Hydrogeology of Groundwater

Region 10

The Karst Belt

R Meyer

WATER RESEARCH COMMISSION

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HYDROGEOLOGY OF GROUNDWATER REGION 10: THE KARST BELT

Report to the
Water Research Commission

by

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PREFACE AND ACKNOWLEDGEMENT

At the time when this project was initiated and awarded by the WRC, the geohydrological consulting company Water Geoscience Consultants was contracted by the Department of Water Affairs to prepare a comprehensive set of reports on carbonate rock aquifers across South Africa. In short the project was referred to as the “DWA Dolomite Project”. Some of the tasks of this DWA project could almost be described as a duplication of the tasks envisaged by the WRC project for the Groundwater Region 10 report. As a result, and with the approval of the DWA and the WRC Reference Group for this project, certain components of the DWA project have been included in this report. Sections 8 to 10 of this WRC report consist of the relevant "Activities" of the DWA project with only a few minor changes made to the original text.

The author wishes to express his sincere thanks and acknowledgement to Water Geoscience Consulting and the Department of Water Affairs for the permission to include parts of the original reports in this WRC document. In particular Dr Martin Holland is thanked for his assistance and for providing the electronic editions of the text and figures that were used in the compilation of this report. This report should be considered as a joint publication by Dr Martin Holland and staff of Water Geoscience Consulting who participated in the DWA Dolomite Project, the Department of Water Affairs and the author.

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1 INTRODUCTION

A process of systematically describing South Africa's groundwater resources was initiated by a Water Research Commission report prepared by Mr Vegter, previously the head of the Directorate of Geohydrology of the Department Water Affairs and Forestry (DWAF) (Vegter, 2000). According to this report the concept of interstices, or the openings that form receptacles and conduits for groundwater, is fundamental to groundwater hydrology and was therefore used as a basis for the delineation of groundwater regions within South Africa. Geological formations are water-bearing as a result of the presence of (i) primary or (ii) secondary openings in the formations, where primary openings are considered to have formed contemporaneously with the genesis of the rock type in which they are present, while secondary openings are the result of processes acting on the rock to create such openings after the rocks have been formed. It was further argued that to only base the division of the country into areas of primary and secondary water-bearing characteristics, would, due to the relative sizes of the areas covered by the two types, be ineffective. Therefore additional factors were also taken into consideration in defining and delineating the groundwater regions.

To effectively describe the groundwater occurrence across a large, geologically diverse and complex area such as South Africa, requires the delineation of areas that have uniform occurrence characteristics. The occurrence and availability of groundwater is determined by:

- (i) the storage and transmissive properties of the geological formation;
- (ii) the volume and frequency of recharge;
- (iii) the rate of groundwater movement to discharge areas;
- (iv) the rate of groundwater discharge as springs and seepage to streams; and
- (v) loss through evapotranspiration (Vegter, 2000).

As the proposed subdivision into groundwater regions was based on the groundwater occurrence and water-bearing properties, and while these are largely controlled by rock type, and structural and other geological characteristics, lithostratigraphic subdivision served as a primary basis for the subdivision of the country into groundwater regions. As defined by Kent (1980) a lithostratigraphic unit is one which is unified by consisting dominantly of a certain rock type or a characteristic combination of rock types or by possessing other significant unifying lithological features.

Climate and physiography are important components in the occurrence and replenishment of groundwater. Transmissivity and topographic relief largely control groundwater movement, its discharge and loss. Vegter (2000) therefore argued that the conformity between lithostratigraphic units and physiographic features strengthens the decision to base the division into groundwater regions on lithostratigraphy. In delineating the different groundwater regions, the aim was to obtain some uniformity in respect of lithostratigraphy, physiography and climate and this led to a subdivision primarily based on geological and not geohydrological characteristics.

In this way Vegter subdivided the country into 65 so-called groundwater regions each identified by its number and a short descriptive name. In this report the hydrogeological conditions of Groundwater Region 10: Karst Belt are described.

However, probably the most prolific water bearing formations in South Africa, are not included in the above descriptions. These are the karst terrains which differ from other groundwater bearing terrains as they are composed of dolomite and limestone where the presence of distinct solution features such cavities and conduits developed in the rock. This report describes the groundwater conditions of one such terrain in South Africa, referred to by Vegter as Groundwater Region 10: The Karst Belt.

In the original request for proposal for ground water Region 10 was to prepare a report with the two main objectives described as:

- Summarizes and synthesizes the present-day knowledge about the occurrence of groundwater in the Karst Region; and
- Will serve as a guide in the exploration and further development of groundwater supplies.

As far as available data and information will allow the compilation of the report is to be achieved by

- Describing the physiographic and geological aspects of the Karst Belt Groundwater Region that are relevant to the occurrence of groundwater.
- Abstracting from reports and borehole records the geological conditions under which groundwater occurs and is struck in boreholes
- Analysing statistically:
    - the distribution of water level depths,
    - the distribution of water strikes below surface
    - the distribution of water strikes below groundwater level
    - the distribution of water strikes in relation to depth of weathering and dyke contacts
    - strike-yield relationship
    - potability and hydrochemical character of groundwater
    - Examining critically the application of geophysical prospecting and other methods for siting boreholes.

Two requirements for the end product were described:

- A "print ready" ground water occurrence and exploration guide with a similar look and feel to the existing WRC groundwater regions reports; and
- The final report will also include complete data sets on CD.

Just prior to the start of this project, the Department of Water Affairs requested a firm of consulting geohydrologists, Water Geoscience Consulting, to prepare a comprehensive report the dolomitic groundwater resources of South Africa. The objectives of the DWA project, referred to as the Dolomite Project, were very similar and included as part of the project, also the Karst Belt of Groundwater Region 10.

2 DESCRIPTION OF THE PHYSICAL ENVIRONMENT

2.1 Location and geographical setting

Groundwater Region 10 stretches from approximately Delmas and Springs, east and southeast of Johannesburg respectively, to the Botswana border north of Mafeking, an east-west distance of just over 300 km. It has a roughly triangular shape extending from the Delmas/Springs area in the east to a maximum width of almost 100 km in the west where it abuts against granitic basement rocks and a short section of the Botswana/South Africa border. Towns along or close to the northern border include Delmas, Pretoria, Magaliesburg, Koster/Derby and Zeerust, while Springs, Centurion, Randfontein, Ventersdorp, Lichtenburg and Mafeking define roughly the southern boundary of the region (Figure 2.1). The region, covering a surface area of approximately 15 000 km^2, stretches across three provinces; Mpumalanga in the east, Gauteng and North West. In the west the region borders on the Limpopo River forming the border between South Africa and Botswana, near the border posts Schilpad Nek/Pioneer Gate, just east of Lobatse in Botswana. Groundwater Region 9 occurs to the north of Region 10, while Groundwater Regions 17 and 18 border on the southern side of Region 10. The boundary of the entire region is defined by a well mapped geological boundary.

2.2 Physiography

The area is characterized by low topographic relief and gently undulating plains especially towards the western part of the Region. In general the elevation is around the 1 600 m level with only isolated and localized areas where elevations of 1750 m are reached. No prominent or striking topographic features are present within the entire region. In the Centurion, Pretoria and Tarlton areas prominent ridges adjacent and to the north of Region 10 are formed by some of the formations of the Pretoria Group. Obbes (2000) states that the presence or absence of chert in the geological succession largely controls topographic expressions. The chert-poor formations weather to a smooth topography with red soils devoid of chert, while the chert-rich units weather to an uneven topography characterized by dissolution openings, chert pinnacles and a permeable chert residue with red silty and brown manganiferous soils. Along the larger river courses cutting across the region, low areas reaching 1 500 mamsl are present. The topography of Groundwater Region 10 is illustrated in Figure 2.1.

Groundwater Region 10 stretches across four Primary surface water Drainage regions or catchments: (i) Primary Drainage region A draining towards the Limpopo River, and (ii) Primary Drainage Region B draining into the catchment of the Olifants River, both of these eventually flowing towards the Indian Ocean in the east, (iii) Primary Drainage Region C, draining initially to the Vaal River System and eventually the Orange River on its way to the Atlantic Ocean in the west, and (iv) Primary drainage Region D feeding into the ephemeral westerly flowing Molopo River along the southern boundary of Botswana. Due to substantial crustal uplift north of Upington during Pleistocene times, the Kuruman River, into which the Molopo River drains, has no outlet to the Atlantic Ocean. Due to the proximity of Groundwater Region 10 to the upstream boundaries of major primary drainage regions, no major river courses are present in the region. The Quaternary catchments and the more prominent river courses originating in the different Primary Catchment regions are:

- Primary Drainage Region A:
  - Quaternary catchments: A10A, A21A, A21B, A21 D to A21H, A31A, A31C and A31D
  - the Rietvlei, Hennops, Apies, Jukskei and Crocodile Rivers near Pretoria; and the Marico River in the west;
- Primary Drainage Region B:
  - Quaternary catchments: B20A and B20B
  - the Bronkhorstspruit
- Primary Drainage Region C:
  - Quaternary catchments: C21D, C21E, C23D, C23E, C23F, C23C, C24D, C24E, C24F, C31A to C31D
  - the Blesbokspruit, Mooi River, Skoonspruit and Harts River
- Primary Drainage Region D:
  - Quaternary catchments: D41A and D41B
  - the Molopo, Polfonteinspruit, Kareespruit and Maretsane River.

The distribution of the different Quaternary catchment across Groundwater Region 10 are shown in Figure 2.2.

It is important to note that some of these rivers and streams originate at or are sustained by springs and baseflow from the dolomite formations, for example the Apies River (Pretoria Fountains), the Rietvlei River (springs at the Rietvlei Dam), the Hennops River, the Molopo and Marico rivers (Molopo, Marico [or Kaaloog] springs) in the west. However, large areas within the region are also devoid of surface drainage systems, a feature that is often observed in areas underlain by dolomitic rocks.

Two streams, the Tweelopiespruit and the Blaauwbankspruit traverse the dolomitic areas around Tarlton, eventually draining into the north flowing Crocodile River. Both these streams originate in the gold producing West Rand region and are recepticals for storm and surface water runoff, mining, sewage and domestic effluent from the larger towns to the south before reaching the Steenkoppies and Zwartkrans dolomitic compartments (Holland, 2009). Groundwater from the Steenkoppies compartment surfaces at Maloney's Eye where the north draining Magalies River originates.

The elevations of the generally flat and featureless highlands in the western part of Region 10 range from around 1 600 m in the northeast to 1 430 m in the west, hosting small drainage valleys. The surface drainage in the western part of Region 10 is restricted to the upper reaches of the Marico River, and the westerly draining Molopo and Malmani Rivers.

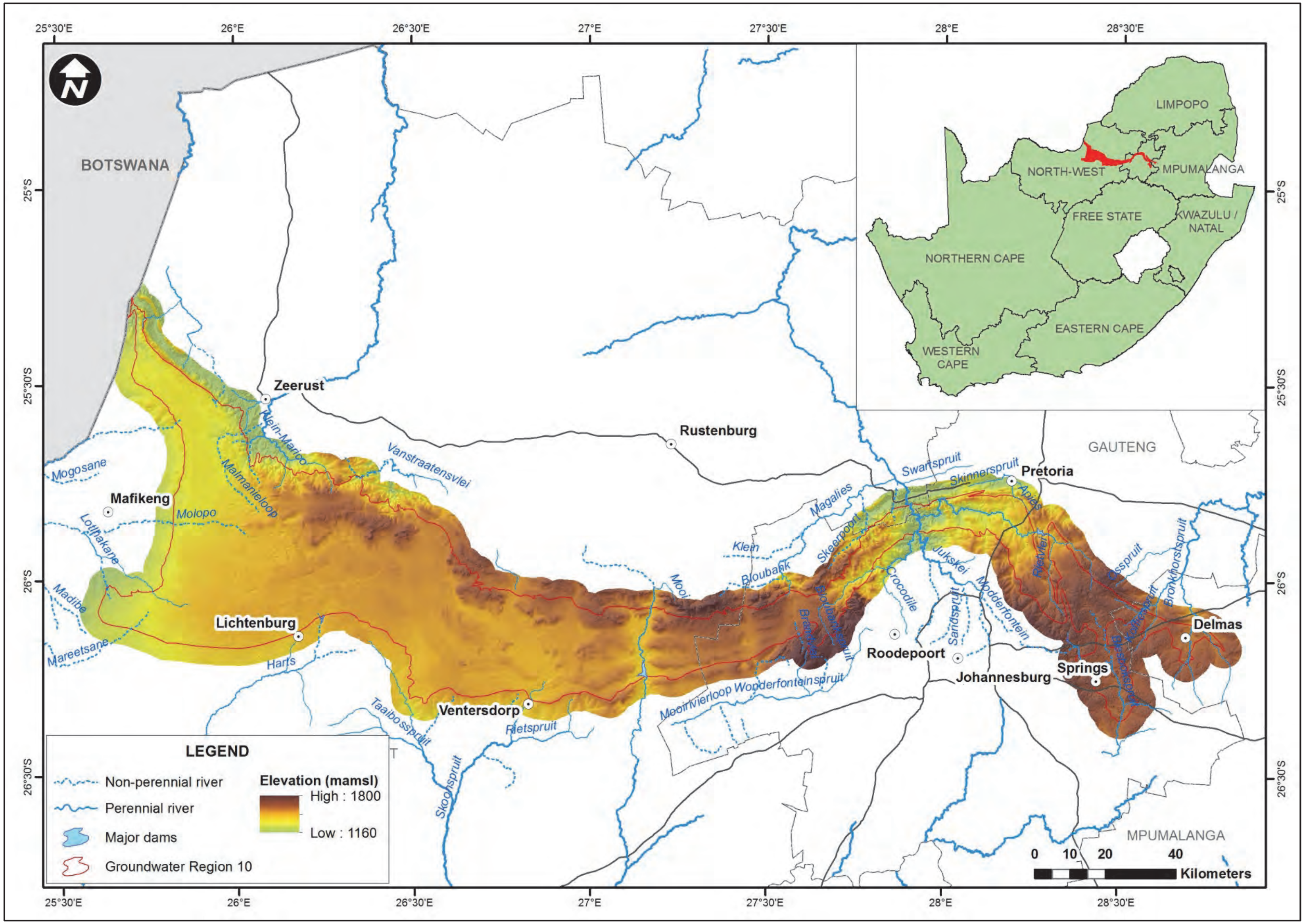


Figure 2.1: Map of Groundwater Region 10 showing the topographic relief across the region.

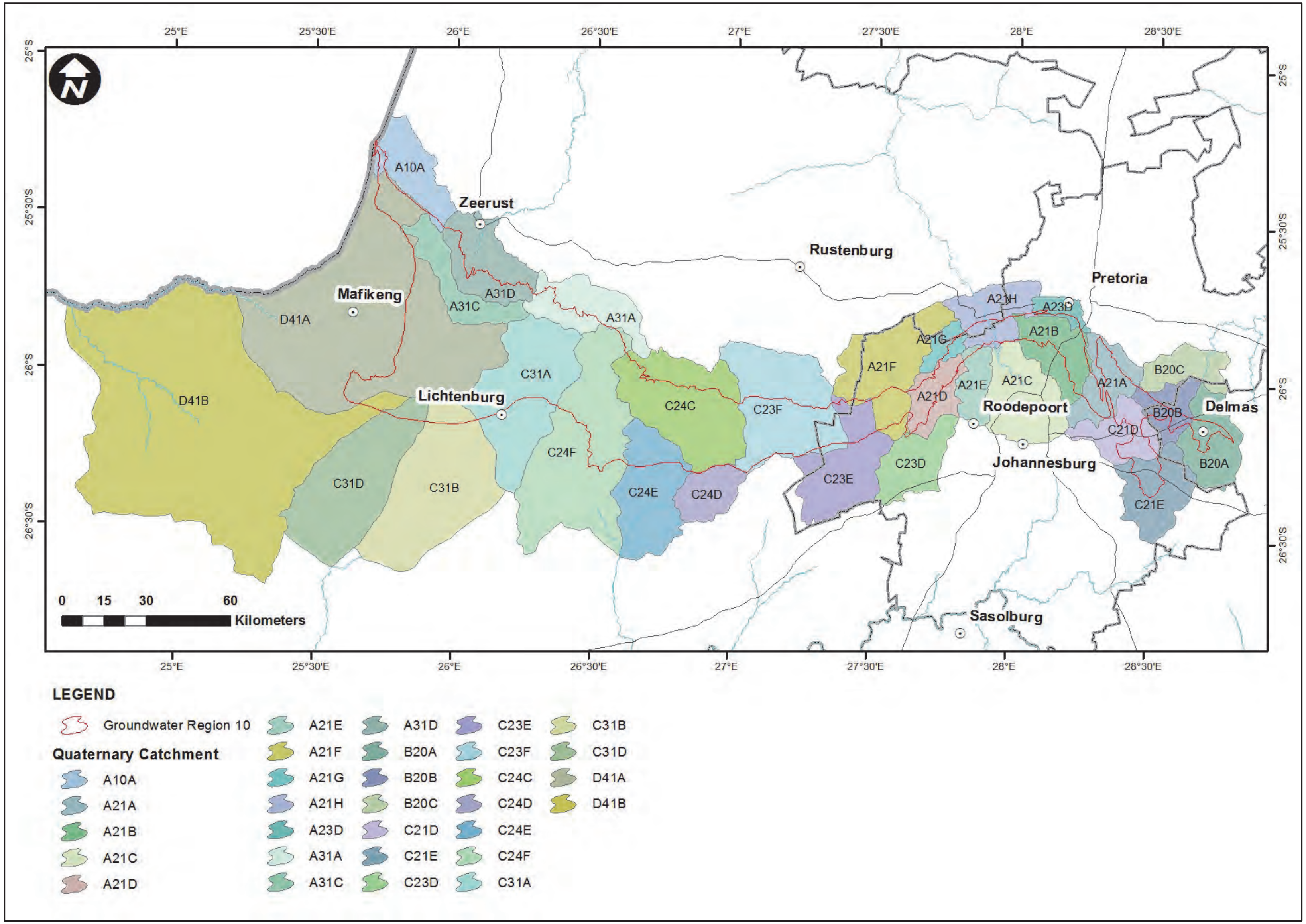


Figure 2.2: Map of Groundwater Region 10 displaying the Quaternary catchment areas in and around the region.

2.3 Climate

The climate across Region 10 is characterized by warm summers and cool dry winters. Frost is often experienced in depressions and low areas during cold nights of the winter months. Rainfall occurs predominantly in the summer months (October to March) in the form of thunderstorms, occasionally also with some hail. The mean annual precipitation (MAP) has its maximum in the eastern part of the Region (>800 mm/a in places), and gradually decreases towards the west where a MAP of less than 450 mm/a is recorded. The Delmas/Pretoria/Tarlton area annually receives more than 600 mm of rain, the central part of the region 500-600 mm/a, while the western regions receive generally between 400 and 500 mm/a. The regional MAP distribution derived from Schulze and Lynch (2007) is shown in Figure 2.3.

A high potential evaporation (A-pan equivalent) and associated evapotranspiration is experienced across the Region. The Mean Annual Potential Transpiration according to Schulze (1997) varies between ~2 100 mm/a in the east to ~2 500 mm/a in the west. This exceeds the MAP by a factor of up to 3. The Mean Annual Reference Evapotranspiration as published by Schulze (1997) and based on the 1992 FAO Penman-Monteith method varies across Region 10 from ~1 500 mm/a in the east to ~1 850 mm/a in the west. Hobbs (1988) refers to calculations of annual evapotranspiration using the Thornthwaite method for the recording station 513/382 in Irene south of Pretoria that gave a value of only 742 mm which only slightly exceeds the mean annual rainfall of 675 mm for the area.

2.4 Vegetation types and land cover

The vegetation occurring in Groundwater Region 10 and adjacent areas is illustrated in Figure 2.4. This map was compiled from information supplied by the South African National Botanical Institute (SANBI). The majority of the area is covered by grasslands of the Vaal-Vet Sandy type (Gh10), the Western Highveld Sandy type (Gh 14), the Carletonville Dolomite type (Gh 15), the Rand Highveld type (Gm11) and the Eastern Highveld type (Gm 12). Along the northern edge of the Johannesburg Dome, grasslands of the Egoli Granite type (Gm 10) are found. Along the northwestern fringe of Groundwater Region 10, Bushveld and Thornveld vegetation of the types Zeerust Thornveld (SVcb 3), Dwarsberg-Swartruggens Mountain Bushveld (SVcb 4) and Moot Plains Bushveld (SVcb 8) are found. Along the outer fringe of Region 10 near Pretoria and north of Tarlton vegetation of the types Marikana Thornveld, Gold Reef Mountain Bushveld and Andesite Mountain Bushveld are present.

Around Springs on the East Rand grasslands of the type Soweto Highveld (Gm 8) and Tsakane Clay (Gm 9) types occur. Across the western half of the Region isolated pans occur that are classified as Highveld Salt Pans.

A map depicting the land cover across Region 10 is displayed as Figure 2.5 using the 2009 information from the National Land Cover survey by SANBI. The map indicates that by far the largest portion of the map is covered by cultivated and natural and basically undisturbed areas. Closer to the towns and cities especially in the eastern part of Region 10, large areas a classified as built-up areas. Around Springs on the East Rand, gold mining activities take up a good proportion of the land, while the area west of Roodepoort and close to Lichtenburg some isolated mining activities are indicated.

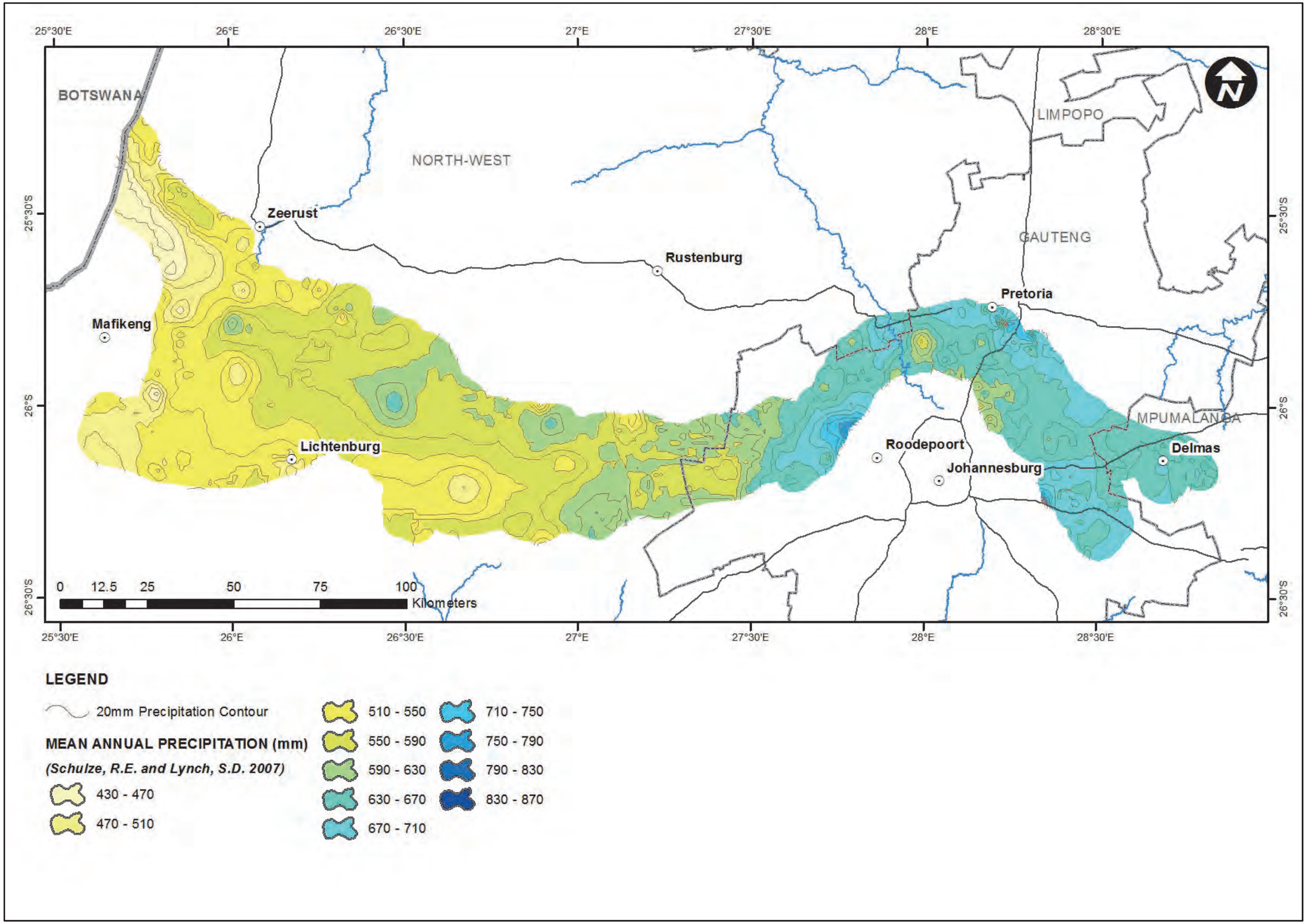


Figure 2.3: Map of Groundwater Region 10 displaying Mean Annual Precipitation across the Region

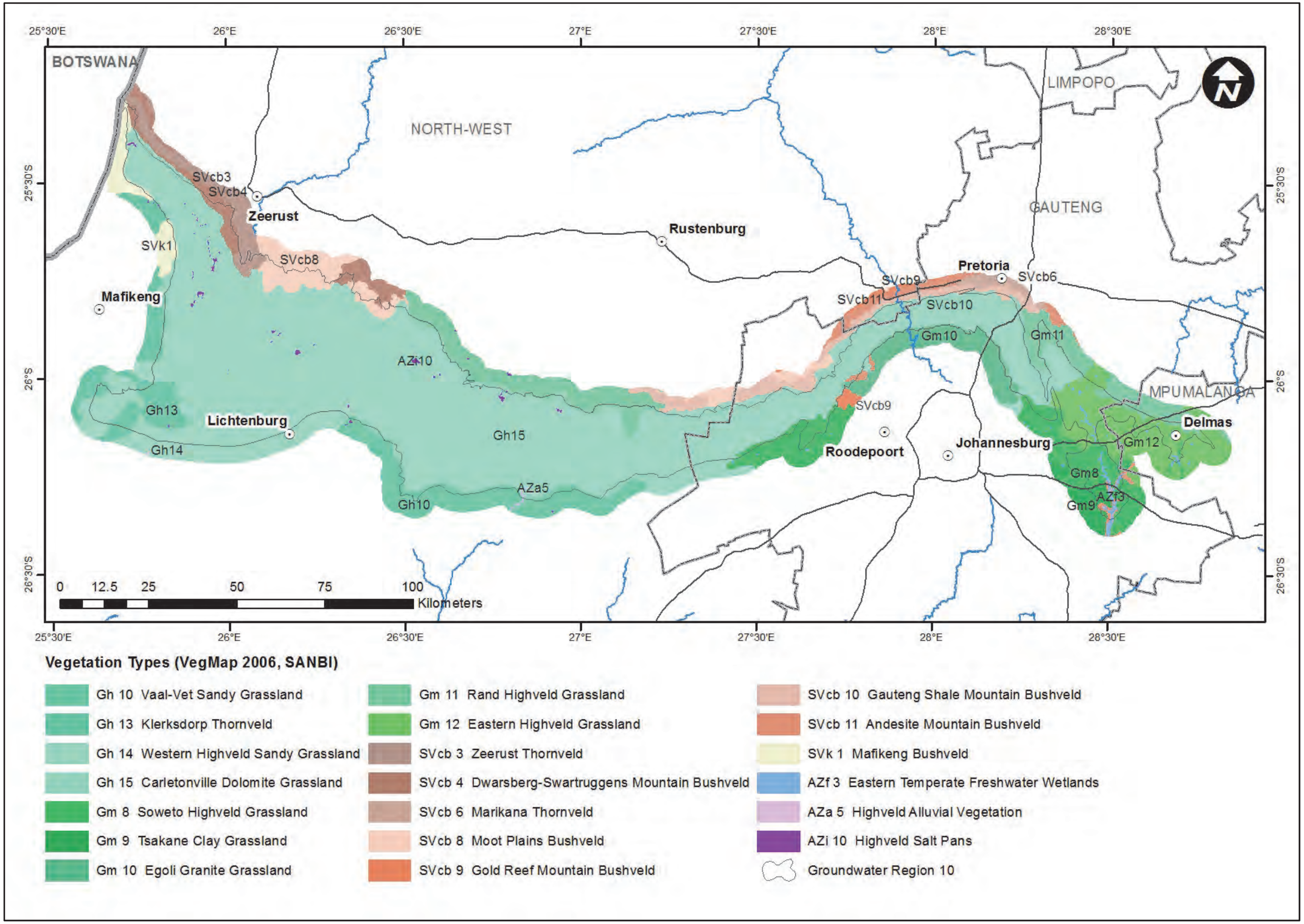


Figure 2.4: Map of Groundwater Region 10 displaying the Vegetation types across the Region.

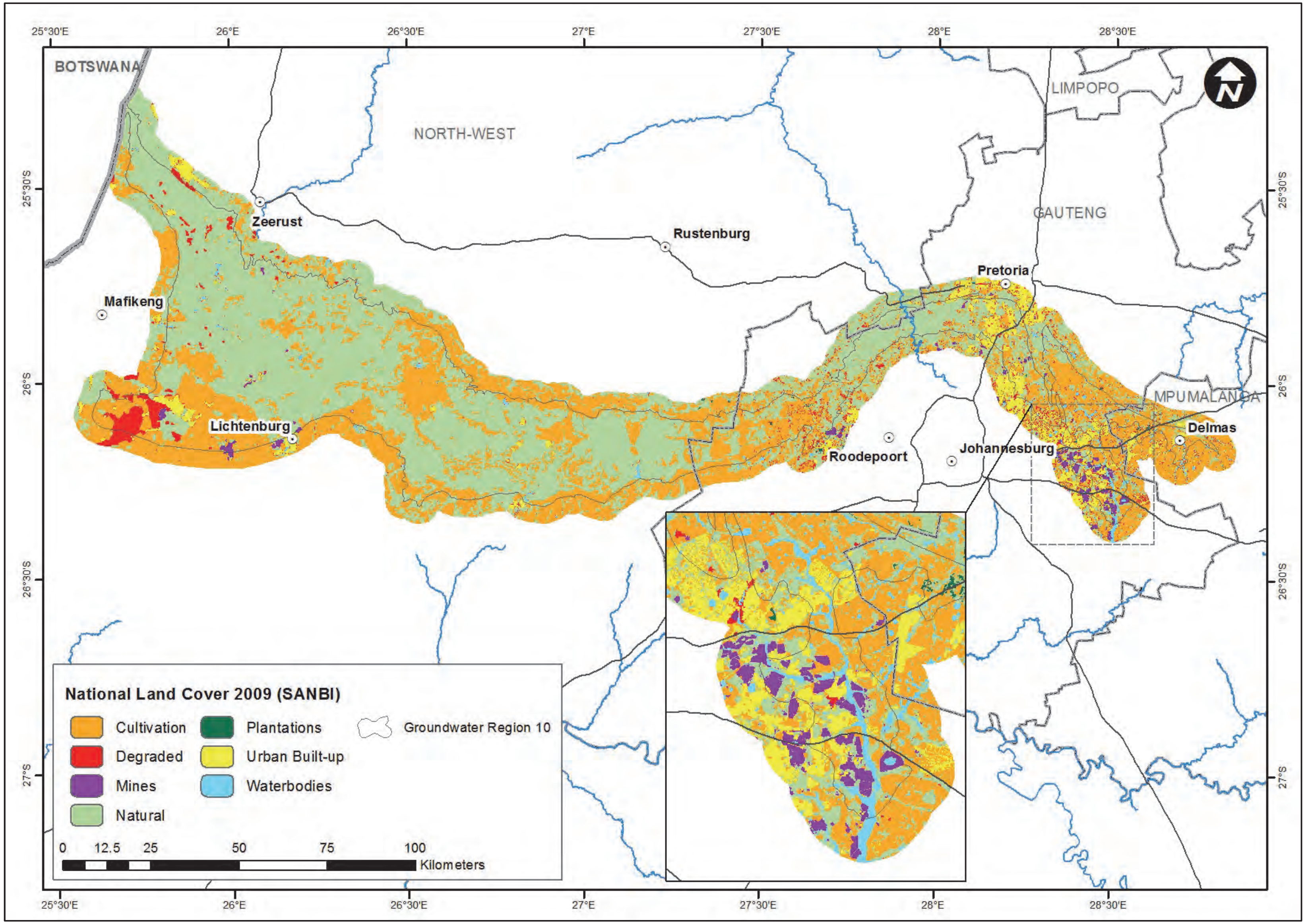


Figure 2.5: Map of Groundwater Region 10 displaying the SANBI National Land Cover types across the Region.

