusives and Bushveld Complex)
 - The groundwater potential of the Hout River Gneiss is in general moderate to good with two thirds of all the successful boreholes yielding > 3 l/s. High yielding boreholes in the Hout River Gneiss appear to be related to pegmatite occurrences in the area. Water in the gneisses is also obtained in deep basins of weathering and transitional zones between weathered and solid gneiss. Deep weathering in excess of 40m is not uncommon in the gneiss. The thickness of the regolith in the generally extends to between 15 and 50 metres below surface. Below the weathered zone is a zone of fracturing, which according to geohydrological studies done by Dziembowski (1976) and Jolly (1986) in the Dendron/Mogwadi area may extend to depths greater than 120 m. This area is known for its high yielding boreholes which far exceed the typical expectations of crystalline aquifers with blow yields of more than 40 l/s often recorded.
 - The groundwater potential of granite intrusives (batholiths), forming distinct inselbergs is generally poor, however boreholes located along the contact zones of these batholiths provide the highly productive boreholes.

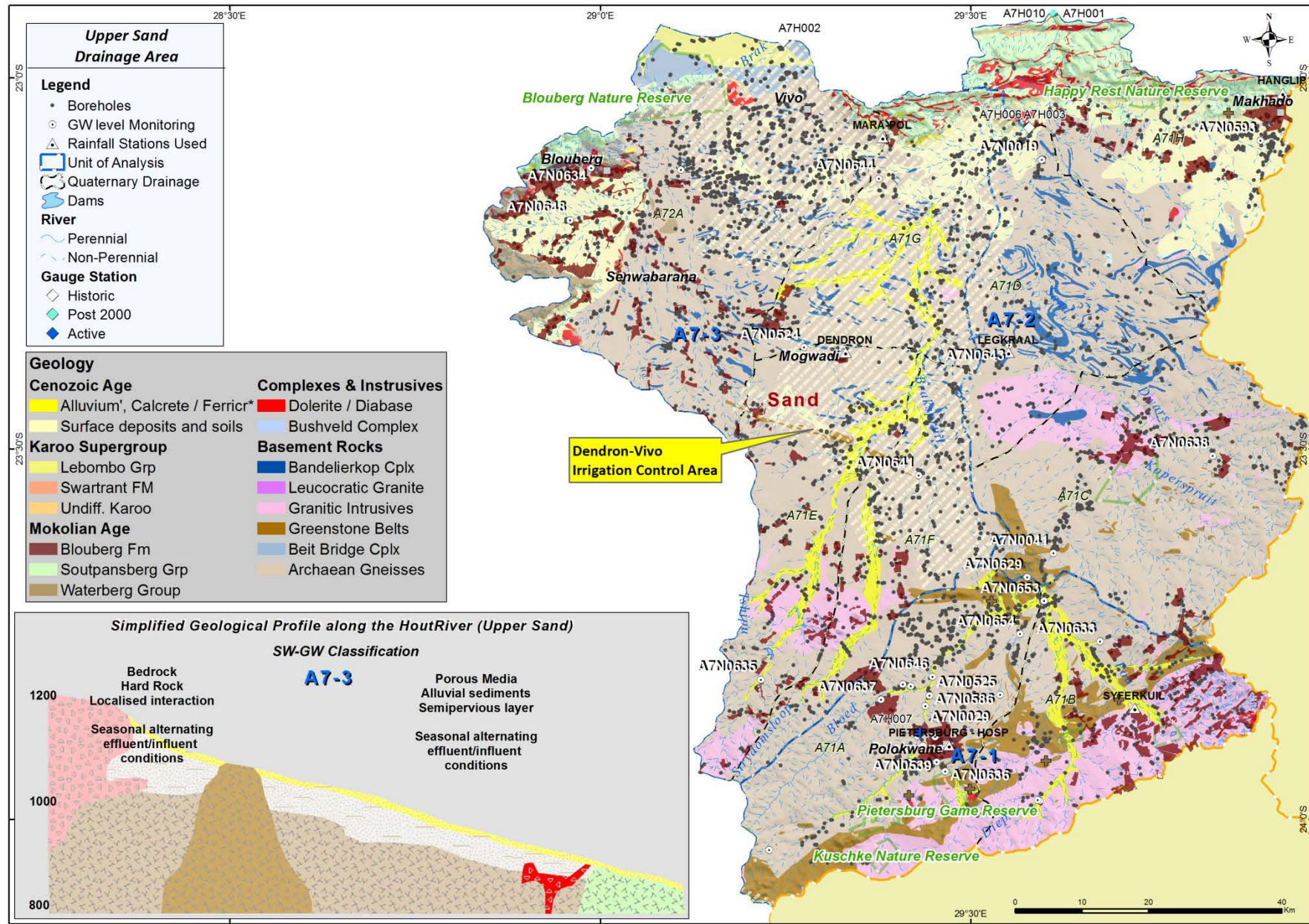


Figure 4-20. Geology, GUAs and SW-GW classification of the Upper Sand drainage region.

- Fractured aquifers
 - These aquifers are mainly represented by the sedimentary successions of the Waterberg and Soutpansberg Group. They do not possess any primary porosity and groundwater occurrences are controlled by geological structures. In general groundwater yields are low.
- Intergranular Alluvial aquifers (Limited to the main river stems)
 - Alluvial aquifers are recharged during periods of high stream-flows as well as during the rainfall season. It is an important local, major aquifer and exists in equilibrium with surface water, adjacent groundwater systems and ecosystems along the rivers. The only substantial deposits of alluvium occur along the major surface drainage courses (i.e. Sand- and Hout Rivers). Orpen (1986) estimated the thickness of alluvium deposits along the Sand River to be not more than 8 to 15 m. Nel (2000) suggested that in the absence of a continuous impermeable clay (colmation) layer, the alluvial and weather-fractured aquifers are in hydraulic continuity. The alluvial deposits typically consist of red or sandy clay (calcified in places) which overlies sand, gravel and pebbles.

4.6.1 Groundwater recharge

The climate of the Upper Sand is semi-arid with mean annual rainfall spatially varying between 350 mm and 700 mm (Table 63). The flat and almost featureless plateau can be described as an extremely old erosion surface underlain by crystalline bedrock into which several mature rivers have incised themselves. Low and variable rainfall together with evaporation rates (2 000 mm) considerably exceeding rainfall result in a low expectation of natural recharge to groundwater. (Recharge vary from approximately 10 mm/a to less than 3 mm/a north of Mogwadi (see Figure 2-7).

Table 63. Rainfall Data for selected stations in the Upper Sand region.

Station*	<i>Start Date</i>	<i>MAP (mm)</i>	<i>Elevation (mamsl)</i>
Polokwane	1960	458	1 318
Legkraal	1960	380	1 002
Mara	1960	431	1 051
Hanglip	1960	686	1 037

*- South African Weathers Services.

A review of previous work done on the GRA II project, Vegter's (1995) estimates and recharge estimates based on specialist reports were made. These values were calculated for each of the quaternaries constituting the unit of analysis and are summarised as Table 64.

Table 64. Recharge estimation (Upper Sand).

GMA	UA	Quat	MAP (mm)	Area (km ²)	GRA II		Vegter (1995)	Specialist report Mm ³	Used Mm ³	Recharge %
					(Wet) Mm ³	(Dry) Mm ³	Mean Mm ³			
Upper Sand	A7-1	A71A	468.3	1144	16.71	11.48	12.66	13.39	13.56	2.5
		A71B	450.4	882	9.99	6.81	11.17	9.93	9.48	2.4
Middle Sand	A7-2	A71C	417.8	1331	10.43	7.04	15.78	11.12	11.09	2.0
		A71D	390.0	892	2.39	1.60	7.62	6.96	4.64	1.3
		A71H	490.8	1012	15.07	10.40	18.37	9.93	13.44	2.7
Hout en Brak	A7-3	A71E	420.8	893	6.38	4.31	10.30	5.64	6.66	1.8
		A71F	400.2	683	4.29	2.88	6.27	4.10	4.38	1.6
		A71G	427.2	875	4.80	3.26	9.40	7.48	6.23	1.7
		A72A	464.5	1908	19.96	13.72	22.79	10.64	16.78	1.9

Water level trends

A summary of the water level data obtained from selected monitoring boreholes within the different GUA is presented in Table 65. Average groundwater level fluctuations observed from the data vary from 6.7 m in the upper GUA (A7-1), 8 m in A7-2 and 4 m in the lower GUA (A7-3). Extreme fluctuations of more than 5 m may relate to anthropogenic influences on groundwater levels (i.e. A7N0524 is located near the Mogwadi (Dendron) irrigation groundwater control area). Greatest average water level declines are observed within this GUA (A7-3). Although evidence of over-abstraction is aggravated by below average rainfall, (e.g. the 1980s drought) the groundwater level dropped by 4 m since the early 1970s. In A7-1 declining groundwater levels is observed at specific monitoring stations e.g. A7N0586 and A7N0549, overall groundwater levels appear to have recovered back to long term averages due to above average rainfall in late 1990s and early 2000s (Table 66 to Table 69). Similar observations for the long term groundwater level trend for stations A7N00019 in GUA A7-2 is observed, however, despite a recovery of water levels in the early 2000s and again in the last couple of year's water levels have declined 3.8 m since the onset of monitoring in 1984.

Groundwater levels are deepest in A7-3 followed by A7-2, while average water levels in A7-1 are only 11 mbgl. A well-identified seasonal water-level fluctuation is observed over most stations. Rapid increases in water levels are associated with extreme single rainfall events, while progressive increases are related to long periods of low intensity rainfall events. For comparative purposes the long term water level data extends back to 1989 and the short term from January 2007 to January 2011 (Table 66 to Table 69).

Table 65. Summary of groundwater level data within the Upper Sand region.

GUA	ID	Start Date	Last Date	Count	Min (mbgl)	Mean (mbgl)	Max (mbgl)	Fluctuation (Max-Min) (m)	Difference 1st and last (m)
A7-1	A7N0525	May-75	10-Nov	416	15.3	22.4	33.0	17.7	-0.4
	A7N0538	Nov-73	10-Nov	425	3.3	10.1	30.1	26.7	0.9
	A7N0539	Jan-76	10-Nov	408	1.9	10.5	20.7	18.8	4.6
	A7N0549	Nov-71	10-Nov	461	2.3	7.3	16.4	14.1	-4.6
	A7N0561	Nov-73	10-Nov	408	2.6	7.1	9.2	6.6	0.2
	A7N0586	Jun-89	10-Nov	249	1.7	6.7	20.5	18.8	-5.5
	A7N0629	Aug-07	10-Nov	35	11.4	12.5	13.8	2.4	1.0
	A7N0631	Mar-05	10-Nov	65	2.1	2.6	3.2	1.1	-0.3
	A7N0632	Jun-05	10-Nov	63	1.9	2.8	3.6	1.8	-0.4
	A7N0633	Mar-06	10-Nov	57	12.7	16.5	19.9	7.2	-4.3
	A7N0636	Feb-05	10-Nov	70	6.9	9.2	11.0	4.1	-1.9
	A7N0637	Jul-05	10-Nov	65	6.8	10.0	14.3	7.5	-2.4
	A7N0639	Jul-06	10-Nov	53	30.7	31.4	32.0	1.3	-0.1
	A7N0642	Aug-07	10-Nov	37	11.4	11.7	12.1	0.7	0.0
	A7N0646	Aug-07	10-Nov	38	4.7	5.5	6.2	1.6	-0.5
	A7N0647	Dec-07	10-Nov	36	3.7	5.8	8.1	4.3	4.0
A7N0653	Jul-08	10-Nov	25	17.3	18.2	19.2	1.9	0.3	
A7N0655	Jul-08	10-Nov	29	16.9	18.0	19.3	2.4	1.1	
				Mean	8.5	11.2	15.2	6.7	0.1
A7-2	A7N0019	Jun-84	10-Nov	305	4.0	11.3	16.0	12.0	-3.8
	A7N0041	Sep-89	10-Nov	236	3.6	8.7	15.0	11.4	3.1
	A7N0593	Aug-93	10-Nov	180	27.2	32.4	37.1	9.9	2.2
	A7N0638	Sep-06	10-Nov	51	19.6	20.5	21.0	1.5	-0.7
	A7N0643	Jul-07	10-Nov	41	26.8	30.3	31.9	5.1	4.7
	A7N0019	Jun-84	10-Nov	305	4.0	11.3	16.0	12.0	-3.8
				Mean	16.2	20.6	24.2	8.0	1.1
A7-3	A7N0524	Sep-65	10-Nov	483	21.3	28.9	35.4	14.1	-3.2
	A7N0634	Dec-04	10-Nov	70	25.4	26.3	27.9	2.5	-2.2
	A7N0635	Apr-06	10-Nov	57	6.1	7.1	7.7	1.6	0.5
	A7N0641	Jul-07	10-Nov	38	29.5	30.3	31.0	1.5	-1.4
	A7N0644	Jul-07	10-Nov	41	77.1	78.7	79.6	2.5	-2.5
	A7N0648	Jan-05	10-Nov	62	8.0	9.7	11.2	3.3	-3.0
				Mean	27.9	30.2	32.1	4.2	-2.0

Table 66. Water level trends for selected monitoring stations in the Upper Sand GUA (A7-1).

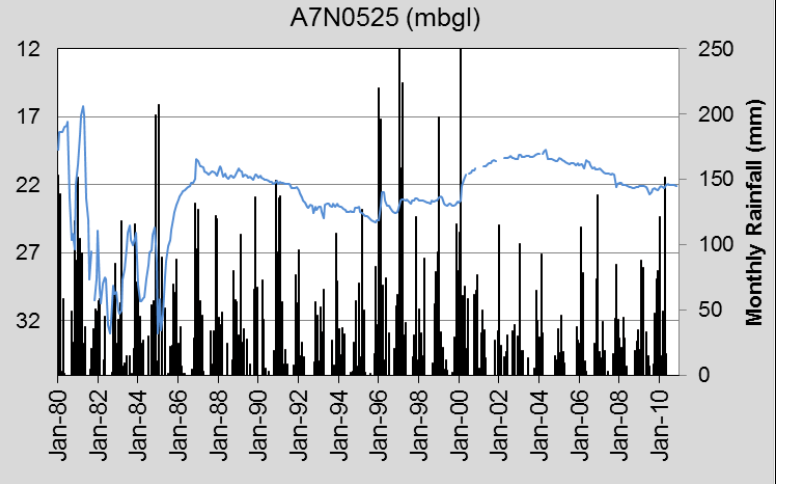
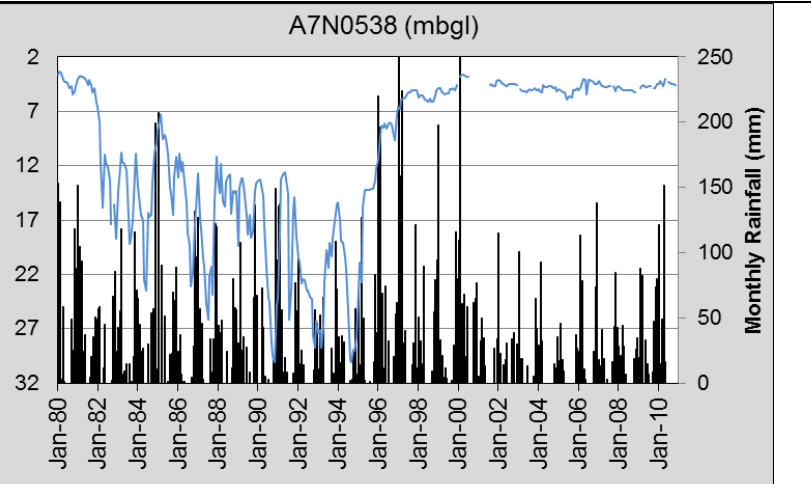
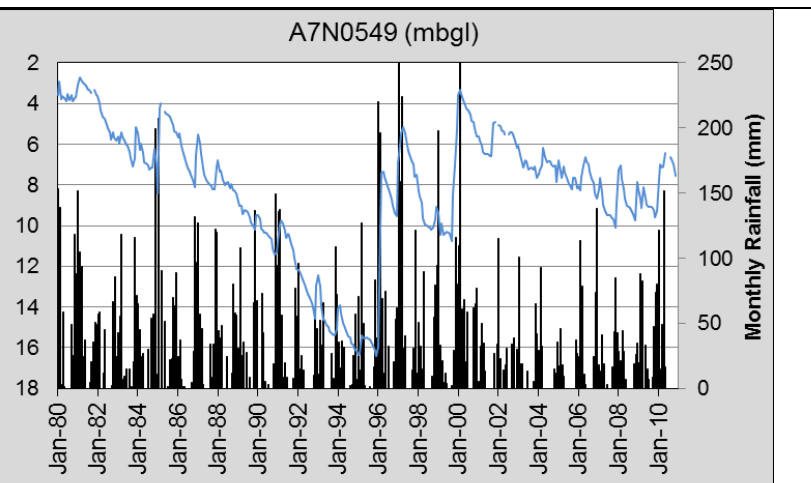
<p>A7-1 A7N0525 Date WL (mbgl) Jan-89 19.44 Nov-10 22.10 Difference (m) -2.66 Rainfall Data Polokwane Hos (Jan-80 to June-10)</p>	
<p>A7-1 A7N0538 Date WL (mbgl) Jan-89 3.58 Nov-10 4.62 Difference (m) -0.87 Rainfall Data Polokwane Hos (Jan-80 to June-10)</p>	
<p>A7-1 A7N0549 Date WL (mbgl) Jan-80 3.56 Nov-10 7.57 Difference (m) -4.01 Rainfall Data Polokwane Hos (Jan-80 to June-10)</p>	

Table 67. Water level trends for selected monitoring stations in the Upper Sand GUA (A7-1).

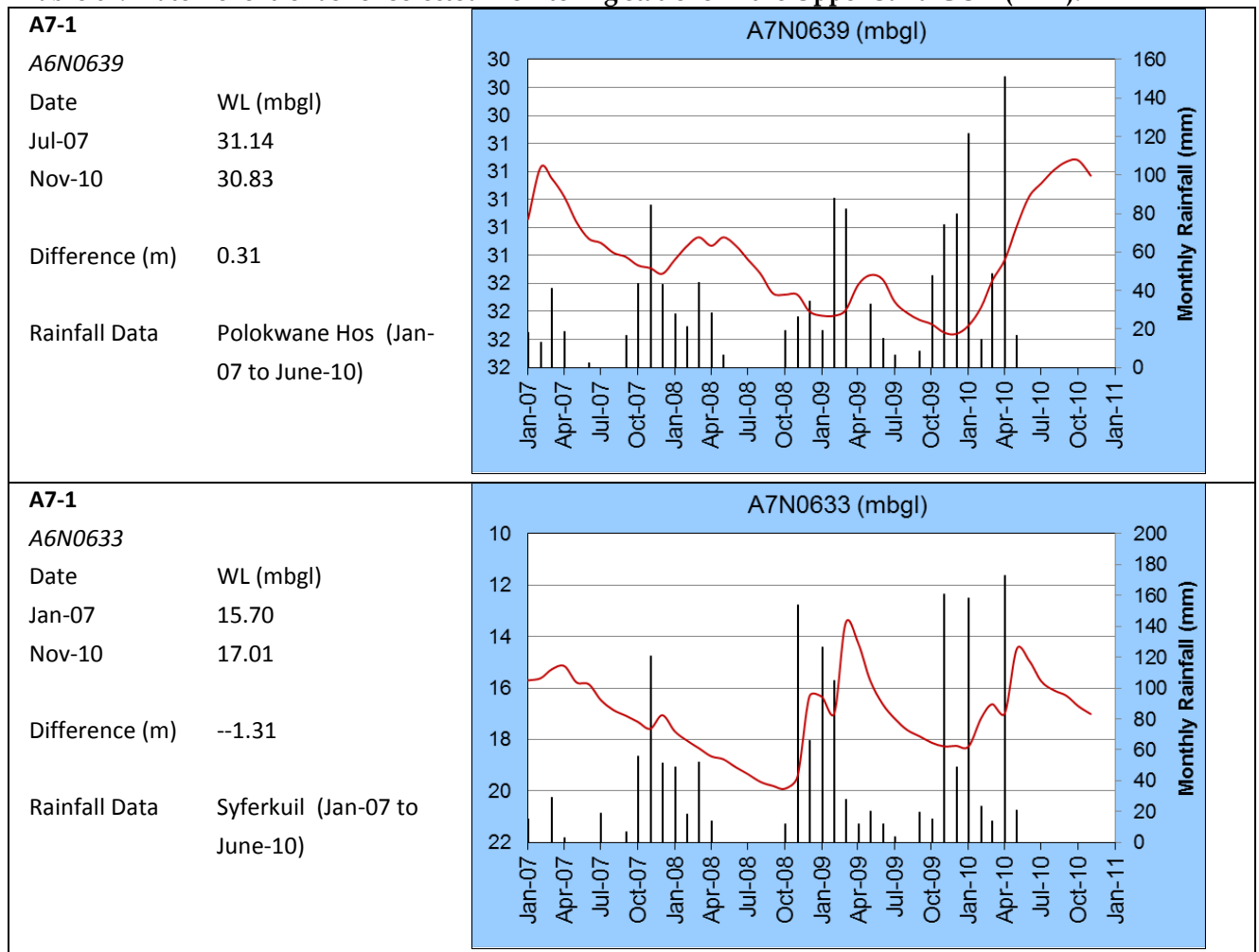


Table 68. Water level trends for selected monitoring stations in the Middle Sand GUA (A7-2).

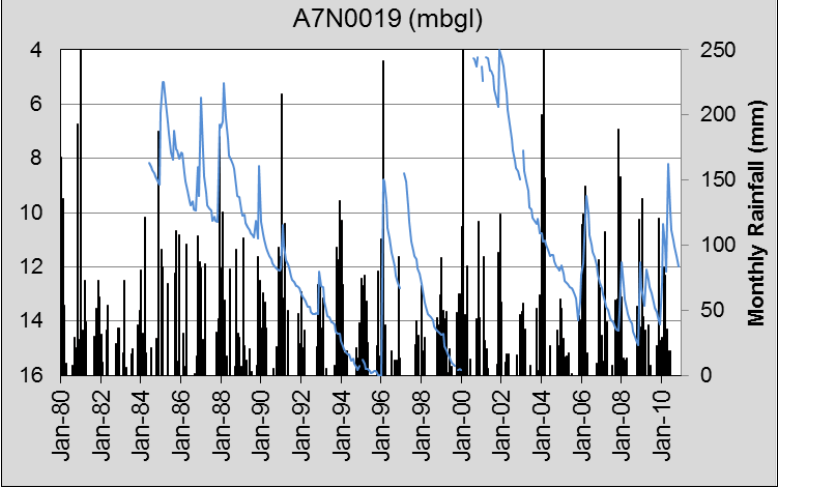
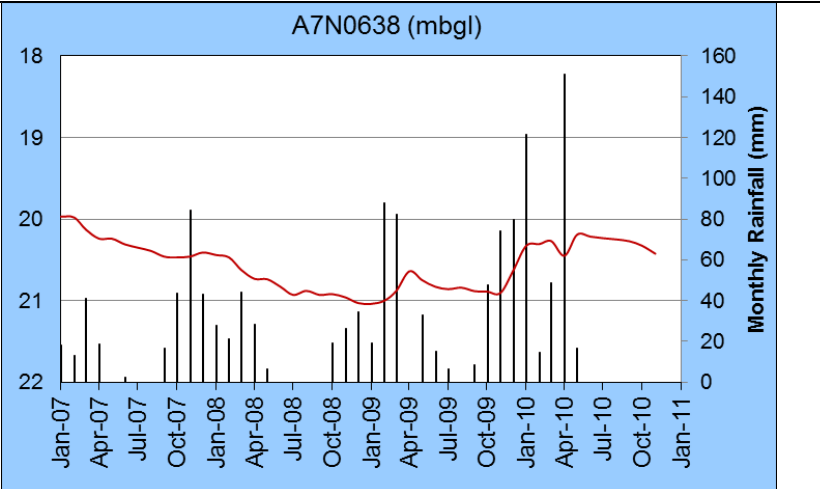
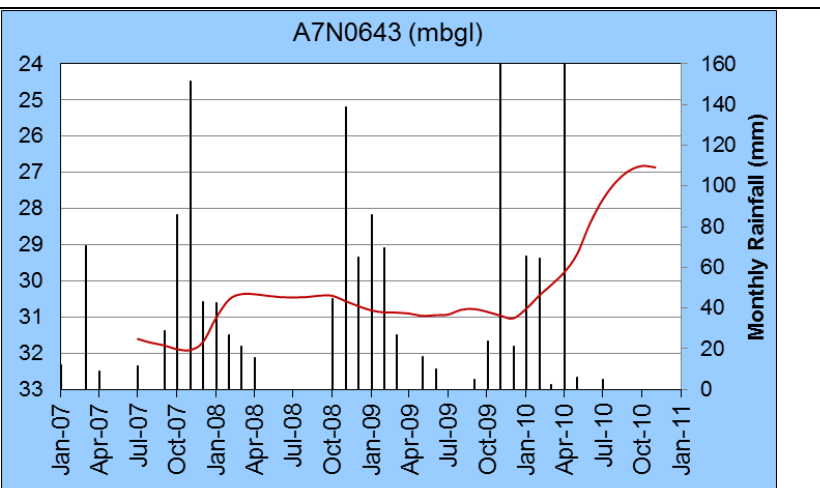
<p>A7-2 A7N0019 Date WL (mbgl) Jun-07 8.17 Nov-10 11.98 Difference (m) -3.81 Rainfall Data Mara (Jan-80 to June-10)</p>	
<p>A7-2 A7N0638 Date WL (mbgl) Jan-07 19.97 Nov-10 20.42 Difference (m) -0.45 Rainfall Data Polokwane Hos (Jan-07 to June-10)</p>	
<p>A7-2 A7N0643 Date WL (mbgl) Jul-07 31.61 Nov-10 26.86 Difference (m) 4.75 Rainfall Data Legkraal (Jan-07 to June-10)</p>	

Table 69. Water level trends for selected monitoring stations in the Hout en Brak GUA (A7-3).

<p>A7-3 A7N0524 Date WL (mbgl) Jan-80 27.08 Nov-10 30.57 Difference (m) -3.49 Rainfall Data Legkraal (Jan-80 to June-10)</p>	
<p>A7-3 A7N0635 Date WL (mbgl) Jan-07 7.06 Nov-10 6.41 Difference (m) 0.65 Rainfall Data Polokwane Hos (Jan-07 to June-10)</p>	
<p>A7-3 A7N0645 Date WL (mbgl) Jul-07 40.14 Nov-10 42.46 Difference (m) -2.32 Rainfall Data Legkraal (Jan-07 to June-10)</p>	

4.6.2 Groundwater contribution to baseflow

Based on the groundwater-surface water classification described in section 2.7.5 the Upper Sand and more specifically the Hout River stretch can be classified into a localised interacting weathered hard rock system in the upper reaches, while In the lower reaches alluvium replaces the weathered material which can be classified as a porous media underlain by a semi-pervious layer (Figure 4-20). In both cases seasonal alternating effluent / influent conditions can be experienced. Both analytical and numerical models could be applied to evaluate groundwater-surface water interaction of the Upper Sand River (Similar SW-GW interactions is expected for the Sand River stretch).

Alluvium is present to various degrees in all the major surface water drainage courses grading from clay through sand to pebbles and in places is covered superficially by deposits of calcrete. In general, the thickness and lateral extent of the alluvium increases down-gradient towards the north. The porous nature of the alluvium makes this a natural repository for groundwater recharged periodically from ephemeral flows in the drainage courses. However, the natural groundwater-surface water interaction has been modified by the artificial recharge of treated sewage effluent that is continuously being discharged from the municipal sewage treatment works into the Sand River. This effluent is either abstracted directly from the Sand River by some riparian farmers downstream for irrigation purposes or it serves as a source of recharge of the groundwater stored in the alluvium.

According to baseflow data in the GRA II dataset groundwater baseflow to surface water courses does not exist in the area. Because of a complete lack of any river gauging stations within the Upper Sand drainage area no data on river flows are available which further compounds the problem of attempting to evaluate the groundwater-surface water interaction. As a result few baseflow results are available from catchment surface water models. Comparison of groundwater contribution to baseflow estimates for the Upper Sand drainage region are summarised in Table 70. The hydrograph separation curve for station A7H007 is shown in Figure 4-21.

Table 70. Groundwater contribution to baseflow estimates.

GMA	GRU	Quat	Hughes Mm ³ /a	Shultz Mm ³ /a	Pitmann Mm ³ /a	GRA II (WR2005) Mm ³ /a	Maint. Low flow Mm ³ /a	Specialist*/ Hydrograph# Mm ³ /a	Average Mm ³
Upper Sand	A7-1	A71A	0.13				0.03	0.85	0.44
		A71B	0.01				0.42	0.46	0.44
Middle Sand	A7-2	A71C	0.01				0.24	0.52	0.38
		A71D					0.12	0.26	0.19
		A71H	0.19				0.75	0.83	0.79
Hout en Brak	A7-3	A71E					0.37	0.40	0.39
		A71F					0.23	0.25	0.24
		A71G					0.02	0.43	0.22
		A72A	0.34				0.06	1.25	0.66

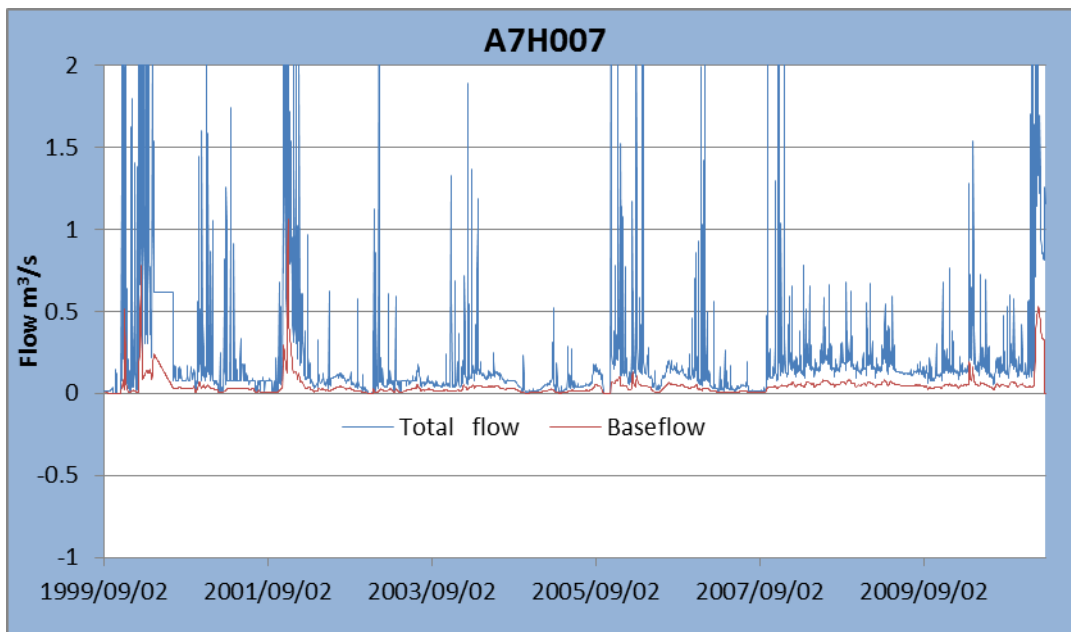


Figure 4-21. Baseflow separation for A7H007 (A71A).

4.6.3 Basic Human Needs (BHN)

Table 71. Basic human needs estimates.

GMA	GRU	Quat	Population*	BHN Estimate Mm ³
Upper Sand	A7-1	A71A	170591	1.557
		A71B	156430	1.427
Middle Sand	A7-2	A71C	132356	1.208
		A71D	2237	0.020
		A71H	90919	0.830
Hout en Brak	A7-3	A71E	62674	0.572
		A71F	62255	0.568
		A71G	21758	0.199
		A72A	111727	1.020

* - Based on 2001 statistics and the Limpopo ISP (DWA, 2004b).

4.6.4 Reserve determination summary

The Reserve assessment is firstly provided on a groundwater resource unit level in Table 72 and summarized for the Limpopo WMA on a quaternary level in Appendix A.

Table 72. Groundwater Reserve summary (Upper Sand region).

Description	GUA	Area (Km ²)	Recharge Mm ³	GW to Baseflow Mm ³	BHN Mm ³	Reserve Mm ³	Reserve as % of Recharge
Upper Sand	A7-1	2026	23.04	0.66	2.98	3.64	16%
Middle Sand	A7-2	3235	29.18	0.67	1.43	2.10	7%
Hout en Brak	A7-3	4359	25.50	1.77	2.00	3.77	15%

4.6.5 Groundwater use and availability

Groundwater use estimates vary significantly between the GRA II dataset and the recently validated WARMS dataset (Table 73). However, groundwater is heavily utilized over in the entire region and irrigation has expanded way beyond previous estimates.

Table 73. Groundwater availability and stress index (Upper Sand region).

GMA	GUA	Quat	RE Mm ³	Groundwater availability Mm ³ /a		Groundwater Use Mm ³ /a			GW Use as % of HP	Stress Index (GW Use as % of Recharge)
				HP	UGEP	GRA II Mm ³	WARMS (*validated)	Final Estimate		
Upper Sand	A7-1	A71A	13.56	12.30	1.67	27.34	#42.73	42.73	347%	315%
		A71B	9.48	8.81	7.63	2.86	4.58*	4.58	52%	48%
Middle Sand	A7-2	A71C	11.09	13.27	1.82	5.93	4.51*	5.93	45%	53%
		A71D	4.64	7.49	8.53	2.28	4.41*	4.41	59%	95%
		A71H	13.44	10.35	13.21	4.74	0.35*	4.74	46%	35%
Hout en Brak	A7-3	A71E	6.66	10.41	0.65	9.51	6.53*	9.51	91%	143%
		A71F	4.38	6.35	1.70	8.46	7.30*	8.46	133%	193%
		A71G	6.23	8.94	7.37	16.95	9.92*	16.95	190%	272%
		A72A	8.23	20.98	22.22	14.43	9.61*	14.43	69%	175%

- Specialist DWA report.

4.6.6 Groundwater quality

Groundwater samples in the Upper Sand region vary from a Na-HCO₃ to a Na-Mg-HCO₃ and Na-Cl water type. A high percentage of samples relate to a fresh recharge type (Ca/Mg-HCO₃) water, while cation and anion exchange process may be occurring within the strata hence Na-Cl type water present (Figure 4-22).