3 GEOLOGY

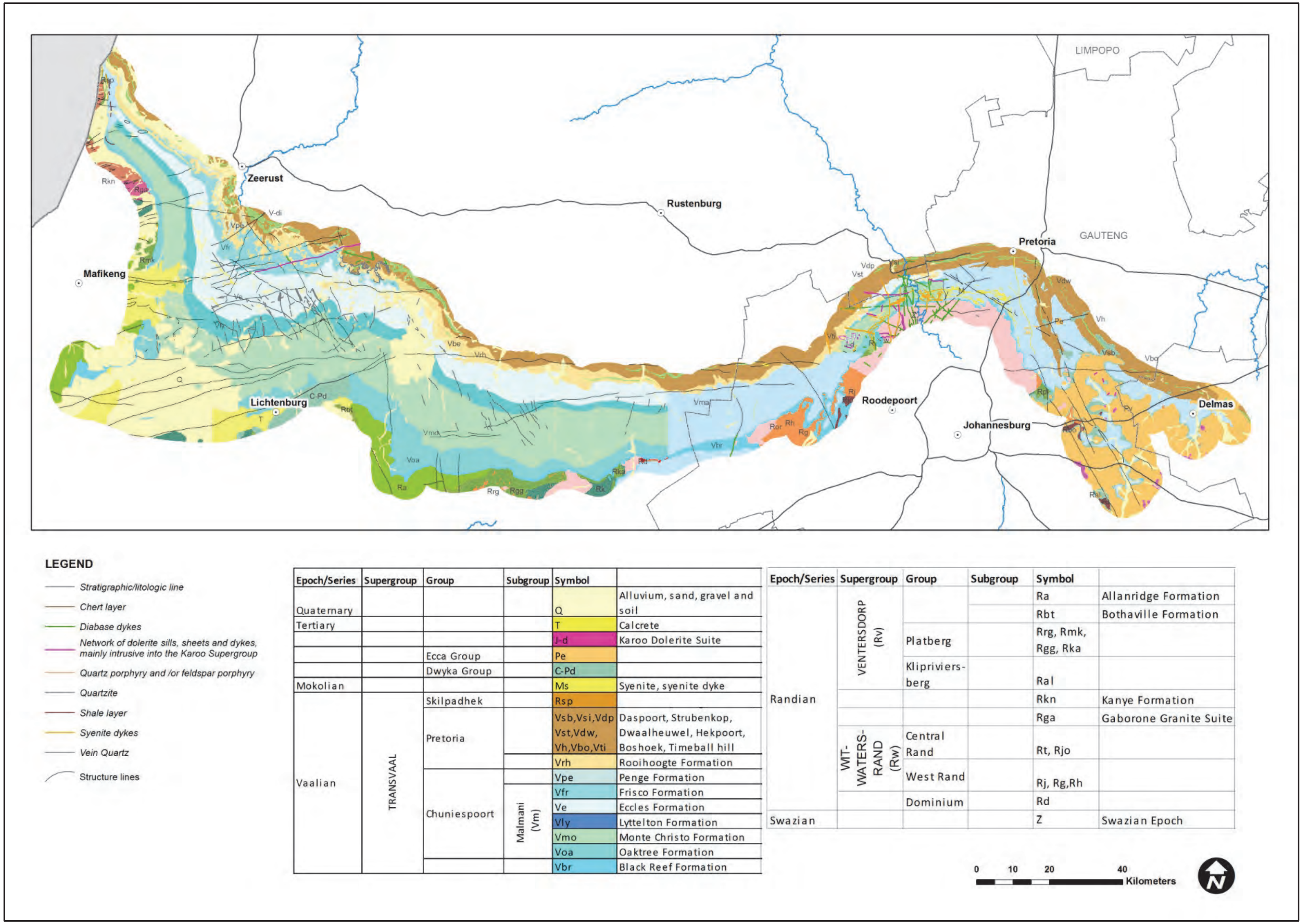
3.1 Regional geological setting

The Karst Belt comprises of five formations forming the Malmani Subgroup, a subdivision of the Transvaal Supergroup. This Supergroup is preserved in three structural basins on the Kaapvaal Craton in which carbonates, iron-formation and minor silica-clastics were deposited. Two of these basins, the Transvaal and Griqualand West basins, are situated in South Africa, while the third, the Kanye basin, is in Botswana. The succession preserved in the three basins is very similar, with correlation being best for the lower chemical sedimentary units, the Malmani and Ghaap Subgroups, while the correlation in the upper clastic sedimentary and volcanic lithologies of the Pretoria and Postmasburg Groups is relatively poor (Eriksson et al, 2006). The Transvaal Supergroup represents one of the world's earliest carbonate platform successions (Beukes, 1987) and overlies rock formations representing the Archaean basement, and the Witwatersrand and Ventersdorp Supergroups.

3.2 Lithostratigraphy

The Karst Belt forms part of the late Archaean to early Protorozoic Transvaal Supergroup spanning the time period from approximately 2 640 Ma to 2 500 Ma (Eriksson *et al*, 2006). This Supergroup is preserved in three structural basins on the Kaapvaal Craton in which carbonates, iron-formation and minor silica-clastics were deposited. The stratigraphic column showing the position of the geological sequence represented by the Karst Belt is shown in Table 3.1. The basal formation of the Transvaal Supergroup is the Black Reef Formation consisting predominantly of quartzite with some subordinate shale and conglomerate. The Chuniespoort Group of the Transvaal Supergroup consists of the lower Malmani Subgroup which is subdivided into five formations, and two overlying formations, the Penge and Duitschland formations. The Penge formation consists of banded Ironstone while the Duitschland Formation is represented by carbonaceous mudrocks, limestone and dolomite. These latter two formations are however, mainly present in the northeastern part of the Transvaal Basin and only relatively small outcrops occur in the western part of Groundwater Region 10. The geological map of the Region is shown in Figure 3.1.

The Karst Belt, as Groundwater Region 10 is also referred to, is represented by the up to 2000 m thick Malmani Subgroup which is subdivided into five formations, referred to as the Oaktree, Monte Christo, Lyttleton, Eccles and Frisco Formations. The subdivision is based on the chert content, as well as the variety, absence or presence of stromatolite structures, intercalated shales and erosion surfaces (Button, 1973; Eriksson and Truswell, 1974 in Eriksson *et al*, 2006; Obbes, 2001). Previously, Clendenin (1988) proposed a slightly different subdivision based on geochronometry and identified six unconformable bounded packages. He referred to these packages as the Oaktree, the Lower Monte Christo, the Upper Monte Christo, the Lyttleton-Eccles, the Frisco-Penge and the Duitschland. The two main lithological types are normally referred to "chert-free" and "chert-rich" dolomite. Different views on the reason for the variation in chert content are held by Clendenin (1988) and Foster (1988). Foster (1988) attributes the difference in chert content to the different depositional environments; chert-free units were deposited in subtidal environments, while chert-rich units are from intra-tidal to supra-tidal zones, while Clendenin (1988) has the view that the different depositional packages were



Epoch/Series	Supergroup	Group	Subgroup	Symbol	
Quaternary				Q	Alluvium, sand, gravel and soil
Tertiary				T	Calcrete
				J-d	Karoo Dolerite Suite
		Ecca Group		Pe	
		Dwyka Group		C-Pd	
Mokolian				Ms	Syenite, syenite dyke
Vaalian	TRANSVAAL	Skilpadhek		Rsp	
		Pretoria		Vsb,Vsi,Vdp Vst,Vdw, Vh,Vbo,Vti	Daspoort, Strubenkop, Dwaalheuwel, Hekpoort, Boshoek, Timeball hill
				Vrh	Rooihoogte Formation
		Chuniespoort		Vpe	Penge Formation
			Malmani (Vm)	Vfr	Frisco Formation
				Ve	Eccles Formation
				Vly	Lyttelton Formation
				Vmo	Monte Christo Formation
				Voa	Oaktree Formation
				Vbr	Black Reef Formation

Epoch/Series	Supergroup	Group	Subgroup	Symbol	
Randian	VENTERSDORP (Rv)			Ra	Allanridge Formation
				Rbt	Bothaville Formation
		Platberg		Rrg, Rmk, Rgg, Rka	
		Klipriviers-berg		Ral	
				Rkn	Kanye Formation
				Rga	Gaborone Granite Suite
	WIT-WATERS-RAND (Rw)	Central Rand		Rt, Rjo	
		West Rand		Rj, Rg,Rh	
		Dominium		Rd	
Swazian				Z	Swazian Epoch

Figure 3.1: Geological map of Groundwater Region 10 including the 5 km buffer zone around the Region.

lithofied before the next one was deposited and therefore particular units contain such high percentages of chert.

Areas where chert-free formations outcrop, are generally of low relief and with no distinctive geomorphic expression, whereas outcrops of chert-rich dolomite formations show moderate to prominent topographic expression that can be recognized on aerial photographs (Obbes, 2000). The prominent Skurweberge is an example of more resistant nature of the chert-rich formations, in this case the Eccles Formation.

The chert-free Oaktree formation is at the base and conformably overlies the Black Reef Formation. It consists of between 10 m and 200 m of carbonaceous shales, stromatolitic dolomite and some quartzite. Areas representing this formation usually have a low relief, with no distinctive geomorphic expressions. The contact to the overlying Monte Christo Formation is gradational. This chert-rich formation consists of 300-500 m and is subdivided by Obbes (2001) into four Members, of which the upper two members, the Rietspruit and Crocodile River Members have abundant chert in the form of chert-in-shale and silicified chert breccias, and chertified stromatolites. The other members consist predominantly of dolomite with some chert. At the base of the formation erosive breccias are present alternating with stromatolitic and oolitic dolomite. The Monte Christo Formation is followed by 100-200 m of dolomite, shale, and quartzite forming the Lyttleton Formation. This formation generally regarded as being chert-free, but does contain some chert in the central part. The Lyttleton Formation is in turn overlain by up to 600 m of a thick chert-rich dolomite sequence of the Eccles Formation, also containing a series of erosion breccias. One of these erosion breccias separates the Eccles Formation from the overlying up to 400 m thick, massive dolomite of the Frisco Formation.

Foster (1988) describes the chert-free, massive dolomites of the Oaktree and Lyttleton Formations as fundamentally different to the interbedded chert and dolomite of the Eccles and Monte Christo Formations. This difference is also seen in the different weathering characteristics and the development of karst features. This difference in weathering patterns is important when describing the geohydrological characteristics of these different groups. According to Foster (1988) the chert-free units weather to form dolomite pavements with a high density of incipient joints. However, major dissolution occurs only in well-spaced discontinuities. The chert-rich units again have a rugged outcrop appearance where large voids resulting from the dissolution of the carbonate rocks are supported by the more resistant chert. The chert-rich dolomite units support much more dissolution along joints and bedding planes between the alternating dolomite and chert bands. Foster also states that residual gravity maps reveal zones of preferential weathering of the chert-rich formations and that extensive zones of porous and permeable material only form where the weathering of closely spaced geological structures intersect or coalesce in the Monte Christo and Eccles Formations.

For the most part Groundwater Region 10 is overlain by the sedimentary sequence of the Timeball Hill Formation of the Pretoria Group. In the eastern part of Groundwater Region 10 and especially within the triangle formed by Pretoria, Delmas and Springs, large areas of the Malmani dolomite formations can be covered by the much younger shale and mudrocks representing the basal section of the Vryheid Formation, Karoo Supergroup, and often underlain by diamictite and shale of the Dwyka Group. The Dwyka Group seldom exceeds 25 m in thickness, while the Vryheid formation can form a cover of up to 60 m thick. Apart from three large areas where dolomite is overlain by young unconsolidated alluvial deposits, west and northeast of Lichtenburg and to the east of Mafikeng, several small and thin elongated deposits of unconsolidated sands cover dolomitic areas throughout the region.

Table 3.1: Simplified lithostratigraphic column representing Groundwater Region 10 and surrounding geological conditions

Age (Ma)	Thick-ness (m)	Super-group	Group	Formation	Lithology
~25 to 0				Recent	Unconsolidated material
~180					Dolerite/diabase dykes and sills
~320 to ~250		Karoo	Ecca	Vryheid	Shale and sandstone
			Dwyka		Diamictite and shale
~1200					Syenite dykes and sills
~2000					Diabase dykes and sills
	≤200	Transvaal	Pretoria	Rayton	Mudrock, sandstone
	150-430			Magaliesberg	Sandstone, mudrock lenses
	~500-1300			Silverton	Shale
	~65-120			Daspoort	Sandstone, mudrock
	~50-120			Strubenkop	Mudrock, subordinate sandstone
	~15-70			Dwaalheuwel	Sandstone, conglomerate
~2224	~190-890			Hekpoort	Basaltic andesite
	~35-70			Boshoek	Sandstone, conglomerate
	~450-1500			Timeball Hill	Mudrock, quartzite,
~2720 to ~2050	10-150			Rooihoogte	Quartzite, mudrock, Bevets conglomerate/ breccia Member
			Chunies-poort	Duitschland	Carbonaceous mudrocks, limestone and dolomite
~2500				Penge	Banded iron stone
2640-2500	~400			Malmani Subgroup: Frisco	Chert-free dolomite
	~600			Eccles	Dolomite and chert
	100-200			Lyttleton	Chert-poor dolomite
	300-500			Monte Christo	Chert-rich dolomite
				Oaktree	Chert-free dolomite
	25-30			Black Reef	Quartzite, conglomerate and shale
			Buffels-fontein	Four formations	Sandstone, conglomerate, shale and lava
			Wolkberg	Eight formations	Sandstone, conglomerate, basalt and mudrock
~2770 to ~2650		Venters-dorp	Platberg	Four formations	Clastic and chemical sediments to mafic and felsic volcanics
			Klipriviers berg	Six formations	Lava and conglomerate
~3000 to ~2800		Witwaters-rand	Central Rand	Nine formations in two subgroups	Predominantly quartzites and conglomerates
			West Rand	Sixteen formations in three subgroups	Primarily quartzites and shales
~3200		Halfway House			Granite

3.3 Structural geology

3.3.1 Dykes, sills and lineaments

Based on ground magnetic surveys done in the 1930s three different dyke systems in southern Gauteng have been described by Gelletich (1937). Aided by aeromagnetic data, Day (1980) identified different dyke trends and recognised four dyke groups: (i) Pilansberg dykes, (ii) East-Rand dykes, (iii) East-west dykes and a fourth group termed "Other dykes". Characteristics of the different groups are:

Pilansberg dykes: Age: ~1310 Ma, strike ~ N-S, produce negative magnetic anomalies.

East-Rand dykes: Age: ~ 1120 Ma, Strike mainly NNW, produce positive magnetic anomalies.

East-west dykes: Age: post-Karoo, strike direction E-W or ENE, produce positive magnetic anomalies.

"Other dykes": Age: unknown, strike direction varies, but ENE is common, produces both positive and negative magnetic anomalies.

Because of their prominent magnetic signatures, magnetic surveys, both airborne and ground based, are extensively used to delineate these dyke intrusions. Two examples of aerial magnetic surveys presented by Holland (2009) are shown in Figures 3.2 and 3.3.

Two prominent near vertical dolerite dyke swarms associated with the Pilanesberg Complex intruded into the Malmani Group rocks. The Pilanesberg dyke swarm has been dated at about 1310±60 Ma while the East Rand dyke swarm is slightly younger at 1120±45 Ma. A third group of dykes occupying an almost east-west direction are of post-Karoo age (~182 Ma). Within Region 10 the more prominent dykes are often referred to under specific names, for example the Pretoria, Irene, Olifantsfontein and Sterkfontein dyes. These dykes are believed to be vertical or near vertical mafic intrusions. As these dykes are generally considered to be mostly impermeable or having a low permeability, act as barriers to groundwater flow within Groundwater Region 10. As a result Region 10 can be subdivided into numerous groundwater compartments. For reference purposes each of the compartments has been given a name and in this report the subdivision and names given by Holland (2009) will be used. Close to surface these dykes usually weathered and allow groundwater flow across dykes does occur, while at depth the dykes are considered to be essentially impermeable. Bredenkamp (2002) is of the opinion that fracturing at depth due to tectonic activity does occur thereby allowing some trans-compartmental flow, and not necessarily creating a no flow boundary.

Numerous syenite sills and dykes, associated with the Pilansberg alkali volcanic event, are present in the lower formations of the Malmani Subgroup south of Pretoria. The most extensive syenite dyke, referred to as the Pretoria dyke, extends from Pretoria to Tembisa in the south.

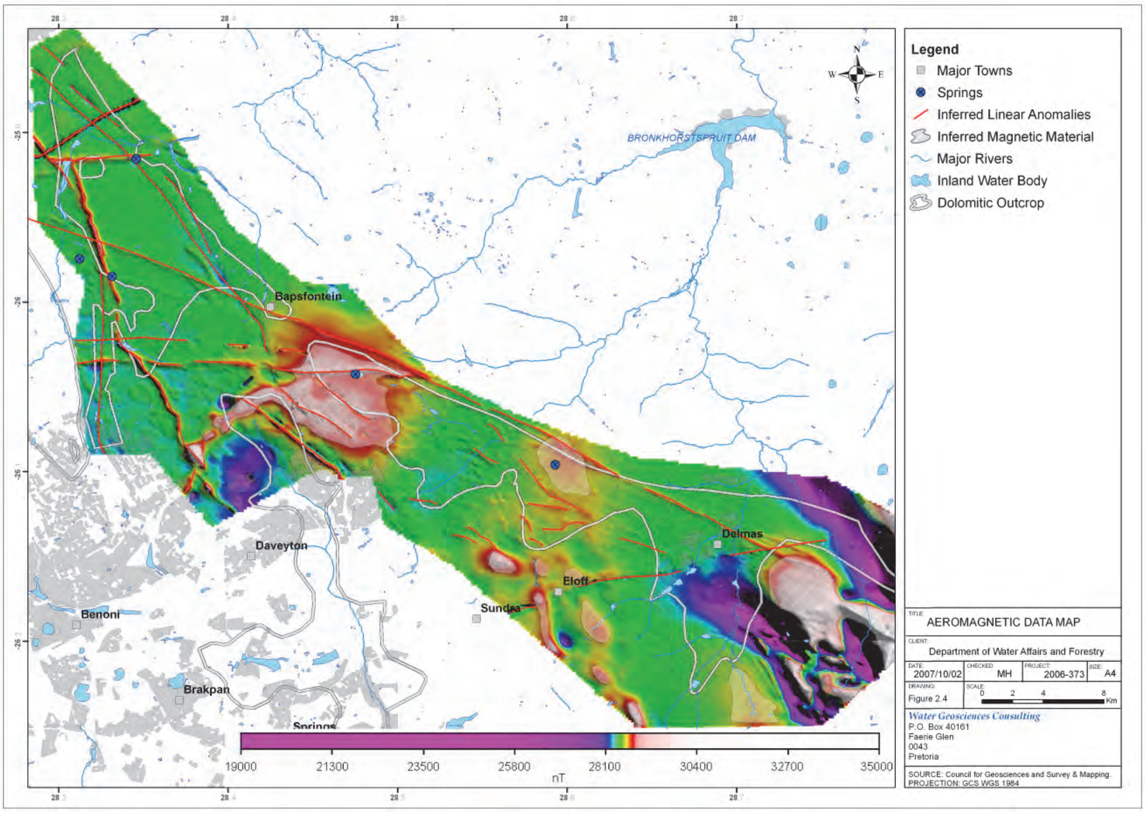


Figure 3.2: Aeromagnetic data showing the intrusive dyke pattern northeast of Brakpan, East Rand that are used to delineate compartment boundaries (from Holland, 2009).

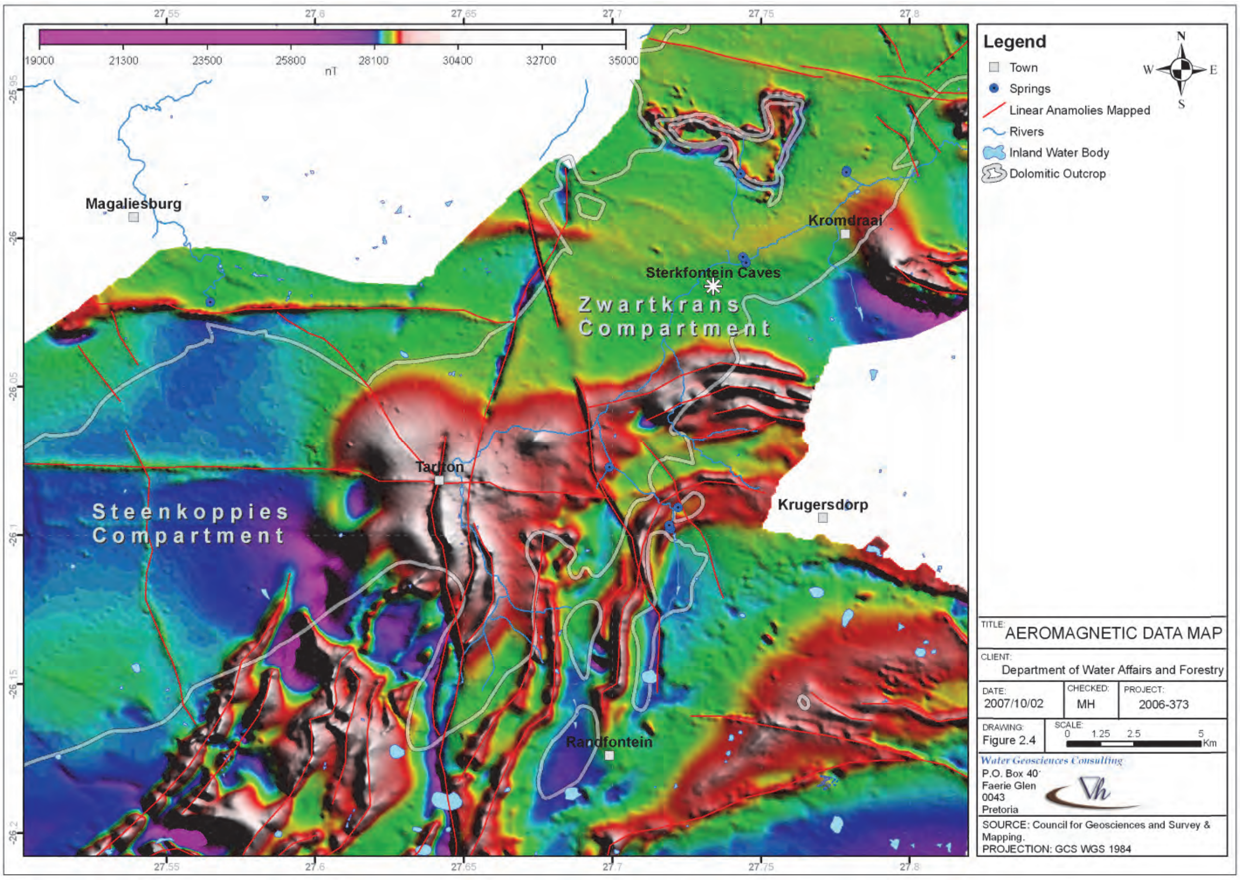


Figure 3.3: Aeromagnetic data showing the intrusive dyke pattern west of Krugersdorp that are used to delineate compartment boundaries (from Holland, 2009).

3.3.2 Faults

Only a few major normal faults intersect the Chuniespoort Group strata. Michaluk and Moen (1991) describe the presence of east-west trending faults prominent in the Black Reef Formation and the Chuniespoort Group to the east of Mafikeng. Parallel to these faults are sets of linear structures recognizable on aerial photographs due to vegetation associated with these structures. These structures also manifest themselves as prominent magnetic lineaments on aerial magnetic surveys as they are often also associated with dyke intrusions. Some of the more prominent faults are the WNW trending Rietfontein fault near Krugersdorp, and a NNW trending fault extending from east of Carltonville to Pilansberg. Obbes (2001) has mapped many relatively short faults present mainly in the Black Reef, Oak Tree and Monte Christo Formations which are radially arranged around the Johannesburg Dome between Pretoria and Krugersdorp.

3.3.3 Dip angle and strike directions

In the far western part of Region 10 close to the Botswana border, the Malmani strata thins dramatically from about a 10 km and more wide outcrop area east of Mafikeng to only a few hundred metres at the Botswana border. Here the strike direction is N-S with a dip of about 10-20° to the east. The Malmani Subgroup is deposited onto the conglomerate, quartzite and shale forming the Black Reef Formation which in turn rests on felsitic rocks of the Kanye Formation. Further south and to the west of Lichtenburg the Malmani Subgroup rests on the volcanic rocks of the Ventersdorp Supergroup. In some places the Black Reef Formation is also present. From east of Lichtenburg the Black Reef Formation is present almost uninterrupted up to Springs in the east. A low north directed dip angle of around 5° is indicated on the geological maps for the Black Reef Formation. From the Botswana border to Delmas in the east, the Malmani Subgroup is overlain by the various formations representing the lower section of the Pretoria Group. For a distance of approximately 40 km to the south west the Botswana border, the Frisco Formation is overlain by the Penge Formation, while further east the Rooihoogte Formation rests unconformably on the Frisco Formation. The dip angle of the sedimentary strata directly overlying the Malmani formations west of Krugersdorp is of the order of 10° and directed towards the centre of the Transvaal depositional basin. Towards the east the dip directions are controlled by the Johannesburg or Halfway House Dome and change from northwesterly direction west of the Dome, to north and then northeast on the eastern side of the Dome.

3.4 Geological Boundaries of Groundwater Region 10

Groundwater Region 10 is described by Vegter (2000) as *"Chuniespoort dolomite and chert; subordinate Black Reef quartzite, conglomerate and shale".* Between Ventersdorp and Randfontein the Black Reef Formation is exposed along the axis of an anticlinal structure. To the south of this anticline, dolomite of the Chuniespoort Group is present where it overlies formations of the Witwatersrand Supergroup constituting the Far West Rand Goldfields. These dolomites extend from Vereeniging in the southeast, through Soweto, Carltonville, and down to Stilfontein in the southwest. Although the Black Reef Formation should form part of Groundwater Region 10 according to the classification by Vegter (2000), he defined the boundary between Groundwater Regions 10 and 17 to be the Black Reef Formation exposed at the anticlinal structure. The reasoning behind this classification is not clear as according to his description of the Karst Belt, the vast dolomitic areas to the south of the anticlinal structure should strictly speaking also be part of Groundwater Region 10 and not Region 17 as shown on the maps included in the original report (Vegter, 2000).

Another discrepancy exists between the southeastern boundary of the digitally available outline of Groundwater Region 10 and published 1:250 000 scale geological maps. Between Bapsfontein and Delmas dolomite outcrops of which only a small portion appears to be included in Region 10. In the central area of the triangle formed by Springs, Delmas and Bapsfontein the dolomite is according to Bredell (1978) directly overlain by up to 100 m Vryheid Formation including a thin layer of Dwyka tillite. It could therefore be argued that the Region 10 could be extended in an easterly direction. In this report the boundary of Region 10 was extended to include the areas where dolomite outcrops around Springs and Delmas are present.

4 KARST DEVELOPMENT AND CAVES

4.1 Karst terminology and karstification

The term karst is primarily associated with terrains underlain by limestone, or as is the case in Region 10, dolomite and refers to a distinctive terrain and landforms that evolve through the dissolution of the bedrock and where an efficient underground drainage system consisting of fissures enlarged by solution, conduits and caves develop with time (International Association of Hydrogeologists, Karst Commission, 1999). Waltham et al. (2005) define karst as a landscape that is distinguished by its underground drainage, so that its landforms evolve in response to rainfall and surface water flowing into the ground. By implication, river valleys cannot develop in a mature karst. The upper formation of the Malmani Subgroup is over large distances, and especially the stretch between Pretoria and Mafeking, overlain by the Rooihoogte Formation of the Pretoria Group. The Rooihoogte Formation unconformably overlies a deeply weathered karstic palaeotopography of the Frisco Formation in this area. According to Eriksson et al. (2006) a period of about 80 Ma at the end of Frisco Formation deposition was available for the formation of this palaeo karstic topography. This period of weathering gave rise to the composition of the Rooihoogte Formation which consists of a basal chert breccia often reworked to form a chert conglomerate, also known as the Bevets Member or just the Bevet's conglomerate. This conglomerate is best developed in the western part of Region 10 can reach a thickness of 250 m (Eriksson et al, 2006).

Karstification is the result of a process of solution of carbonate rocks. Weakly acidic water circulating through dolomitic rocks causes the solution of the carbonate minerals which are in the case of Region 10, predominantly dolomite, a calcium/magnesium carbonate (MgCa $(CO_3)_2$). This results in the formation of cavities and caves through the chemical process

$$CaMg(CO_3)_2 + 2H_2CO_3 \rightarrow Ca(HCO_3)_2 + Mg(HCO_3)_2$$

Holland et al. (2010) state that the dissolution process during karstification has been more active in the chert-rich dolomite, thereby implying that karstification is best developed in the Eccles and Monte Christo Formations.

4.2 Geomorphology

Martini and Kavalieris (1976) identified four types of karst morphology present on the dolomites in the region which are schematically illustrated in Figure 4.1:

- *Plateau type* that is present between Krugersdorp and the Botswana, and as the name indicates, forms a flat plateau region marking the approximate position of the watershed between the Primary Drainage Regions of the Limpopo and Orange Rivers. The "plateau" nature is also well illustrated in the map showing the topography in the region (Figure 4.1). According to Marker and Moon (1969) this surface corresponds to the African Erosion Surface of King (1963). Large scale karst morphology is developed on this plateau area with few surface water streams. This agrees with the observation by Waltham et al. (2005) that the hydrology of karst areas is normally all underground. Despite of the lack of any significant relief, Martini and Kavalieris (1976) are of the opinion that this plateau area has not reached the "mature stage" of karstification (Figure 4.1) of their model.