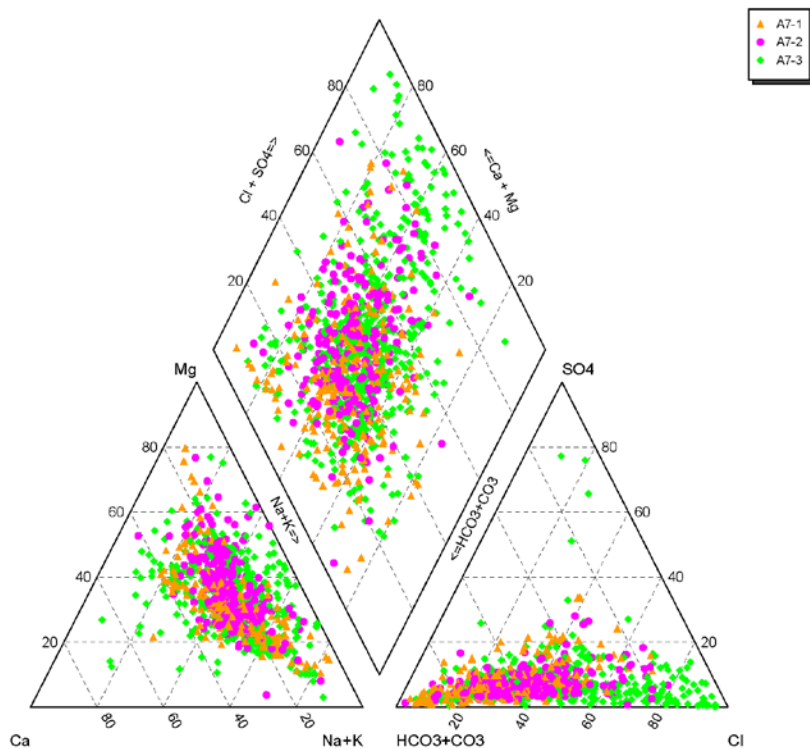


Figure 4-22. Piper diagram for the Upper Sand drainage region.

Groundwater quality in the Upper Sand region is considered to be marginal to poor with only 41 % of samples in the Upper reaches within the recommended drinking limit while less than 30 % of samples in the lower reaches comply with the drinking water quality standard. The most notable elements of concern include NO_3 as N with average concentrations above the maximum allowable recommended drinking limit in the Middle Sand GUA (A7-2) (Table 74). In addition, several samples show major ion concentrations (e.g. Cl) beyond acceptable limits. This can mostly be related to evaporative concentration of elements in discharge areas or due to low recharge values as well as long residence times for selected samples.

Table 74. Groundwater quality for the Upper Sand region (All units in mg/l, EC in mS/m).

GUA	Parameter	pH	EC	Ca	Mg	Na	K	SO ₄	Cl	NO ₃ as N	F	Compliance (% of samples within Class I)	Present Category
A7-1	Nr	287	287	270	270	270	267	277	287	257	279	41 %	II*
	Mean	8.0	99.3	46.2	39.9	109.2	7.4	33.5	97.8	11.3	0.6		
A7-2	Nr	336	334	316	315	315	311	320	326	323	333	24 %	III
	Mean	8.0	134.7	62.2	67.5	129.7	10.0	43.9	168.4	20.0	0.6		
A7-3	Nr	690	690	648	647	646	638	654	691	635	677	34 %	III
	Mean	8.0	145.0	64.2	63.6	144.5	11.4	50.7	241.4	13.4	0.5		

Class I

Class II

Exceed Class II

4.6.7 Final Categorisation

A summary of the categorisation for the Upper Sand region is shown in Table 75 and summarized for the Limpopo WMA on a quaternary level in Appendix A.

Table 75. Groundwater categorisation for each GUA (Upper Sand).

Description	GUA	Area (Km ²)	Recharge Mm ³	Groundwater Use Mm ³ /a	Stress Index (SI)	Present Category (SI)	Present Category (Impact)	Present Category (Quality)
Upper Sand	A7-1	2026	23.04	47.31	205%	III	II	III
Middle Sand	A7-2	3235	29.18	27.29	94%	III	II	III
Hout en Brak	A7-3	4359	25.50	24.80	97%	III	III	III

4.7 (Lower) Sand and Limpopo Tributaries Drainage System

The Lower Sand River passes through the gorge at the Soutpansberg Mountains before flowing north-east towards its confluence with the Limpopo River. Smaller urban centers (e.g. Musina) and numerous mining activities (e.g. Venetia diamond Mine) obtain water supplies from locally developed groundwater sources along the Limpopo River. Quaternary catchment A63E and A71L do not drain towards the Sand River but towards the Limpopo River via a number of smaller tributaries. Quaternary catchment A71L has the lowest rainfall and highest MAE of all of the catchments in the Sand River drainage area (tertiary catchment A71). The majority of water usage comes from the primary aquifer or directly from river flow. Numerous coalfields are being explored along the Limpopo River and north of the Soutpansberg.

In this assessment the lower Sand River have been delineated in two GUAs, namely A7-4 and A7-5, while quaternary catchment A71L have been grouped with A63E to form a separate GUA, namely A6/7-3 (Figure 4-23). Limited pumping test data are available from the GRIP dataset for the region due to the large coverage of private farms where no or little borehole information is made available.

Table 76. Borehole information for the Upper Sand drainage region

Drainage system	UA	Info	BH Depth (mbgl)	Water Level (mbgl)	Transmissivity (m ² /day)	Rec. Yield (l/s for 24hrs)	Airlift Yield (l/s)
Lower Sand	A7-4	N	388	332	3	4	130
		Mean	59	27.0	3.27	0.27	3.7
	A7-5	N	206	185	3	3	19
		Mean	50	24.9	3.53	0.68	2.94
Limpopo Tributaries	A6/7-3	N	346	265	2	2	99
		Mean	43	18.2	38.20	1.40	2.6

N = Number of boreholes

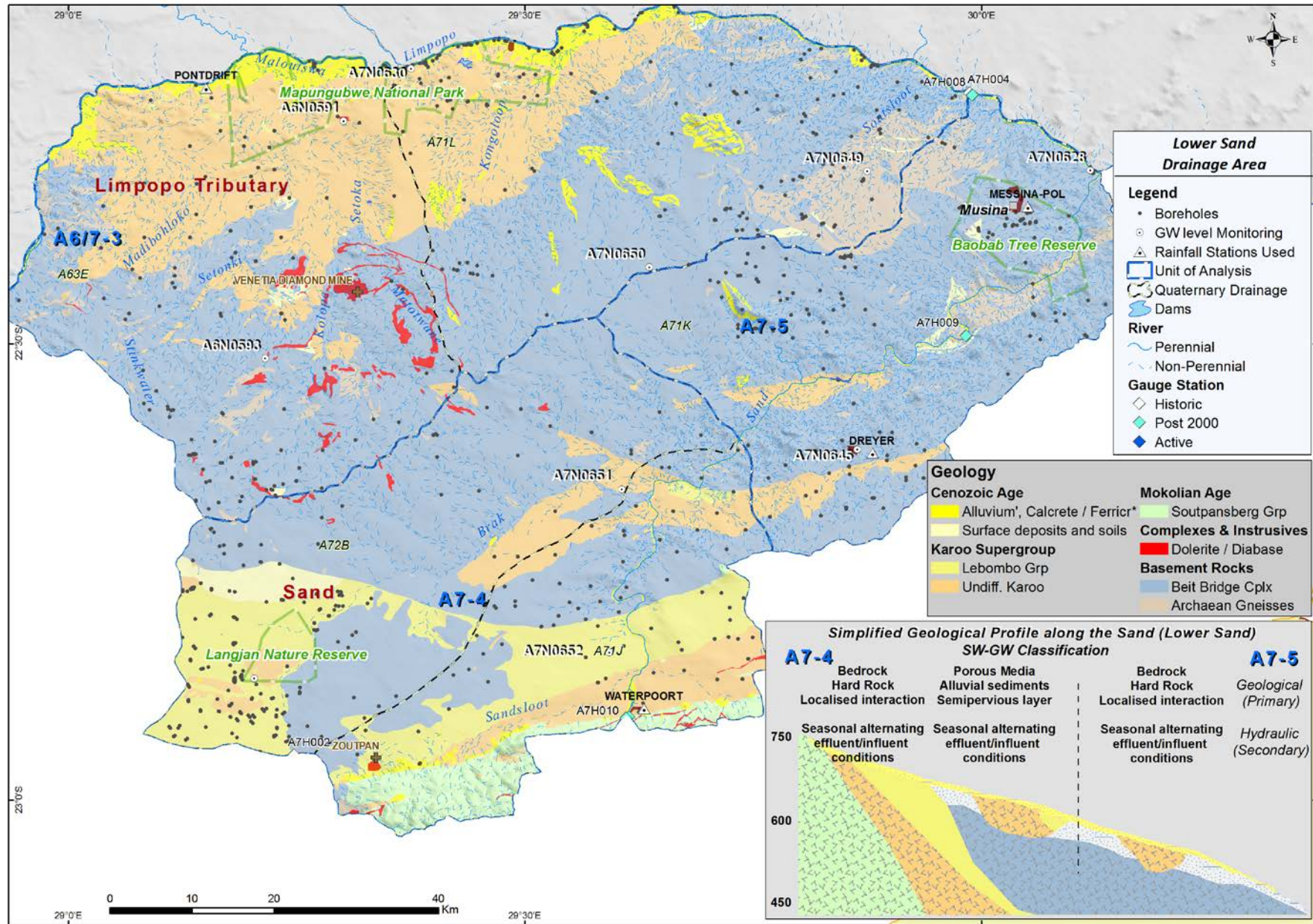


Figure 4-23. Geology, GUAs and SW-GW classification of the Lower Sand drainage region.

Borehole yields generally range between 0.1 – 2 l/s. The main aquifer types include:

- Fractured aquifers (Soutpansberg Group and Karoo Supergroup)
 - The Soutpansberg Group does not possess any primary porosity and groundwater occurrences are controlled by geological structures. In general groundwater yields are low.
 - The stratified rocks of the Karoo can generally be regarded as being of low groundwater potential away from structures with the inter-bedded sandstones having a moderate potential.
- Intergranular Alluvial aquifers (Limited to the main river stems)
 - Alluvial aquifers are recharged during periods of high stream-flows as well as during the rainfall season. It is an important local, major aquifer and exists in equilibrium with surface water, adjacent groundwater systems and ecosystems along the rivers. The depths of the alluvium generally decrease away from the river.
- Intergranular and fractured (Beit Bridge Complex)
 - The granite-gneissic rocks of the Beit Bridge Complex cover large parts of the area with moderate groundwater potential and boreholes yield between 0.5 and 2 l/s. Ground water is entrapped in small relatively shallow, locally developed basins and troughs revealing that mechanical and chemical weathering appear to be associated with surface drainage channels. Although dykes have intruded the host rock extensively they are generally poor water suppliers.

4.7.1 Groundwater recharge

The Lower Sand receives on average 350 mm rainfall per annum making it one of the arid areas in the Limpopo WMA (Table 77). Recharge are considered to be low over most of the area however, recharge can be slightly higher in the fault zones, and significantly higher in the alluvial area where no surface runoff is evident. Recharge vary from approximately 8 mm/a to less than 2 mm/a in the northeast (see Figure 2-7).

Table 77. Rainfall Data for selected stations in the Lower Sand region.

Station*	<i>Start Date</i>	<i>MAP (mm)</i>	<i>Elevation (mamsl)</i>
Waterpoort	1978	379	739
Musina	1965	318	524
Potndrift	1965	355	532

*- South African Weathers Services.

A review of previous work done on the GRA II project, Vegter's (1995) estimates and recharge estimates based on specialist reports were made. These values were calculated for each of the quaternaries constituting the unit of analysis and are summarised as Table 78.

Table 78. Recharge estimation (Lower Sand).

GMA	UA	Quat	MAP (mm)	Area (km ²)	GRA II		Vegter (1995)	Specialist report Mm ³	Used Mm ³	Recharge %
					(Wet) Mm ³	(Dry) Mm ³	Mean Mm ³			
Lower Sand	A7-4	A71J	396.1	1162	12.80	8.57	9.49	8.28	9.79	2.1
		A72B	343.9	1554	9.05	5.96	9.67		8.23	1.5
	A7-5	A71K	304.7	1668	9.47	6.12	5.19		6.93	1.4
Limpopo Tributaries	A6/7-3	A63E	357.9	1992	13.72	8.99	12.05	7.84	10.65	1.5
		A71L	287.8	1765	9.57	6.02	5.30	7.62	7.13	1.4

Water level trends

Only short term water level data is available for the Lower Sand region. For comparative purposes all hydrographs were based on a four year period (January 2007 to January 2011) (Table 79 and Table 80). Groundwater level seasonal fluctuations of approximately 2 m are observed for most stations. However, some stations have shown a declining trend since the onset of monitoring in 2007 (e.g. A7N0645 and A7N650). It appears that despite good rainfall seasons water levels declined throughout the season with little or no recharge at all. The drop in water levels may be to over-abstraction in the vicinity of the monitoring boreholes.

Table 79. Water level trends for selected monitoring stations in the Lower Sand region.

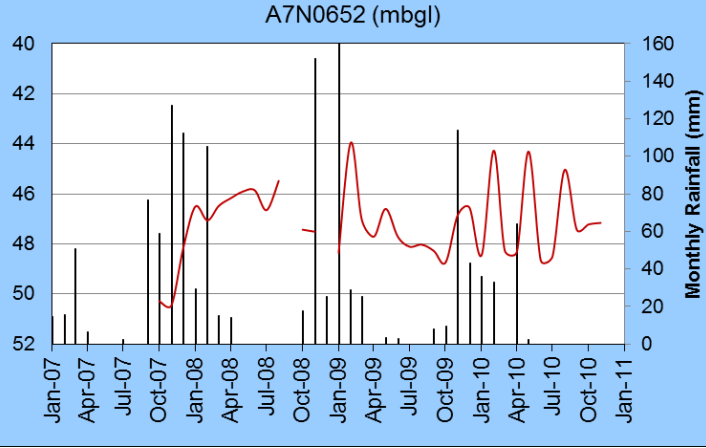
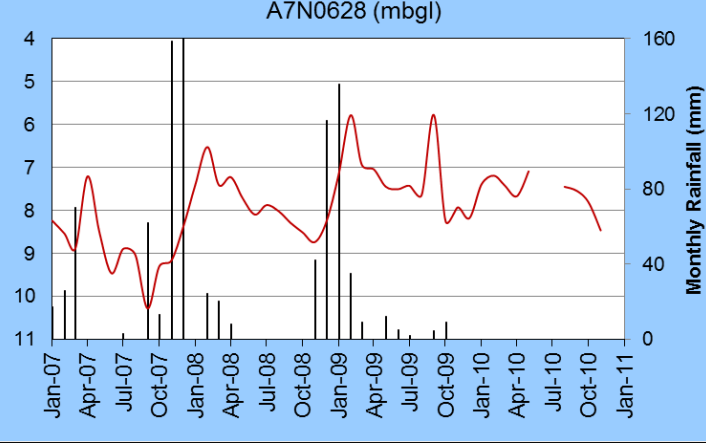
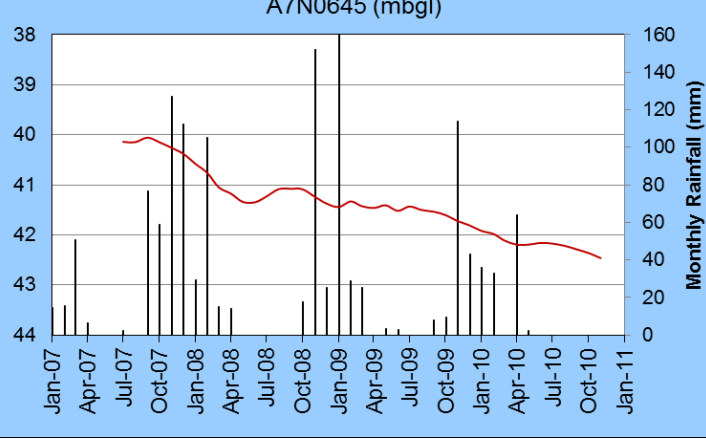
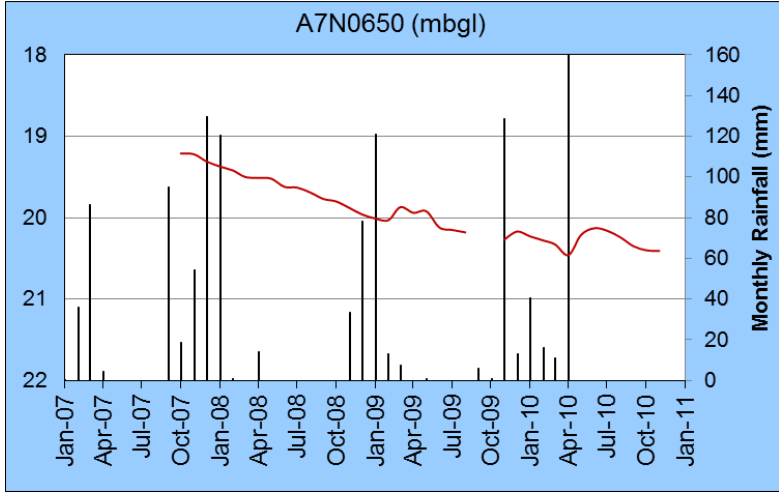
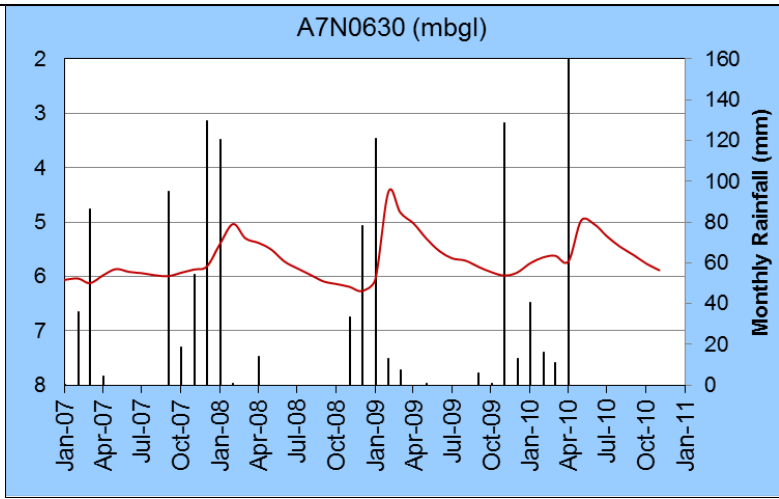
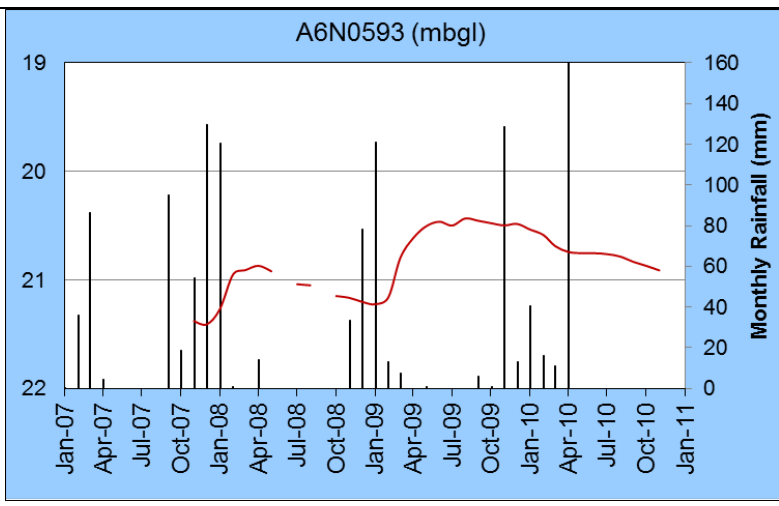
<p>A7-4 A7N0652 Date WL (mbgl) Oct-07 50.28 Nov-10 47.16 Difference (m) 3.12 Rainfall Data Waterpoort Hos (Jan-07 to June-10)</p>	
<p>A7-5 A7N0628 Date WL (mbgl) Jan-07 8.24 Nov-10 8.47 Difference (m) -0.22 Rainfall Data Musina (Jan-07 to June-10)</p>	
<p>A7-5 A7N0645 Date WL (mbgl) Jul-07 40.14 Nov-10 42.46 Difference (m) -2.32 Rainfall Data Waterpoort (Jan-07 to June-10)</p>	

Table 80. Water level trends for selected monitoring stations in the Limpopo Tributaries GUA.

<p>A6/7-3 A7N0650 Date WL (mbgl) Oct-07 19.21 Nov-10 20.41 Difference (m) -1.20 Rainfall Data Pontdrift (Jan-07 to June-10)</p>	
<p>A6/7-3 A7N0630 Date WL (mbgl) Jan-07 6.06 Nov-10 5.89 Difference (m) 0.18 Rainfall Data Pontdrift (Jan-07 to June-10)</p>	
<p>A6/7-3 A6N0593 Date WL (mbgl) Jan-07 21.38 Nov-10 20.91 Difference (m) 0.47 Rainfall Data Pontdrift (Jan-07 to June-10)</p>	

4.7.2 Groundwater contribution to baseflow

Based on the groundwater-surface water classification described in section 2.7.5 the Lower Sand and more specifically the Sand River stretch can be classified into a localized interacting weathered hard rock system in the upper reaches, while In the lower reaches alluvium replaces the weathered material which can be classified as a porous media with a continuous interaction with the River system (Figure 4-23). Similarly groundwater-surface water interaction with the Limpopo River in GUA A6/7-3 can be classified as a porous media underlain by a semi-pervious layer. In these cases seasonal alternating effluent / influent conditions can be experienced. Both analytical and numerical models could be applied to evaluate groundwater-surface water interaction.

According to baseflow data in the GRA II dataset groundwater baseflow to surface water courses does not exist in the area, hence, natural recharge must be lost through riverine vegetation and spring discharge. In addition because of a complete lack of any river gauging stations within the Lower Sand drainage area no data on river flows are available which further compounds the problem of attempting to evaluate the groundwater-surface water interaction. As a result no baseflow results are available from catchment surface water models. Comparison of groundwater contribution to baseflow estimates for the Lower Sand drainage region are summarised in Table 81.

Table 81. Groundwater contribution to baseflow estimates.

Description	GUA	Quat	Hughes Mm ³ /a	Shultz Mm ³ /a	Pitmann Mm ³ /a	GRA II (WR2005) Mm ³ /a	Maint. Low flow Mm ³ /a	Specialist*/ Hydrograph# Mm ³ /a	Average Mm ³
Lower Sand	A7-4	A71J	-	-	-	-	0.72	0.81*	0.76
		A72B	-	-	-	-	0.52	0.58*	0.55
	A7-5	A71K	-	-	-	-	0.35	0.39*	0.37
Limpopo Tributaries	A6/7-3	A63E	-	-	-	-	0.32	0.76*	0.54
		A71L	-	-	-	-	0.30	0.33*	0.31

* - Desktop SPATSIM model.

4.7.3 Basic Human Needs (BHN)

Table 82. Basic human needs estimates.

Description	GUA	Quat	Population*	BHN Estimate Mm ³
Lower Sand	A7-4	A71J	3092	0.028
		A72B	2953	0.027
	A7-5	A71K	23782	0.217
Limpopo Tributaries	A6/7-3	A63E	3014	0.028
		A71L	6530	0.060

* - Based on 2001 statistics and the Limpopo ISP (DWA, 2004b).

4.7.4 Reserve determination summary

The Reserve assessment is firstly provided on a groundwater resource unit level in Table 83 and summarized for the Limpopo WMA on a quaternary level in Appendix A.

Table 83. Groundwater Reserve summary (Lower Sand region).

Description	GUA	Area (Km ²)	Recharge Mm ³	GW to Baseflow Mm ³	BHN Mm ³	Reserve Mm ³	Reserve as % of Recharge
Lower Sand	A7-4	2716	23.70	0.92	1.24	2.16	9%
	A7-5	1668	9.79	0.76	0.03	0.79	8%
Limpopo Tributaries	A6/7-3	3757	17.78	0.85	0.09	0.94	5%

4.7.5 Groundwater use and availability

Groundwater use estimates vary significantly between the GRA II dataset and the recently validated WARMS dataset (Table 84). In many quaternary catchments registered groundwater use exceeds both the harvest potential and natural recharge. At the same time groundwater is potentially still available from development is quaternary catchment A72B and A71L.

Table 84. Groundwater availability and stress index (Lower Sand region).

GMA	GUA	Quat	RE Mm ³	Groundwater availability Mm ³ /a		Groundwater Use Mm ³ /a			GW Use as % of HP	Stress Index (GW Use as % of Recharge)
				HP	UGEP	GRA II Mm ³	WARMS (*validated)	Final Estimate		
Lower Sand	A7-4	A71J	16.78	7.58	7.93	1.97	10.71*	15.56	141%	64%
		A72B	6.93	9.83	5.01	0.84	2.1*	3.55	21%	30%
	A7-5	A71K	9.79	5.32	3.72	1.48	1.88*	8.97	35%	19%
Limpopo Tributaries	A6/7-3	A63E	10.65	11.62	3.57	20.69	#8.06*	20.69	178%	194%
		A71L	7.13	5.25	4.43	0.55	#24.74*	24.74	470%	347%

- Includes abstraction from the Limpopo River alluvium.

4.7.6 Groundwater quality

A limited number of groundwater samples are available for the Lower Sand drainage region. Based on the piper diagram the main water types vary from a Ca/Mg-HCO₃, to a Na-Cl dominance (Figure 4-24). Na-Cl water type is a result of prolonged residence and fluid-rock interaction times in the subsurface in areas of discharge (i.e. alluvium along rivers) or areas of low recharge.

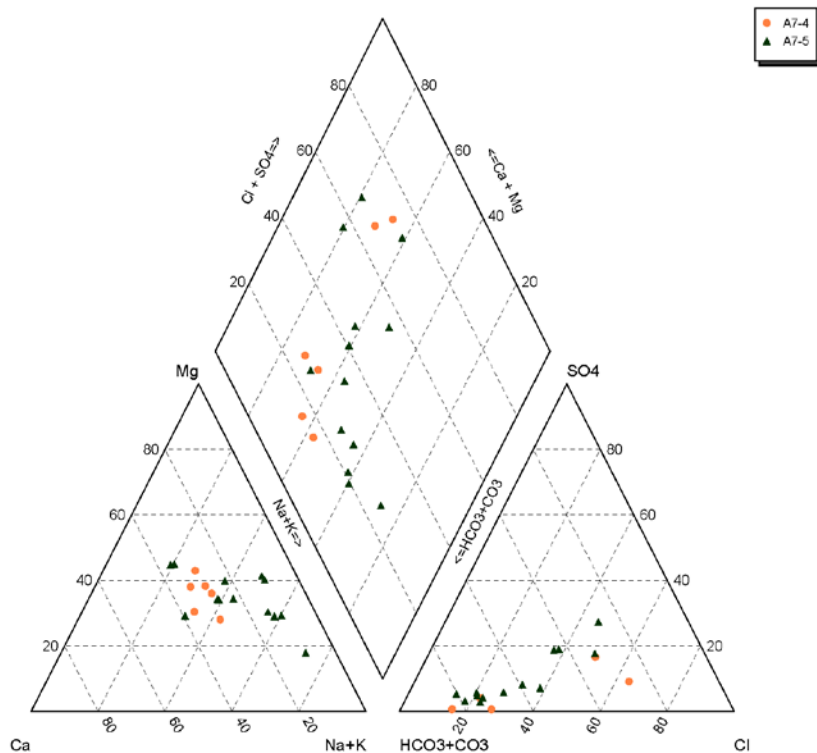


Figure 4-24. Piper diagram for the Lower Sand drainage region.

Groundwater quality in the Lephalala region is considered to be marginal to poor with only 38 % of samples in the Upper reaches within the recommended drinking limit while less than 29 % of samples in the lower reaches comply with the drinking water quality standard. From 14 water samples in the A7-5 GUA not a single sample comply with the recommended drinking water quality standard. The most notable elements of concern include NO_3 as N and F with average concentrations above the allowable recommended drinking limit (Table 85). In addition, several samples show major ion concentrations (e.g. Mg, Na and Cl) and subsequently electric conductivities (EC) beyond acceptable limits. This can mostly be related to evaporative concentration of elements in discharge areas or due to low recharge values as well as long residence times for selected samples.

Table 85. Groundwater quality for the Lower Sand region (All units in mg/l, EC in mS/m).

GUA	Parameter	pH	EC	Ca	Mg	Na	K	SO ₄	Cl	NO ₃ as N	F	Compliance (% of samples within Class I)	Present Category
A7-4	Nr	8	8	7	7	7	7	7	8	6	8	38 %	II*
	Mean	8.0	92.8	58.6	41.2	76.1	2.0	19.7	98.0	14.9	0.5		
A7-5	Nr	14	14	14	14	14	14	14	14	14	14	0 %	III
	Mean	7.9	149.4	74.9	71.4	155.0	7.4	78.1	166.3	15.7	1.4		
A6/7-3	Nr	84	84	83	83	83	82	84	84	63	83	29 %	III
	Mean	8.0	163.1	74.5	62.5	191.3	5.1	99.8	274.4	13.2	1.3		

Class I

Class II

Exceed Class II

4.7.7 Final Categorisation

A summary of the categorisation for the Lower Sand region is shown in Table 86.

Table 86. Groundwater categorisation for each GUA (Lower Sand).

Description	GUA	Area (Km ²)	Recharge Mm ³	Groundwater Use Mm ³ /a	Stress Index (SI)	Present Category (SI)	Present Category (Impact)	Present Category (Quality)
Lower Sand	A7-4	2716	23.70	16.30	69%	III	I	III
	A7-5	1668	9.79	10.71	109%	III	II	III
Limpopo Tributaries	A6/7-3	3757	17.78	45.42	256%	III	II	III

4.8 Nzhelele and Nwanedzi Drainage System

The Nzhelele River and the Nwanedzi River drains the most north-eastern part of the Limpopo WMA. These originate in the Soutpansberg and northern extremity of the Great Escarpment respectively. The drainage region has high rainfall in the upper reaches of the catchment and is semi-arid in the central and lower reaches of the catchment.

The Nzhelele River comprises a perennial reach upstream of the Nzhelele Dam with considerable water abstraction. The upper reaches, which flow through forestry areas and steep mountainous areas, have several red data species. The waterfalls along several of the river reaches in the mountainous areas create breaks which prevent migration of fish species. Numerous flow dependent species occur in the upper Nzhelele and its tributaries. The downstream reach has been highly modified by the construction of the Nzhelele Dam. The Nwanedzi River drains a small catchment in the north-eastern part of the WMA. This river is considered important from a conservation perspective due to the occurrence of the endangered snake catfish in the river (DWAF, 2003a).

Water use in the region is dominated by irrigation which is supplied by the major Dams, farm dams and run-of-river in the upper reaches of the catchment. Although the groundwater is used extensively in certain areas, according to the Limpopo ISP any additional water requirements for domestic use will have to be sourced from groundwater and groundwater has still potential for future use.

In this assessment the Nzhelele have been delineated in two GUA, namely A8-1 and A8-2, while the Nwanedzi drainage region have been delineated in only the one GUA, namely A8-3 (Figure 4-14). Most pumping test data is available from the upper reaches of GUA A8-1. Compared to other regions the average transmissivity of 14 m²/day is relatively low.

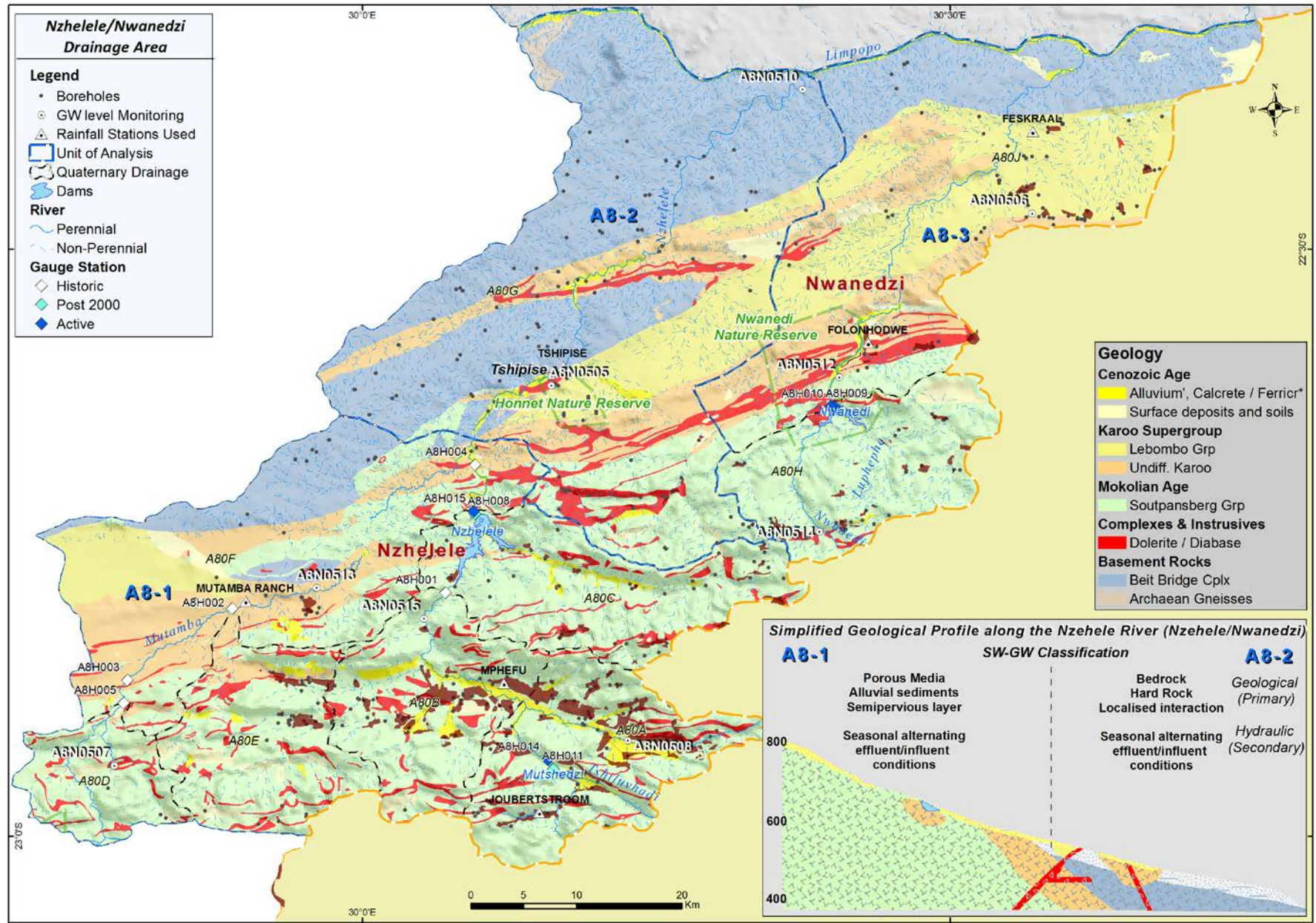


Figure 4-25. Geology, GUAs and SW-GW classification of the Nzhelele and Nwanedzi drainage region.