- *Escarpment type* is characterized by a rugged topography. In Region 10 this type can be seen between Pretoria and Krugersdorp and well illustrated in the Skurweberg area (see also the topography map, Figure 2.1).
- *Bushveld type*. This type occurs between Thabazimbi and the Botswana border, to the north of Region 10, and where the Chuniespoort Group forms the northern edge of the Transvaal basin.
- *Vaal River type*. This type is occurs, as the name indicates, mainly in the Vaal River basin, to the south of Region 10.

According to Martini and Kavalieris (1976) the Chuniespoort Group was subjected to four periods of karstification since the end of its formation around 2 400 Ma ago. These were:

- Pre-Pretoria Group period (>2 350 Ma)
- Pre-Waterberg Group period (>1 950 Ma)
- Pre-Karoo Supergroup (>320 Ma), and
- Tertiary to Recent (>65 Ma).

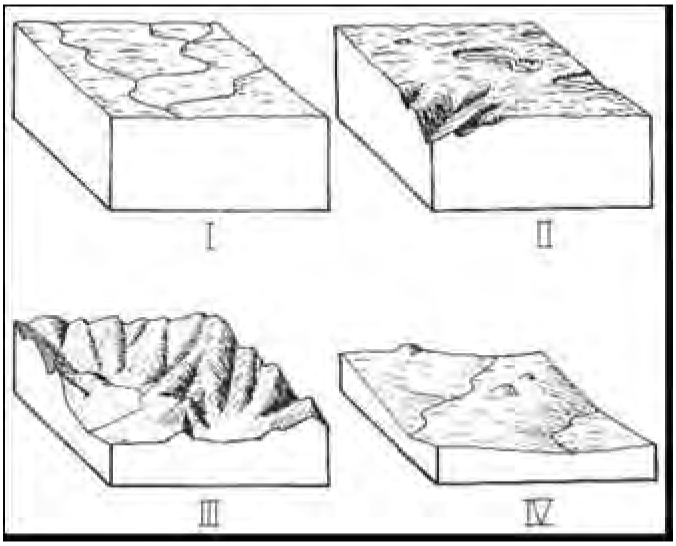


Figure 4.1: Morphological types identified by Martini and Kavalieris. I: Mature type; II: Plateau type; III: Escarpment type, and IV: Bushveld type. (From Martini and Kavalieris, 1976).

To illustrate the earliest karstification process the authors refer to the presence of palaeo-sinkholes filled with siliceous material, collapsed cave chambers and breccias bodies occasionally mineralized with fluorspar, lead and zinc. Such features are particularly prevalent south of Zeerust in the far west of Region 10. A unique example of such a deposit into a palaeo-sinkhole is provided by the Delmas silica deposit where silica is mined commercially. Martini and Horn (1996) proposed that this large pure quartzite deposit is the result of infilling of a mega sinkhole during a marine transgression that occurred during the sedimentation of basal Pretoria Group formations. This proposed origin of the Delmas silica deposit suggests that karstification and sinkhole formation probably was already active during early Pretoria times, i.e. around 2 350 Ma ago

Large areas of Region 10 are covered by red silty soils and other residual solution debris, such as chert remnants, of variable thickness giving rise to valuable agricultural soils. These are the result of weathering and dissolution of dolomitic material of older karst regoliths.

In especially the eastern parts of Region 10 large areas are also covered by younger formations, for example sediments of the Pretoria Group and the Karoo Supergroup. These were often deposited in depressions and palaeo-sinkholes.

During dissolution of the carbonate rocks, the residual consisting of silica, iron and manganese oxides, left behind form a compressible, low density and high void volume material often referred to as “wad”. Geological structures such as faults, joints and other lineaments, are preferential zones of weathering and could form drainage patterns filled with debris. Where the residual matrix consists of a high percentage of coarse chert, this often results in relatively shallow highly permeable chert gravel deposits that can sustain high-yielding boreholes (Bredenkamp et al, 1986).

4.3 Sinkholes and Subsidences

Depressions present on a karst landform are referred to as *sinkholes* or *dolines*. Lately, South African engineering geologists prefer the use of the term *subsidence* instead of doline (CGS, 2003). In terminology widely used in South Africa, a sinkhole is a subsidence which appears suddenly, and sometimes with catastrophic consequences, as a cylindrical and steep-sided hole in the ground. It is usually but not always, circular in plan, and can be more than 100 m across and 50 m deep (Brink, 1979). The formation of sinkholes is a natural process, and it forms either by solution of surface carbonate such as dolomite, or by the collapse of underground caves (Johnson and Joubert, 2004). The mechanism of sinkhole formation is described in a CGS publication to be as follows (CGS, 2003):

- Cavities exist within bedrock or overburden which may be in a state of equilibrium.
- Active subsurface erosion caused by concentrated ingress of water will result in transportation of materials downwards into the nearest cavity or receptacle.
- Headward erosion leads to successive arch collapse.
- A triggering mechanism leads to the breaching of the last arch.

A doline, or compaction subsidence, is an enclosed surface depression which forms a result of the compression at depth of low-density dolomite residuum (CGS, 2003). According to this source two main types can be identified based on the mechanism of formation, namely dewatering type and surface saturation type. In the case of the dewatering type, the rapid lowering of the groundwater level with the exposure of previously submerged and unconsolidated debris and leads to rapid surface settlement. Such subsidence features may be circular, oval or linear in plan. The periphery of a subsidence feature is characterized by tension cracks within a zone of shear (Brink, 1979).

The Council for Geoscience evaluate all proposed new developments on dolomitic areas and as such regulate the safe development on such areas. As part of this function they have over the years compiled an extensive database of known sinkhole and subsidence occurrences across Groundwater Region 10 and have made this information available to this project. The positions of all known sinkhole and subsidence occurrences within Groundwater Region 10 are shown in Figure 4.2.

4.4 Caves

Martini and Kavalieris (1976) describe three types of caves found in the karst regions of the northern part of South Africa. They termed these as:

- Fissure caves. This is the most common type in Region 10 and the development is controlled by jointing and strongly influenced by groundwater.
- Simple pattern caves. These medium to large caves usually only have a few passages and are not as common as the fissure type caves.
- Collapse caves. These are large caves with irregular shape and were mostly formed due to roof collapse which is made possible as a result of the high density of joints present in the dolomitic rocks. Roof collapse could have occurred below the ground water level or also as a result of gradual lowering of the groundwater level due to climatic conditions or large scale groundwater abstraction.

Martini and Kavalieris (1978) identified the location of 12 caves of different size with Region 10. Most of these are concentrated in the dolomite formations present around the Johannesburg Dome. The best known are the Sterkfontein Caves and Wonder Cave within the Cradle of Humankind World Heritage Site near Krugersdorp (SA Karst Working Group, 2010).

The directions along which cave passages have developed for the area west of Johannesburg were studied by Kavalieris and Martini (1976) and Moon (1972). They concluded from their cave surveys that the most passages had an east-west orientation with another secondary direction being almost perpendicular to it (Figure 4.2). Kavalieris and Martini (1976) relate this orthogonal pattern of passages to post-Karoo crustal arching along a NNE-SSW axis. The major east-west joint set is comparable to the dominant strike trend of the post-Karoo dykes.

A WNW trending shear system, including the Rietfontein Wrench Fault System has been identified by Holland et al. (2010) as the principle control of cavern development in the area west of Krugersdorp. In this region most of the caves, sinkholes, dolines and fissures are located on the WNW shear zones.

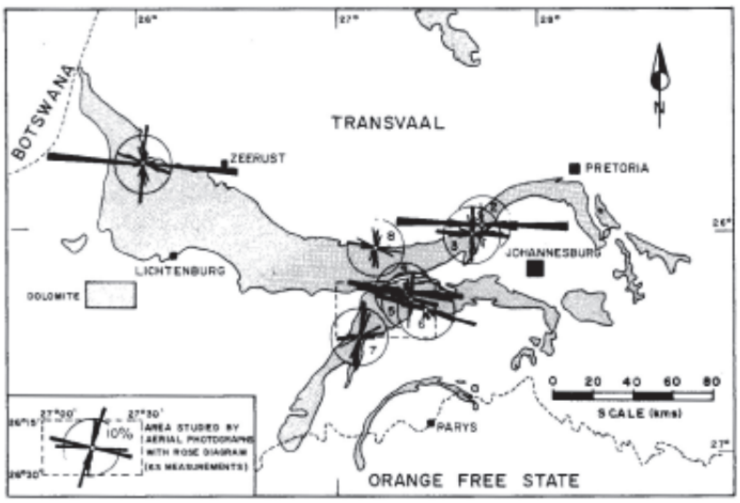


Figure 4.2(a): Strike directions of cave passages in caves to the southwest of Johannesburg and near Zeerust in the Northwest Province (after Kavalieris and Martini, 1976).

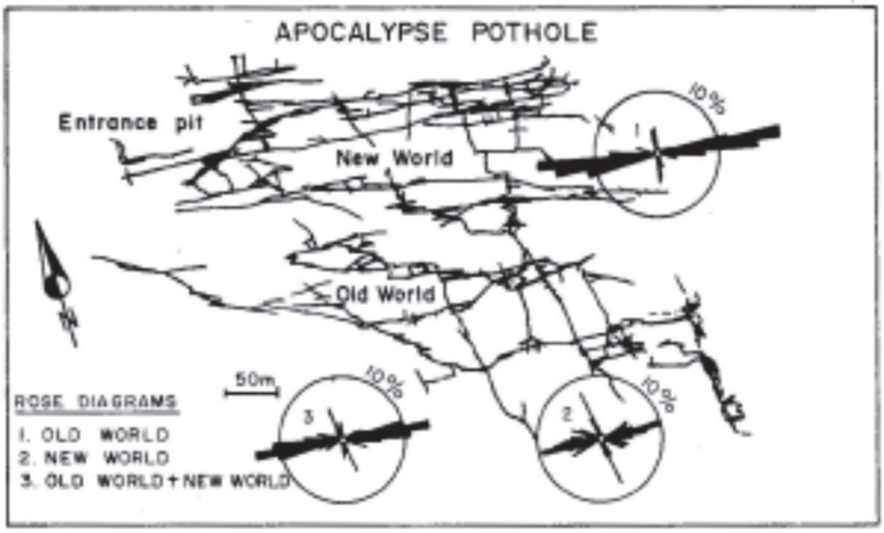


Figure 4.2(b)**:** Strike direction of fissures in one of the largest known caves to the southwest of Johannesburg (after Kavalieris and Martini, 1976).

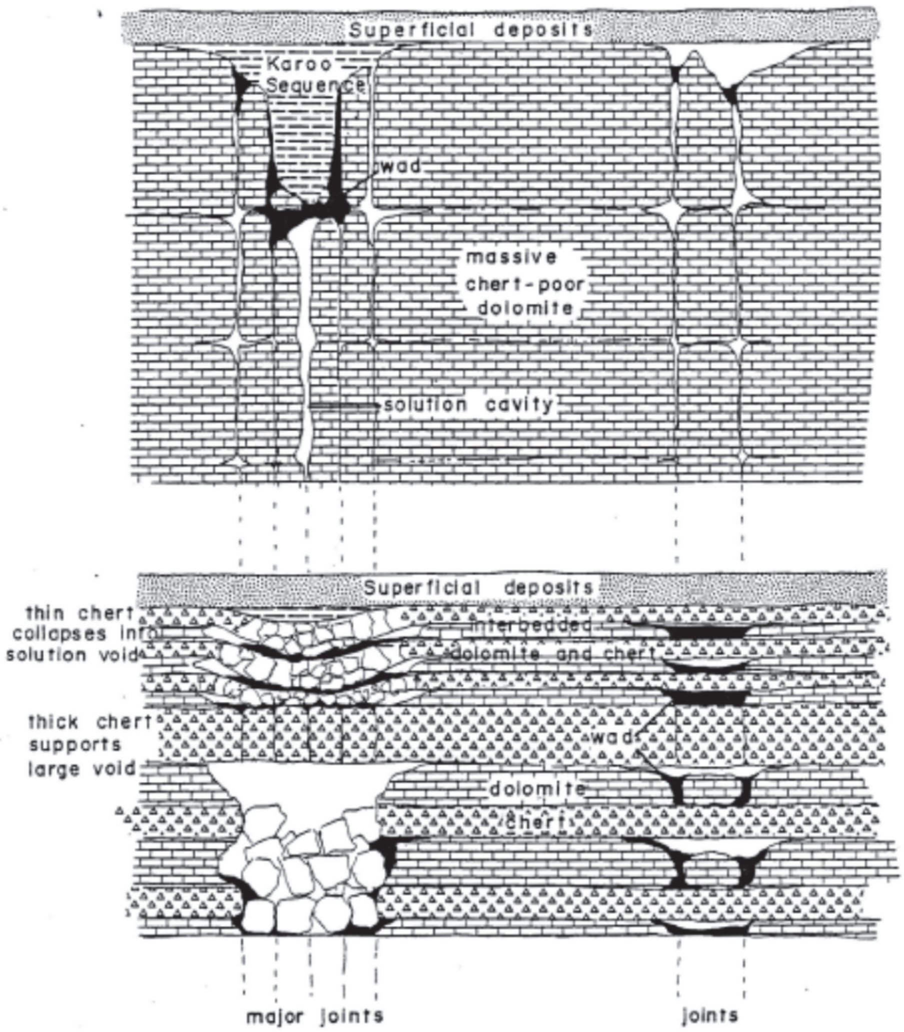


Figure 4.3**:** Conceptual model of dissolution and weathering patterns along joints in chert-rich and chert-poor formations of the Malmani Group (after Foster, 1988).

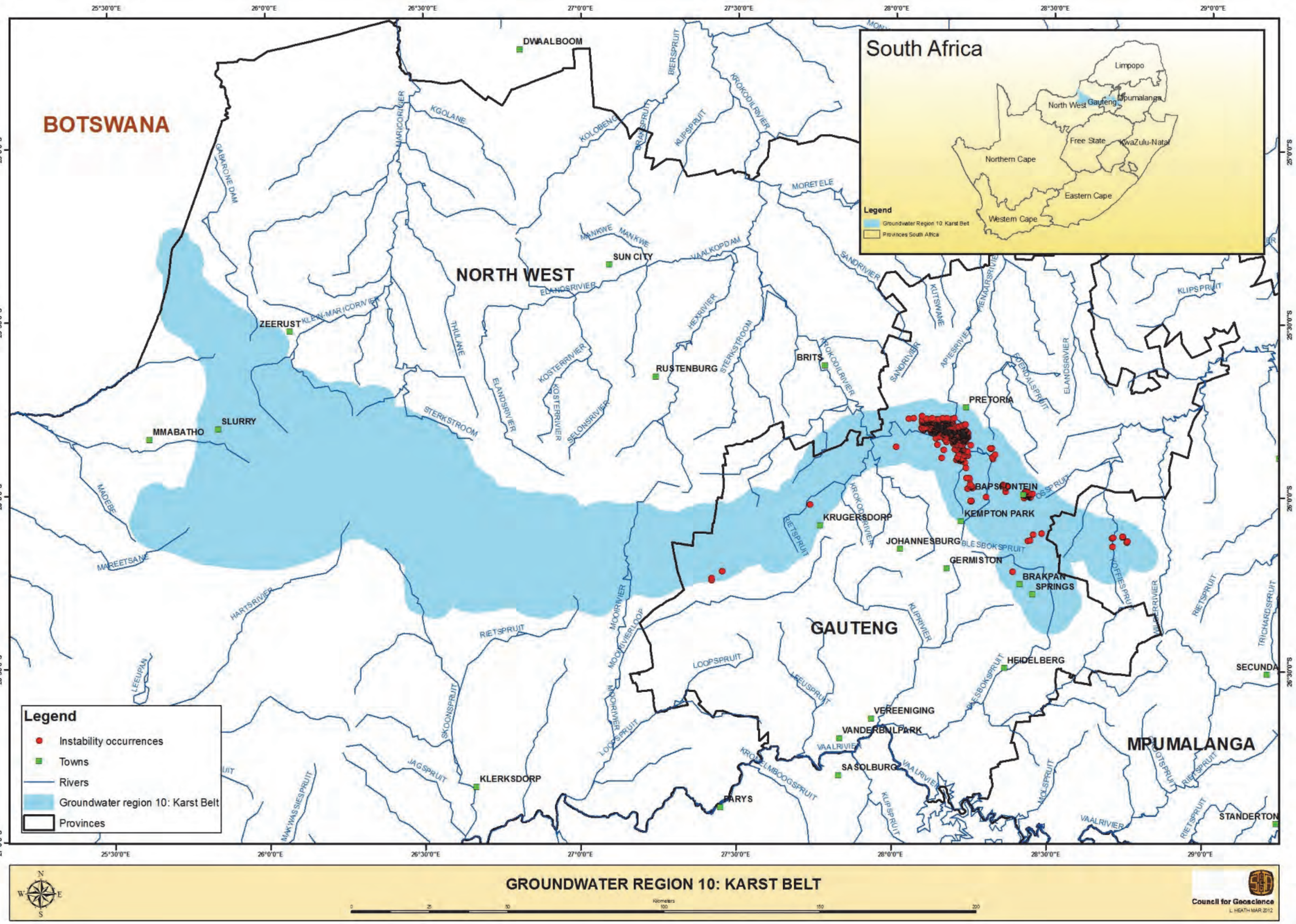


Figure 4.4: Sinkhole and subsidence occurrences across Groundwater Region 10 (Data provided with courtesy of the Council for Geoscience, Pretoria).

5 BRIEF REFERENCE TO PREVIOUS GROUNDWATER INVESTIGATIONS AND REPORTS

5.1 Geohydrological investigations initiated by the Department of Water Affairs

From references cited in the final report of an interdepartmental committee regarding dolomitic mine water of the Far West Rand published in 1960 (Department of Water Affairs, 1960), it is apparent that the groundwater potential of the dolomitic formations of the larger area around Johannesburg has received significant attention since the late 1800s. The initial interest was directed at water supply for the fast developing mining and related activities, but in later years the focus shifted towards the especially safety related problems resulting from the presence of large amounts of groundwater associated with the dolomitic rocks overlying the gold mining areas (Venter, 1986). The initial ideas for utilizing the large volumes of groundwater stored in dolomitic compartments in the West Rand, came from investigations described in a paper by Enslin and Kriel (1968). This led to extensive geohydrological studies in especially the West Rand starting during the period 1950 to 1980.

The next major research drive to obtain a better understanding of the geohydrology of the dolomitic rocks of the so-called PWV area (Pretoria-Witwatersrand-Vereeniging), started in the early 1980s. The annual inflow into the Vaal Dam, the major storage facility for the Rand Water Board, the water utility company responsible for water supply to the larger area around Johannesburg and Pretoria, remained consistently below average from 1977 for a period of 11 years (Roberts, 1988). This was the severest drought the area experienced in 64 years of flow observations. This drought resulted in the development of emergency water supply initiatives, one of which was obtaining an additional water supply from the dolomitic ground water resource.

Intensive geohydrological, geophysical and engineering geological investigations were started in 1983 in the area around Delmas, Springs, Pretoria, Tarlton and Vereeniging. In the following 5-10 years this area was intensely investigated by the Department assisted by several consulting firms in an attempt to firstly, better understand the geological and hydrogeological conditions and controls on groundwater occurrence, secondly, to assess the volume of groundwater held in the dolomitic strata and to establish the assured yield of this water resource based on recharge determinations, thirdly to delineate target areas to developing high yielding boreholes, and finally, assess the consequences as a result of high abstraction volumes on the development of subsidence and sinkholes and other possible associated engineering geological aspects.

A large collection of technical reports emerged from these studies, long term groundwater monitoring programmes were developed, many new research initiatives were identified, researched and addressed in later years, some of which are still continuing. Lately, and perhaps in part due to the implementation of the new South African legal conditions, for example the new Water Act (Act 36 of 1998) and the National Environmental Management Act (Act 107 of 1998), the emphasis has shifted towards the management of the groundwater resources of the dolomitic formations and environmental aspects, such as groundwater-dependent ecosystems and groundwater reserve determinations.

The reference list to this report contains references to several of these reports from an extensive collection of technical reports, publications and other relevant material resulting from the investigations of the dolomitic ground water resources in and adjacent to Groundwater Region 10 since about 1970.

5.2 Brief outline of Department of Water Affairs and Forestry Dolomite Project

The Department of Water Affairs contracted Water Geoscience Consultants of Pretoria in 2008 to prepare a comprehensive set of reports on carbonate rock aquifers across South Africa. In short the project is referred to as the "DWA Dolomite Project". This project was structured along 28 different "Technical Activities" each addressing specific aspects of the geohydrology, management of groundwater within these aquifers, development of land underlain by the rock formations, data collection, development of guidelines, and future research priorities. Some of the tasks of this project can almost be described as a duplication of the tasks envisaged by the WRC for the Region 10 report and thereby being very relevant to Groundwater Region 10, are briefly described below.

- Activity 5: *Northwest Dolomites – Coordination and integration of projects*
  Deliverable: Report that summarizes and evaluates past groundwater related studies on the dolomite rocks in the Zeerust-Lichtenburg-Mafeking area.
- Activity 6: *Desktop geohydrological assessment of the Delmas/Bapsfontein dolomite area.*
  Deliverable: Report which describes geology, hydrogeology, ground water levels and trends, groundwater quality and evaluates current water use from the dolomites rocks east and northeast of Johannesburg (including the Rietvlei, Elandsfontein, Witkoppies, Bapsfontein-Delmas.
- Activity 7 *Ground stability in dolomitic areas – Tshwane*
  Deliverable: Compilation of an inherent ground stability risk classification for the Centurion CBD area.
- Activity 13: *Desktop geohydrological assessment of the Tarlton dolomites.*
  Deliverable: Report describing geology, hydrogeology, ground water levels and trends, ground water quality, and evaluating current ground water use in the Zwartkrantz and Steenkoppies compartments respectively to the east and west of Tarlton. Discuss issues around acid mine drainage and proposes management recommendations.
- Activity 14: *Desktop geohydrological assessment of the Tshwane dolomites*.
  Deliverable: Report describing geology, hydrogeology, ground water levels and trends, ground water quality, and evaluating current ground water use in the Aalwynskop, Erasmia, East and West Fountains, and East and West Doornkloof compartments to the south of Pretoria. Discussion of management issues such as pollution, data collection, and protection zoning.
- Activity 19: *Dolomite compartment maps*
  Deliverable: Preparation of a series of A0 size maps summarizing groundwater conditions and management units in the Tshwane, Natalspruit, Tarlton, North West and Ghaap Plateau dolomite areas aimed at planners and managers at various levels.

- Activity 20: *Desktop study of future research priorities for the North West dolomites*
  Deliverable: Refined and prioritized list of technical and management recommendations arising from Activity 5 in collaboration with F Wiegmans and D Bredenkamp.
- Activity 21: *Implementation of generic dolomite guidelines*
  Deliverable: Report that recommends management activities and actions, particularly as they apply to two study areas (Tshwane and Sudwala/Pilgrim's Rest). To include technical and policy background material to ground water management in South Africa, and a summary of current management issues.
- Activity 25: *Geohydrological assessment of the Steenkoppies dolomite compartment.*
  Deliverable: Technical assessment of groundwater conditions in the Steenkoppies compartment near Tarlton, with particular reference to the low flows at Maloney's Eye spring and associated disputes. Includes analysis of rainfall in the area and correlation of rainfall with spring flows, a review of previous work, and recommendations for management interventions.

Comparing the items described above with the original requirements as formulated by the WRC for Ground water Region 10 (see introduction to this report), it is clear that there is considerable duplication of tasks in the two projects. Suggestions as to the incorporation of some of the Dolomite Project reports to be included in the WRC report, are addressed later in this report.

6 SUBDIVISION OF GROUNDWATER REGION 10

6.1 Boundaries of Groundwater Region 10

In the original description of the different groundwater regions by Vegter (2000), Groundwater Region 10 is described by Vegter (2000) to comprise of the *"Chuniespoort dolomite and chert; subordinate Black Reef quartzite, conglomerate and shale".* Between Ventersdorp and Randfontein the Black Reef Formation is exposed along the axis of an anticlinal structure. To the south of this anticline, the Chuniespoort Group is present over a very large area where it overlies formations of the Witwatersrand Supergroup constituting the Far West Rand Goldfields. Although the Black Reef Formation forms part of Groundwater Region 10 according to the classification by Vegter (2000), he defined the boundary between Groundwater Regions 10 and 17 to be the Black Reef Formation exposed by the anticlinal structure. This aspect was discussed with Mr Vegter and he confirmed that it was his intention to separate the two dolomitic areas to form Regions 10 and 17 with the Black Reef Formation.

Another discrepancy between the southeastern boundary of the digitally available outline of Groundwater Region 10 obtained from DWAF and those shown on the maps in the report by Vegter (2000), was described in the previous progress report. The published 1:250 000 geological map 2628 East Rand (CGS, 1978) indicates large dolomite outcrop areas roughly within the triangle formed by Bapsfontein, Delmas and Springs. However, only a small portion of the area shown as a dolomite outcrop area on the geological map has been included within the original digital outline area of Region 10 as supplied by DWAF. During follow-up discussions with Mr Vegter it became apparent that the exclusion of this roughly triangular region was not intentionally, and that this must be an error introduced during the digitizing of his original maps. He was not aware of this error on the printed and digital versions of the Region 10 outlines. This error also affects the outline of adjoining Regions. Mr Vegter agreed that this should be changed and with his input the outline was changed to that shown in Figure 3.1 as well as on all other maps included in this report where the outline of Region 10 is shown.

6.2 Compartments

The package of Chuniespoort Group formations has been subdivided into "compartments" by dyke intrusions of different strike directions and ages. That these dyke intrusions to a large extent control groundwater movement was already realized at an early stage of the groundwater investigations in the gold mining areas of the West Rand. In 1986 Vegter prepared a map of the Pretoria-Witwatersrand-Vereeniging area on which the compartments in the Delmas-Pretoria-Tarlton were delineated. Essentially all geohydrological studies of the Malmani Subgroup during the last approximately 40 years were based on the compartementalisation of the area. Holland (2009) prepared a comprehensive map of the dolomitic groundwater resources of the Gauteng and Northwest Provinces in which divided the Groundwater Region 10 into 25 compartments and allocated a name to each of these compartments (Figure 6.1). Some of these compartments are subdivided into smaller units where the boundaries to these subdivisions are also based on dyke intrusions. Groundwater conditions within each of these compartments are considered to ebb fairly uniform, with low groundwater gradients, but at compartment boundaries, significant differences in water level can be present. Based on the water level differences observed across compartment or dyke boundaries, the dykes are considered to be impermeable, at least at deeper levels, while some flow across the boundaries may occur within the upper weathered section of the dyke. Along the downstream compartment boundaries, springs or “eyes” are often present, where the groundwater held in storage in the upstream compartment, decants into the adjacent downstream compartment (Figure 6.2).

Table 6.1: Groundwater Management Areas (or Dolomitic compartments)

Position	Name	Quaternary catchment	Area (km^2)	Position	Name	Quaternary catchment	Area (km^2)
West	Dinokana	A31D		East	Tweefontein	A21G	162
	Zeerust	A31C	699		Hennops	A21H	190
	Molopo/ Grootfontein	A31D	985		Aalwynskop	A21B-A	155
					Fountains West	A21B-F	141
	Marico	D41A	535		Fountains East	A21D	74
	Isoteng	C31D	95		Rietvlei	A21A-R	73
	Dudfield	C31B	105		Kaalspruit	A21B-K	117
	Lichtenburg	A31A	781		Sterkfontein	A21A-S	219
	Holpan	C24F	516		Elandsfontein/ Bapsfontein	A21A-B	209
	Schoonspruit	C24C	1320		Rietfontein	B20B	185
	Mooirivier	C23F	827				
	Holfontein	C23E-H	74		East Rand Basin	C21	936
Central	Steenkoppies	A21F	313		Delmas	B20A	424
	Zwartkrans	A21D	292				

The presence of subvertical dolerite and diabase dykes intruded into the dolomitic strata is of great importance in all descriptions of the hydrogeology of the dolomitic aquifers between the Botswana border in the west and Delmas in the east. . These intrusions occurred along the two main directions, NNW and approximately east-west and are regarded as being mostly impermeable and therefore form barriers to lateral groundwater movement. As such they subdivide the dolomite in what is generally described as “compartments”. The boundaries to these compartments have mostly been defined geophysically and each of these major compartments has been named after the area in which it located (Table 6.1). During the Dolomite Project of DWAF, the entire area in which dolomitic aquifers are present in the North West and Gauteng provinces, has again been subdivided into compartments by using aeromagnetic maps of the whole region. It is believed that the compilers of the maps on which the boundaries to these compartments have been allocated, have taken into account older reports and investigations where boundaries and names for the different compartments have been allocated and that the new maps are to be taken as final and representative of the current status of these compartment boundaries. Therefore the compartment boundaries and names shown in the Dolomite Project reports and reflected in Table 6.1 are taken to be those that will be used from now on to eliminate future confusion with these aspects.

6.3 Groundwater management in karst aquifers

6.3.1 Groundwater management

Prolific yields obtained from well-constructed boreholes in certain areas within Region 10 often result in the over-exploitation of groundwater resources especially where extensive irrigation is practiced. This requires some management intervention and control, preferably beyond the routine monitoring of water level, abstraction volumes, water quality and rainfall in order to ensure long term sustainability of the resource. Apart from this, other important reasons for managing dolomitic groundwater abstraction, are to minimize or prevent the formation of sinkholes or subsidence, and to maintain spring flow in areas where towns or communities are dependent on the natural flow to satisfy their water resource requirements.

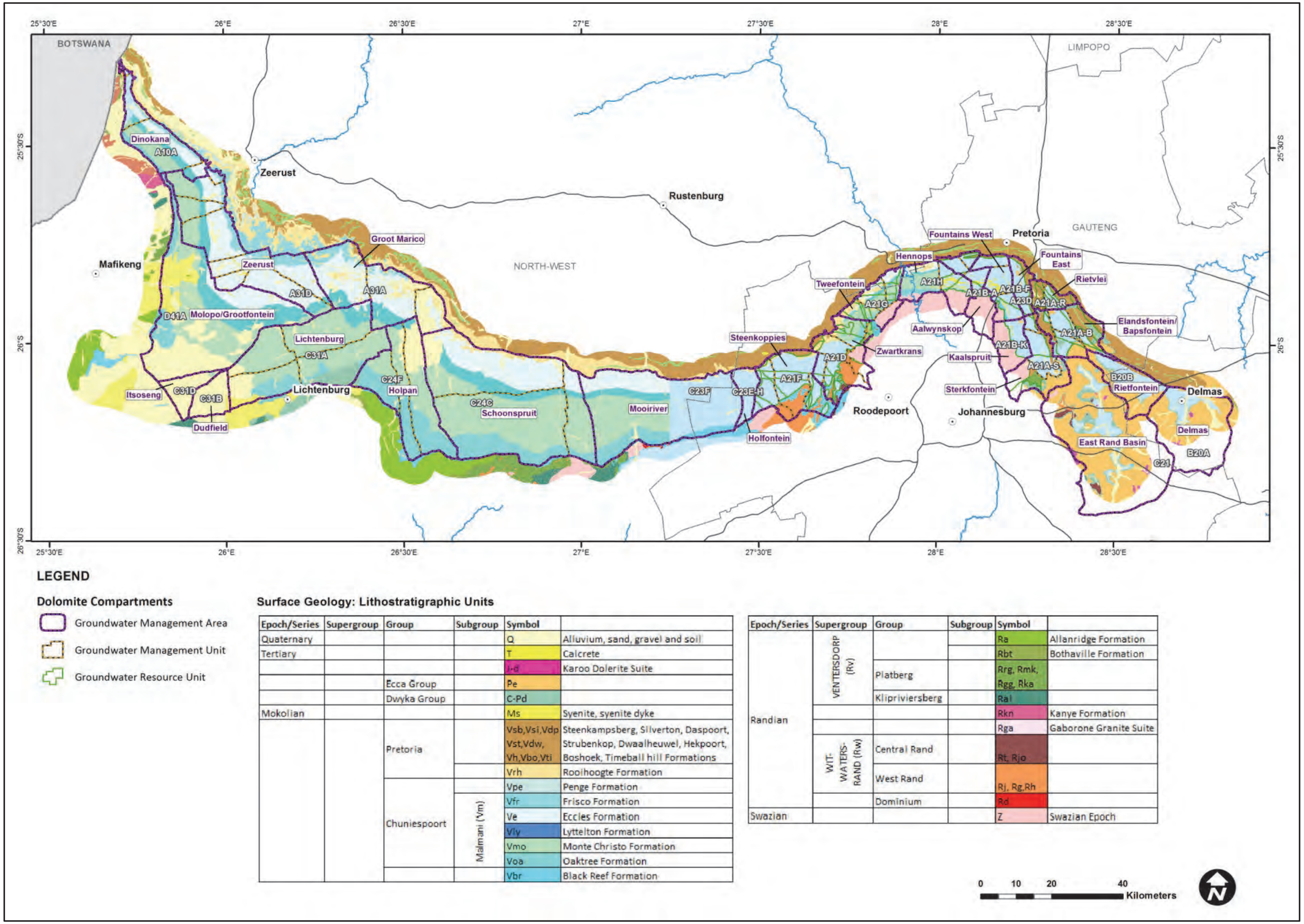
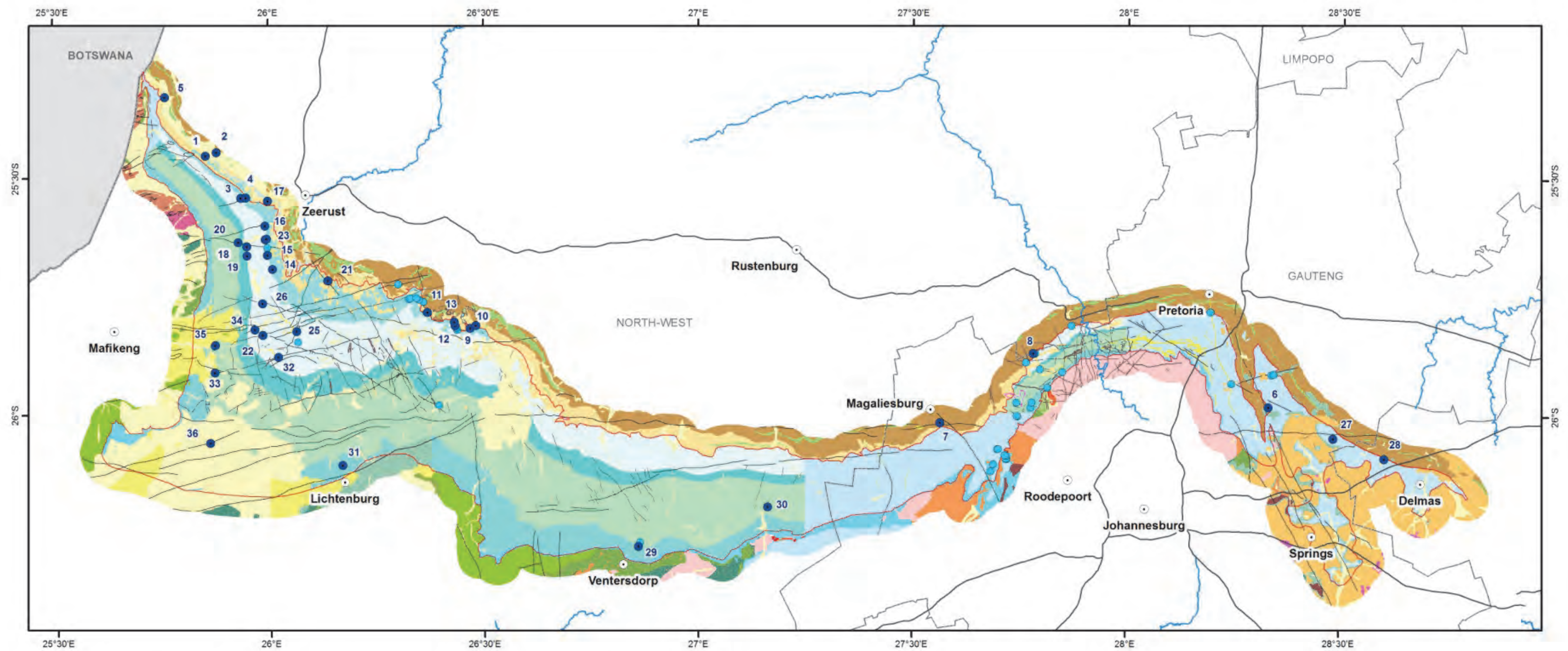


Figure 6.1: Map of Region 10 showing the boundaries to the different GMAs or compartments.



LEGEND

Springs documented in NGA

Major springs (gauged)

1	Dinokana Upper	13	Rietspruit	25	Malmani Eye
2	Dinokana Lower	14	Buffelshoek	26	Doornplaat
3	Tweefontein Upper	15	Stinkhoutboom	27	Rietfontein Eye
4	Tweefontein Lower	16	Vergenoegd	28	Olifantsfontein
5	Skilpad Eye	17	Klaarstroom	29	Schoonspruit
6	Elandsfontein Eye	18	Kraalfontein	30	Bovenste
7	Maloney's Eye	19	Rietpoort	31	Aslaagte
8	Nouklip	20	Doornfontein	32	Molopo Eye
9	Bokraal1	21	Rhenosterfontein Eye	33	Grootfontein Mafikeng
10	Bokraal2	22	Kareebosch	34	Welgedacht
11	Grootfontein (Kaalooq)	23	Paardevlei	35	Olivendraai
12	Rhenosterhoek	24	Paardevlei2	36	Polfontein

Surface Geology: Lithostratigraphic Units

Epoch/Series	Supergroup	Group	Subgroup	Symbol	
Quaternary				Q	Alluvium, sand, gravel and soil
Tertiary				T	Calcrete
				J-d	Karoo Dolerite Suite
		Ecca Group		Pe	
		Dwyka Group		C-Pd	
Mokolian				Ms	Syenite, syenite dyke
		Pretoria		Vsb,Vsi,Vdp Vst,Vdw, Vh,Vbo,Vti	Steenkampsberg, Silverton, Daspoort, Strubenkop, Dwaalheuwel, Hekpoort, Boshoek, Timeball hill Formations
				Vrh	Rooihoogte Formation
		Chuniespoort	Malmani (Vm)	Vpe	Penge Formation
				Vfr	Frisco Formation
				Ve	Eccles Formation
				Vly	Lyttelton Formation
				Vmo	Monte Christo Formation
				Voa	Oaktree Formation
				Vbr	Black Reef Formation

Epoch/Series	Supergroup	Group	Subgroup	Symbol	
Randian	VENTERSDORP (Rv)			Ra	Allanridge Formation
				Rbt	Bothaville Formation
		Platberg		Rrg, Rmk, Rgg, Rka	
		Klipriviersberg		Rai	
				Rkn	Kanye Formation
				Rga	Gaborone Granite Suite
	WIT-WATERS-RAND (Rw)	Central Rand		Rt, Rjo	
		West Rand		Rj, Rg,Rh	
		Dominium		Rd	
Swazian				Z	Swazian Epoch

Dykes and lineaments

Faults

0 10 20 40 Kilometers

Figure 6.2: Map showing the major springs across Groundwater Region 10. Each spring is numbered and the names are shown in the table at the bottom left.

Although numerical groundwater models have been developed for specific areas or compartments within Region 10 (Van Rensburg, 1992; Bredenkamp and Nel, 1997), such techniques are not routinely used for groundwater management in the region. The lack of reliable quantitative estimates of hydraulic parameters such as storage, transmissivity and recharge, and the aerial variation thereof has contributed to the non-application of modeling techniques for management purposes.

The Department of Water Affairs maintains an extensive network of dedicated monitoring boreholes mostly for water level monitoring, flow gauges at springs, and rainfall recording stations throughout the region. For the larger compartments and where the Department is aware of potential over-exploitation, this monitoring information is analysed regularly with the aim of identifying continuous long-term negative water level trends. Despite numerous studies to develop groundwater management techniques for the karst aquifers, in practice water level monitoring and control remains the most widely applied technique for groundwater management in the area.

6.3.2 Groundwater Managements Units

Using the compartments as departure point, Holland (2009) proposed the use of practical groundwater management entities. For this purpose the compartments are regarded as closed or isolated groundwater units and as such are convenient for the management of groundwater resources in the karst groundwater environment. Based on an analysis of the available groundwater information in karstic terrains, he identified what he terms *hydrogeological response units* and developed his management concept on these units. For this purpose he defined the following groundwater management terminology that can be applied to the karst groundwater conditions present in Region 10:

- *Groundwater Management Area or GMA:*
  Areas that usually coincide with compartment and surface water catchment boundaries and can include a number of dyke delineated groundwater compartments. A GMA normally comprises of a number of GMUs or GRUs.
- *Groundwater Management Unit or GMU*
  The boundaries of these are based on surface water drainage and hydrogeological considerations. Each of these units represents a hydrogeologically homogeneous zone and boreholes tapping the groundwater resources within this unit are in hydraulic connection to each other
- *Groundwater Resource Unit or GRU*
  This unit represents a groundwater body that has been delineated or grouped into a single significant water resource based on one or more characteristics that are similar across that unit.

6.4 Subdivision of Groundwater Region 10

The hydrogeological discussions presented in this report are based primarily of the work by Holland (2009) who made a thorough analysis of available information up to 2009. He subdivided Region 10 into three areas and prepared excellent and detailed maps for each of the areas. The maps represent areas for which small gaps are present between the different areas, but the maps cover areas where large amounts of hydrogeological information is available. The information presented in this report follows the same subdivision and will be presented under the headings

- Northwest area (between the Botswana border and longitude 27°)
- Tarlton area (between approximate longitudes 27°30’ and 28°), and
- Pretoria/Bapsfontein area (between approximate longitudes of 28° and 28° 30’).

Table 6.2 Proposed subdivision of Groundwater Region 10 (Holland, 2009).

Position	Name	Area (km^2)	Position	Name	Area (km^2)
West	Dinokana	277	East	Tweefontein	162
	Zeerust	699		Hennops	190
	Molopo/Grootfontein	985		Aalwynskop	155
	Itsoseng	95		Fountains West	141
	Dudfield	105		Fountains East	74
	Lichtenburg	781		Rietvlei	73
	Groot Marico	535		Kaalspruit	117
	Holpan	516		Sterkfontein	219
	Schoonspruit	1320		Elandsfontein/ Bapsfontein	209
	Mooirivier	827		Rietfontein	185
Central	Holfontein	74		Delmas	424
	Steenkoppies	313		East Rand Basin	936
	Zwartkrantz	292			

7 HYDROGEOLOGY OF THE WESTERN SECTION OF GROUNDWATER REGION 10

7.1 Water Management Areas (WMAs) or "compartments" in this section

The area described in this section extends from the Dinokana compartment close to the Botswana border to the Mooifontein Compartment west of Tarlton and comprises of the compartments listed in Table 7.1 and shown in Figure 6.1. The hydrogeology of each Water Management Area will be discussed under separate headings.

7.2 Hydrogeology of the Northwestern Region

7.2.1 Dinokana and Zeerust Groundwater Management Areas

These two GMAs are located in the northwestern part of Groundwater Region 10 and consist of the following Groundwater Management Units (GMUs):

- *Dinokana GMA*
  - Tweefontein (A10A-01);
  - Dinokana (A10A-02;
  - Skilpad Eye (A10A-03); and
  - Skilpadhek (A10A-04).

The combined surface area of these four units is 273 km^2. The boundaries between the different compartments are formed by:

- the Tweefontein dyke forms the boundary between the Tweefontein and Dinokana GMUs;
- the Dinokana dyke forms the boundary between the Dinokana and Skilpad Eye GMU';
- an unnamed short dyke forms the boundary between the Skilpad Eye and the Skilpadhek GMUs.

- *Zeerust GMA*
  - Wonderfontein (A31D-01);
  - Malmani (A31D-02);
  - Kareebosch (A31D-03);
  - Welgedacht (A31D-04);
  - Ottoshoop (A31D-05);
  - Doornforntein (A31D-06);
  - Paardevlei (A31D-07)

The combined surface area of these seven GMUs is 922 km^2. The Vlakplaas, Tweefontein and Klippan dykes separate the Zeerust GMA from the Molopo/Grootfontein GMA, while other prominent dykes present in the GMA include the Ottoshoop, Vergenoeg, Doornpoort, Rietfontein, Slurry, Kareebosch, Welgedacht, Doornplaat and Witkop dykes. The boundaries to the different GMUs in each of these two GMAs are shown in Figure 7.1.

Seventeen springs are present in these two GMAs. These are referred to as the Upper (1) and Lower Dinokana (2), Upper (3) and Lower Tweefontein (4), Skilpad Eye (5), Malmani Upper (25), Kareebosch (22), Welgedacht (34), Doornplaat (26), Buffelshoek (14), Stinkhoutboom (15), Doornfontein (20), Rietpoort (19), Kraalfontein (18), Paardevlei1 (23), Paardevlei 2 (24),

Table 7.1. Subdivisions and Groundwater Management Units (GMUs) for the compartments in the western part of Groundwater Region 10 as prepared by Holland (2009).

Compartment name (Holland's GMAs)	Subdivisions names and Holland's GMUs		Area (km^2)	Compartment name (Holland's GMAs)	Subdivisions names and Holland's GMUs		Area (km^2)
Dinokana	A10A-01	Tweefontein	26	Schoonspruit	C24C-01	Klippan	166
	A10A-02	Dinokana	188		C24C-02	Vetpan	509
	A10A-03	Skilpad Eye	55		C24C-03	Schoonspruit	634
	A10A-04	Skilpadhek	6	Holpan	C24F-01	Klippan	124
Zeerust	A31D-01	Wonderfontein	103		C24F-02	Roodepoortje	250
	A31D-02	Malmani	138		C24F-03	Tweebuffels	137
	A31D-03	Kareebosch	37	Dudfield	C31B-01	Isoteng	94
	A31D-04	Welgedacht	73	Isoteng	C31D-01	Dudfield	104
	A31D-05	Ottoshoop	172	Lichtenburg	C31A-01	Zamekoms	243
	A31D-06	Doornfontein	60		C31A-02	Manana	225
	A31D-07	Paardevlei	96		C31A-03	Houthaalsdoorns	143
	A31D-08	Klaarstroom	14		C31A-04	Aslaagte	162
Groot Marico	A31A-01	Grootpan	95	Molopo / Grootfontein	D41A-01	Molopo	229
	A31A-02	Groot Marico	205		D41A-02	Hendriksdal	56
	A31A-03	Grootfontein	231		D41A-03	Kliplaagte	239
Mooirivier*	C23F	Mooirivier East	~1000		D41A-04	Polfontein	142
	C23F	Mooirivier West			D41A-05	Khutotswana	22
Holfontein*	C23F	Holfontein	~200		D41A-06	Slurry	286

Vergenoeg (16) and Klaarstroom (17). The numbers in brackets refer to the numbers shown on Figure 6.2. The positions of these springs area also shown in Figure 7.1.

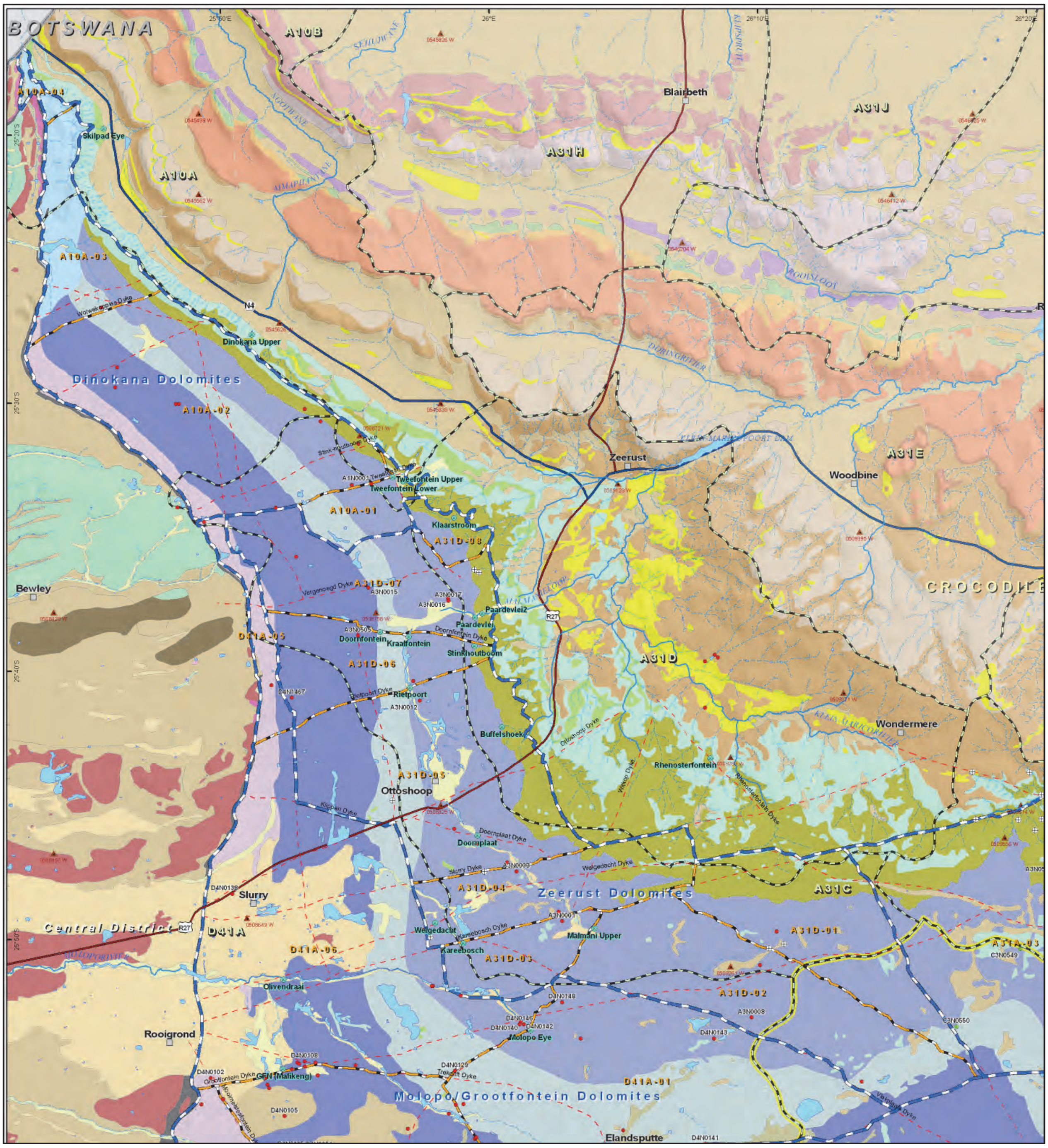


Figure 7.1. Map showing the extent of the Dinokana and Zeerust GMAs (map sourced from Holland, 2009)

The groundwater resources within these compartments, and especially the Zeerust Compartment, are of great importance as the town of Zeerust is totally dependent on groundwater from this GMA. The water demand increased from 1.4 Mm^3/a in 1978 to a fairly constant value of 2.6 Mm^3/a for the period between 1983 to 1995. Stephens et al. (2005) provided an estimate for the groundwater abstraction for 2005 which amounted to 44.8 Mm^3/a compared to a recommended sustainable abstraction of 39.9 Mm^3/a for the Zeerust compartment. An over-abstraction of 12% in 2005 clearly indicates that careful management of this resource is already, and will become even more, important in future. As it has always been recognized that the management of this resource is important, studies have concentrated on the determination of aquifer characteristics, recharge determinations and how to estimate the impact of abstraction of groundwater on spring flow.

Geohydrological conditions of the Rietpoort compartment were studied in detail by Bredenkamp and Zwarts (1988) and Botha (1994) and are considered as providing a good and representative view of the regional conditions within the GMA. The Rietpoort compartment is bounded by the Rietpoort dyke in the north, the Elizabeth dyke in the west, and the Ottoshoop dyke in the south (Figure 7.2). The eastern boundary is formed by rocks of the Penge formation of the Pretoria Group. The three upper formations of the Malmani Subgroup, the Frisco, Eccles and Lyttleton, are present within this compartment and have a N-S strike direction. The chert-rich Eccles formation hosts the main aquifer. Two springs are draining the sub compartments; the Rietpoort eye in the north draining the western compartment and the Buffelshoek eye against the contact between the Frisco and Penge formations in the east. It is interesting to note that the Rietpoort Spring issues at the contact between the Eccles and the Lyttleton Formations and not at the Rietpoort dyke constituting the northern boundary of the compartment. Groundwater flow is towards the north at a gradient of approximately 1:1 700.

To obtain reliable values for aquifer storativity and recharge the Saturated Volume Fluctuation (SVF), Cumulated Rainfall Departure (CRD), spring flow, Direct Parameter Estimation (DPE) and the chloride methods were used. The application of these methods resulted in the following results:

Effective recharge:	10% of MAP(equivalent to ~48 mm/a)
Effective recharge for compartment:	3.37 Mm^3/a
Storativity:	2.5-5%
Outflow from aquifer:	1.35 Mm^3/a

The data used in the different methods used to determine these parameters are shown in Figures 7.2 to 7.9.

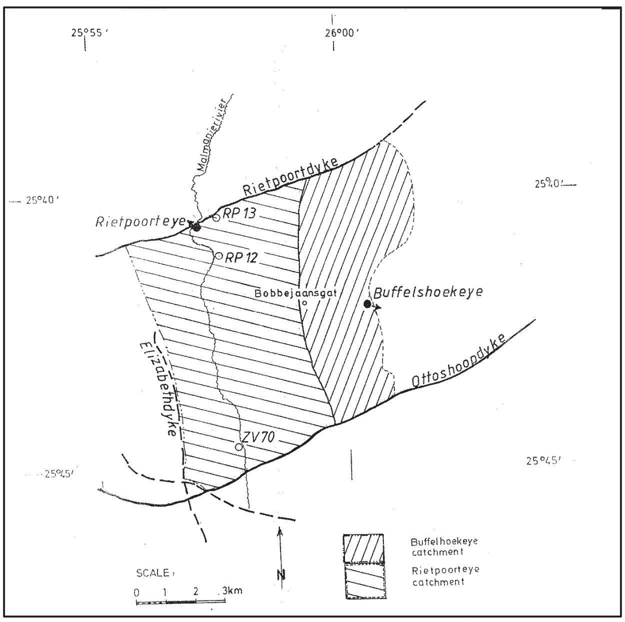


Figure 7.2. The Rietpoort GMU, a subdivision of the Zeerust GMA (from Botha, 1993).

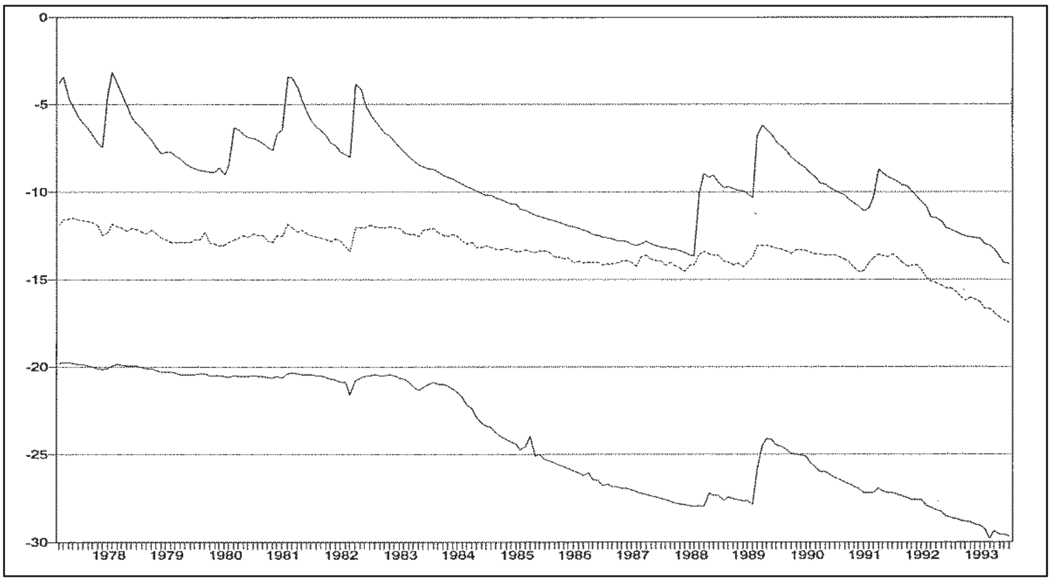


Figure 7.3. Water level records from three boreholes in the Rietpoort GMU (Botha, 1983).

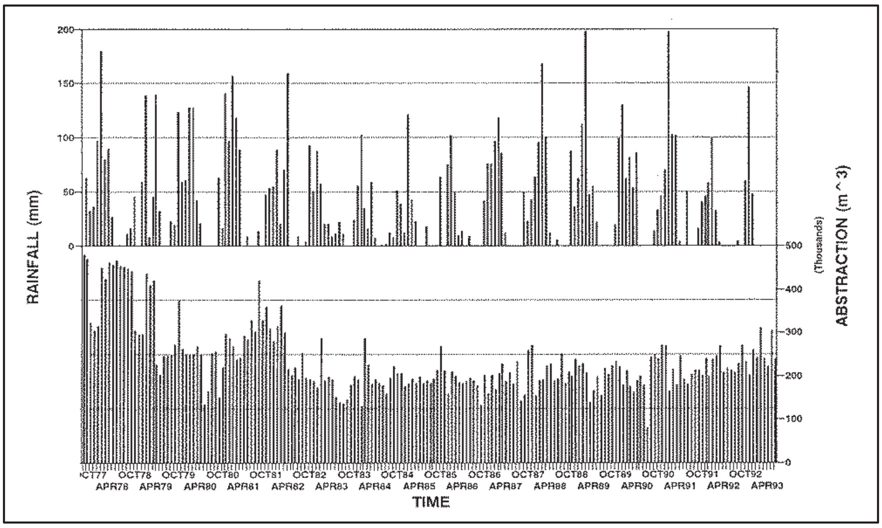


Figure 7.4. Rainfall and abstraction record from the mid 1970s to 1995 for the Rietpoort GMU. Rainfall is shown in upper graph and abstraction in lower graph (from Botha, 1993).

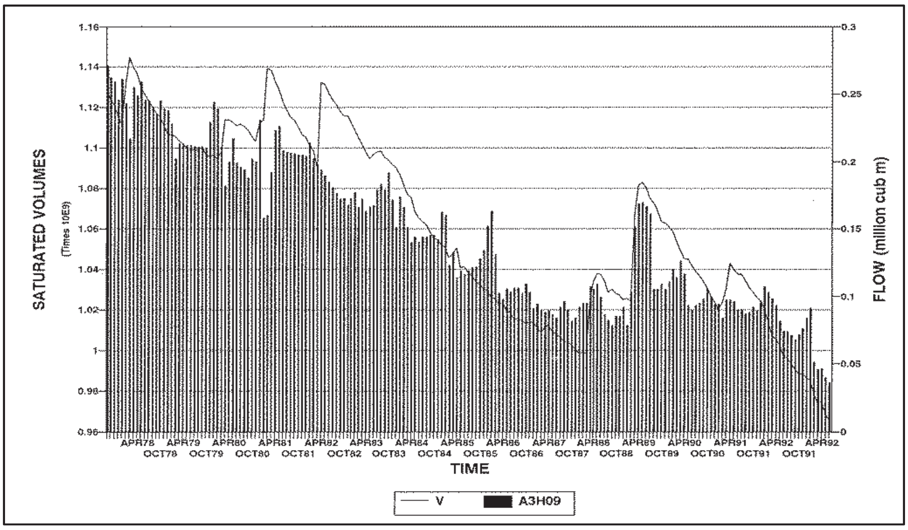


Figure 7.5. Spring flow measurements of the Buffelshoek eye (A3H09) in relation to the integrated water levels in the Rietpoort GMU (from Botha, 1993).

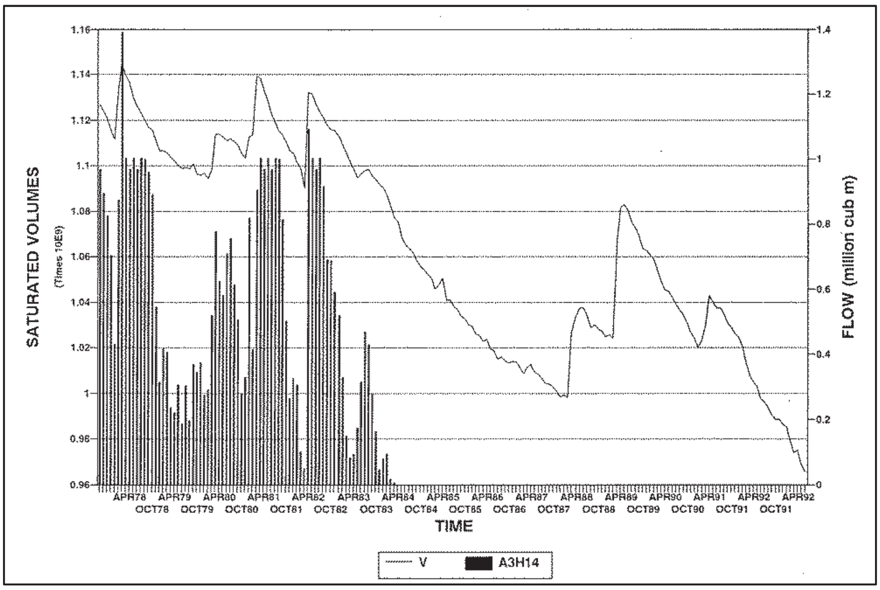


Figure 7.6. Springflow measurements of the Rietpoort eye (A3H14) in relation to the integrated water levels in the Rietpoort GMU (from Botha, 1993).