Table 87. Borehole information for the Nzhelele and Nwanedzi drainage region

Drainage system	UA	Info	BH Depth (mbgl)	Water Level (mbgl)	Transmissivity (m ² /day)	Rec. Yield (l/s for 24hrs)	Airlift Yield (l/s)
Upper Nzhelele	A8-1	N	226	184	115	150	4
		Mean	62	14.0	14.20	0.69	0.5
Lower Nzhelele	A8-2	N	156	166	14	15	-
		Mean	56	18.4	7.49	0.59	-
Nwanedzi	A8-3	N	116	84	5	67	-
		Mean	75	16.1	114.32	1.03	-

N = Number of boreholes

Borehole yields generally range between 0.1 – 2 l/s. The main aquifer types include:

- Fractured aquifers (Soutpansberg Group and Karoo Supergroup)
 - The Soutpansberg Group does not possess any primary porosity and groundwater occurrences are controlled by geological structures. In general groundwater yields are low.
 - The stratified rocks of the Karoo can generally be regarded as being of low groundwater potential away from structures with the inter-bedded sandstones having a moderate potential.
- Intergranular Alluvial aquifers (Limited to the main river stems)
 - Alluvial aquifers are recharged during periods of high stream-flows as well as during the rainfall season. It is an important local, major aquifer and exists in equilibrium with surface water, adjacent groundwater systems and ecosystems along the rivers. The depths of the alluvium generally decrease away from the river.
- Intergranular and fractured (Beit Bridge Complex)
 - The granite-gneissic rocks of the Beit Bridge Complex cover large parts of the area with moderate groundwater potential and boreholes yield between 0.5 and 2 l/s. Ground water is entrapped in small relatively shallow, locally developed basins and troughs revealing that mechanical and chemical weathering appear to be associated with surface drainage channels.

4.8.1 Groundwater recharge

The upper reaches of the drainage region drains the mountainous region to the south and has a relatively high rainfall (Table 88). For a small portion in the Soutpansberg the MAP is 1 000 mm and higher. In comparison the plains north of the Soutpansberg have a relatively low rainfall of only 300 mm per annum. Recharge vary from approximately 18 mm/a to less than 2 mm/a in the northeast (see Figure 2-7).

Table 88. Rainfall Data for selected stations in the Nzhelele and Nwanedzi region.

Station*	Start Date	MAP (mm)	Elevation (mamsl)
Joubert Stroom	1986	919	1 252
Mutamba Ranch [#]	1960	352	687
Tshipise	1965	349	526
Folonhodwe	1960	300	495

*- South African Weathers Services.

[#] - Closed in 2002.

A review of previous work done on the GRA II project, Vegter's (1995) estimates and recharge estimates based on specialist reports were made. These values were calculated for each of the quaternaries constituting the unit of analysis and are summarised as Table 89.

Table 89. Recharge estimation (Nzhelele and Nwanedzi).

GMA	UA	Quat	MAP (mm)	Area (km ²)	GRA II		Vegter (1995)	Specialist report Mm ³	Used Mm ³	Recharge %
					(Wet) Mm ³	(Dry) Mm ³	Mean Mm ³			
Upper Nzhelele	A8-1	A80A	938.0	287	26.11	20.40	14.77		20.43	7.6
		A80B	659.3	251	12.11	8.85	6.94		9.30	5.6
		A80C	576.3	294	11.26	8.00	6.88		8.71	5.1
		A80D	621.9	128	4.59	3.30	3.35	3.98	3.81	4.8
		A80E	622.3	247	9.79	7.01	6.45		7.75	5.0
		A80F	388.1	630	7.78	5.18	6.01	2.80	5.44	2.2
Lower Nzhelele	A8-2	A80G	332.6	1230	11.84	7.76	6.35		8.65	2.1
Nwanedzi	A8-3	A80H	620.6	266	10.75	7.72	3.81	2.48	6.19	3.7
		A80J	292.1	870	4.43	2.82	3.75	3.05	3.51	1.4

Water level trends

Only short term water level data is available for the Nzhelele and Nwanedzi region. Groundwater level seasonal fluctuations of approximately 1 to 2 m are observed for most stations (Table 90). For comparative purposes all hydrographs were based on a four year period (January 2005 to January 2011) (Table 91 to Table 93). A well-identified seasonal fluctuation is evident from most stations and water levels increase after rainfall events, while a recession period follows after the wet season. However, one station appears to decline throughout the wet season with little or no recharge at all, namely A8N0506. The drop in water levels may be to over-abstraction in the vicinity of the monitoring borehole.

Table 90. Summary of groundwater level data within the Nzhelele and Nwanedzi region.

GUA	ID	Start Date	Last Date	Count	Min (mbgl)	Mean (mbgl)	Max (mbgl)	Fluctuation (Max-Min) (m)	Difference 1st and last (m)
A8-1	A8N0507	May-06	Nov-10	55	6.31	9.03	11.89	5.59	2.08
	A8N0508	Jul-05	Nov-10	63	3.43	4.51	5.12	1.69	-0.33
	A8N0509	Mar-05	Nov-10	67	1.89	2.35	2.62	0.73	0.05
	A8N0513	May-07	Nov-10	40	9.18	10.17	11.21	2.03	1.06
	A8N0515	Nov-06	Nov-10	47	4.85	5.34	5.66	0.81	-0.16
				Mean	5.13	6.28	7.30	2.17	0.54
A8-2	A8N0505	Feb-05	Nov-10	68	9.14	9.63	10.39	1.26	0.69
	A8N0510	Jun-06	Nov-10	39	6.28	6.72	7.51	1.23	-0.56
A8-3	A8N0506	May-06	Nov-10	55	17.65	18.46	19.15	1.50	-1.50
	A8N0514	Mar-06	Nov-10	43	0.70	1.75	2.36	1.66	-0.12
	A8N0512	Nov-04	Aug-08	45	0.72	1.12	2.33	1.61	0.25

Table 91. Water level trends for selected monitoring stations in the Upper Nzhelele region (A8-1).

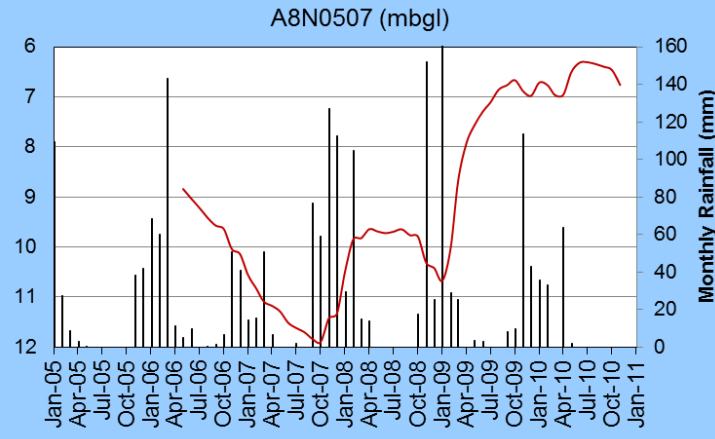
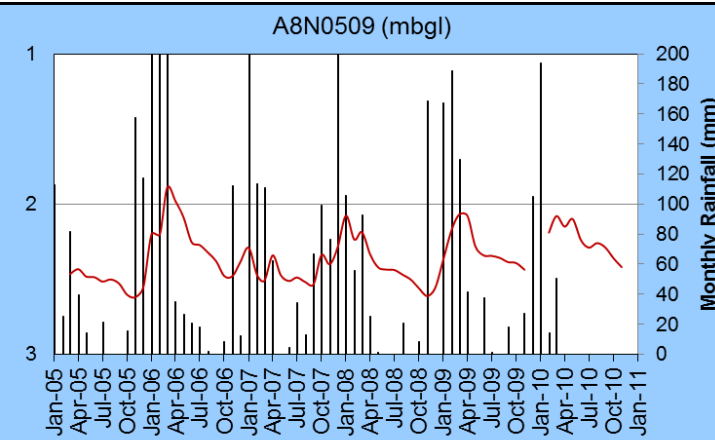
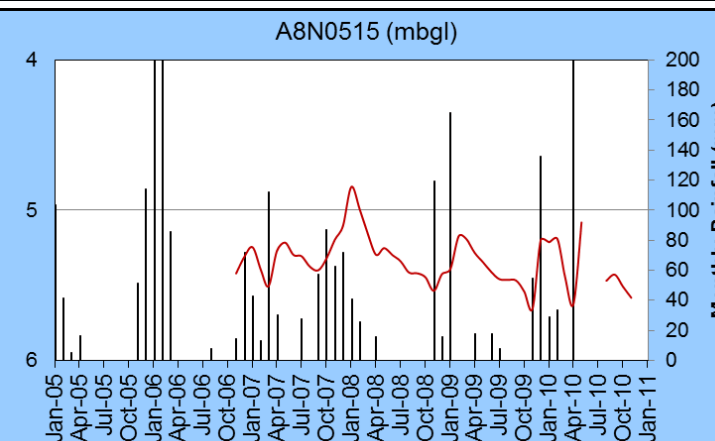
<p>A8-1 <i>A8N0507</i> Date WL (mbgl) May-06 8.84 Nov-10 6.76 Difference (m) 2.08 Rainfall Data Waterpoort Hos (Jan-05 to June-10)</p>	
<p>A8-1 <i>A8N0509</i> Date WL (mbgl) Mar-05 2.47 Nov-10 2.42 Difference (m) 0.05 Rainfall Data Joubert Stroom (Jan-05 to June-10)</p>	
<p>A8-1 <i>A8N0515</i> Date WL (mbgl) Nov-06 1.02 Nov-10 0.76 Difference (m) 0.25 Rainfall Data Folonhodwe (Jan-05 to June-10)</p>	

Table 92. Water level trends for selected monitoring stations in the Lower Nzhelele region (A8-2).

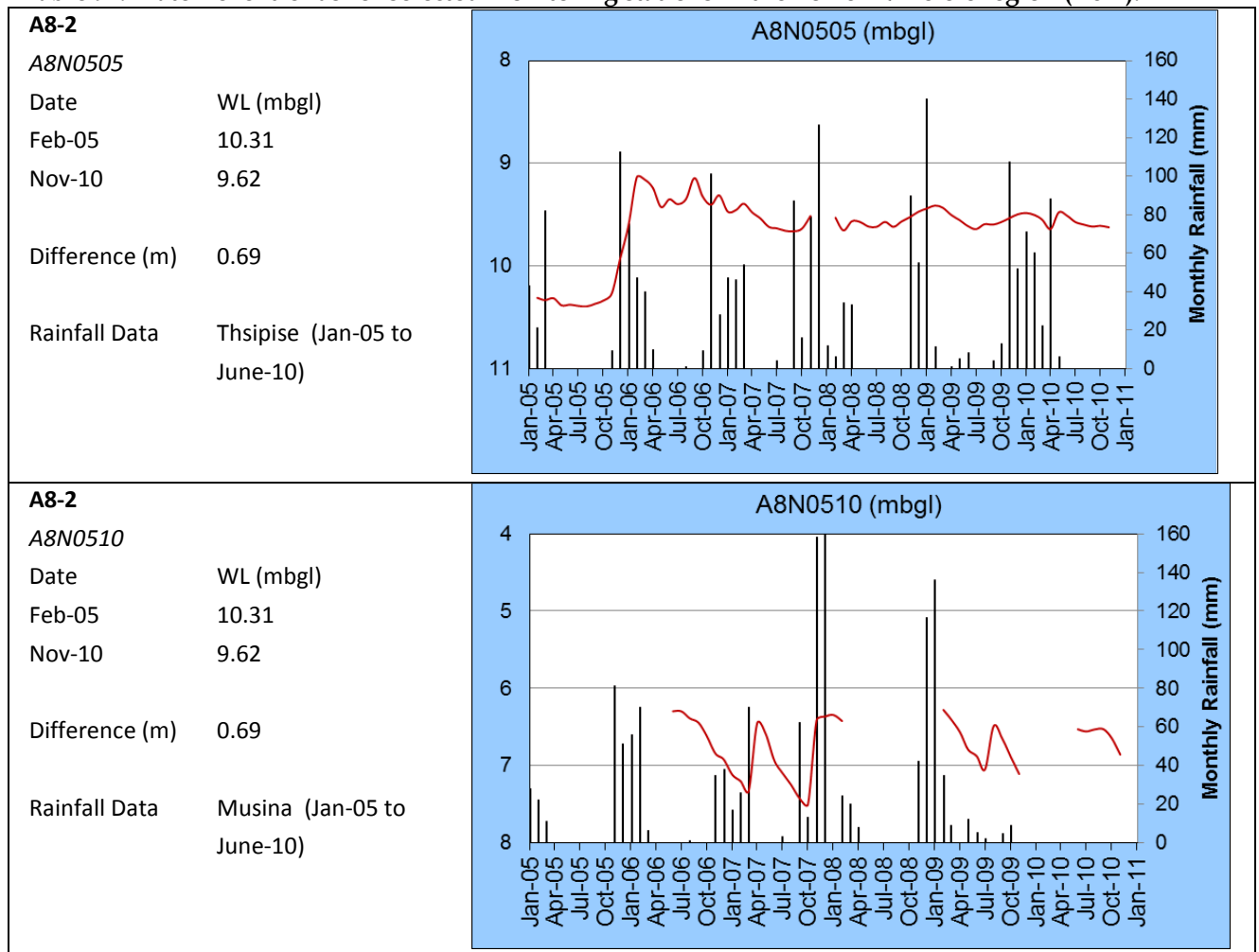


Table 93. Water level trends for selected monitoring stations in the Nwanedzi region (A8-3).

<p>A8-3 <i>A8N0514</i> Date WL (mbgl) Mar-07 1.87 Nov-10 1.99 Difference (m) -0.12 Rainfall Data Folonhodwe (Jan-05 to June-10)</p>	<p>A8N0514 (mbgl)</p>
<p>A8-3 <i>A8N0512</i> Date WL (mbgl) Jan-05 1.77 Nov-10 0.76 Difference (m) 1.01 Rainfall Data Folonhodwe (Jan-05 to June-10)</p>	<p>A8N0512 (mbgl)</p>
<p>A8-3 <i>A8N0506</i> Date WL (mbgl) Mar-06 17.65 Nov-10 19.15 Difference (m) -1.5 Rainfall Data Folonhodwe (Jan-05 to June-10)</p>	<p>A8N0506 (mbgl)</p>

4.8.2 Groundwater contribution to baseflow

Based on the groundwater-surface water classification described in section 2.7.5 the Nzhelele drainage region more specifically the Nzhelele River stretch can be classified as a porous media underlain by a semi-pervious layer. Along the lower reaches where the alluvium thinness or don exist at all the River stretch can be classified as localized interacting weathered hard rock system (Figure 4-25). Similarly groundwater-surface water interaction conditions may exist in the Nwanedzi drainage region. In both drainage areas seasonal alternating effluent / influent conditions can be experienced. Both analytical and numerical models could be applied to evaluate groundwater-surface water interaction.

The Soutpansberg Mountain range is an important area for groundwater recharge and drainage base flow. In the upper catchments groundwater contributes to base flow via sub surface seepage and springs. The probability of baseflow diminishes down-gradient towards the northeast. Comparison of groundwater contribution to baseflow estimates for the Nzhelele and Nwanedzi drainage region are summarised in Table 94. The hydrograph separation curve for station A8H014 is shown in Figure 4-26.

Table 94. Groundwater contribution to baseflow estimates.

Description	GUA	Quat	Hughes Mm ³ /a	Shultz Mm ³ /a	Pitmann Mm ³ /a	GRA II (WR2005) Mm ³ /a	Maint. Low flow Mm ³ /a	Specialist*/ Hydrograph# Mm ³ /a	Average Mm ³
Upper Nzhelele	A8-1	¹ A80A	15.60	2.62	8.90	2.30	4.80	5.90#	3.90
		A80B	4.66	1.23	3.31	1.98	1.24		2.28
		A80C	3.18	0.96	2.70	1.81	0.38		1.58
		A80D	1.98	0.57	1.43	0.99	0.52		1.01
		A80E	3.86	1.14	2.77	1.84	1.01		1.96
		A80F					0.01	0.30*	0.16
Lower Nzhelele	A8-2	A80G					0.02	0.40*	0.21
Nwanedzi	A8-3	¹ A80H	9.00	2.91		2.41	1.08	1.32*	1.93
		A80J					0.01	0.19*	0.10

¹ –Hughes excluded for the final estimate as it may overestimate the groundwater component to baseflow.

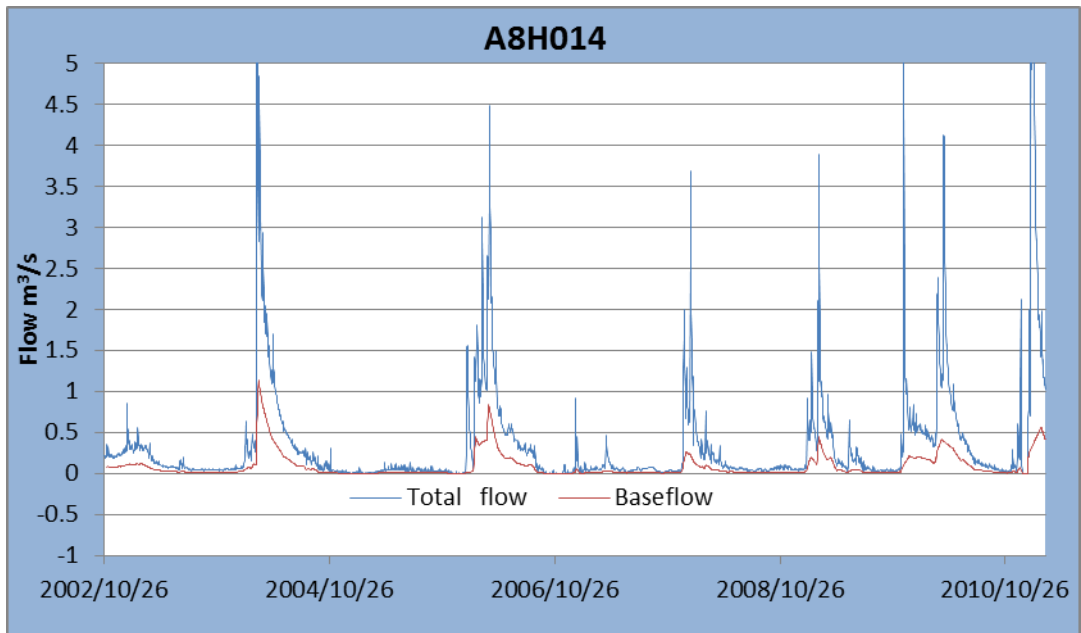


Figure 4-26. Baseflow separation for A8H014 (A80A).

4.8.3 Basic Human Needs (BHN)

Table 95. Basic human needs estimates.

GMA	GRU	Quat	Population*	BHN Estimate Mm ³
Upper Nzhelele	A8-1	A80A	87054	0.794
		A80B	84512	0.771
		A80C	28029	0.256
		A80D	13046	0.119
		A80E	12718	0.116
		A80F	5947	0.054
Lower Nzhelele	A8-2	A80G	7820	0.071
Nwanedzi	A8-3	A80H	12763	0.116
		A80J	16248	0.148

* - Based on 2001 statistics and the Limpopo ISP (DWA, 2004b).

4.8.4 Reserve determination summary

The Reserve assessment is firstly provided on a groundwater resource unit level in Table 96 and summarized for the Limpopo WMA on a quaternary level in Appendix A.

Table 96. Groundwater Reserve summary (Nzhelele and Nwanedzi region).

Description	GUA	Area (Km ²)	Recharge Mm ³	GW to Baseflow Mm ³	BHN Mm ³	Reserve Mm ³	Reserve as % of Recharge
Upper Nzhelele	A8-1	1837	55.44	10.90	2.11	13.01	23%
Lower Nzhelele	A8-2	1230	8.65	0.21	0.07	0.28	3%
Nwanedzi	A8-3	1136	9.70	2.03	0.26	2.30	24%

4.8.5 Groundwater use and availability

Groundwater use estimates vary significantly between the GRA II dataset and the recently validated WARMS dataset (Table 97). Apart for the Lower Nzhelele region, groundwater is generally under-utilized. It is likely that, with an adequate and even distribution of production boreholes in accessible portions of most catchments or aquifer systems, that the HP volumes or where abstraction exceeds the HP up to 65 % of Recharge may be annually abstracted on a sustainable basis. In cases where the HP is lower than the natural recharge it may provide a better estimate of the availability and further exploitation potential of groundwater.

Table 97. Groundwater availability and stress index (Nzhelele and Nwanedzi region).

GMA	GUA	Quat	RE Mm ³	Groundwater availability Mm ³ /a		Groundwater Use Mm ³ /a			GW Use as % of HP	Stress Index (GW Use as % of Recharge)
				HP	UGEP	GRA II Mm ³	WARMS (*validated)	Final Estimate		
Upper Nzhelele	A8-1	A80A	20.43	2.41	10.93	1.56	0.20	1.56	65%	8%
		A80B	9.30	2.14	4.84	0.85	0.38*	0.85	40%	9%
		A80C	8.71	2.45	2.64	0.27	0.04	0.27	11%	3%
		A80D	3.81	1.04	1.60	0.08	0.05	0.08	8%	2%
		A80E	7.75	1.99	4.40	0.38	1.76*	1.76	88%	23%
		A80F	5.44	4.73	5.70	0.09	0.25*	0.25	5%	5%
Lower Nzhelele	A8-2	A80G	8.65	5.24	5.02	0.14	3.18*	3.18	61%	37%
Nwanedzi	A8-3	A80H	6.19	1.75	3.04	0.12	0.05	0.12	7%	2%
		A80J	3.51	3.26	2.67	0.15	0.50	0.50	15%	14%

4.8.6 Groundwater quality

Based on the piper diagram the main water types for the Nzhelele and Nwanedzi region vary from a Ca/Mg-HCO₃, to a Na-Cl dominance (Figure 4-24). A number of samples relate to a fresh recharge type (Ca/Mg-HCO₃) water, while cation and anion exchange process may be occurring within the strata hence Na-Cl and Ca/Mg-Cl type water present.

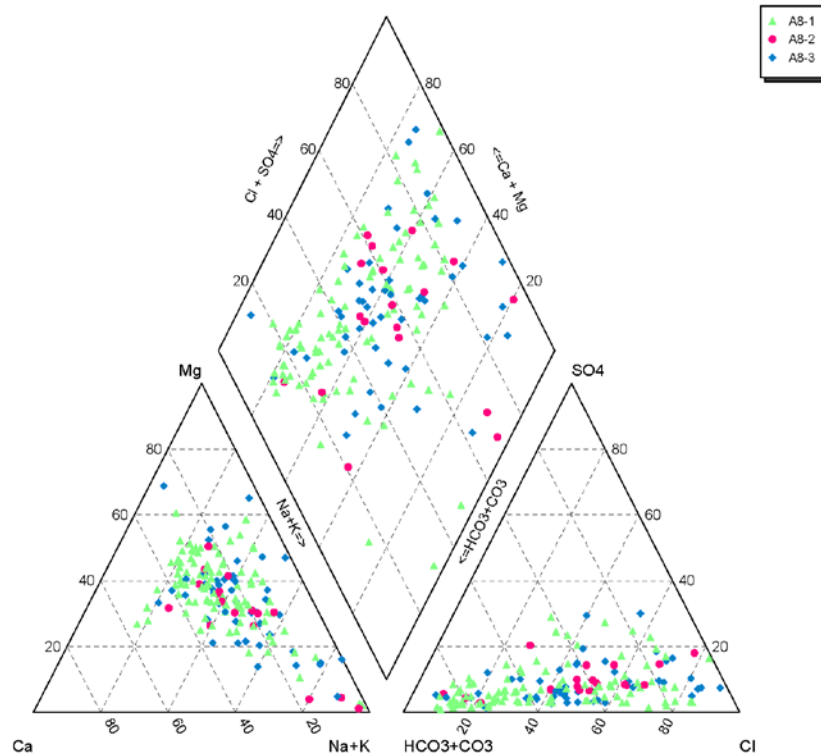


Figure 4-27. Piper diagram for the Nzhelele and Nwanedzi drainage region.

Groundwater quality in the Nzhelele and Nwanedzi region is considered to be poor with only a third of samples complying with the recommended drinking water quality standard. The most notable elements of concern include NO₃ as N with average concentrations above the recommended drinking limit (Table 98). In addition, several samples show major ion concentrations (e.g. Cl) and subsequently electric conductivities (EC) beyond acceptable limits. This can mostly be related to evaporative concentration of elements in discharge areas or due to low recharge values as well as long residence times for selected samples.

Table 98. Groundwater quality for the Nzhelele and Nwanedzi region (All units in mg/l, EC in mS/m).

GUA	Parameter	pH	EC	Ca	Mg	Na	K	SO ₄	Cl	NO ₃ as N	F	Compliance (% of samples within Class I)	Present Category
A8-1	Nr	189	188	183	183	183	114	185	188	138	184	65 %	II*
	Mean	7.7	102.4	51.5	51.0	82.8	1.9	27.3	158.8	9.4	0.4		
A8-2	Nr	25	25	21	21	21	19	22	25	16	25	36 %	III
	Mean	7.6	152.2	59.4	47.6	174.6	3.5	64.5	255.1	18.9	0.9		
A8-3	Nr	79	79	75	75	74	58	76	79	61	73	54 %	II*
	Mean	7.7	116.3	48.3	48.3	136.0	5.7	40.8	207.0	14.0	0.5		

Class I

Class II

Exceed Class II

* - Natural high chloride concentrations (reduced to Present Category II).

4.8.7 Final Categorisation

A summary of the categorisation for the Middle- and Lower Mogalakwena region is shown in Table 99.

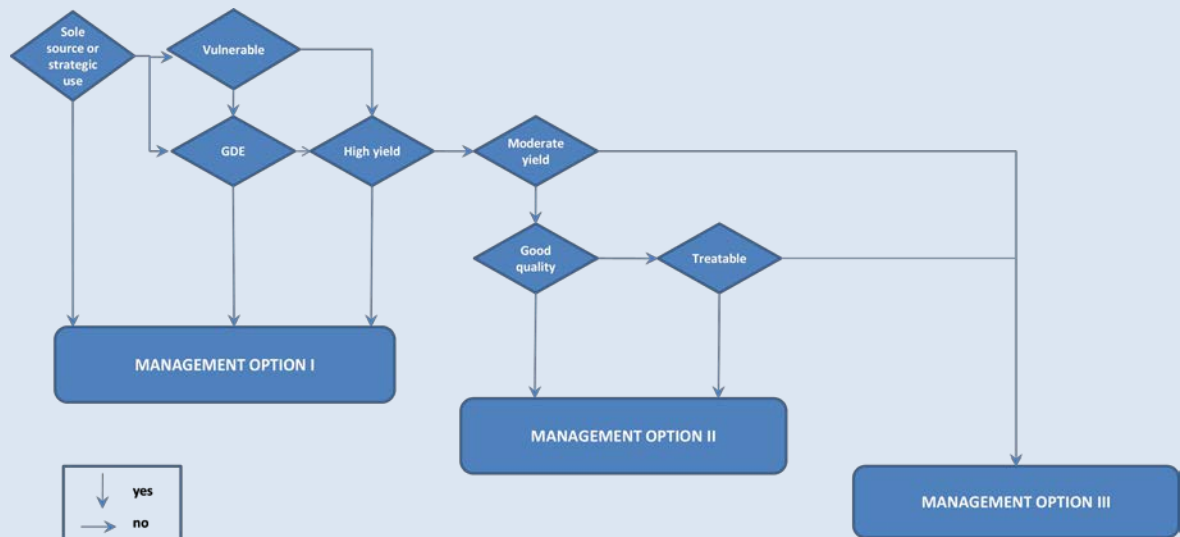
Table 99. Groundwater categorisation for each GUA (Nzhelele and Nwanedzi).

GMA	GUA	Area (Km ²)	Recharge Mm ³	Groundwater Use Mm ³ /a	Stress Index (SI)	Present Category (SI)	Present Category (Impact)	Present Category (Quality)
Upper Nzhelele	A8-1	1837	55.44	4.79	9%	I	I	II
Lower Nzhelele	A8-2	1230	8.65	3.18	37%	II	I	III
Nwanedzi	A8-3	1136	9.70	0.62	6%	I	I	II

5 MANAGEMENT OPTIONS AND RESOURCE QUALITY OBJECTIVES

Management Options

Monitoring forms an essential part of what must be a seamless process of managing the country's water resources. Monitoring essentially falls outside the GRDM process, but is required to ensure that the Reserve and Resource Quality Objectives are both realistic and are adhered to. Groundwater monitoring has the simple goal of quantifying the behaviour and response of groundwater systems to various controls and stressors (recharge, discharge, abstraction, etc.). Extensive monitoring already takes place, but both surface and groundwater monitoring programmes need to be revised and updated on a regular basis. However it is costly and labour intensive to monitor extensively. Considering that also moderate yielding aquifers can have a significant contribution to water supply schemes, it is proposed to combine the actual or potential importance of an aquifer and the groundwater quality to arrive at a recommended monitoring class for all aquifers as shown below.



The management options are defined according to table below.

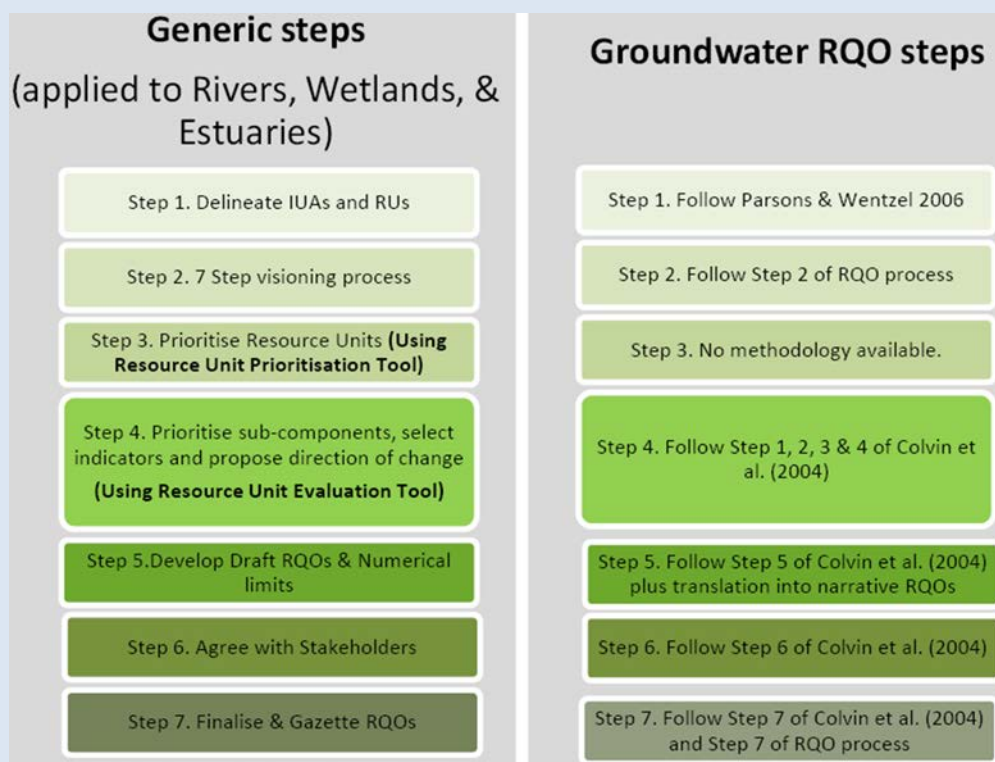
MANAGEMENT OPTION	RECOMMENDED MONITORING*
I	Monthly monitoring of groundwater levels and chemistry
II	Monitoring of groundwater levels and chemistry every 3 months.
III	Monitoring of groundwater levels and chemistry every 6 months

Water quality analysis should include the following parameters: pH, EC, Ca, Mg, Na, K, Palk, MAIk, F, Cl, Br, NO₃(N), PO₄, SO₄.

Resource Quality Objectives (RQOs)

RQOs must set objectives for the management of water resources in a catchment or other GUAs, (if applicable) and by its very nature be applicable on that scale. In general terms, RQOs establish clear goals relating to the quantity and quality of a water resource. They provide goals and objectives that frame the vision for sustainable use of a water resource, and hence form the basis for catchment decision-making and management. When setting RQOs, a balance must be found between the need to protect and sustain water resources on the one hand, and the need to develop and use them on the other.

Although no formal methodologies exist with respect to setting RQOs for the groundwater component. Guidelines and methodologies are documented in Colvin et al. (2004) and Parsons and Wentzel (2007). A generic process to develop and implement RQOs has been developed in 2011 (DWA, 2011). In the process groundwater is dealt with separately as not only are the Resource Units completely different to the surface water systems, so are the variables of concern. These processes have been aligned with the above mentioned guidelines but the most notable difference is the description of RQOs as narrative and with attendant Numerical Limits.



According to the National Water Resources Strategy (DWA, 2004) deals with RQOs for groundwater saying that “resource Quality Objectives for groundwater resources are considered crucial for the effective protection of groundwater. Numeric or descriptive statements for a groundwater resource will be set in order to guide the use and management thereof, typically these will relate to - groundwater levels or gradients (time and locality specific); groundwater abstraction rates; groundwater quality; spring flow; and targets for the health and terrestrial ecosystems that are dependent on groundwater”.

5.1 Matlabas region

The Matlabas catchment has non-perennial flow and is regarded as semi-pristine. Groundwater use is low and generally under-exploited (Table 100). Water supply allocations can be made from groundwater.

Table 100. Groundwater Reserve and categorisation for the Matlabas Region.

Description	GUA	Area (Km ²)	Recharge Mm ³	GW to Baseflow Mm ³	BHN Mm ³	Reserve Mm ³	GW Use Mm ³	*Allocable Mm ³	Final Present Category	Management Option
Upper Matlabas	A41-1	1050	25.53	6.33	0.11	6.44	1.37	8.78	I	III
Lower Matlabas	A41-2	3024	29.95	1.16	0.12	1.28	3.00	15.18	III	III
Steenbokpan	A41-3	1940	12.41	0.35	0.07	0.42	1.79	5.86	II	II

* - Taken as 65 % of Recharge minus (Reserve and groundwater use).

5.1.1 Upper and Lower Matlabas RQOs (A41-1 and A41-2)

- GUA A41-1 is largely covered by the Marikela Nature Reserve and as a result limited groundwater data (specifically quality) is available.
- For both A41-1 and A41-2 the groundwater potential is generally low and as a result groundwater is being under-utilised.
 - Based on the current groundwater use no significant impacts are likely and water levels appear to recover after wet periods.
 - Groundwater abstraction should be promoted but at the same time monitored for above normal fluctuations and declining trends.
- Ecological Reserve is relatively high for the upper GUA and is set at approximately 25 % of groundwater recharge.
 - Boreholes within close proximity of the river must be checked for abstraction volumes and the potential of these boreholes to impact on the hydraulic gradient towards the River course.
- Groundwater quality data indicate that only a third of all groundwater samples are within acceptable limits.
 - Further groundwater quality data is necessary to increase the limited dataset in GUA A41-1.
 - Water treatment might be required prior to use.

5.1.2 Steenbokpan RQOs (A41-3)

- The groundwater potential of this GUA is generally low; however, high yielding boreholes may be encountered in the confined Waterberg Group underlying the Karoo aquifer.

- The Steenbokpan area is part of the Lephalale coalfield and numerous mining developments are foreseen for this region. Although no declining water level trends are observed, any groundwater development should be managed and monitored to prevent depleting of groundwater resources.
- Groundwater quality data indicate that only a third of all groundwater samples are within acceptable limits.
 - Impacts on groundwater quality need to be addressed via groundwater monitoring programs and some concerted effort to address sources where they persist/occur.
 - Impacts caused by mining need to be identified and remediated if necessary. EMPR's need updating, closure plans required for mining to assess impacts of decant.