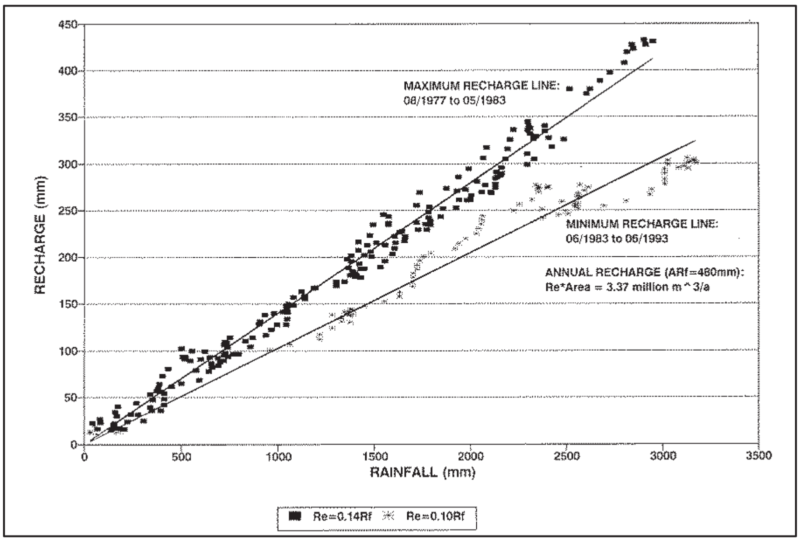


Figure 7.7. Recharge estimation graphs for the Rietpoort GMU (from Botha, 1993).

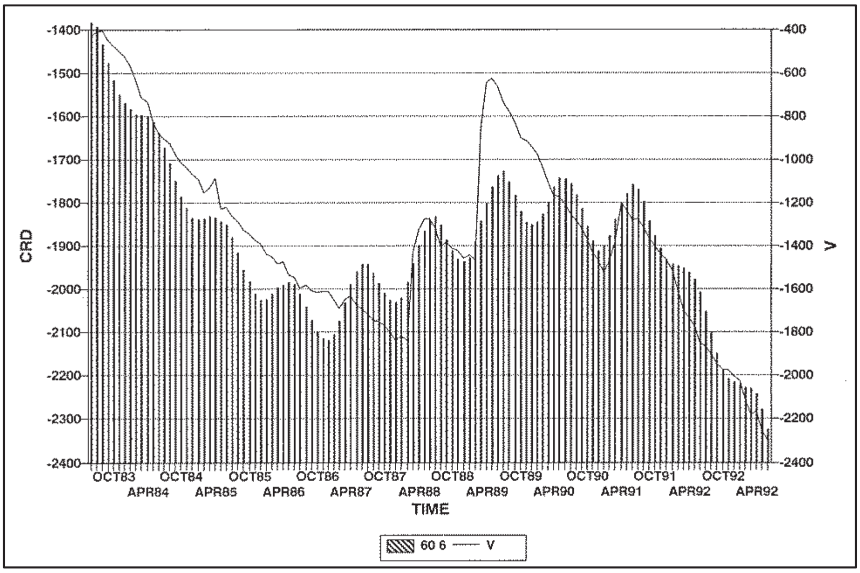


Figure 7.8. Comparison between the best CRD fit and groundwater level for the Rietpoort GMU (from Botha, 1993).

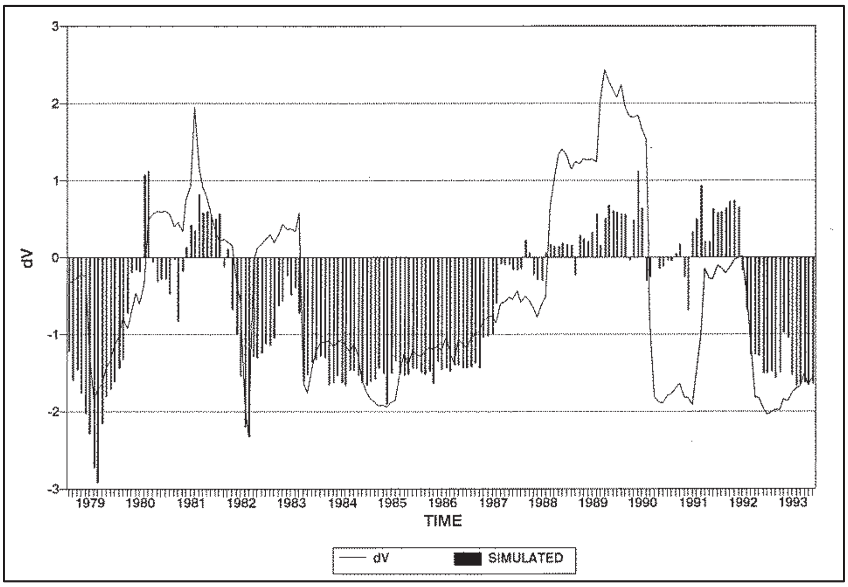


Figure 7.9. Simulation of Rietpoort water levels with the Direct Parameter Estimation Method (DPEM) for the Rietpoort GMU (from Botha, 1993).

7.2.2 Molopo Grootfontein, Itsoseng and Dudfield GMAs

The southern boundary of the Molopo-Grootfontein GMA is formed by the Paarl, Hendriksdal and Stryd dykes in the south, while the eastern and northeastern boundary is formed by the Klippan and Vlakplaas dykes. In the west the GMA ends against rocks of the Ventersdorp Supergroup. Other dykes include the Verlies, Grootfontein, Trekdrift, Slurry, Mooimeisjesfontein, Elizabeth and Kareebosch dykes. The Elizabeth and Mooimeisjesfontein dykes are N-S directed, and most of the others approximately E-W. The N-S directed ones are classified as Pilansberg age, while the others represent post-Karoo age dykes (150-190 Ma). The Itsoseng and Dudfield GMAs have a total area of ~200 km^2. The northern boundary of Itsoseng is formed by the Paarl dyke, and eastern boundary of Dudfield GMA is the N-S Elizabeth dyke.

Comprehensive studies have been done on the Kliplaagte (previously referred to as the Grootfontein Compartment), Polfontein and Molopo GMUs by Van Rensburg (1985; 1987a; 1987b; 1992), Bredenkamp (1964, 1984, 1992, 1996, 1999, 2000), Cogho (1982), Gombar (1974), Hauger (1973), Palmer (1972), Vipond (1979), Partridge and Maud (1990).

These three GMAs with a total surface area of 1172 km^2, consist of six GMUs in the Molopo-Grootfontein GMA (Molopo, Hendriksdal, Kliplaagte, Polfontein, Khunotswana and Slurry), and one each in the Itsoseng and Dudfield GMAs. The area is shown in Figure 7.10.

Four springs issue from this area: the Molopo, Grootfontein, Polfontein and Olievendraai springs. The well-known Grootfontein spring is the main source of water to the town of Mafikeng. The Molopo and Grootfontein springs are situated on the southern side of the Verlies and Grootfontein dykes respectively. According to the surveys reported in the work by van Rensburg (1987) the groundwater flow direction is to the NW in the southeastern part of the Grootfontein Compartment, then turns west in the central part, and again to the NW in the northwestern part of the compartment. Because of the fractured and cavernous conditions often encountered in dolomitic rocks, Bredenkamp states in Stephens and Bredenkamp (2002) that aquifer storativity determined by means of pumping tests does not provide representative storativity values. Bredenkamp et al. (1974; 1987), Bredenkamp (1995; 1999), and Cogho (1982) have all attempted to determined representative recharge and storativity values for this compartment using different techniques.

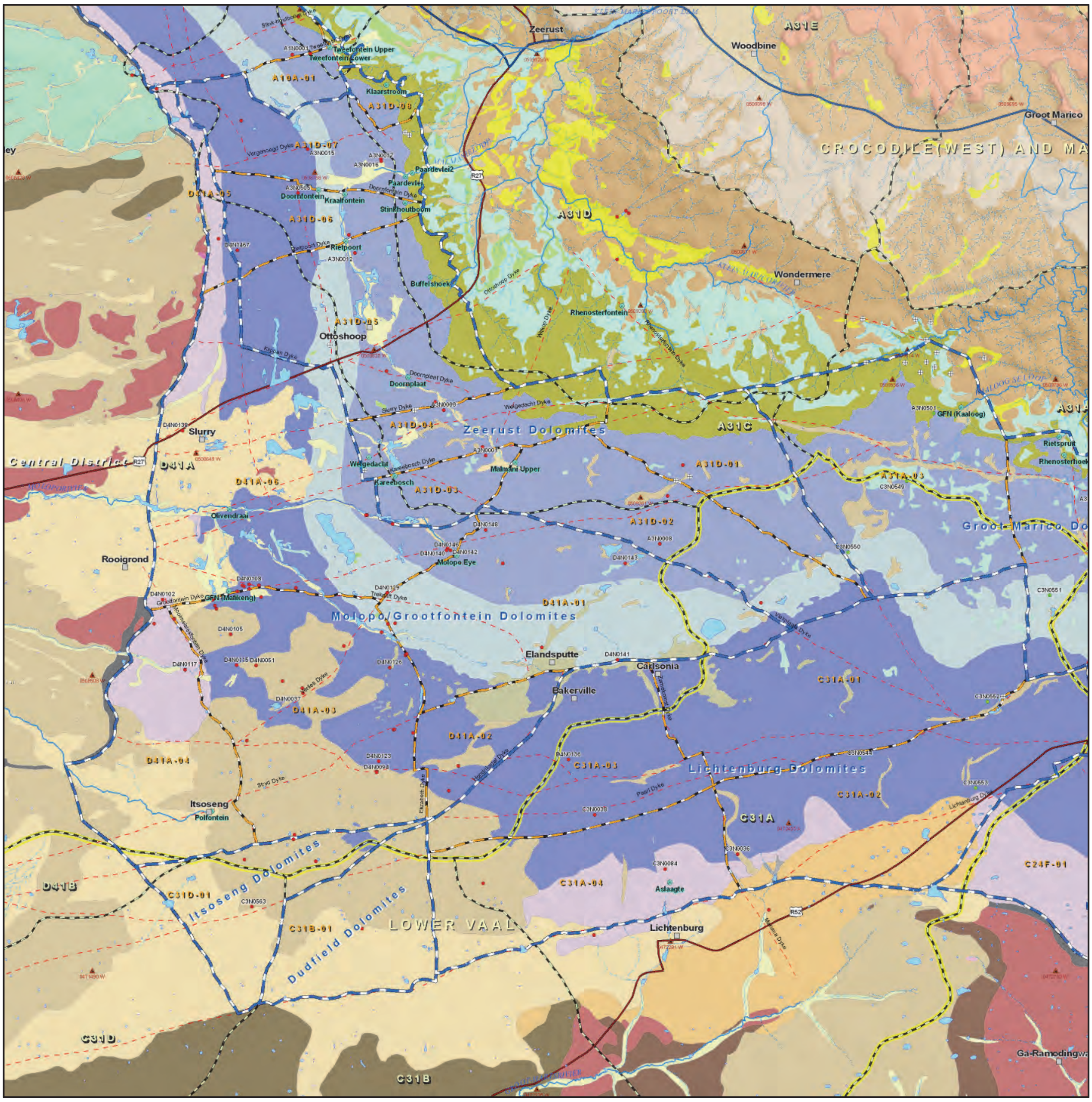


Figure 7.10. The Molopo-Grootfontein, Itsoseng and Dudfield GMAs (from Holland, 2009)

The storativity values derived from the work of Cogho (1982) and Bredenkamp et al. 1991) are based on numerical simulations done for different compartments in the area. Using the Saturated Volume Fluctuation (SVF) method Van Tonder et al. (1994) and Van Rensburg (1995) calculated the recharge and storativity value for the Grootfontein compartment to be 8.4 Mm^3/a and 0.0225 respectively. Bredenkamp (2000) also reports a storativity value of 0.03 in the vicinity of the Grootfontein spring based on the application of the Cumulative Rainfall Departure (CRD) method. He attributes the somewhat higher S value to increased dolomite leaching close to the spring.

Stephens and Bredenkamp (2002) list that the total water consumption from the Grootfontein area to mainly supply Mafikeng has increased from 1 Mm^3/a in 1967 to 5 Mm^3/a in 1994, while the total water consumption by agriculture, mining, domestic and environmental sectors as determined by DWAF for 2000, was 46.4 Mm^3/a. This consumption exceeds the annual recharge of 8.4 Mm3/a calculated in 1995 by far and has caused water levels to steadily decline.

7.2.3 Lichtenburg GMA

The boundaries of this GMA, covering a total area 873 km^2, are formed by the Hendriksdal, Stryd and Elizabeth dykes and the Lichtenburg dyke forms the southern boundary (Figure 7.11). Other dykes in the GMA include the Vlakplaas (NW-SE), Zamekomst (N-S), Paarl (E-W), Manana (N-S) and Lichtenburg (E-W). Only one significant spring, the Aslaagte spring just to the north of Lichtenburg, occurs in this GMA. This spring is situated in the Oaktree Formation and appears not to be associated with dyke or geological contact structures. According to a groundwater flow direction map in Bredenkamp (2005), from the north towards the spring.

Botha and Bredenkamp (1993) state that Lichtenburg obtains its water from the Aslaagte (or Lichtenburg) spring and boreholes in the Oaktree and Monte Christo Formations. The Monte Christo Formation is the more chert-rich and karstified formation of the two, and as such production boreholes located on this formation usually have a higher sustainable yield than those drilled into the Oaktree Formation.

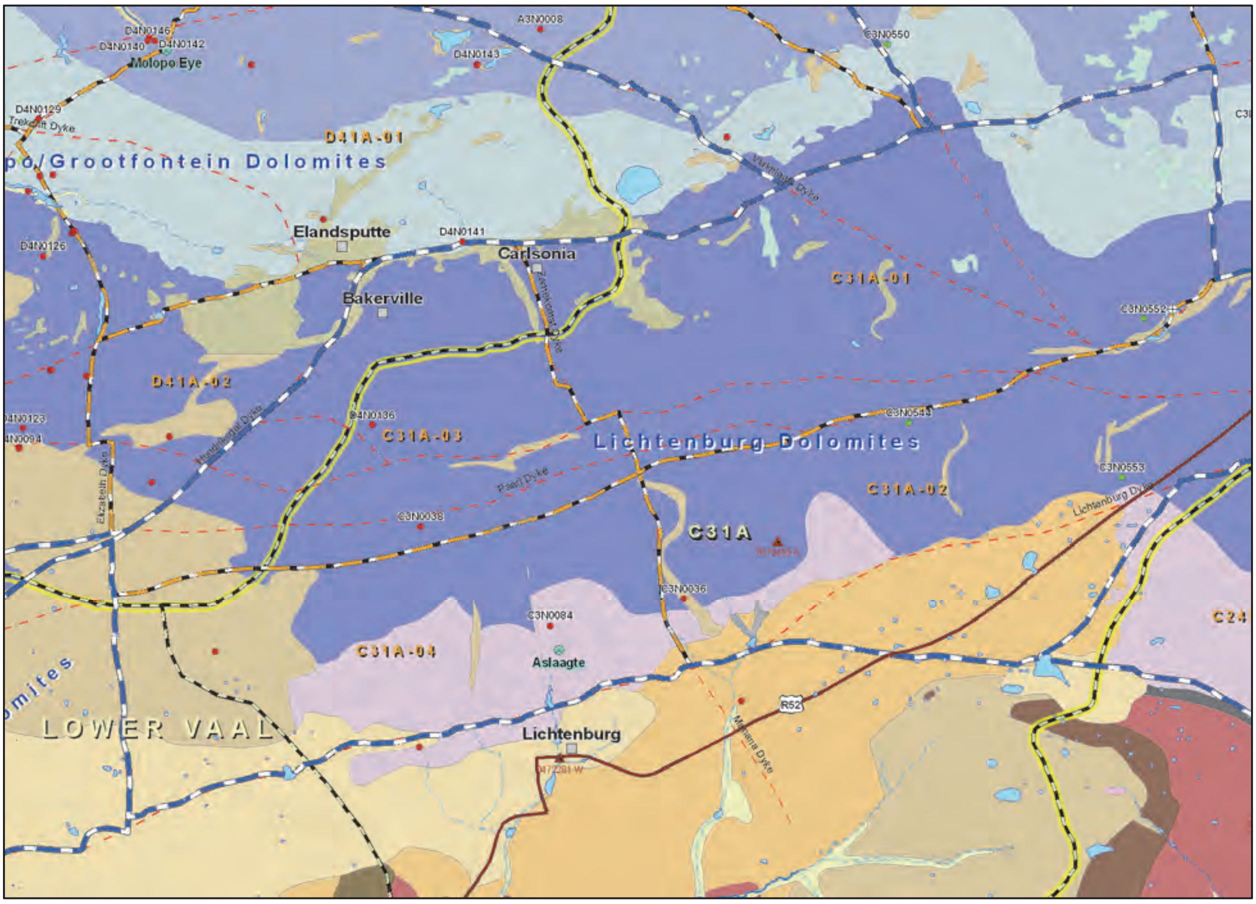


Figure 7.11. Map showing the outline of the Lichtenburg GMA (from Holland, 2009)

As is the case for most of the dolomitic compartments, ground water management is crucial and primarily depends on representative values for groundwater recharge and storativity. Similar methods as described under Section 7.3.1 above have been applied here by Botha and Bredenkamp (1993). In addition they have also applied the Boussinesq approach to determine recharge and storativity. A summary of the results are displayed in Table 7.2 below.

Table 7.2. Aquifer parameters for the Lichtenburg WMA using different methods (from Botha and Bredenkamp, 1993).

Method	Parameter	Value	Comment
Equal volume RE = a(Rf - c)	a c S	0,78 35,8 0,005	period: 1985 - end of record
	a c	0,067 283	for the whole period
	a c	0,049 103	hand fitted line for period before 1985
Q/dV vs Rf	S	0,01 - 0,021	minimum - maximum values
Zero Recharge periods	S I-O	0,025 $-6.5 \times 10^6 m^3$	% recharge taken as Rf < 15 mm/month for prolonged periods. The solution seems to give an overestimation of S and an underestimation of (I-O)
DPEM	S I-O recharge% r	-0,006 $-11{,}65 \times 10^6 m^3$ 2,61% 0,84	RE = a.Rf meaningless results because of incorrect Q
	S I-O recharge% r	0,006 $-10{,}04 \times 10^6 m^3$ 1,17% 0,85	RE = a.Rf $\left(\frac{Rf}{ARf}\right)$ meaningless results because of incorrect Q
Theoretical approach (Boussinesq)	k/S RE/k RE/S	637996 $2{,}116 \times 10^{-5}$ 13,5	m/month = 19.5 m/day month/m = $6.45 \times 10_{-4}$ day/m
CRD	RE/S ARf ARf	3,1 620 mm/annum 681 mm/annum	Data over whole period Data ignored: March 1988 to January 1989
Relationship between T & S	T/S	4.36 m^2/day	For arbitrary chosen S values, the computed T values seem unrealistically small

7.2.4 Groot Marico GMA

This GMA covers a total area of 530 km^2. The northern boundary is formed by Kareebosch dyke while the southern boundaries are formed by the Stryd and Greefslaagte dykes. The GA is bounded in the northeast by outcrops of the Pretoria Group formations (Figure 7.12). Springs that occur in this compartment include Bokkraal 1 and 2, Kaaloog, Rhenosterhoek and Rietspruit (Figure 7.12). Spring flow is not monitored regularly, but has been measured during the survey of Polivka (1987). The spring flow for the different springs listed by Polivka are shown in Table 7.3.

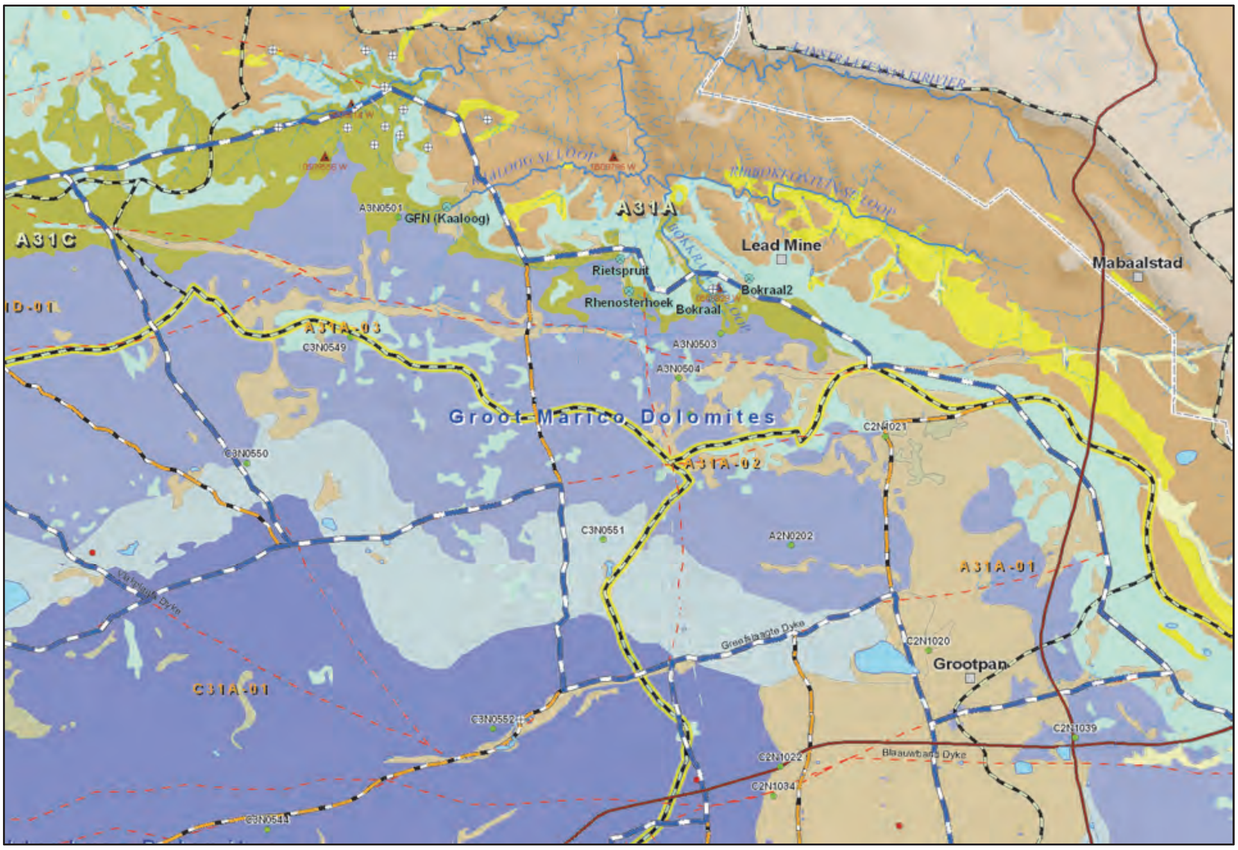


Figure 7.12: Map showing the outline of the Groot Marico GMA (from Holland, 2009)

Table 7.3. Spring flow of springs in the Groot Marico GMA (after Polivka, 1987).

Farm/spring name		Estimated annual flow (Mm3/a)
Rietspruit:	RT 1	2.37
Rhenosterhoek:	RK 1	0.22
	RK 2	3.07
Duikerfontein	DN 2	1.26
Bronkhorstfontein	BN 15	0.13
Bokkraal	BK 1	0.9
	BK 2	1.4

The geohydrological survey for this compartment is described in Polivka (1987). According to Stephens and Bredenkamp (2002) numerous sinkholes and pans, for example Grootpan, are present in this compartment. Large areas are covered by the chert-rich Monte Christo and Eccles formations and this is also reflected by the high percentage of high yielding boreholes that occur here. The results of an analysis of borehole yields relative to the geological formation in which they were drilled, was done by Polivka (1987). His results are displayed in Table 7.4 below.

In the northern parts of this compartment groundwater flow is towards, i.e. towards the Bokkraal and Kaaloog springs, whereas in the southern part the groundwater flow is directed towards the south (Stephens et al, 2005).

Table 7.4: Borehole yields from boreholes drilled in different geological formations in the Groot Marico GMA (after Polivka, 1987).

Formation	No. of boreholes	Ave. borehole yield (l/s)
Frisco	20	39.4
Eccles	89	17.9
Lyttleton	188	21.6
Monte Christo	73	18.8
Oaktree	45	12

In terms of groundwater use, Stephens and Bredenkamp (2002) state that about 3500 ha were under irrigation at the time and were abstracting 44.6 Mm^3/a. However, based on irrigated areas and crop requirements, the water requirements should only be about 28 Mm^3/a. This indicates that farmers have claimed higher allocations that they are actually using. Irrigation represents about 95% of water use and stock watering only ~5%. Recharge to the aquifer is estimated to be ~13% of MAP. A similar value for recharge has been obtained using the chloride method.

7.2.5 Holpan GMA

The northern boundary of this WMA is formed by the E-W Greefslaagte dyke, while the eastern boundary also forms the western boundary of the Schoonspruit compartment to the east. The total surface area according to Holland (2009) is 512 km^2. Other dykes present in the area include the E-W directed Lichtenburg dyke. The southwestern half of the compartment is underlain by the Oaktree formation, while the upper northeastern half is underlain by the Monte Christo formation (Figure 7.13). No reports on geohydrological studies in this specific compartment could be traced.

7.2.6 Schoonspruit GMA

This WMA has a total area of 1308 km^2 and is bounded by the formations of the Ventersdorp Supergroup and Pretoria Group in the south and north respectively. Another important dyke that occurs in the compartment is the Blaauwbank dyke (Figure 7.14).

Except for the Frisco Formation, the upper formation in the Malmani sequence, the full succession of Malmani formations are present across the compartment; from the Oaktree in the south, followed by the Monte Christo, Lyttleton, to the Eccles in the north. In the north the Eccles Formation is unconformably overlain by the Rooihoogte Formation. The analysis of borehole yields done by Polivka (1987), indicated that boreholes drilled in the Eccles and Monte Christo have higher yield that those drilled in the Oaktree and Lyttleton formations.. This observation supports the general conclusion from similar analyses across Groundwater Region10 that the chert-rich formations produce higher borehole yields compared to the chert-poor formations.

Several springs occur in the compartment. The Schoonspruit Spring near the southern boundary of the compartment is the most productive one (Stephens and Bredenkamp, 2002). Different average annual spring flow values are quoted by different authors, i.e. 24 Mm^3/a (Kotze et al, 1994); 48 Mm^3/a (Bredenkamp et al,1996); 60 Mm^3/a (Stephens and Bredenkamp, 2002). The significant decline in flow of this spring since about 1986 has been attributed to the dramatic increase of irrigation from groundwater and resulted in the proclamation of the assumed recharge area of the spring in 1995 (Figure 7.15). A more reliable estimate of the groundwater abstraction of 24 Mm3/a was calculated in 1996 following a new survey of the area (Schoeman and Partners, 1996).

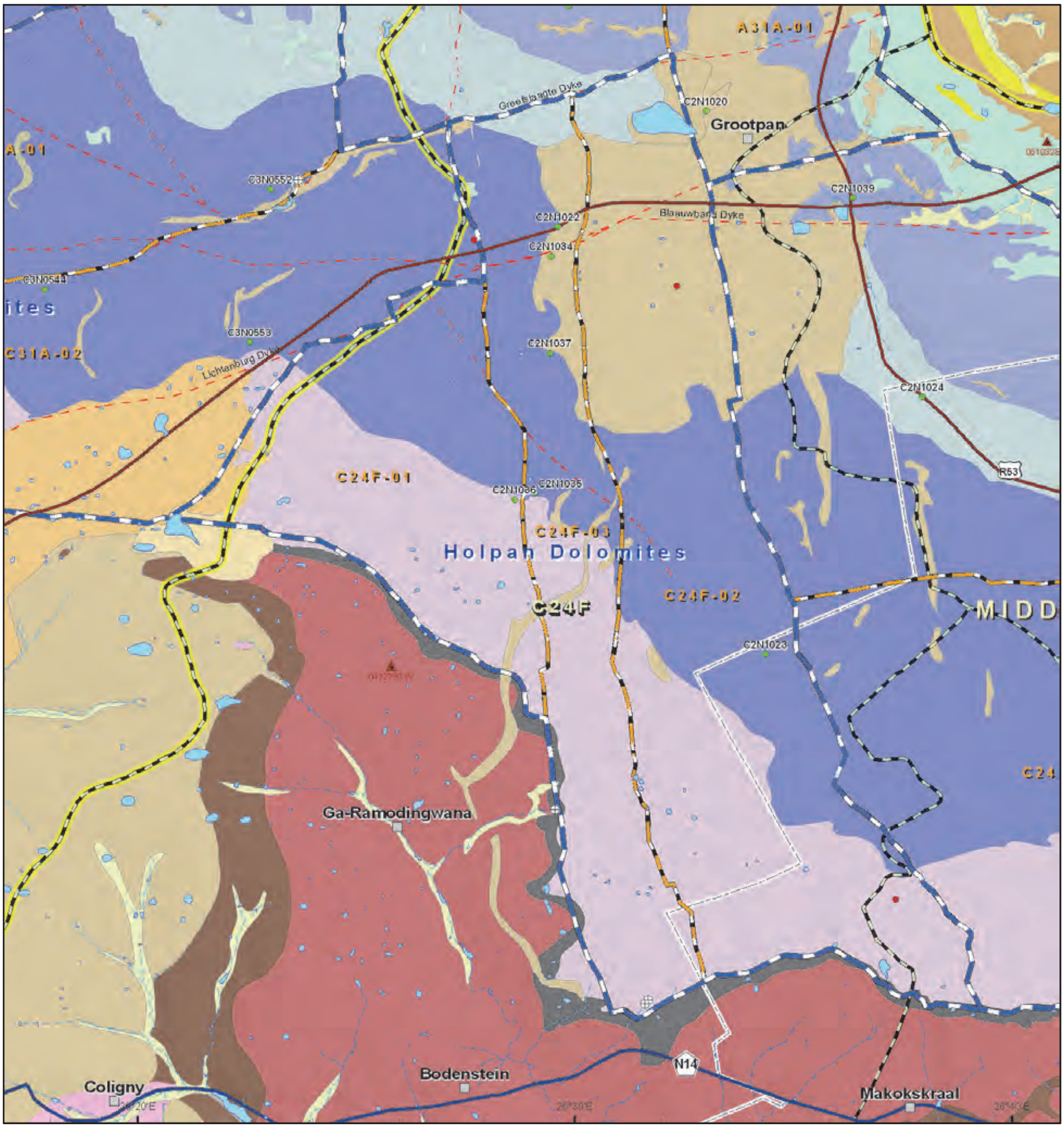


Figure 7.13. Map showing the outline of the Holpan GMA (from Holland, 2009).

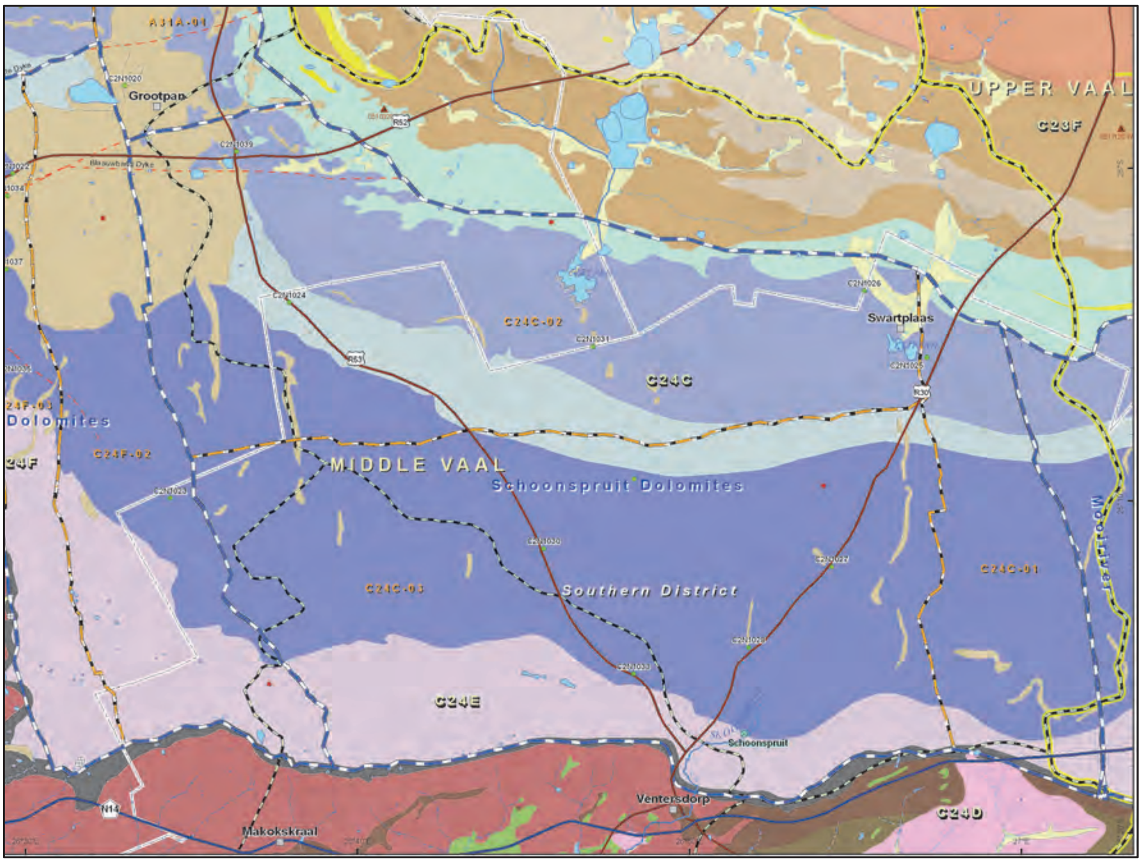


Figure 7.14. Map showing the outline of the Schoonspruit GMA (from Holland, 2009).

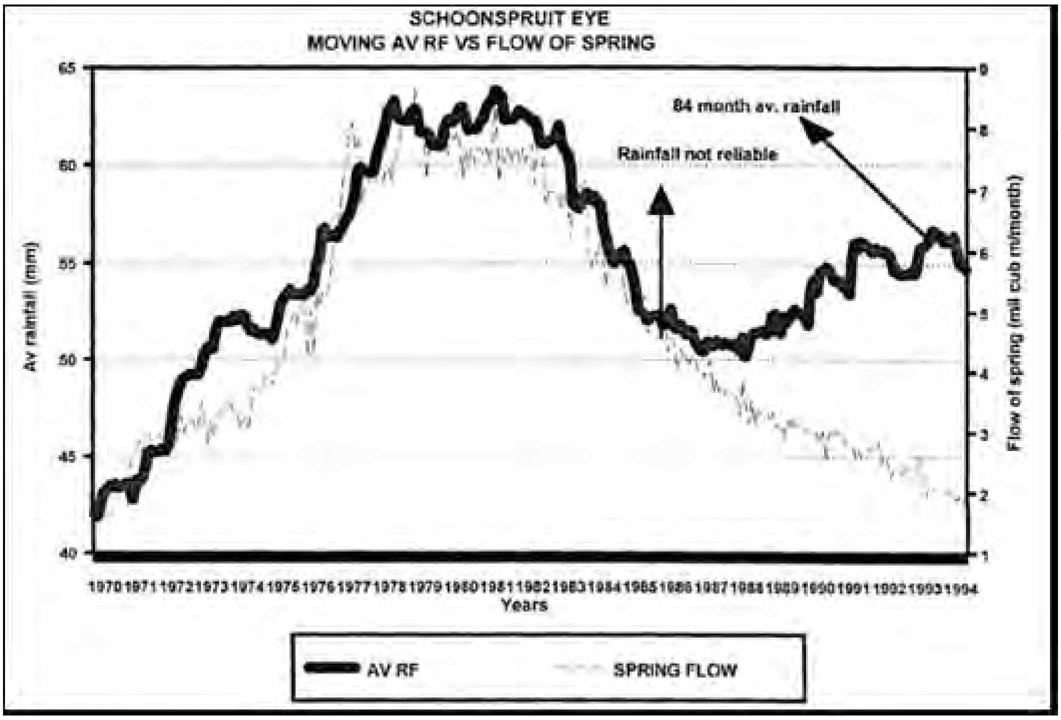


Figure 7.15. Comparison between the average rainfall and flow of the Schoonspruit for the period 1970 to 1994 and showing the decline in flow from about 1986 due to increased groundwater abstraction (after Stephens and Bredenkamp, 2002).

According to a map in Stephens et al. (2005), groundwater flow is towards the south (to the Schoonspruit spring), while Stephens and Bredenkamp (2002) state that the water levels decline abruptly closer to the large N-S fault forming the southwestern boundary of the compartment. According to them this is an indication that the fault acts as a partial flow boundary rather than a conduit for high groundwater flow.

7.2.7 Mooirivier GMA

Leskiewics (1989) reported on a survey of this compartment which he referred to as the Mooirivier compartment situated between the Schoonspruit compartment to the west and the Steenkoppies compartment to the east. The Mooirivier compartment is subdivided into 2 subcompartments, Mooirivier West and Mooirivier East. The western boundary is formed by the N-S directed Almoro dyke and the eastern boundary also by a N-S directed Eigendoms dyke (also referred to as the Holfontein dyke by Leskiewics, 1989). The N-S striking Mooifontein dyke separates the western and eastern subcompartments. The Mooirivier and Almoro dykes are diabase dykes with a positive magnetic anomaly response, while the Holfontein dyke is syenitic and has a negative magnetic anomaly response. One E-W striking dyke traverses the compartment and is referred to as the Wolwekrans dyke by Bredenkamp et al. (1986) and extends to Tarlton in the east. The same geological succession as is present to the west in the Schoonspruit Compartment also covers the Mooirivier Compartment. Based on deep exploration drilling done by Anglo American, the dolomite succession has a combined thickness of about 1200 m in this compartment (Leskiewics,1989).

The survey by Leskiewics (1989) confirmed again that the chert-poor formations (Oaktree and Lyttleton) constitute low yielding aquifers. To illustrate this statement, he refers to one farm (Wildfontein 52IQ) on which 60 boreholes were drilled of which only four were successful (yielding >1 l/s). More leaching and solution channels are present in the chert-rich formations (Monte Christo and Eccles) and as a result constitute the major aquifers. The borehole statistics shown in Table 7.5 were compiled from the work by Leskiewics (1989) in the Mooirivier Compartment.

Table 7.5. Borehole statistics from the Mooirivier Compartment (Leskiewics, 1989)

Geological Formation	Total number of reported boreholes	Number of successful boreholes	Average yield (l/s)	Number of dry boreholes	Success ratio (%)
Eccles (chert-rich)	120	30	10	90	25
Lyttleton (chert-poor)	60	19	4	41	32
Monte Christo (chert-rich)	210	53	12	159	26
Oaktree (chert-poor)	96	26	3	70	28
Totals	486	128	7	358	26

From the water level information Leskiewics (1989) concluded that there was no conclusive evidence that the bounding dykes result in completely separate compartments. In places, however, there is sufficient evidence that indicate that a dyke does act as impermeable barrier. One good example is found around the E-W Wolwekrans dyke where a change of up to 100 m in water level depth occurs over a distance of only one to two kilometres. This drop in water level coincides with the transition between the Pretoria Group and the Eccles Formation that is faulted in an E-W direction and intruded by the Wolwekrans dyke. The outcropping quartzites of the Black Reef Formation in the south also act as a boundary due to the much lower transmissivity. All three N-S trending dykes, the western Almoro, the central Mooirivier, and the eastern Holfontein dykes act as flow boundaries.

Two springs emanate from the compartment. These are the Bovenste Oog located on the eastern side of the Mooi River dyke and the Holfontein spring that stopped flowing in 1985. The termination of flow at the Holfontein spring was attributed to increased ground water abstraction as a result of the increased demand for irrigation.

The groundwater level map compiled by Leskiewics (1989) indicates that groundwater inflow to the compartment occurs from the southwest and to a lesser extent along the northern Wolwekrans dyke because of the steep gradients in this area. An area of very anomalous deep groundwater levels (up to 100 m deeper that the surrounding areas) occurs towards the central part of the eastern Mooirivier compartment. In the report Leskiewics (1989) attributes the groundwater depression to a possible deep conduit draining the groundwater to the underlying Black Reef and Ventersdorp Supergroup formations and speculates that it may enter the adjacent Ventersdorp, Oberholzer and Bank compartments to the south which were at that time being dewatered for gold mining purposes.

Other observations and conclusions made by Leskiewics (1989) include:

- Very low groundwater gradient (<0.001) and water level depth <5 m over large areas in the western compartment.
- Large number of shallow boreholes yielding >20 l/s.
- Much steeper and variable groundwater gradients in the eastern compartment.
- Deep to very deep water levels in the eastern compartment (>70 m with a recorded maximum of 136 m in 1989).
- The majority of boreholes in the eastern compartment are >150 m deep and are low yielding (3-5 l/s).
- Recharge estimates for the compartment were based on results from the adjacent Tarlton area.
- A large number of new sinkholes in the vicinity of the groundwater level depression in the eastern compartment had been reported in 1988.

7.2.8 Groundwater level distribution

In some of the older reports on investigations of specific compartments, water level maps can be found (van Rensburg, 1987b; Leskiewics, 1989) but no map indicating the water level variations and inferred flow directions across the entire western area of Groundwater Region 10 could be traced. Holland (2009) presented the results of a water level analysis for each of the compartments across the whole of Groundwater Region 10 on the regional geohydrological maps prepared for the DWA Dolomite Project. His results for the western compartment are shown in Table 7.6. Although he has used only a limited number of boreholes in this analysis, some patterns do emerge:

- Boreholes close to the downstream side of dykes show much deeper water levels (examples are Bh A1N0001 on the northern side of the Tweefontein dyke; C3N0553 on the northern side of the Lichtenburg dyke)
- Water levels less than 10 mbgl in the Molopo/Grootfontein and Itsoseng and Dudfield compartments.

- Relative small variations (~10-15 m) around the median water level values over the entire western part of Groundwater Region 10.
- In the Zeerust, Marico, Lichtenburg and Holpan compartments the average water level is around 20 mbgl.

Using the most recent water level information from the NGA of DWA a water level map indicating water level elevation above mean sea level was constructed (Figure 7.17). It is acknowledged that in this exercise the influence of dyke structures on water levels was not acknowledged, and therefore the map is not a true reflection of the conditions within each compartment. Nevertheless, it provides some indication of regional conditions and flow directions.

In the explanation accompanying the geohydrological map sheet 2526 Johannesburg, Barnard (2000) mentions that unlike most other formations the groundwater level in dolomitic aquifers does not necessarily follow the topographic profile. The level follows more often a nearly horizontal surface with a very low gradient and indicative of highly permeable formations. This characteristic partly explains the occurrence of very deep groundwater rest levels in areas of raised topography.

Holland (2009) also reported the mean change in water level for the period 2004 to 2009 within each compartment. This information is presented in Table 7.6. Several of the compartments have recorded a decline in water level over this 5 year period which can most probably be attributed to an increased abstraction from springs and groundwater for irrigation and town water supply schemes.

Table 7.6. Long term water level changes in the Western area of Groundwater Region 10.

Compartment or GMA	Area (km^2)	No of DWA operational monitoring stations	Mean water level change since 2004 (m)	Registered ground-water use for irrigation (Mm^3/a)
Dinokana	277	11	6.9	0.7
Zeerust	699	18	-2.9	3.4
Molopo/ Grootfontein	985	63	-6.9	26.1
Itsoseng	95	5	-0.1	-
Dudfield	105	1	-7.9	4.6
Groot Marico	535	10	-0.4	10.9
Lichtenburg	781	10	-3.5	24.1
Holpan	516	8	-3.9	17.8
Schoonspruit	1320	13	-2.9	26.7
Mooirivier	827	2	1.4	2.7

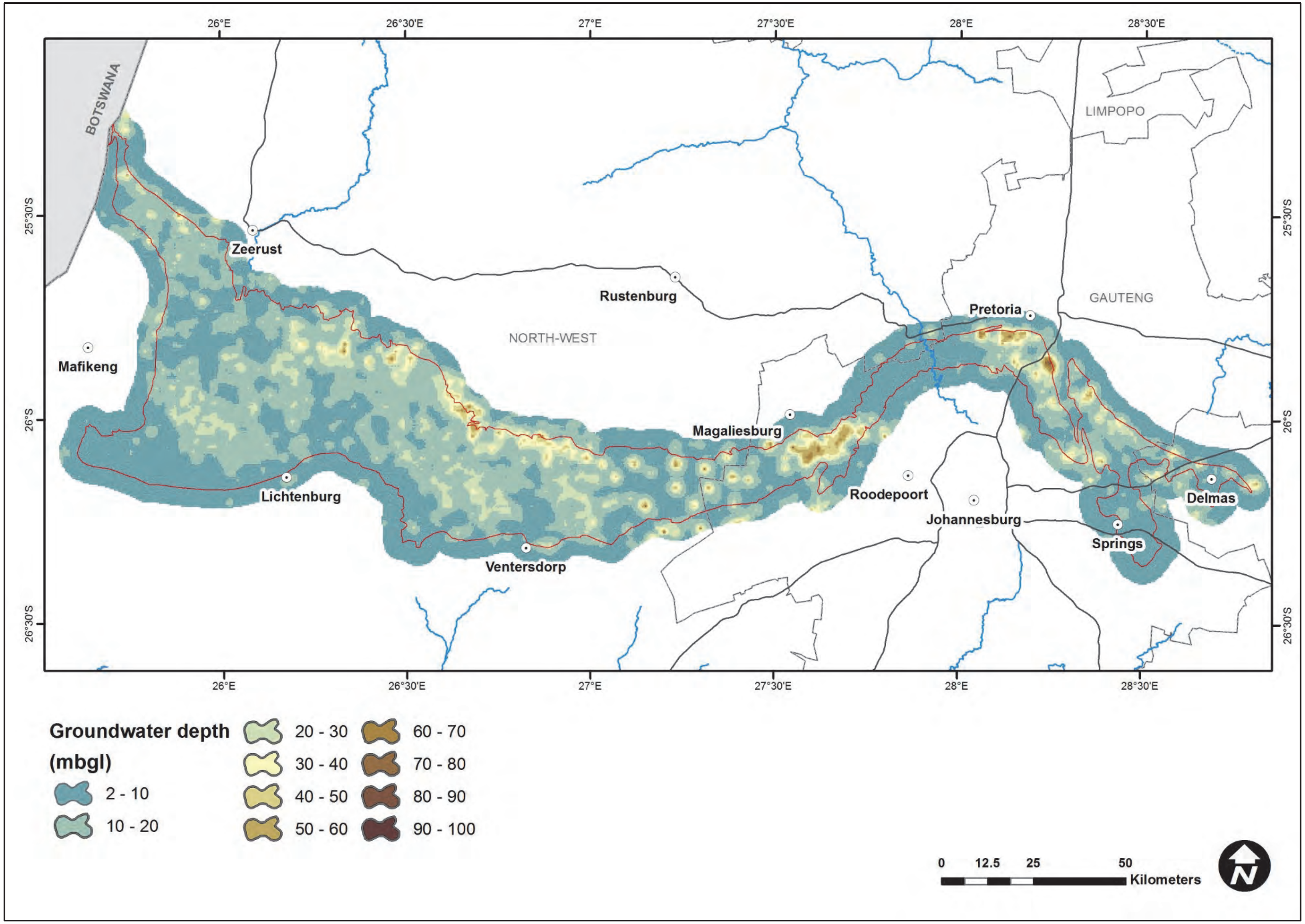


Figure 7.16. Depth to groundwater level (mbgl) across Groundwater Region 10.

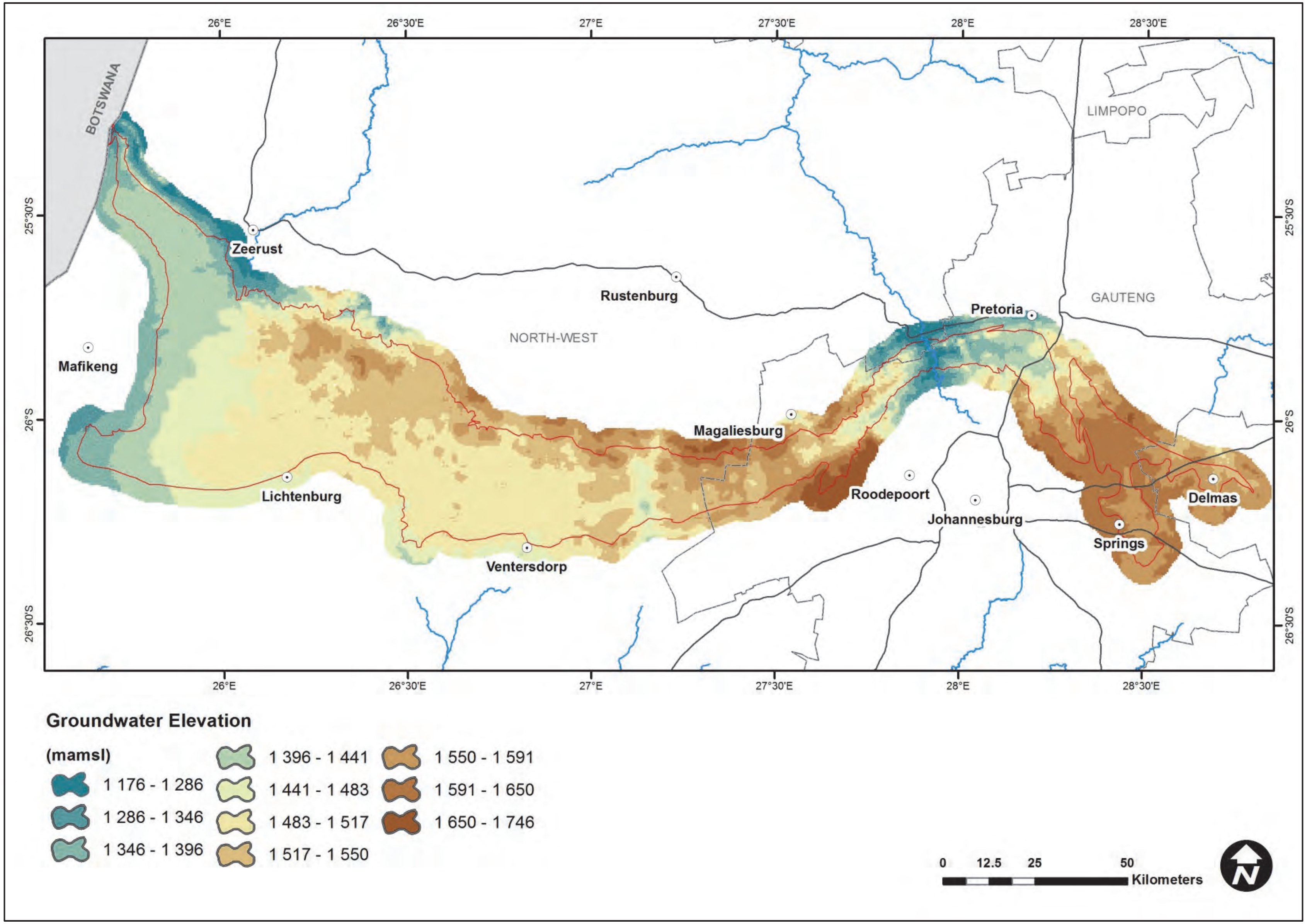


Figure 7.17. Groundwater level elevation (mamsl) across Groundwater Region 10.

7.2.9 Spring flow and borehole yield

Throughout the preceding sections the presence of numerous high yielding springs emanating from the dolomitic formations has often been referred to. In Table 7.8 a summary is presented of the latest measured flow from springs in the western part of Groundwater Region 10 based on information from Holland (2009). Flow records for four of the larger springs in the northwestern region are presented in Figure 7.17. Flow records for springs Dinokana Upper, Malmani Eye, Schoonspruit and Molopo Eye are included in the figure.

A map combining aquifer type and borehole yield was prepared and is shown in Figure 7.18. The aquifer type units, and the four classes of borehole yield (<0.5 l/s; 0.5-2 l/s, 2-5 l/s and >5 l/s) on this map are based on the classification model used by the Department of Water Affairs for the hydrogeological map series where karst is acknowledged as a separate aquifer type, are shown on this map. It is clear from this map that over most of Region 10 borehole yields in excess of 5 l/s are found, and only in relatively small areas in the far western part of the Region, borehole yields are generally <5 l/s.

Barnard (2000) did an analysis of borehole yield information and found that the yield potential is excellent as 50% of the boreholes on record produced more than 5 l/s, with the higher recorded yield being 126 l/s. The borehole yield distribution for boreholes in all the formations of the Chuniespoort Group is shown in Figure 7.19.

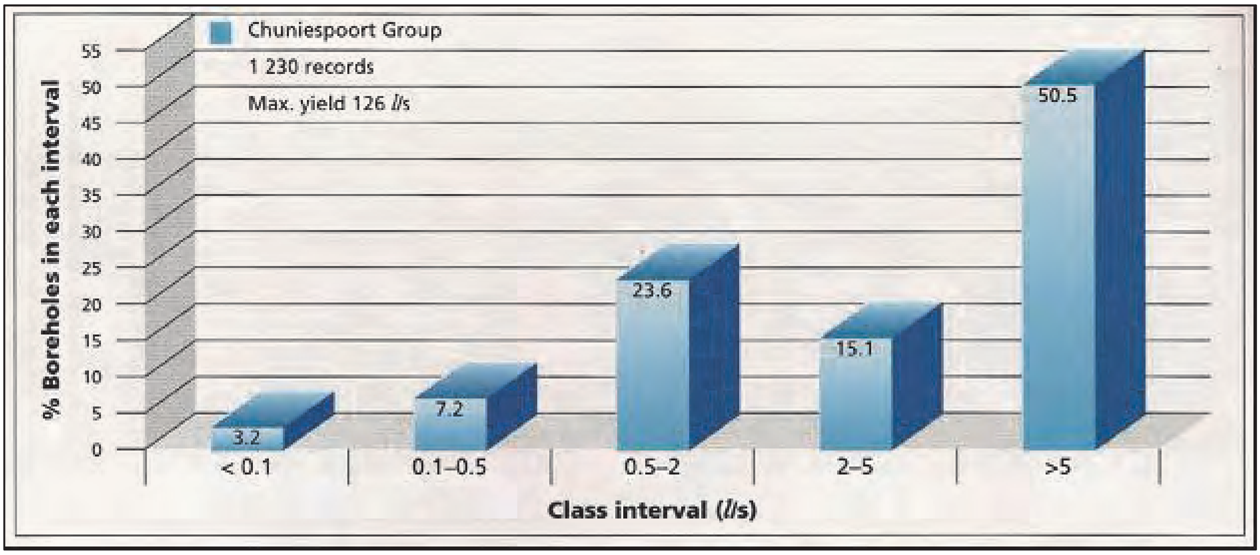


Figure 7.19. Borehole yield distribution for the Chuniespoort Group (from Barnard, 2000).

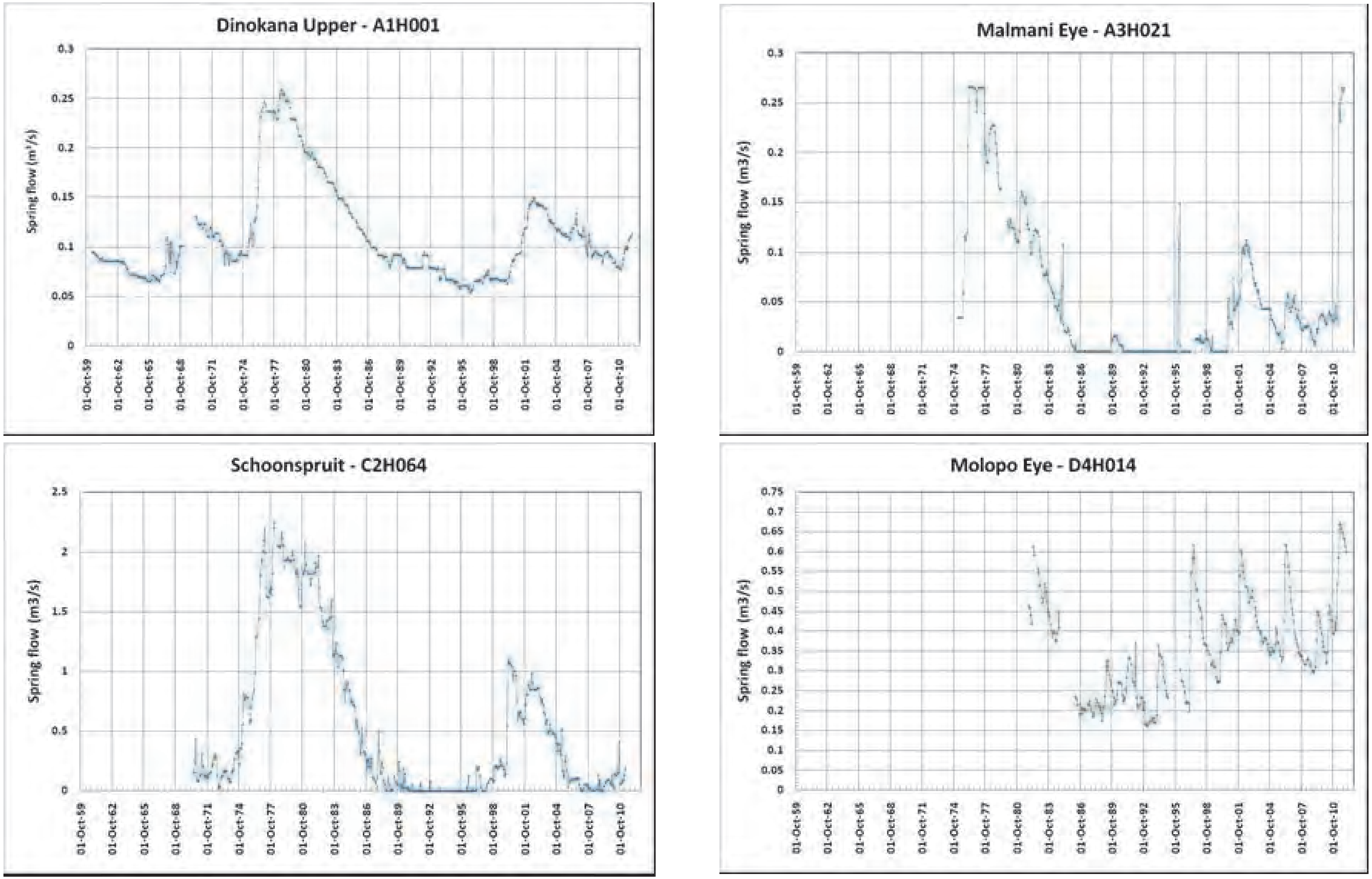


Figure 7.18. Spring flow record for four springs in the western section of Groundwater Region 10.