5.2 Mokolo Region

The Mokolo River system is perennial, however, the flow regime in the lower reaches have been modified extensively by releases of the Mokolo Dam. A preliminary high confidence Reserve for the Mokolo River system was determined in 2010. Overall the groundwater potential is considered to be moderate to poor, however groundwater potential of the confined Waterberg underlying the Karoo aquifer and the alluvial systems are considered good. Groundwater is generally underutilised in Middle and Lower Mokolo (Table 101).

Table 101. Groundwater Reserve and categorisation for the Mokolo region.

Description	GUA	Area (Km ²)	Recharge Mm ³	GW to Baseflow Mm ³	BHN Mm ³	Reserve Mm ³	GW Use Mm ³	*Allocable Mm ³	Final Present Category	Management Option
Upper Mokolo	A42-1	1095	33.96	14.97	0.05	15.02	9.02	0	II	II
	A42-2	3224	99.33	31.20	0.22	31.42	19.20	13.94	II	III
Middle Mokolo	A42-3	1207	26.40	2.59	0.02	2.61	0.13	14.42	III	II
Lower Mokolo	A42-4	2869	30.95	2.11	0.18	2.29	2.21	15.62	III	II

* - Taken as 65 % of Recharge minus (Reserve and groundwater use) 0 if allocable water is negative.

5.2.1 Upper Mokolo RQOs (A42-1 and A42-2)

- Although groundwater use amounts to a small percentage of recharge, the Reserve in A42-1 is relatively high at 44 % of Recharge. As a result no groundwater is allocable in this GUA based on current groundwater use estimates. Allocation of groundwater is possible in A42-2.
 - A detailed assessment on the sustainability of groundwater use is still required prior to large scale allocations.
 - Water levels recover after periods and no declining water level trends are observed for the Upper Mokolo.

- Boreholes within close proximity of the river must be checked for abstraction volumes and the potential of these boreholes to impact on the hydraulic gradient towards the River course.
- Groundwater quality data for indicate that 65 % and 87 % of groundwater samples for 42-1 and A42-2 respectively, are within acceptable limits and should be maintained.

5.2.2 Middle- and Lower Mokolo RQOs (A42-3 and A42-4)

- Due to the high rainfall variability and low recharge the groundwater potential are considered to be poor. Similar to the Matlabas region large groundwater yields can be obtained from the confined Waterberg aquifer or alluvial sediments along the Mokolo River. Although groundwater use is currently low and limited mainly along the River mining developments will increase the demand for groundwater.
 - Selected water level in A42-4 indicates a slight decreasing trend.
 - Any groundwater development should be managed and monitored to prevent depleting of groundwater resources.
- Groundwater quality data indicate that less than 20 % of groundwater samples are within acceptable limits. The most notable elements of concern are SO₄, Cl and NO₃ as N. The elevated SO₄ concentrations may be directly related to the mining activities.
 - Impacts on groundwater quality need to be addressed via groundwater monitoring programs and some concerted effort to address sources where they persist/occur.
 - Impacts caused by mining need to identified and remediated if necessary. Prevention measures must be put in place. EMPR's need updating, closure plans required for mining to assess impacts of decant. Monitoring programmes to be established and maintained.

5.3 Lephalala Region

The middle reaches of the Lephalala River consist of a wilderness area, while the dry lower reaches support irrigation from an alluvial aquifer and small weirs which are fed by the Lephalala River. Overall the groundwater potential is considered to be moderate and groundwater use occur extensively especially in the middle and lower GUAs of the Lephalala region (Table 102).

5.3.1 Upper Lephalala RQOs (A50-1)

- Most of the Lephalala ecological Reserve volumes are required in this GUA. The region is of high conservation value and development should be limited to maintain this important conservation.

- Despite the relatively high Reserve component groundwater is being underutilised and based on the current groundwater use no significant impacts are likely. Water levels appear to recover after wet periods.
- Groundwater quality data indicate that almost half of the groundwater samples are within acceptable limits and should be maintained. The element of concern is NO₃ as N.
 - Impacts on groundwater quality need to be addressed via groundwater monitoring programs and some concerted effort to address sources where they persist/occur.

Table 102. Groundwater Reserve and categorisation for the Lephalala region.

Description	GUA	Area (Km ²)	Recharge Mm ³	GW to Baseflow Mm ³	BHN Mm ³	Reserve Mm ³	GW Use Mm ³	*Allocable Mm ³	Final Present Category	Management Option
Upper Lephalala	A50-1	2704	69.27	14.95	0.04	14.99	5.43	24.60	II	III
Middle Lephalala	A50-2	821	7.16	0.25	0.30	0.55	0.67	3.44	III	I
Lower Lephalala	A50-3	1945	11.49	0.46	0.33	0.80	8.44	0	III	II
Limpopo Stem	A50-4	1255	9.29	0.61	0.02	0.63	3.83	1.58	III	II

* - Taken as 65 % of Recharge minus (Reserve and groundwater use) 0 if allocable water is negative.

5.3.2 Middle- and Lower Lephalala RQOs (A50-2 to A50-3)

- The Lephalala River forms a main source of water supply to hundreds of rural communities distributed densely along the River banks and for the irrigation sector.
 - The groundwater potential is generally moderate and as a result groundwater is used extensively, especially in GUA A50-3. Water levels have shown declining trends for the last couple of years and as far back as the late 1980s.
 - Any groundwater development in A50-3 should be managed and monitored to prevent depleting of groundwater resources.
 - Groundwater use should be verified and validated. Compulsory licensing should be introduced.
- Further groundwater development is potentially possible in GUA A50-2 however; any additional allocations should consider existing groundwater use in both time and space.
- Groundwater quality data in both A50-2 and A50-3 is poor with less than 10 %of groundwater samples within acceptable limits. The most notable elements of concern are NO₃ as N and F. Nitrate concentrations exceed the maximum allowable drinking limit for both A50-2 and A50-3.
 - Groundwater is the only source of water for many communities. Impacts on groundwater quality need to be addressed via groundwater monitoring programs and some concerted effort to address sources where they persist/occur.
 - In certain irrigation areas the application of fertiliser should be better managed.

- Numerous iron ore exploration activities have been undertaken in the area. Impacts caused by mining need to be identified and remediated if necessary. Prevention measures must be put in place

5.3.3 Limpopo Stem (Lephalala) RQOs (A50-4)

- Due to the high rainfall variability and low recharge the allocation of large scale groundwater abstraction is not advised. Groundwater is used extensively and further development may lead to declining water levels.
 - The monitoring of water levels is advised for this GUA. Currently no water level monitoring equipment is installed in this GUA.
- Groundwater quality data in both A50-4 is poor with less than 5 % of groundwater samples within acceptable limits. The most notable elements of concern are NO₃ as N and F. Nitrate concentrations exceed the maximum allowable drinking limit.
 - Impacts on groundwater quality need to be addressed via groundwater monitoring programs and some concerted effort to address sources where they persist/occur.

5.4 Upper Mogalakwena Region

The Nylsvley in the south-western region of the Upper Mogalakwena is the only proclaimed RAMSAR site in the Limpopo WMA. Groundwater is extensively used and any further development of groundwater should be based on a proper aquifer management plan (Table 103). In addition the two subterranean government water control areas namely, the Nyl River Valley and Dorps River Valley should be converted into Water User's Association (WUA). Through the establishment of a WUA measures could be introduced to reduce private groundwater abstraction and will encourage all groundwater users to register and license their usage.

Table 103. Groundwater Reserve and categorisation for the Upper Mogalakwena region.

Description	GUA	Area (Km ²)	Recharge Mm ³	GW to Baseflow Mm ³	BHN Mm ³	Reserve Mm ³	GW Use Mm ³	*Allocable Mm ³	Final Present Category	Management Option
Nyl River Valley	A61-1	2333	63.67	8.82	0.49	9.31	16.23	15.85	II	I
Doordraai	A61-2	1403	44.27	11.28	0.03	11.31	14.22	3.24	III	III
Dorps River Valley	A61-3	1716	37.11	6.49	1.94	8.43	16.73	0	III	I

* - Taken as 65 % of Recharge minus (Reserve and groundwater use) 0 if allocable water is negative.

5.4.1 Nyl River- and Dorps River Valley (A61-1 and A61-3)

- Indications are that most of the groundwater resources in the two GUA are heavily utilised. Some water level has declined steadily since the mid-1980s. A number of local cone of depression have formed surrounding abstraction boreholes for large scale irrigation.
 - Although water levels are extensively being monitored, the management of the aquifer is largely dependent on the interpretation of the results and decision making regarding a reduction in groundwater abstraction.
- Based on the Reserve estimates further groundwater allocation is not recommended in the Dorps River Valley. Although groundwater is potentially available for development in the Nyl River Valley (A61-1) the allocation of large quantities of groundwater is not recommended without a detailed aquifer management plan.
 - In this regard compulsory licensing is recommended for both GUAs.
- Groundwater quality data in the Nyl River Valley is slightly better compared to the Dorps River Valley where only a quarter of samples comply with the recommended drinking water quality limit. Elements of concern are NO₃ as N and F.
 - Impacts on groundwater quality need to be addressed via groundwater monitoring programs and some concerted effort to address sources where they persist/occur.

5.4.2 Doorndraai RQOs (A61-2)

- The Doorndraai have a relatively high Reserve of 26 % of recharge. Groundwater use occurs throughout the region mainly for irrigation and domestic use.
 - Currently only one water level monitoring logger is installed in this GUA. The monitoring of water levels should be expanded for this GUA.
- Further groundwater development is potentially possible in GUA A50-2 however; any additional allocations should consider existing groundwater use in both time and space.
- Limited groundwater quality data is available for the GUA and should be augmented with sampling programmes. Based on the limited dataset only 20 % of groundwater samples are within acceptable drinking limits.
 - Impacts on groundwater quality need to be addressed via groundwater monitoring programs and some concerted effort to address sources where they persist/occur.

5.5 Middle- and Lower Mogalakwena Region

The groundwater potential of the Middle- and Lower Mogalakwena is moderate to high and as a result groundwater has been developed extensively (Table 104). The middle reaches of the region is densely populated by rural communities, while a number of mines also occur. Large scale irrigation from groundwater abstraction occurs in the lower reaches of the Mogalakwena drainage region.

Although future groundwater allocations are probable it should consider the preliminary Reserve estimation and the distribution of current groundwater abstraction in both time and space.

Table 104. Groundwater Reserve and categorisation for the Middle- and Lower Mogalakwena region.

Description	GUA	Area (Km ²)	Recharge Mm ³	GW to Baseflow Mm ³	BHN Mm ³	Reserve Mm ³	GW Use Mm ³	*Allocable Mm ³	Final Present Category	Management Option
Middle Mogalakwena	A62-1	2126	44.15	7.14	0.95	8.09	4.19	16.41	III	II
	A62-2	1241	13.79	0.75	1.05	1.80	1.89	5.0	III	III
	A62-3	2428	24.65	1.20	0.79	1.99	0.77	13.27	III	III
Lower Mogalakwena	A63-1	4752	35.05	0.41	0.90	1.31	14.35	7.12	III	II
Limpopo Stem (Mogalakwena)	A63-2	1323	9.21	0.84	0.09	0.93	1.76	3.3	III	II

* - Taken as 65 % of Recharge minus (Reserve and groundwater use) 0 if allocable water is negative.

5.5.1 Middle Mogalakwena RQOs (A62-1 and A62-3)

- Based on the current groundwater use no significant impacts are likely and water levels appear to recover after wet periods.
 - Groundwater abstraction should be promoted but at the same time monitored for above normal fluctuations and declining trends.
- Groundwater quality data in the Middle Mogalakwena is considered poor with less than a third of groundwater samples within acceptable drinking limits. The most notable elements of concern are NO₃ as N, F and Cl.
 - Impacts on groundwater quality need to be addressed via groundwater monitoring programs and some concerted effort to address sources where they persist/occur.
 - Implement strategy of education and training to protect borehole head areas from water spillage, damage by cattle drinking, etc.
 - Water treatment is required prior to use.

5.5.2 Lower Mogalakwena RQOs (A63-1)

- Groundwater is extensively used in this GUA and more specifically quaternary catchment A63A. Groundwater use estimates far exceeds the harvest potential and equals the volume of natural recharge.
 - Water levels have declined steadily throughout the last couple of years despite above average rainfall.
 - Further groundwater development is potentially possible in selected areas however; any additional allocations should consider existing groundwater use in both time and space.

- Groundwater use estimates should be verified and where necessary abstraction rates should be cut back. It is also recommended that quaternary catchment A63A (within GUA A63-1) be considered for compulsory licensing.
- Groundwater quality data in the Lower Mogalakwena is considered poor with less than a third of groundwater samples within acceptable drinking limits. The most notable elements of concern are NO₃ as N, F and Cl.
 - Impacts on groundwater quality need to be addressed via groundwater monitoring programs and some concerted effort to address sources where they persist/occur.
 - Water treatment is required prior to use in some instances.

5.5.3 Limpopo stem (Mogalakwena) RQOs (A63-2)

- Due to the high rainfall variability and low recharge new allocation of groundwater abstraction should take into consideration existing groundwater use and the sustainability of the groundwater resource. Large volumes groundwater use occurs mainly in the vicinity of the Limpopo River.
 - Based on the limited short term data water levels appear to recover after wet periods.
- Groundwater quality is poor with less than 10 % of samples within acceptable drinking limits. The most notable elements of concern are NO₃ as N and F.
 - Impacts on groundwater quality need to be addressed via groundwater monitoring programs and some concerted effort to address sources where they persist/occur.
 - Water treatment is required prior to use.
 - Pollution of groundwater by mining effluent and acid mine drainage. The possibility of decant from the old mine at Musina must be considered and any impacts identified and remediated. Although, Venetia mine is ecologically aware and undesirable impacts are unlikely. Nevertheless, the potential for impacts caused by mining needs to be recognised and prevention measures put in place.

5.6 Upper Sand Region

The groundwater potential of the Upper Sand River is exceptional and have sustained “supposedly sustainable” water supply to a number of towns and rural communities through the region, in addition to large scale irrigation in the lower reaches of the Upper Sand catchment (Table 105). There is a very real concern that the groundwater resource has been over-exploited and more attention should be given in management of the resource.

Table 105. Groundwater Reserve and categorisation for Upper Sand region.

Description	GUA	Area (Km ²)	Recharge Mm ³	GW to Baseflow Mm ³	BHN Mm ³	Reserve Mm ³	GW Use Mm ³	*Allocable Mm ³	Final Present Category	Management Option
Upper Sand	A7-1	2026	23.04	0.66	2.98	3.64	47.31	0	III	I
Middle Sand	A7-2	3235	29.18	0.67	1.43	2.10	27.29	0	III	II
Hout en Brak	A7-3	4359	25.50	1.77	2.00	3.77	24.80	0	III	I

* - Taken as 65 % of Recharge minus (Reserve and groundwater use) 0 if allocable water is negative.

5.6.1 Upper- and Middle Sand RQOs (A7-1 and A7-2)

- Despite a deficit between groundwater use and recharge observed for the Upper Sand GUA (A7-1), the system haven't shown any regional water level declines of great proportions since the onset of monitoring in some cases dating back to the mid-1970s. However, selected monitoring stations show extreme water fluctuations in excess of 20 m suggesting the impact of anthropogenic abstraction. Water level fluctuations observed in the Middle Sand GUA (A7-2) is les compared to Upper Sand GUA. Similarly some water levels have increased since the onset of monitoring while others have decreased.
 - To sustain the current groundwater abstraction volumes a detailed monitoring network coupled with a proper groundwater management plan for both GUAs are required.
- Groundwater quality in the Upper Sand GUA is considered to be moderate to poor with 41 % of samples within acceptable drinking limits, while for the Middle Sand GUA only 24 % comply with the recommended drinking water quality limit. In both GUAs Nitrate is the element of concern.
 - Impacts on groundwater quality need to be addressed via groundwater monitoring programs and some concerted effort to address sources where they persist/occur.
 - Implement strategy of education and training to protect borehole head areas from water spillage, damage by cattle drinking, etc.
 - Water treatment is required prior to use.

5.6.2 Hout en Brak RQOs (A7-3)

- Indications are that most of the groundwater resources in this GUA are heavily utilised. Water levels have declined steadily since the early 1980s. A number of local cone of depression have formed surrounding abstraction boreholes for large scale irrigation.
 - The GUA is largely covered by the Dendron-Vivo subterranean government water control area. As a result very limited recent groundwater data is available from these private farms.

- Monitoring of water levels in this unit is insufficient and a monitoring programme should be one of the first management priorities for the region.
- In this regard the Dendron-Vivo area should be converted into a Water User's Association (WUA). Through the establishment of a WUA measures could be introduced to reduce private groundwater abstraction and will encourage all groundwater users to register and license their usage. In this regard compulsory licensing is recommended for the GUAs.
- Many rural communities including the town of Senwabarwana are dependent on groundwater and should form part of the planning of future aquifer management strategies (WUA area need to incorporate the communal lands). As a result the delineated area should extend to include quaternary catchment A72A. As a result General Authorisations should be excluded.
- Groundwater quality in the Hout en Brak GUA is considered to be poor with only 34 % of samples within acceptable drinking limits. Elements of concern are NO₃ as N and Cl.
 - Impacts on groundwater quality need to be addressed via groundwater monitoring programs and some concerted effort to address sources where they persist/occur.
 - Water treatment is required prior to use.

5.7 Lower Sand and Limpopo tributaries Region

The area is mostly agricultural with arable land and stock farming. Irrigation is practiced along the Limpopo River areas, especially on the old flood plains. Groundwater potential is generally low but is significant in the alluvial deposits along the Limpopo- and Sand Rivers. The Limpopo tributaries GUA (A6/7-3) is known to have groundwater dependent vegetation and is ecologically sensitive, however baseflow is virtually absent and hence natural recharge must be lost through riverine vegetation.