Table 7.7. Water level distribution across the western part of Groundwater Region 10 (according to Holland, 2009)

Compartment name (Holland's GMAs)	Subdivision names and Holland's GMUs		HYDSTRA borehole information			Monitoring period		Start WL (mbgl)	End WL (mbgl)	# of measure-ments	Water level range (mbgl)		
			Bh #	Latitude (Cape)	Longitude (Cape)	From	To				Min.	Median	Max.
Dinokana	A10A-01	Tweefontein	A1N0001	25.54972	25.92750	01/1977	12/2004	27.4	16.8	273	16.4	38.9	52.7
Zeerust	A31D-02	Malmani	A3N0008	25.88111	26.16333	01/1977	12/2004	22.5	22.8	298	19.6	23.8	29.4
	A31D-03	Kareebosch	A3N0001	25.82139	26.04583	01/1977	12/2004	16.4	16.7	291	10.1	16.7	69.8
	A31D-04	Welgedacht	A3N0003	25.79056	26.01750	03/1977	12/2004	11.1	12.3	296	10.8	11.6	13.5
	A31D-05	Ottoshoop	A3N0012	25.68444	25.95750	01/1977	04/2005	11.8	13.6	3138	11.5	13.4	20.4
	A31D-06	Doornfontein	D4N1467	25.68250	25.87806	07/1997	04/2005	28.4	25.9	18177	19.4	19.5	28.9
	A31D-07	Paardevlei	A3N0017	25.62222	25.97528	01/1977	12/2004	14.1	19.6	295	14.1	19.8	23.0
Groot Marico	A31A-01	Grootpan	C2N1020	25.95806	26.55028	09/1990	07/2009	16.1	20.2	178	14.4	18.8	21.1
	A31A-02	Groot Marico	A2N0202	25.91806	26.49806	09/1986	07/2009	21.1	26.0	1037	21.1	23.7	27.1
	A31A-03	Grootfontein	C3N0550	25.88667	26.29028	08/1990	07/2009	13.3	12.6	180	11.7	13.3	23.7
Molopo/ Grootfontein	D41A-01	Molopo	D4N0141	25.95944	26.13472	02/1976	12/2004	10.0	14.0	304	10.0	13.8	16.6
	D41A-03	Kliplaagte	D4N0075	25.91833	25.86222	08/1979	04/2005	3.6	21.1	15420	2.6	17.3	28.4
	D41A-04	Polfontein	D4N0117	25.96611	25.84278	01/1975	12/2004	0.9	5.8	321	0.5	4.1	9.2
	D41A-06	Slurry	D4N0138	25.80444	25.84111	08/1964	03/2004	6.2	4.8	403	0.6	4.3	9.5
Itsoseng	C31D-01	Itsoseng	C3N0563	26.12639	25.88806	12/1998	04/2005	3.5	5.0	2311	2.1	3.7	5.5
Dudfield	C31B-01	Dudfield	C3N0028	26.14111	25.96222	08/1975	12/2004	4.7	12.2	315	1.5	7.3	21.7
Lichtenburg	C31A-01	Zamekoms	C3N0552	25.98778	26.38444	08/1990	07/2009	7.3	8.0	145	7.3	8.3	10.1
	C31A-02	Manana	C3N0553	26.04611	26.37639	08/1990	07/2005	29.8	32.3	179	13.7	31.1	39.6
	C31A-03	Houthaalsdoorns	D4N0136	26.02694	26.10167	02/1976	12/2004	20.6	20.8	305	17.0	20.8	33.1
	C31A-04	Aslaagte	C3N0084	26.10083	26.16694	05/1985	12/2004	21.2	23.6	200	19.1	23.0	26.0
Schoonspruit	C24C-01	Klippan	C2N1025	26.10611	26.47750	01/1990	07/2009	25.6	36.9	169	25.6	32.0	48.1
	C24C-02	Vetpan	C2N1026	26.06111	26.92139	07/1990	07/2009	70.0	71.9	155	67.9	70.7	73.9
	C24C-03	Schoonspruit	C2N1029	26.15528	26.80583	07/1990	07/2009	23.0	24.3	182	22.5	24.0	26.7
Holpan	C24F-01	Klippan	C2N1036	26.10611	26.47750	09/1990	07/2009	13.4	15.2	172	7.7	14.5	18.8
	C24F-02	Roodepoortje	C2N1023	26.16500	26.57306	12/1989	07/2009	30.0	28.0	180	24.9	27.6	30.5
	C24F-03	Tweebuffels	C2N1037	26.05028	26.49083	01/1990	08/2009	40.4	40.2	168	32.2	39.8	42.3

Table 7.8. Information on springs in the western part of Groundwater Region 10

Compartment name (Holland's GMAs)	Spring name	Coordinates		Measuring station number	Measurement period		Last observation		Mean flow (Mm^3/a)
		Latitude	Longitude		Start	End	Flow (Mm^3/a)	Year	
Dinokana	Dinokana Upper	25.4558	25.8539	A1H001	1960	Active	3.1	2008	3.6
	Dinokana Lower	25.4481	25.8789	A1H002	1960	1995	0.5	1994	
	Tweefontein Upper	25.5450	25.9353	A1H003	1960	1993	0.5	1992	
	Tweefontein Lower	25.5442	25.9475	A1H004	1960	1993	0.3	1990	
	Skilpad Eye Lower	25.3311	25.7600	A1H005	1960	1999	0	1993	
Groot Marico	Bokkraal 1	25.8225	26.4681	A3H002	1907	1943			
	Bokkraal 2	25.8167	26.4817	A3H003	1907	1943			
	G/fontein (Kaaloog)	25.7886	26.3686	A3H004	1907	1931			
	Renosterhoek	25.8167	26.4333	A3H005	1907	1943			
	Rietspruit	25.8086	26.4314	A3H006	1907	1943			
Zeerust	Buffelshoek	25.6958	26.0083	A3H009	1960	2002	0.4	1994	
	Stinkhoutboom	25.6661	25.9964	A3H010	1960	2000	0.7	1999	
	Vergenoegd	25.6042	25.9914	A3H011	1960	1992	3.7	1983	
	Klaarstroom	25.5517	25.9975	A3H012	1960	1978			
	Kraalfontein	25.6472	25.9489	A3H013	1960	1993	0.4	1983	
	Rietpoort	25.6672	25.9489	A3H014	1960	1996	4.1	1983	
	Doornfontein	25.6383	25.9289	A3H015	1960	Active	0	2008	0.6
	Rhenosterfontein	25.7208	26.1375	A3H017	1968	Active	0.3	2008	0.4
	Kareebosch	25.8347	25.9847	A3H020	1969	1993	0.5	1992	
	Malmani Upper	25.8275	26.0636	A3H023	1970	1990			
	Paardevlei 1	25.6328	25.9919	A3H021	1971	Active	0.7	2008	1.7
	Paardevlei 2	25.6314	25.9950	A3H022	1970	Active	0.4	2008	0.4
	Doornplaat	25.7681	25.9847	A3H026	1970	1993	0.2	1992	
	Welgedacht	25.8231	25.9667	D4H016	1969	1991			
Schoonspruit	Schoonspruit	26.2839	26.8608	C2H064	1970	Active	0.8	2008	17
Lichtenburg	Aslaagte	26.1103	26.1697	C3H011	1963	1967			
Molopo	Molopo Eye	25.8814	26.0206	D4H014	1981	Active	10.3	2008	10.8
	Polfontein	26.0622	25.8606	D4H019	1980	1985	1.9	1984	
	Olivendraai	25.8558	25.8742	D4H017	1969	1995			
	Gr/fontein-Mafikeng	25.9136	25.8722	D4H015					
Mooirivier*	Bovenste Oog	26.2006	27.1625	Not measured			16	1977	
Holfontein*	Holfontein			Not measured			0	1985	

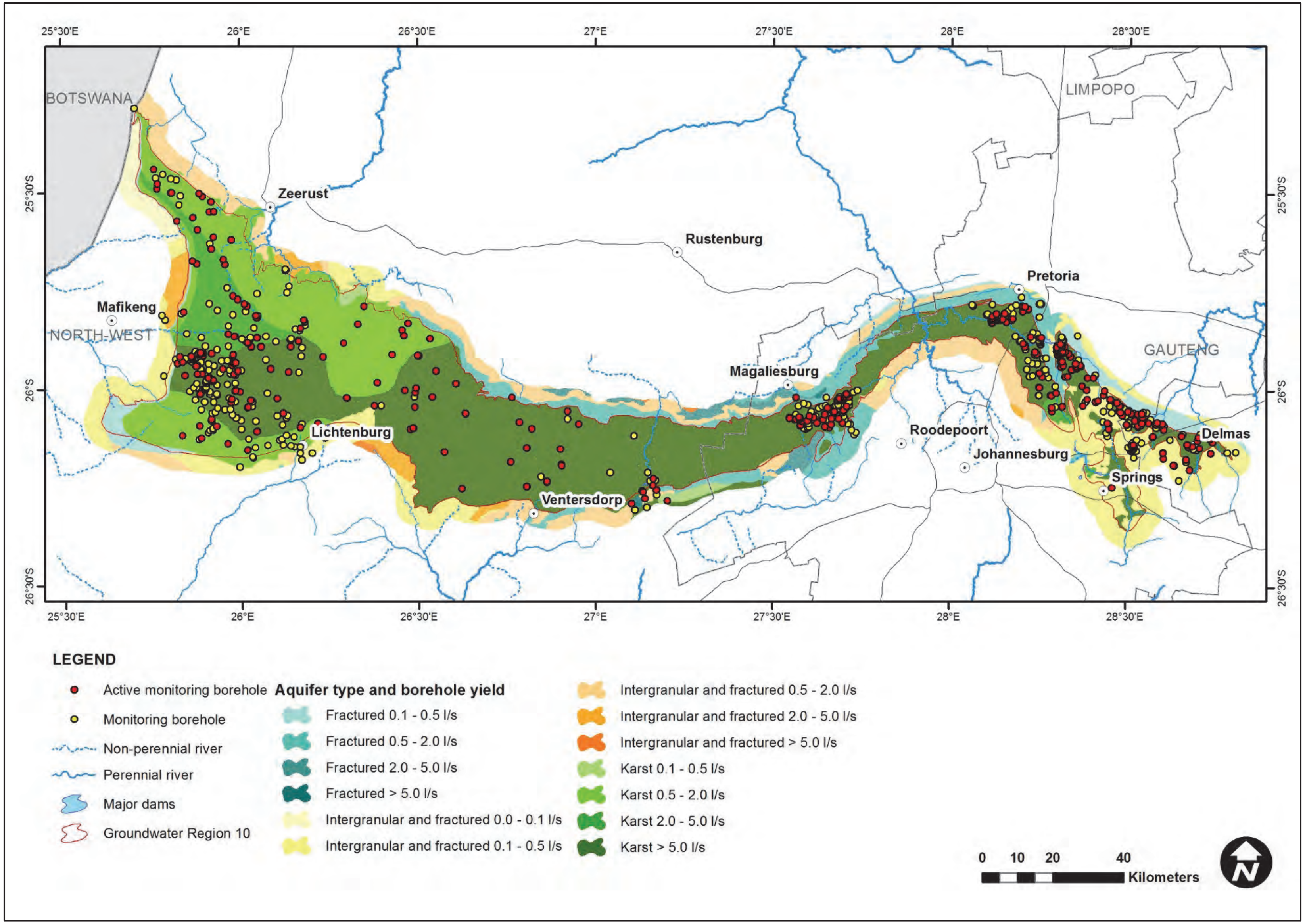


Figure 7.20. Aquifer type and borehole yield across Groundwater Region 10.

8 HYDROGEOLOGY OF THE STEENKOPPIES AND ZWARTKRANS COMPARTMENTS

In this section the hydrogeology of the Steenkoppies and Zwartkrans compartments, also referred to as the Tarlton dolomites, is described. The text is essentially taken from the recent report by Holland (2011) and formed part of a larger DWAF project in which guidelines for the development of the main dolomitic aquifer regions in South Africa were developed. The sections of this document describing the Steenkoppies and Zwartkrans compartments and the Tarlton dolomites, were referred to as Activities 25 and 13 respectively of the larger project.

8.1 Background

The Steenkoppies and Zwartkrans dolomitic compartments comprise areas of approximately 213 and 180 km^2 respectively. The Steenkoppies compartment is directly adjacent to the Cradle of Humankind World Heritage Site (COHWHS) which forms part of the Zwartkrans dolomitic compartment. Holland and Cobbing (2008) also refer to these to compartments as the Tarlton dolomitic aquifers. The understanding of the Zwartkrans compartmentalised karst aquifer has become crucial since the first mine water started to decant south of the COHWHS near Krugersdorp in August 2002. Similarly, the Steenkoppies compartment has received great attention since the naturally discharging and well known spring of the Steenkoppies compartment. known as “Maloney’s Eye”, reached the lowest flow on record. During March 2007 eight of the nine springs constituting the Maloney’s Eye stopped flowing and flow was measured at 0.05 m^3/s (or 1.58 Mm^3/a). This had major consequences for downstream water users as flow from the spring forms a portion of the flow of the Magalies River. Flow measured at the Maloney’s Eye gauging station during 2008 was 0.174 m^3/s (or 5.49 Mm^3/a) compared to a long term average of 14.38 Mm^3/a (100-year record). The Steenkoppies compartment has been exploited through the abstraction of groundwater primarily for agricultural irrigation since the early 1980s and recent studies have indicated declines in groundwater levels in the Steenkoppies compartment, suggesting over abstraction which could lead to a decline in discharges to the Eye. According to Holland (2011) a great deal of controversy exists regarding the functioning of the groundwater system and the extent of the Steenkoppies compartment and more specifically the recharge area of the Maloney’s Eye. A number of contradictory reports exist in terms of the catchment size of the Maloney’s Eye (Bredenkamp *et al*., 1986; Barnard, 1997; Bredenkamp *et al*, 2007; ERM, 2007) and whether the decrease in flow from the Eye is as a direct consequence of excessive groundwater abstraction in the compartment or due to changing (or decreasing) rainfall patterns.

8.2 Locality

The aquifers in the Steenkoppies and Zwartkrans compartments are formed by the Malmani dolomite formations of the Chuniespoort Group. It is within this Group that karst formation has occurred. Dykes that form boundaries to groundwater flow cross the dolomites, creating isolated hydrogeological compartments. The Steenkoppies dolomitic compartment, covering an area of approximately 213 km^2, is located in the upper reaches of the Magalies River catchment (A21F) which comprises a total drainage area of approximately 1000 km^2. The Zwartkrans compartment, to the east of the Steenkoppies compartment, covers an area of 180 km^2 and contains the Sterkfontein and Wonder caves, and the major springs Danielrus, Kromdraai and Zwartkrans (Figure 8.1).

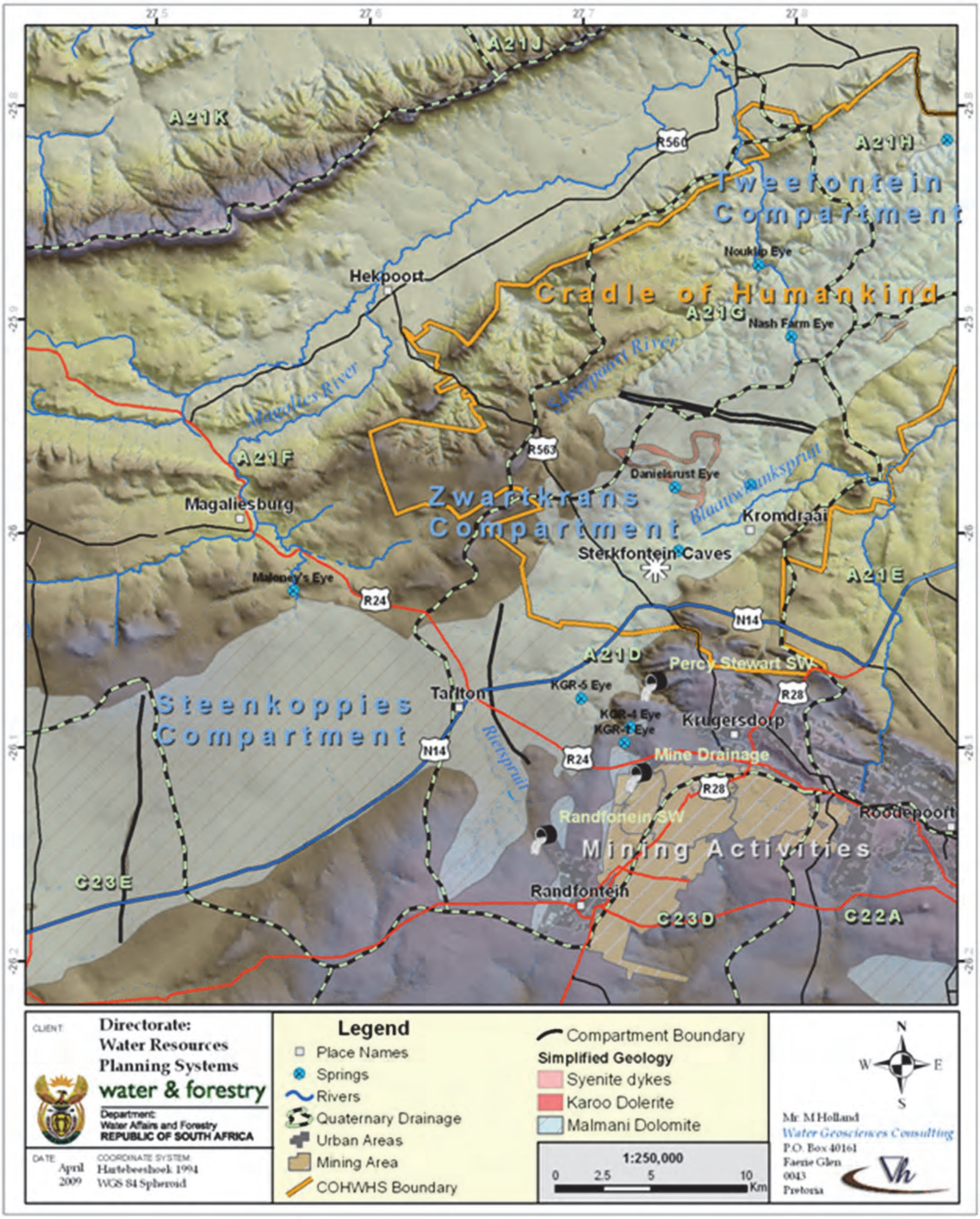


Figure 8.1 Map of the Tarlton area showing the two main compartments, the Steenkoppies and Zwartkrans (from Holland (2011).

Holland and Cobbing (2008) describe the boundaries to the two compartments in the following way: The Steenkoppies compartment is bounded by:

- the Pretoria Group in the north,
- the Zwartkrans compartment in the east,
- the Witwatersrand Supergroup in the south, and
- the Holfontein compartment in the west with the Eigendom dyke as boundary.

The Zwartkrans compartment's hydrogeological boundaries are:

- the Pretoria Group in the north,
- the Tweefontein compartment in the north-east with the Rietfontein dykes as boundary,
- the Basement complex and Witwatersrand Supergroup in the east and south, and
- the Steenkoppies compartment in the west with the Tarlton west dyke as boundary.

8.3 Objectives, Aims and approach of the study by Holland (2009)

In the review of the Steenkoppies and Zwartkrans compartments Holland (2011) focused on the following important aspects:

- The delineation of the Steenkoppies compartment.
- The recharge catchment of the Maloney's Eye.
- An explanation of the Maloney's Eye's behaviour and response to natural recharge (rainfall) and abstraction. The moving average and cumulative rainfall departure methods based on long-term rainfall records were used to predict natural groundwater level trends and simulate impacted or natural spring flows (Bredenkamp *et al*., 1995).
- A geochemical description of collated historically and newly acquired chemical data. A detailed interpretation of major and trace elements as well as environmental isotopes can achieve a good understanding of the flow system if sufficient variability in the chemistry is found (e.g. anthropogenically impacted environments).
- An update of the current conceptual understanding of the Steenkoppies compartment (Maloney's Eye) including a basic water balance based on the interaction and relationship between different parameters such as recharge, abstraction, inflows and outflows.

To achieve these aims, it was important to determine the existence of dykes that act as hydrogeological barriers (compartment boundaries) and that will allow for the determination of hydrogeological response regions such as groundwater management areas. Geophysical data were used extensively to determine the positions of dyke structures. A detailed assessment of all available static and time series groundwater level data and its relationship to rainfall and abstraction patterns was done, which together with the total gravity survey and depth to bedrock information obtained, assisted in the delineation of major groundwater flow paths (or karst conduits).

Holland (2011) prepared a comprehensive compilation of all available information from hydrogeological studies done on the Zwartkrans and Steenkoppies compartments in the early 1980s e.g. (Foster, 1984; Kuhn, 1986; Bredenkamp *et al*., 1986; Kuhn, 1988) and late 90s (Barnard, 1997). More recent studies on the Zwartkrans compartment include those of Krige, 2005; Van Biljon, 2006; Holland, 2007; Hobbs and Cobbing, 2007; Holland and Witthüser, 2009, which mostly pertained to the decanting mine water and the impact thereof on the water resources of the COHWHS (and Sterkfontein caves) and the underlying Zwartkrans dolomite aquifer. These investigations aided the conceptual understanding of the groundwater system in the Zwartkrans compartment and the status and extent of mine water pollution. The influence of the Percy Stewart WWTW effluent discharge on the aquifer was also described by Hobbs and Cobbing (2007) and Holland and Witthüser (2009). These reports indicated the lack of, or poor distribution of groundwater monitoring in the dolomite aquifer.

The Steenkoppies compartment received less attention and recent studies involved mostly desktop hydrogeological assessments (WGC, 2007) or initial hydrogeological reviews (ERM, 2007). Bredenkamp *et al*., 2007 applied ^{14}C simulations to a number of springs in the West Rand, North West and Ghaap Plateau dolomites, which included the Maloney's Eye. A basic numerical groundwater model was constructed by AGES (2007) on the Maloney's Eye catchment as part of the water availability assessment of the Crocodile (West) River catchment.

In the report by Holland (2011) the following was included and discussed:

- Aeromagnetic data for map sheets 2627BA, 2727BB, 2527DC and 2527DD.
- Water level monitoring data (HYDSTRA) extracted from the National Groundwater Database (NGDB) managed by DWAF.
- Groundwater quality data extracted from the NGDB and relevant reports.
- Re-working(digitising) of the gravity survey conducted in 1986.
- Effluent discharge volumes from the Randfontein WWTW.
- Water use validation data (conducted recently for the Crocodile West and Groot Marico).
- Long term monthly rainfall records for all stations within the study area.
- Long term flow records of the Maloney's Eye.

The tributaries of both the Steenkoppies and Zwartkrans compartments catchment play a major role in assimilating or carrying off the mining, industrial and municipal waste-water together with run-off from agricultural land.

The Tarlton dolomitic aquifers are the only readily available water resource for many farms in the region and intensive agricultural activities are carried out throughout the karst basin. As noted in Figure 8.1 the three major anthropogenic influences (effluent discharges) are the Randfontein Waste Water Treatment works (WWTW), the Percy Stewart WWTW and the decanting of acidic mine water due to the rebounding water table after pumping ceased. These waters enter the underground karst network through swallow holes, dolines and leakage from river beds. Such inflows are characteristic of karst terrain and pose a threat to existing surface and groundwater in the area.

8.4 Description of Steenkoppies and Zwartkrans Compartment areas

8.4.1 Physiography and drainage

The topography of these two compartments is generally flat to gently undulating, and is virtually devoid of surface drainage features. Towards the upper reaches of the Zwartkrans compartment the gently undulating landscape of the area is often interrupted by significant topographical differences which is attributed to different erosion and weathering characteristics of the band of dolomites and their associated breccias. The surface features of the Zwartkrans/Steenkoppies dolomites can often be related to the sub-surface characteristics e.g. valleys of surface drainage coincide with fractured zones in karstified dolomite. The chert-poor units weather to a smooth topography covered by red silty type clayey soils devoid of chert. The chert-rich units weather to an uneven topography characterised by dissolution openings and a permeable chert residue with red silty and brown manganiferous soils (Obbes, 2001). The low density of runoff drainage suggests high recharge and a predominance of water flow underground, which eventually drains into surface streams at topographic lows or emanates as springs next to diabase dykes or formation contacts (e.g. Maloney's Eye).

8.4.2 Drainage

The Steenkoppies and Zwartkrans dolomite compartments form part of the upper Crocodile River sub-system and are located within the Crocodile (West) and Marico Water Management Area defined by the DWAF. The tertiary drainage region is A21 with the Steenkoppies compartment falling within the upper reaches of quaternary drainage region A21F and the Zwartkrans compartment almost completely within drainage region A21D (Figure 9.28.2). These surface catchments are immediately north of the sub-continental surface water divide between the Vaal River basin to the south and the Limpopo River basin to the north which suggests that this major watershed will form the most southern boundary of the Maloney's Eye recharge area.

As shown in Figure 9.28.2, the Zwartkrans compartment is drained towards the north-east by the perennial Blaauwbankspruit while the Steenkoppies compartment is drained in its upper most reaches by the Rietspruit.

8.4.2.1 Effluent Return Flows

(i) Zwartkrans Compartment

The most important and influential tributaries on the karst hydrology of Zwartkrans, are 1) the Blougatspruit which is responsible for the drainage of 19.3 Ml/day (or 7.1 Mm^3/a) of treated sewage effluent in addition to surface run-off from the industrial area of Krugersdorp and 2) the Tweelopiespruit which drains mainly acidic (treated & untreated) mine water from the decanting area in the dolomitic outlier to the south of the Zwartkrans dolomite limb, but also receives dolomitic groundwater (unpolluted) from a number of springs (see Figure 9.28.2). The influence of effluent return flows entering the Zwartkrans compartment has been studied in detail by Hobbs and Cobbing (2009) as well as Holland and Witthüser (2009). Both studies revealed deterioration in groundwater and surface water quality downstream of the mine water discharge area and wastewater treatment works.

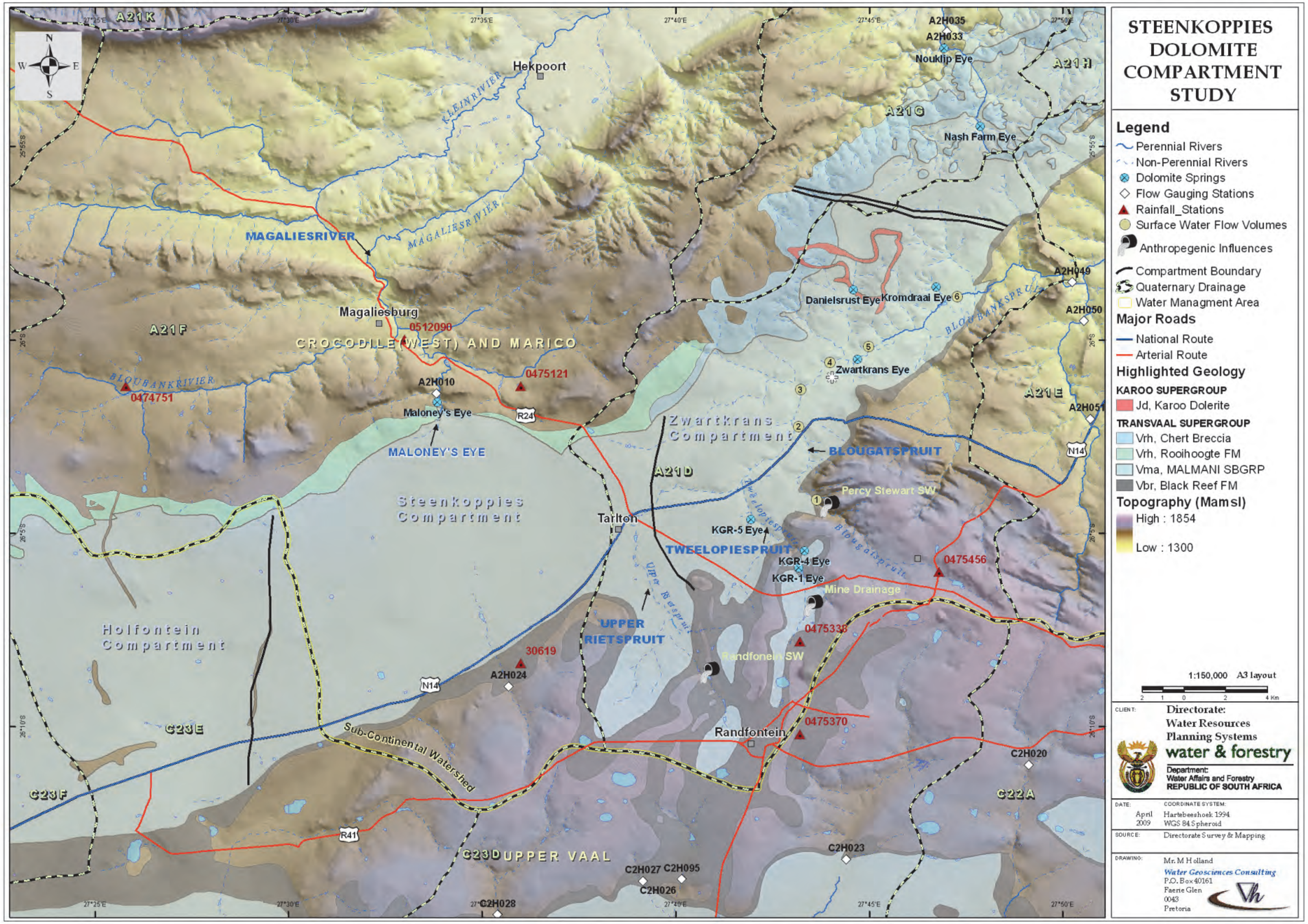


Figure 8.2. Surface water catchments and drainage of the Steenkoppies and Zwartkranz compartment areas (from Holland, 2011).

Hydrological flow volumes at certain locations on the Blougatspruit and Blaauwbankspruit river courses based on investigations by Bredenkamp et al. (1986) are represented in Table 8. together with the major spring discharges. These measuring points are presented in Figure 9.28.2 and illustrate the diminishing of flow as a result of either swallow holes or leakage through the riverbed once it enters the karst system, and the increase of surface flow as it's fed by a number of high yielding springs. Surface flow and spring discharge are not yet monitored on a continuous basis, creating some uncertainly in artificial inflow volumes into the system and outflows via spring discharges.

Table 8.1. Surface water flow measurements and known spring discharges.

Measuring Point	Flow Mm^3/a
1	6.31
2	3.15
3	1.23
4	0.41
5	8.14
6	11.67

Spring	Flow Mm^3/a
Zwartkrans	8.2
Daniels Rust	0.1
Kromdraai	0.9

Based on the knowledge of the authors and all prior investigations no other (additional) effluent or dewatering discharges are taking place in or near the Zwartkrans compartment that would account for artificial recharge into the karst system.

(ii) Steenkoppies Compartment

The upper Blaauwbankspruit is termed the Upper Rietspruit and drains storm water and surface run-off from the town of Randfontein in addition to some 8.1 Ml/day (2.85 Mm^3/a) of treated sewage effluent from the Randfontein Sewage Works facility (Figure 9.28.2). For some distance, stream flow remains constant, but irrigation dams and the leakage from the river bed into the underground network reduces the flow to virtually zero at the Tarlton intersection (an irrigation dam wall). However, during periods of high rainfall more surface run-off increases stream flow up towards the north-east at a second dam wall immediately north of the Tarlton road intersection (on the compartment boundary) (Figure 9.28.2). It is at this location where the Rietspruit stops flowing and no evidence of any river course immediately downstream of the dam wall exists.

Therefore very little if any flow from the Upper Rietspruit reaches the Zwartkrans compartment via surface routes. The volume of surface water recharging the groundwater artificially will be discussed in more detail in the following section. However, the monthly effluent return flow discharges from the Randfontein WWTW were obtained to assist in the quantification of inflows into the system. Unfortunately the monitoring data is only from the year 2004 onward and no historical records could be obtained by the Randfontein Municipality. A summary of the effluent inflows and discharges of the Randfontein WWTW is given in Table 8.2.

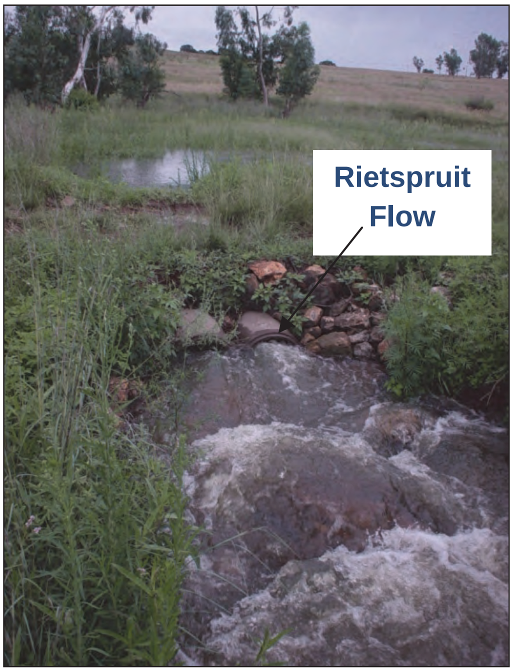


Photo 8.1. Rietspruit flow during periods of high rainfall and the end of flow at the Dam wall.

Based on the information obtained from the Randfontein WWTW average effluent discharge for the past five years amount to 2.85 Mm^3/a of which approximately 1.15 Mm^3/a is discharged into the Upper Rietspruit and 1.71 Mm^3/a is used for irrigation purposes. Currently the irrigation component of the Randfontein WWTW discharge permit is used by the adjoining mine dumps for dust suppression and also for irrigation of newly planted vegetation for rehabilitation. Therefore it is fair to assume that very little or any of these discharge components reaches the Steenkoppies dolomite compartment. A large volume of inflows are not balanced by the discharges and it's not clear where the unaccounted raw inflows are distributed to Table 8.2. Barnard (1997) estimated the volume of effluent discharge from the Randfontein WWTW into the Rietspruit at 5.9 Mm^3/a. This value is much higher than current measured discharge values which could present an adjustment to the water balance put forward by Barnard (1997).

Table 8.2. Randfontein effluent inflows and discharges into the Upper Rietspruit.

Year	Raw Inflows Mm^3/a	Effluent outflow Mm^3/a			Unaccounted Mm^3/a
		River	Irrigation	TOTAL	
2004	**3.60**	1.34	0.94	**2.28**	**1.32**
2005	**3.45**	1.48	1.34	**2.82**	**0.63**
2006	**4.75**	1.52	1.45	**2.97**	**1.78**
2007	**4.95**	0.84	2.07	**2.91**	**2.04**
2008	**5.19**	0.54	2.73	**3.28**	**1.91**

The monthly discharge values are plotted in Figure 8.3 together with monthly rainfall data from the Randfontein rainfall station. Although, no relationship between rainfall and effluent inflow or discharges is evident, an increase in the effluent discharge for irrigation purposes is seen from January 2007 with a slight decrease in discharges to the Rietspruit.

8.4.2.2 Spring flows (Gauging stations)

The most important DWAF hydrological gauging stations near the Steenkoppies compartment are the Maloney's Eye (A2H010) and Brandvlei (A2H024) stations. The Magalies River gauging station (A2H013) is approximately 34km downstream of the Maloney's Eye. The only other useful hydrological gauging station is Nouklip Eye (A2H033) which drains the centre region of the Tweefontein compartment (see Figure 8.2). These stations have long term flow records and chemical data. The monthly flow hydrograph of both A2H010 and A2H024 are illustrated in Figure 8.4.