Groundwater use estimates exceeds the rate of natural recharge and is reason for concern ((Table 106).

Table 106. Groundwater Reserve and categorisation for Lower Sand region.

Description	GUA	Area (Km ²)	Recharge Mm ³	GW to Baseflow Mm ³	BHN Mm ³	Reserve Mm ³	GW Use Mm ³	*Allocable Mm ³	Final Present Category	Management Option
Lower Sand	A7-4	2716	23.70	0.92	1.24	2.16	16.30	0	III	II
	A7-5	1668	9.79	0.76	0.03	0.79	10.71	0	III	II
Limpopo Tributaries	A6/7-3	3757	17.78	0.85	0.09	0.94	45.42	0	III	II

* - Taken as 65 % of Recharge minus (Reserve and groundwater use) 0 if allocable water is negative.

5.7.1 Lower Sand RQOs (A7-4 and A7-5)

- Based on the current groundwater use significant impacts are likely although most short term water levels appear to recover after wet periods. However, selected monitoring stations do

show a decline in water levels over the last couple of years. A 25 m drop in water level has been recorded 1928 and 1980 as noted by Fayazi et al. (1981).

- Groundwater use should be validated and verified before any further large scale groundwater allocations are made. Based on the current dataset allocations of groundwater are not possible without a potential impact on the Reserve.
- Based on the limited groundwater quality data in the Lower Sand GUA the water quality can be regarded as poor with the majority of samples exceeding the recommended drinking water quality limit. Elements of concern include Na, Cl, NO₃ as N and F.
 - Impacts on groundwater quality need to be addressed via groundwater monitoring programs and some concerted effort to address sources where they persist/occur.
 - Water treatment is required prior to use.

5.7.2 Limpopo Tributaries RQOs (A7-3)

- Uncontrolled abstraction from the alluvial aquifer and Karoo aquifers could have adverse impacts on the vegetation of area.
 - Groundwater use should be validated and verified. In the longer term, if can be shown that the groundwater resource has been over-exploited, compulsory licensing may be required in order to reduce abstractions from groundwater to sustainable levels.
 - Indications of declining water levels are observed at selected monitoring stations. The reporting of monitoring data should be a regarded as a priority and where data is lacking the monitoring programme should be expanded.
- Groundwater quality in GUA A6/7-3 can be regarded as poor with only 34 % within the recommended drinking water quality limit. Elements of concern include Na, Cl, NO₃ as N and F.
 - Impacts on groundwater quality need to be addressed via groundwater monitoring programs and some concerted effort to address sources where they persist/occur.
 - Water treatment is required prior to use.

5.8 Nzhelele and Nwanedzi Region

The region comprises mostly agricultural land and game farms, while in the upper reaches of the regions the area comprises communal lands. There is widespread use of groundwater but many of the communities are supplied with conjunctive schemes using surface water together with groundwater as the source (Table 107).

Table 107. Groundwater Reserve and categorisation for the Nzhelele and Nwanedzi region.

Description	GUA	Area (Km ²)	Recharge Mm ³	GW to Baseflow Mm ³	BHN Mm ³	Reserve Mm ³	GW Use Mm ³	*Allocable Mm ³	Final Present Category	Management Option
Upper Nzhelele	A8-1	1837	55.44	10.90	2.11	13.01	4.79	18.24	II	II
Lower Nzhelele	A8-2	1230	8.65	0.21	0.07	0.28	3.18	2.15	III	II
Nwanedzi	A8-3	1136	9.70	2.03	0.26	2.30	0.62	3.39	II	II

* - Taken as 65 % of Recharge minus (Reserve and groundwater use) 0 if allocable water is negative.

5.8.1 Nzhelele RQOs (A8-1 and A8-2)

- Based on the current groundwater use no significant impacts are likely and water levels appear to recover after wet periods.
 - Groundwater abstraction should be promoted but at the same time monitored for above normal fluctuations and declining trends.
- Springs are an important source of water supply for rural communities in the Upper Nzhelele GUA (A8-1).
 - Springs must be protected by establishing protection zones of the most prolific water supply springs.
- Groundwater quality in the Upper Nzhelele GUA is considered to be moderate with 63 % of samples within acceptable drinking limits, while for the Lower Nzhelele only 36 % comply with the recommended drinking water quality limit. In the latter GUAs Cl and NO₃ as N are the elements of concern.
 - Impacts on groundwater quality need to be addressed via groundwater monitoring programs and some concerted effort to address sources where they persist/occur.
 - Implement strategy of education and training to protect borehole head areas from water spillage, damage by cattle drinking, etc.
 - Future mining activities (mainly coking coal) need to have EMPRs in place with closure plans in addition to monitoring programmes.

5.8.2 Nwanedzi RQOs (A8-3)

- Based on the current groundwater use no significant regional impacts are likely. Water level declines have been observed but appear to be local.
 - Groundwater abstraction should be promoted but at the same time monitored for above normal fluctuations and declining trends.
- Groundwater quality in the Nwanedzi GUA is considered to be moderate with 54 % of samples within acceptable drinking limits. Elements of concern are NO₃ as N and Cl.
 - Impacts on groundwater quality need to be addressed via groundwater monitoring programs and some concerted effort to address sources where they persist/occur.

6 CONCLUSIONS AND RECOMMENDATIONS

Some of the greatest groundwater needs in South Africa occur in the Limpopo WMA and groundwater is the only dependable source of water for many users. Groundwater is available and widely used throughout the WMA, but in varying quantities depending upon the hydrogeological characteristics of the underlying aquifer. The WMA is dominated by Intergranular and fractured aquifer systems with borehole yields between 0.1 and > 5 l/s. The groundwater potential of certain areas (e.g. Mogwadi, Baltimore, Tolwe, Polokwane and the Dorps River Valley) is exceptional and as a result has been exploited extensively. In certain cases a real threat of over-exploitation exists and serious management intervention is needed.

In order to support the process of water use licensing while at the same time giving effect to the Reserve, the Department of Water Affairs have requested a Groundwater Reserve assessment for the Limpopo Water Management Area (WMA). A summary of the Limpopo WMA groundwater reserve and categorization is presented in Table 108. A total of 28 groundwater unit of analysis (GUA) were delineated based primarily on the secondary drainage regions and considering geological and hydrogeological aspects. Based on the Reserve assessment results and groundwater use estimates no further groundwater allocations in 9 GUA should be made without further data collection, validation and verification. On the other hand groundwater is underutilised in a number of GUA. The most notable GUAs are the Upper- and Lower Matlabas, Steenbokpan (mining will largely influence the future availability), Middle- and lower Mokolo, Upper Lephalala, Middle Mogalakwena, portion of the Lower Mogalakwena, Upper Nzhelele and Nwanedzi. The Reserve as percentage of mean annual recharge varies between 3 and 44 % with a decrease down gradient from the higher lying to the lower reaches of the Limpopo WMA.

Groundwater quality in the Limpopo WMA is cause for concern which may lead to a large reduction in the exploitation potential of groundwater resources due to water qualities exceeding drinking limits. The impact of groundwater pollution from mining and waste disposal can be controlled and remediated according to the requirements of DWA. Mines and waste disposal sites must prepare EMPRs, EIAs and closure plans which will identify and put preventative and remediation measures, including monitoring, in place. Pollution emanating from settlements, especially rural communities, is more difficult to control. Elevated nitrate levels in groundwater are extensively found in water supply boreholes throughout the Limpopo WMA. The impacts on groundwater quality need to be addressed via groundwater monitoring programs and some concerted effort to address sources where they persist/occur. Groundwater must be abstracted from outside possible impacted areas, i.e., boreholes and well fields have to be located well away from potential pollution sources. In this regard, standards for borehole positioning, construction and protection, as specified by DWAF and the SABS, must be enforced. Further, education about the need for, and ways of, protecting the groundwater resources is required.

Table 108. Summary of the groundwater Reserve and categorisation for the Limpopo WMA.

Description	GUA	Area (Km ²)	Recharge Mm ³	GW to Baseflow Mm ³	BHN Mm ³	Reserve Mm ³	Reserve as % of Recharge	Groundwater Use Mm ³ /a	Stress Index (SI)	*Allocable Mm ³	Final Present Category	Management Option
Upper Matlabas	A41-1	1050	25.53	6.33	0.11	6.44	25%	1.37	5%	8.78	I	III
Lower Matlabas	A41-2	3024	29.95	1.16	0.12	1.28	4%	3.00	10%	15.18	III	III
Steenbokpan	A41-3	1940	12.41	0.35	0.07	0.42	3%	1.79	14%	5.86	II	II
Upper Mokolo	A42-1	1095	33.96	14.97	0.05	15.02	44%	9.02	27%	0	II	II
	A42-2	3224	99.33	31.20	0.22	31.42	32%	19.20	19%	13.94	II	III
Middle Mokolo	A42-3	1207	26.40	2.59	0.02	2.61	10%	0.13	1%	14.48	III	II
Lower Mokolo	A42-4	2869	30.95	2.11	0.18	2.29	7%	2.21	7%	17.00	III	II
Upper Lephhalala	A50-1	2704	69.27	14.95	0.04	14.99	22%	5.43	8%	24.60	II	III
Middle Lephhalala	A50-2	821	7.16	0.25	0.30	0.55	8%	0.67	9%	3.44	III	I
Lower Lephhalala	A50-3	1945	11.49	0.46	0.33	0.80	7%	8.44	73%	0	III	II
Limpopo Stem	A50-4	1255	9.29	0.61	0.02	0.63	7%	3.83	41%	1.58	III	II
Nyl River Valley	A61-1	2333	63.67	8.82	0.49	9.31	15%	16.23	25%	15.85	II	I
Doordraai	A61-2	1403	44.27	11.28	0.03	11.31	26%	14.22	45%	3.24	III	III
Dorps River Valley	A61-3	1716	37.11	6.49	1.94	8.43	23%	16.73	32%	0	III	I
Middle Mogalakwena	A62-1	2126	44.15	7.14	0.95	8.09	18%	4.19	10%	16.41	III	II
	A62-2	1241	13.79	0.75	1.05	1.80	13%	1.89	16%	5.0	III	III
	A62-3	2428	24.65	1.20	0.79	1.99	8%	0.77	3%	13.27	III	III
Lower Mogalakwena	A63-1	4752	35.05	0.41	0.90	1.31	4%	14.35	41%	7.12	III	II
Limpopo Stem (Mogalkwena)	A63-2	1323	9.21	0.84	0.09	0.93	10%	1.76	19%	3.3	III	II
Upper Sand	A7-1	2026	23.04	0.66	2.98	3.64	16%	47.31	205%	0	III	I
Middle Sand	A7-2	3235	29.18	0.67	1.43	2.10	7%	27.29	94%	0	III	II
Hout en Brak	A7-3	4359	25.50	1.77	2.00	3.77	15%	24.80	97%	0	III	I
Lower Sand	A7-4	2716	23.70	0.92	1.24	2.16	9%	16.30	69%	0	III	II
	A7-5	1668	9.79	0.76	0.03	0.79	8%	10.71	109%	0	III	II
Limpopo Tributaries	A6/7-3	3757	17.78	0.85	0.09	0.94	5%	45.42	256%	0	III	II
Upper Nzhelele	A8-1	1837	55.44	10.90	2.11	13.01	23%	4.79	9%	18.24	II	II
Lower Nzhelele	A8-2	1230	8.65	0.21	0.07	0.28	3%	3.18	37%	2.15	III	II
Nwanedzi	A8-3	1136	9.70	2.03	0.26	2.30	24%	0.62	6%	3.39	II	II

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APPENDIX A – Reserve assessment sheet (based on quaternary level)

GUA	Quat	Area (Km ²)	Recharge Mm ³	GW to Baseflow Mm ³	BHN Mm ³	Reserve as % of Recharge	Groundwater Use Mm ³ /a	GW Use as % of Recharge
A41-1	A41A	692	17.66	4.75	0.062	27%	1.22	7%
A41-1	A41B	358	7.86	1.58	0.047	21%	0.15	2%
A41-2	A41C	1111	13.23	0.62	0.071	5%	0.25	2%
A41-2	A41D	1913	16.71	0.54	0.050	4%	2.76	16%
A41-3	A41E	1940	12.41	0.35	0.072	3%	1.79	14%
A42-1	A42A	573	18.19	7.66	0.016	42%	4.56	25%
A42-1	A42B	522	15.77	7.31	0.031	47%	4.47	28%
A42-2	A42C	698	27.02	9.38	0.055	35%	5.51	20%
A42-2	A42D	497	16.86	7.39	0.024	44%	2.93	17%
A42-2	A42E	1007	32.98	10.64	0.122	33%	8.10	25%
A42-2	A42F	1022	22.46	3.79	0.018	17%	2.66	12%
A42-3	A42G	1207	26.40	2.59	0.020	10%	0.13	1%
A42-4	A42H	1057	18.15	1.56	0.158	9%	0.09	< 1%
A42-4	A42J	1812	12.81	0.55	0.026	4%	2.12	17%
A50-1	A50A	298	12.95	3.57	0.008	28%	2.73	21%
A50-1	A50B	406	13.52	5.04	0.006	37%	0.80	6%
A50-1	A50C	362	11.00	3.16	0.010	29%	1.22	11%
A50-1	A50D	637	13.95	1.82	0.006	13%	0.17	1%
A50-1	A50E	629	11.71	0.88	0.005	8%	0.37	3%
A50-1	A50F	372	6.14	0.48	0.004	8%	0.14	2%
A50-2	A50G	821	7.16	0.25	0.305	8%	0.67	9%
A50-3	A50H	1945	11.49	0.46	0.332	7%	8.44	73%
A50-4	A50J	1255	9.29	0.61	0.024	7%	3.83	41%
A61-1	A61A	381	12.41	2.15	0.378	20%	2.29	18%
A61-1	A61B	362	11.10	1.51	0.018	14%	0.63	6%
A61-1	A61C	587	15.40	1.67	0.019	11%	2.11	14%
A61-1	A61D	456	12.63	1.82	0.072	15%	2.69	21%
A61-1	A61E	547	12.12	1.66	0.005	14%	8.50	70%
A61-3	A61F	789	17.80	3.12	1.008	23%	11.76	66%
A61-3	A61G	927	19.31	3.36	0.935	22%	4.97	26%
A61-2	A61H	585	19.99	4.89	0.018	25%	6.26	31%
A61-2	A61J	818	24.28	6.39	0.011	26%	7.96	33%

GUA	Quat	Area (Km ²)	Recharge Mm ³	GW to Baseflow Mm ³	BHN Mm ³	Reserve as % of Recharge	Groundwater Use Mm ³ /a	GW Use as % of Recharge
A62-1	A62A	428	12.16	3.90	0.133	33%	2.88	24%
A62-1	A62B	710	14.74	1.40	0.513	13%	0.54	4%
A62-1	A62C	385	6.71	0.62	0.207	12%	0.13	2%
A62-1	A62D	603	10.54	1.22	0.096	12%	0.65	6%
A62-2	A62E	621	6.66	0.34	0.706	16%	0.79	12%
A62-2	A62F	620	7.12	0.41	0.344	11%	1.36	19%
A62-3	A62G	627	6.83	0.14	0.207	5%	0.28	4%
A62-3	A62H	871	8.64	0.40	0.429	10%	0.48	6%
A62-3	A62J	930	9.18	0.67	0.151	9%	0.38	4%
A63-1	A63A	1928	11.64	0.03	0.383	4%	10.97	94%
A63-1	A63B	1505	11.06	0.02	0.256	2%	1.35	12%
A63-1	A63D	1319	12.35	0.37	0.262	5%	2.02	16%
A63-2	A63C	1323	9.21	0.84	0.089	10%	1.76	19%
A7-1	A71A	1144	13.56	0.34	1.557	14%	27.34	202%
A7-1	A71B	882	9.48	0.32	1.427	18%	4.58	48%
A7-2	A71C	1331	11.09	0.26	1.208	13%	5.93	53%
A7-2	A71D	892	4.64	0.19	0.020	5%	4.41	95%
A7-2	A71H	1012	13.44	0.22	0.199	3%	16.95	126%
A7-3	A71E	893	6.66	0.59	0.830	21%	4.74	71%
A7-3	A71F	683	4.38	0.39	0.572	22%	9.51	217%
A7-3	A71G	875	6.23	0.24	0.568	13%	8.46	136%
A7-3	A72A	1908	8.23	0.55	0.027	7%	2.10	25%
A7-4	A71J	1162	16.78	0.55	1.020	9%	14.43	86%
A7-4	A72B	1554	6.93	0.37	0.217	8%	1.88	27%
A7-5	A71K	1668	9.79	0.76	0.028	8%	10.71	109%
A6/7-3	A63E	1992	10.65	0.54	0.028	5%	20.69	194%
A6/7-3	A71L	1765	7.13	0.31	0.060	5%	24.74	347%
A8-1	A80A	287	20.43	3.90	0.794	23%	1.56	8%
A8-1	A80B	251	9.30	2.28	0.771	33%	0.85	9%
A8-1	A80C	294	8.71	1.58	0.256	21%	0.27	3%
A8-1	A80D	128	3.81	1.01	0.119	30%	0.08	2%
A8-1	A80E	247	7.75	1.96	0.116	27%	1.76	23%
A8-1	A80F	630	5.44	0.16	0.054	4%	0.25	5%
A8-2	A80G	1230	8.65	0.21	0.071	3%	3.18	37%
A8-3	A80H	266	6.19	1.93	0.116	33%	0.12	2%
A8-3	A80J	870	3.51	0.10	0.148	7%	0.50	14%