The following information illustrated in Table 8.3 was obtained from the 100-year flow record of the downstream weir of the Maloney's Eye (A2H010).

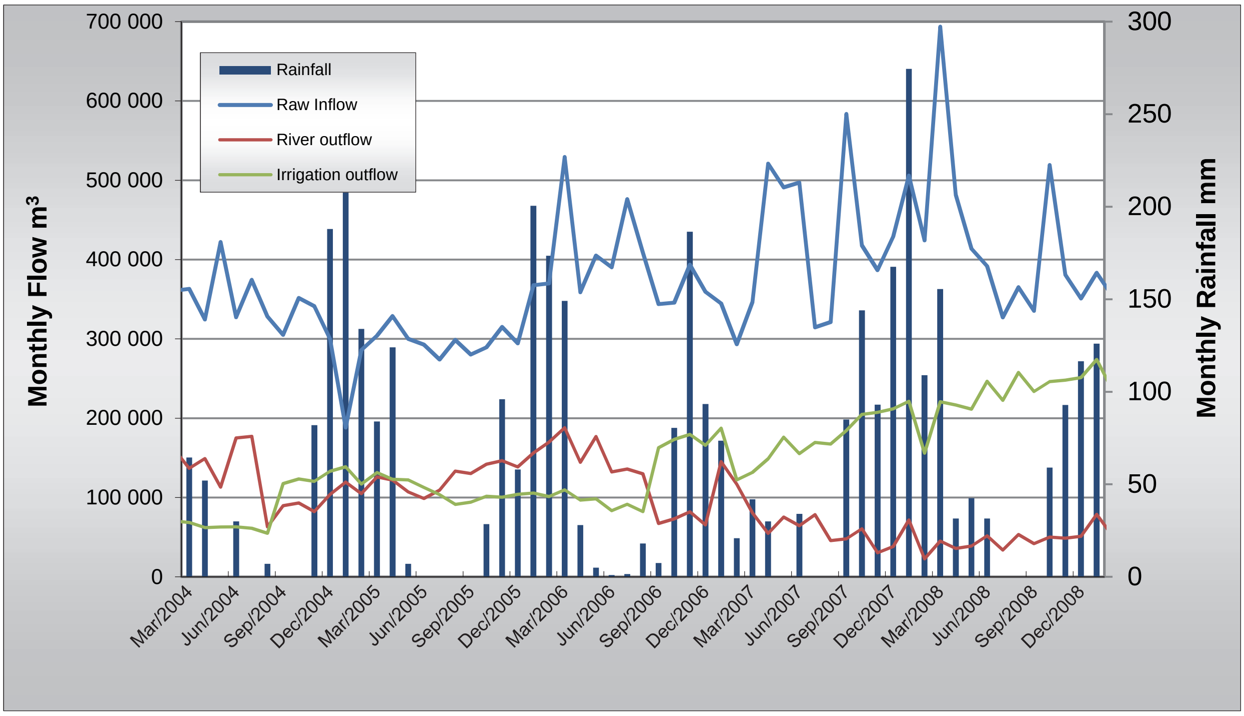


Figure 8.3. Randfontein effluent discharges and raw inflows.

Table 8.3. Maloney's Eye flow summary table (Oct 1908 to Mar 2009).

Year (Record)	Min (Mm^3/a)	Max (Mm^3/a)	10 Percentile (Mm^3/a)	90 Percentile (Mm^3/a)	Median (Mm^3/a)	Average (Mm^3/a)	Current (Mm^3/a)
Pre 1975	10.63	22.04	11.48	18.95	14.13	14.56	-
Post 1975	1.58	32.64	6.34	26.81	12.02	14.01	-
Since 1999	1.58	16.05	3.37	14.82	7.98	8.93	-
1908-2009	1.58	32.64	9.46	20.85	13.81	14.35	**5.49**

Over the last 30 years of flow the Maloney's Eye has achieved both the highest (32.64 Mm^3/a) and lowest (1.58 Mm^3/a) flows recorded to date. Compared to the subtle flow variations of the previous 70 years a significant contrast is seen in flow records. An extreme discharge event occurred during 1976 to 1988 where flow rates doubled from the long term average. In the last 10 years the average flow rate reduced to 8.93 Mm^3/a from a long term average of 14.35 Mm^3/a. It is obvious that the Maloney's Eye has reduced in flow and that short term flow fluctuations (variations) have increased over the last few years. A better understanding of rainfall patterns and detailed analysis of groundwater level trends of the Steenkoppies compartment is necessary to explain such flow behaviour. These issues will be dealt with in the sub-sequent sections.

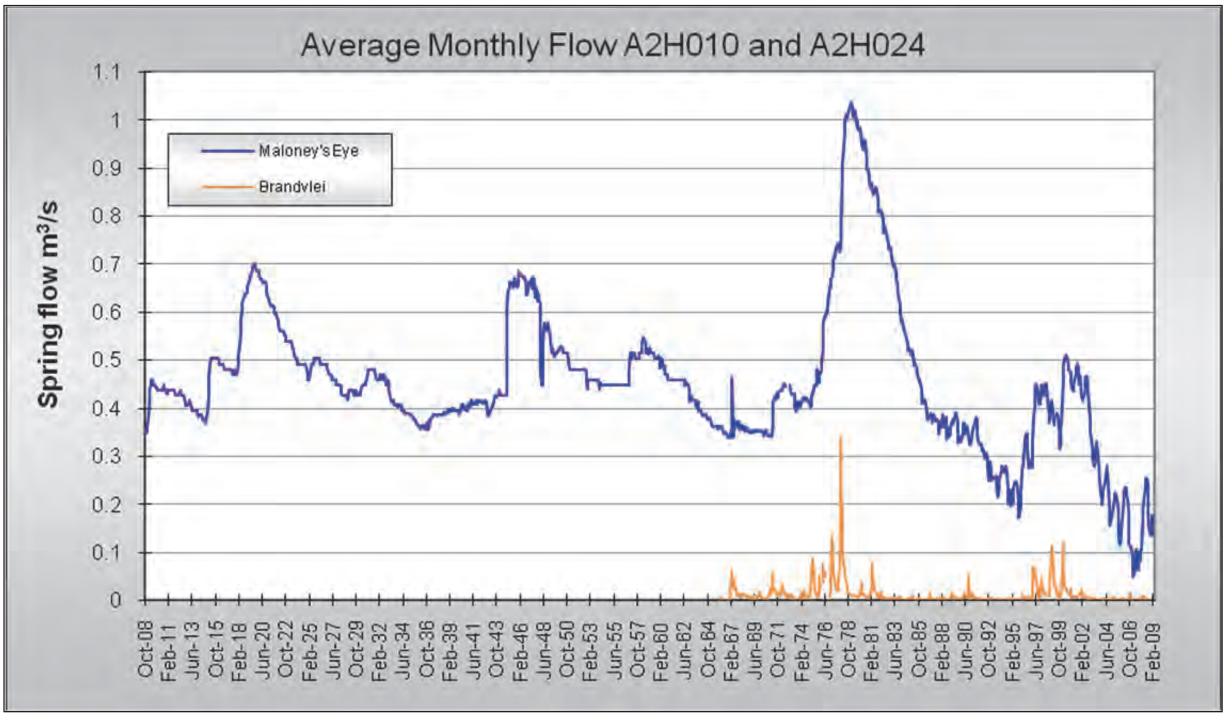


Figure 8.4. Flow hydrographs of DWAF gauging stations A2H010 and A2H024.

8.4.3 Climate and Rainfall

The climate in the area is typical South African "Highveld", characterised by warm summers, when 80% of the rainfall is experienced as thunderstorms, and cool dry winters with cold nights. Frosts are experienced for up to five months of the year and hail falls often. Climatic data of six meteorological stations closest to the study area is summarised in Table 8.4 and spatially presented in Figure 8.2.

Table 8.4. Meteorological stations in the study area.

(SAWS)	Station ID	Rainfall Record		Elevation (mamsl)	Mean Annual Rainfall MAP (mm)	Distance from Maloney's Eye (km)
		Start	End/Current			
Vlakfontein*	474751	1934	1989	1531.0	693.4	13.5
Steenkoppies*	475121	1907	1952	1502.0	664.4	3.7
Randfontein*	475338	1954	2009	1704.8	662.0	19.3
Randfontein GM*	475370	1914	1995	1722.0	708.5	22.7
Randfontein Jamespark*	475370	1980	2000	1722.0	709.1	22.7
Krugersdorp Kroningspark*	475456	1965	2009	1695.0	716.5	23.1
Magaliesburg Pol*	512090	1969	2009	1429.0	613.8	3.2
Deodar[#]	30619	1982	2009	1624.8	639.9	12.9

*– Data obtained from the South African Weather Services (Pretoria)

[#] – Data obtained from the Agricultural Research Council (Pretoria).

The monthly rainfall time series of different meteorological stations in the wider area of interest were screened with regard to their recorded mean annual precipitation. Only four stations (Vlakfontein, Steenkoppies, Randfontein and Deodar) showed a similar mean annual precipitation (MAP), where, the maximum deviation of mean annual precipitation was below 10%. These stations were considered for the compilation of a single, representative time series from 1908 to 2008 (similar to the flow record of the Maloney's Eye). The time series was compiled by calculating a weighting average (using a squared inverse distance weighting method) of all monthly rainfall records available for a given time period (Holland, 2011).

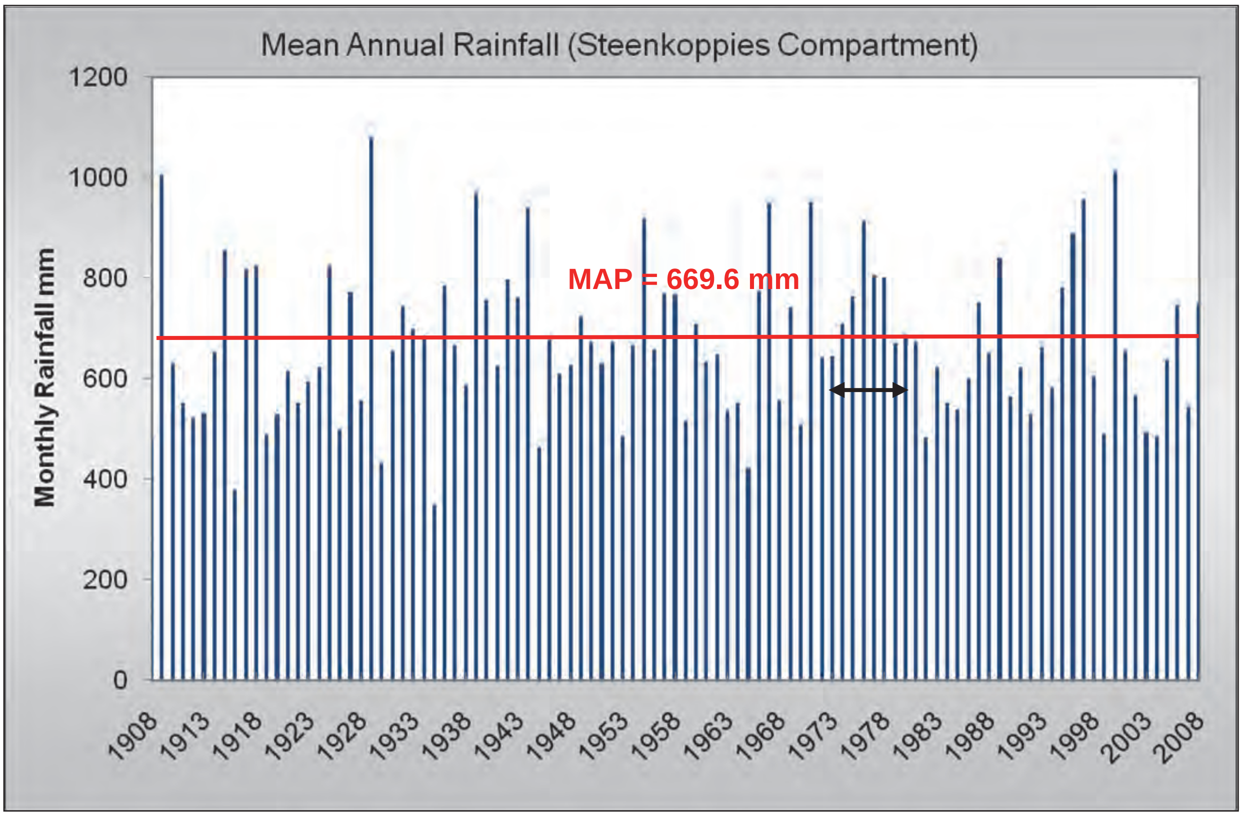


Figure 8.5. Mean annual precipitation based on the compilation of a single long term from 1908 to 2009 (Arrow indicates a rainfall period of 11 years with annual average rainfall above 600 mm).

If a rainfall station did not have any records for a given time period, the station was omitted from the calculations above. The chosen approach ensured the compilation of a continuous 100 year time series of rainfall records for the area of interest (Figure 8.5); though several time periods rely solely on a single operational station (e.g. only Steenkopjes (475121) was operational prior to 1934).

Table 8.5. MAP characteristics for the Steenkoppies compartment.

Year (Record)	MAP (mm)	Years of MAP above or below long term mean		MAP > 1000 mm	MAP < 550 mm	% of Rainfall Below 550 mm over time	MAP (mm)	
		Below	Above				Min	Max
1908 to 1988	669.2	44	37	2	17	21%	348	1081
1989 to 2008	671.1	13	7	1	5	25%	486	1014
Complete	**669.6**	57	43	3	22	22%	348	1081

An analysis of the long term annual rainfall data is illustrated in Table 8.5. Average annual rainfall of 550 mm was used as a reference for particularly dry years.

Although it is evident that over the last 20 years some below average rainfall events occurred, it is no worse than previous dry cycles over the 100-year rainfall record. Lower rainfall over the last 20 years suggests that lower flows at the eye could be expected, although low rainfall alone may not explain the full decline in flow at the eye.

8.4.4 Geomorphology

The present karst forms and geomorphology have been created by the interplay of ancient and recent erosion cycles on lithologies that have undergone many episodes of deformation. Subsequent to the breakup of the super-continent of Gondwanaland (250 million years ago), the dolomites have been uplifted into a high interior plateau and the overlying Karoo cover rocks relatively rapidly stripped off by erosion to reveal a pre-Karoo palaeo-karst surface (King, 1963; Wilkins *et al*., 1987). An episode of quaternary regional up warping on an East-Northeast trending transcontinental axis has caused significant drainage reversal over the whole karst region.

The northern boundary of the Steenkoppies compartment runs along the base of the Pretoria Group comprising of shales of very low permeability. The southern boundary along a number of rock types ranging from igneous basement rocks to the sedimentary succession of the gold bearing Witwatersrand formations forming the faulted rim of the Witwatersrand basin. Dipping off the western flank of the Johannesburg Dome with a disconformable contact is the basal formation of the Transvaal Super-Group consisting of the Black Reef Quartzite Formation underlying the Steenkoppies dolomitic compartments. Based on the abundance of chert, the Malmani Subgroup has been subdivided into five dolomitic formations (Figure 8.6).

8.4.5 Geology

The geology of the Steenkoppies and Zwartkrans compartment has been discussed in the numerous studies conducted in the area (Foster, 1984; Bredenkamp *et al*., 1986; Van Biljon, 2006; Holland, 2007). However, studies relating specifically to geological mapping and structural geology are rare. The geological maps available for the study area is the 1:50 000 and 1:250 000 geological maps from the Council for Geoscience. However the two 1:50 000 map sheets only covers the area north of the 26° latitude. The most comprehensive mapping done in the larger area was done by Obbes (2001). Unfortunately, the author's mapping area covered the Chuniespoort Group dolomites also only from the 26° latitude northwards. The University of Pretoria extended the Obbes (2001) map to the border of the Cradle of Humankind (Figure 8.6).

8.4.6 Mafic dykes and lineaments

A number of intrusive dykes occur in the area, subdividing the dolomite into compartments. The magnetic nature of the dykes makes aeromagnetic data ideal for mapping these features. Aeromagnetic data sourced from the Council for Geoscience was used for the identification of linear anomalies in the region. The total magnetic field (TMF) map together with interpreted linear anomalies is presented in Figure 8.7. These linear anomalies interpreted as dykes forms the basis for the delineation of compartments and groundwater management and hydrogeological response units.

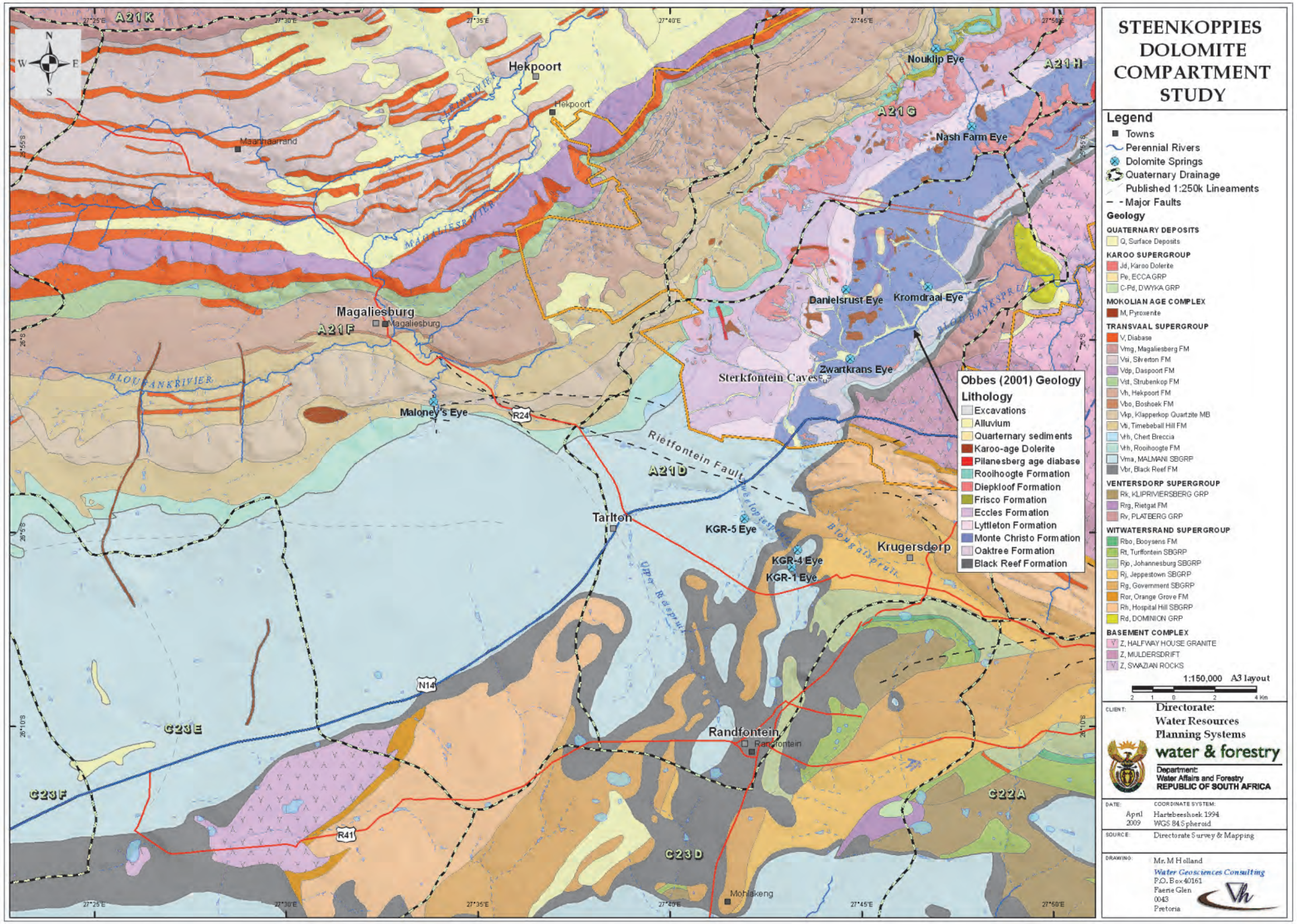


Figure 8.6. Regional geology of the Tarlton dolomites.

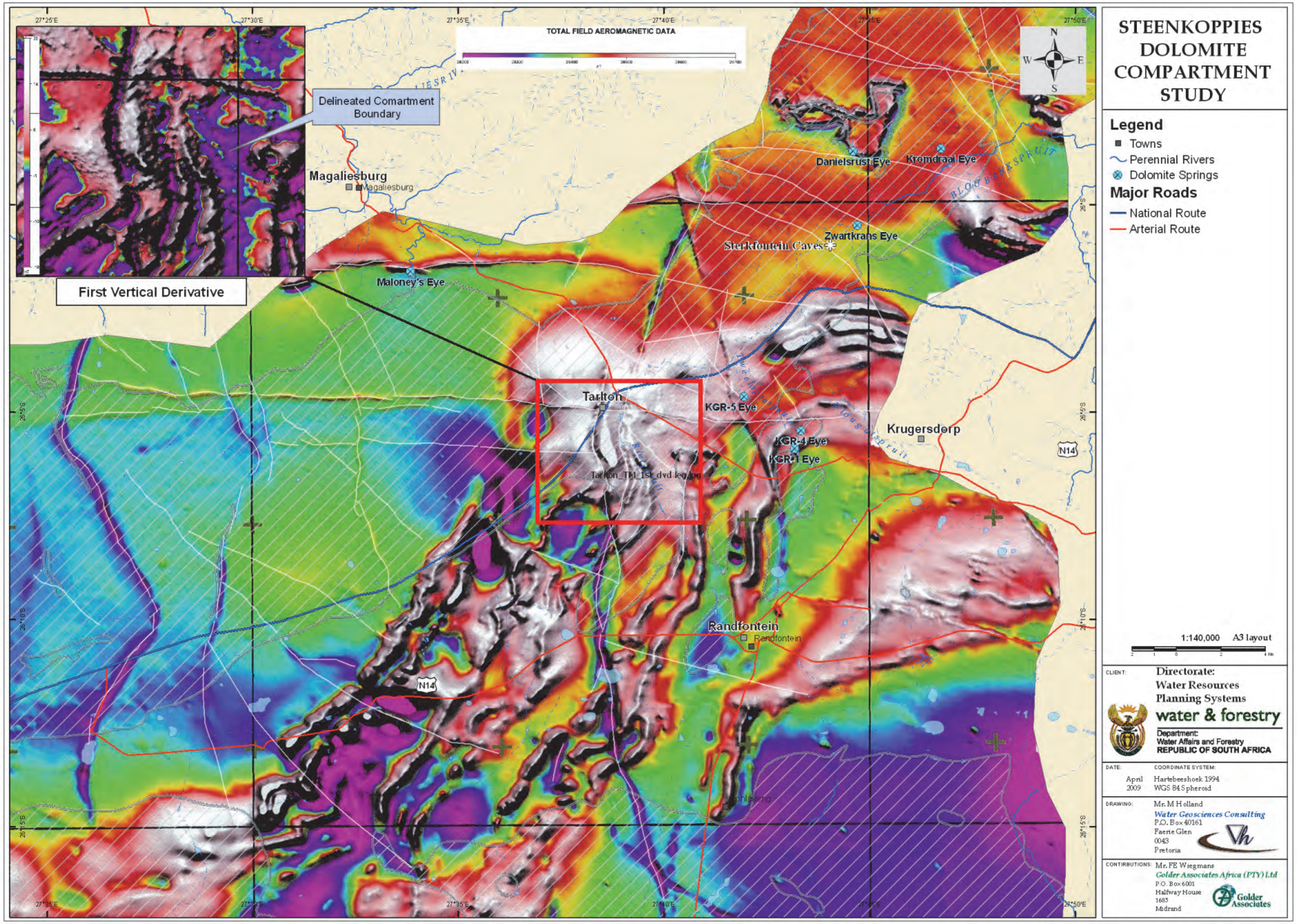


Figure 8.7. Aeromagnetic data interpretation (sourced from: The Council for Geosciences by Holland, 2009).

More recent aeromagnetic and electromagnetic data was captured by Geotech Airborne Ltd during March 2009. The area was surveyed included a portion of Steenkoppies and Zwartkrans compartments. Although the interpreted anomalies from this survey were made available for this study, the raw data does carry a cost and should be considered for future investigations.

8.5 Hydrogeology

8.5.1 General

The low density of runoff drainage suggests high recharge and a predominance of water flow underground, which eventually drains into surface streams at topographic lows or emanates as springs next to dykes or lithologic/formation contacts (e.g. Maloney's Eye). The formations of the dolomites are distinguishable based on their chert content. The chert poor formations weather evenly to produce a low storage potential residue of silty clay. The chert rich formations weather quite differently. The dolomite weathers faster than the chert leaving the rock supported by chert structures. Eventually the chert will weather and collapse under its own weight leaving a permeable coarse chert breccia. Chert rich formations develop a greater concentration of fissures and fractures, which will enhance the process of weathering. These chert rich formations are generally favourable for large-scale development of groundwater. The deep weathering of the dolomite can be indicated by gravity lows (refer to the following section). The weathered part of the dolomite underlain with fractures and fissures is highly heterogeneous. These karst aquifers are often characterised by a dual or triple porosity, comprising of solutional voids, fractures and the rock matrix (intergranular pores). While the fractures and the rock matrix provides most of the storage potential (low permeability), the conduits act additionally as drains (high permeability).

The overlying Pretoria group reveals very low primary permeabilities and signifies weakly developed secondary permeabilities along faults and fractures. Once the dolomite is exploited excessively it is expected that the Pretoria Group will contribute groundwater to the dolomite (Kuhn, 1989). The hydraulic connection between the dolomites and the underlying Witwatersrand and Basement rocks is poor due to low permeability values in these underlying rocks.

8.5.2 Gravity survey

8.5.2.1 Method

The Department of Water Affairs and Forestry conducted an extensive gravity survey during 1985 known as the Tarlton gravity survey which covered an area of 90 km^2. The Tarlton survey conducted by Southern Geophysical Exploration covered large portions of both the Steenkoppies and Zwartkrans Dolomite Compartments at 100 m station intervals along 250 m spaced traverses. The gravity survey targeted the Rietspruit valley and the eastern portion of the Steenkoppies compartment.

The original data that could be obtained was only available as Bouguer anomalies (both absolute and relative) in the form of hard copy maps, with labeled data points. These map plots were used to collate an electronic Bouguer gravity data set. The task entailed repeated data contouring and editing to identify data spikes to correct wrong values, which originated from poorly legible data. Due to budget constraints a very small number of minor data errors may still exist, estimated at less than 50 out of a total number of 9, 909 gravity points. Coordinates of the gravity stations were determined by re-calculating the coordinates according to the original planned survey coordinates for the 100 m grid area. Coordinates for the survey done by Southern Geophysical Explorations were digitized from scanned and geo-referenced maps. The error in the coordinate accuracy may vary from 1 up to 100 metres. The altitudes for the gravity stations were interpolated from DTM data obtained from the Surveyor General. These elevations were also used to compile a conceptual dolomite bedrock elevation map.

The relative Bouguer gravity data was formerly compiled by DWAF applying standard gravity data corrections. A density factor of 2.67 g/cc was used for the surface elevation corrections. The relative Bouguer gravity data was tied into the national network and a constant value of -148.19 mgal should be added to obtain absolute gravity values based on the IGSN71 gravity base system.

Reduction of Bouguer to residual gravity

The relative Bouguer gravity data (anomalies) contains information of two gravity components:

- A regional gravity field reflecting deep density variations of the underlying bedrock, and
- Residual gravity anomalies reflecting near surface (<200 m) and local density differences as a result of leached dolomites or overburden (e.g. Karoo sediments).

In the study of dolomite aquifers we need to remove the deep seated gravity effects. This is done by compiling a regular/smooth regional gravity field and subtracting it from the Bouguer data in such a way that zero gravity values represent solid dolomite at surface. The subsequent compiled residual gravity data represents only near surface density variations. Zero or slightly positive gravity values represent outcropping dolomite bedrock, and negative values leached dolomite zones. Pending the configuration of the underlying leached dolomite and fill material of paleo-channels a 40 to 50 meter factor per -1 mgal residual gravity value can be used to estimate the depth to bedrock.

Conceptual bedrock elevation

A conceptual bedrock elevation map was compiled by multiplying negative residual gravity values by 50 to obtain a bedrock depth estimate. A zero depth to bedrock value was used for positive residual values. These depth estimates were subtracted from the surface altitudes at each gravity station to obtain conceptual bedrock elevations. The Relative Bouguer anomaly map together with the regional gravity field, residual gravity map and the inferred conceptual bedrock elevation map are presented as a mosaic in Figure 8.8.

8.5.3 Results

The gravity method is most effectively used to assist in delineating major karst features within the highly heterogeneous dolomite aquifer. This is based on

- prominent density contrast of > 0.5 g/cc between solid and leached dolomite, and
- sharp lateral contrasts in near surface rock densities related to the highly irregular sub-surface karst topography.

In this study the object of the gravity survey was to locate zones of leached dolomite indicating highly transmissive zones and identifying groundwater conduits feeding the Maloney's Eye. Unfortunately the gravity survey does not extend all the way north the Eye and a few gravity lines in this area is recommended to complete the gap.

The residual gravity map was overlain by the DWAF boreholes drilled in 1986. These boreholes were also pump tested to determine aquifer properties. Transmissivities range from 1 to 25 100 m^2/d suggesting highly heterogeneous conditions. The distribution of high transmissivities generally relates to the broad zones of gravity lows (refer to the residual gravity map in Figure 8.8).

8.5.4 Compartments and ground water management units

Dolomitic compartments are formed by crosscutting dykes that act as barriers to groundwater flow, creating isolated hydrogeological compartments. It is important to note that not all dykes are totally impermeable and an extensive lowering of the water level through groundwater abstraction could clarify the extent of leakage through these boundaries. The major compartments according to the various geohydrological studies conducted in the Tarlton dolomitic area by Foster (1984), Vegter (1986) and Bredenkamp et al. (1986) are Holfontein, Steenkoppies, Zwartkrans, and Tweefontein compartments (see Figure 8.2). The Zwartkrans and Steenkoppies compartments were subdivided into smaller sub-compartments by Bredenkamp et al. (1986) based on field surveys, gravity data, and water level measurements and were shown in detail by WGC (2007). An aim of the study by Holland (2011) was to re-interpret the compartmentalisation that exists in the Steenkoppies compartment and to establish groundwater management areas and hydrogeological units. This involved the capturing of all existing water level databases including time series data, aeromagnetic data interpretation and the re-working (digitising) of the historical gravity dataset that exist for the area. The groundwater drainage (flow) and water levels discussed later, was also considered in the delineation of groundwater units and compartments.

During his investigation potential groundwater units (GU), groundwater management units (GMU) and groundwater management areas (GMA) were identified. GMAs generally coincide with surface drainage boundaries (e.g. quaternary catchments). The GMAs identified by Holland (2011) coincide closely with the delineated Steenkoppies and Zwartkrans compartments with expanded boundaries upstream to include the surface drainages that influence the hydrogeology of the dolomites. The Steenkoppies compartment and also the Maloney's Eye catchment boundaries are represented by GMA A21F and represent an aerial extent of 322 km^2. The following features are regarded as hydrogeological boundaries and illustrated in Figure 8.9.

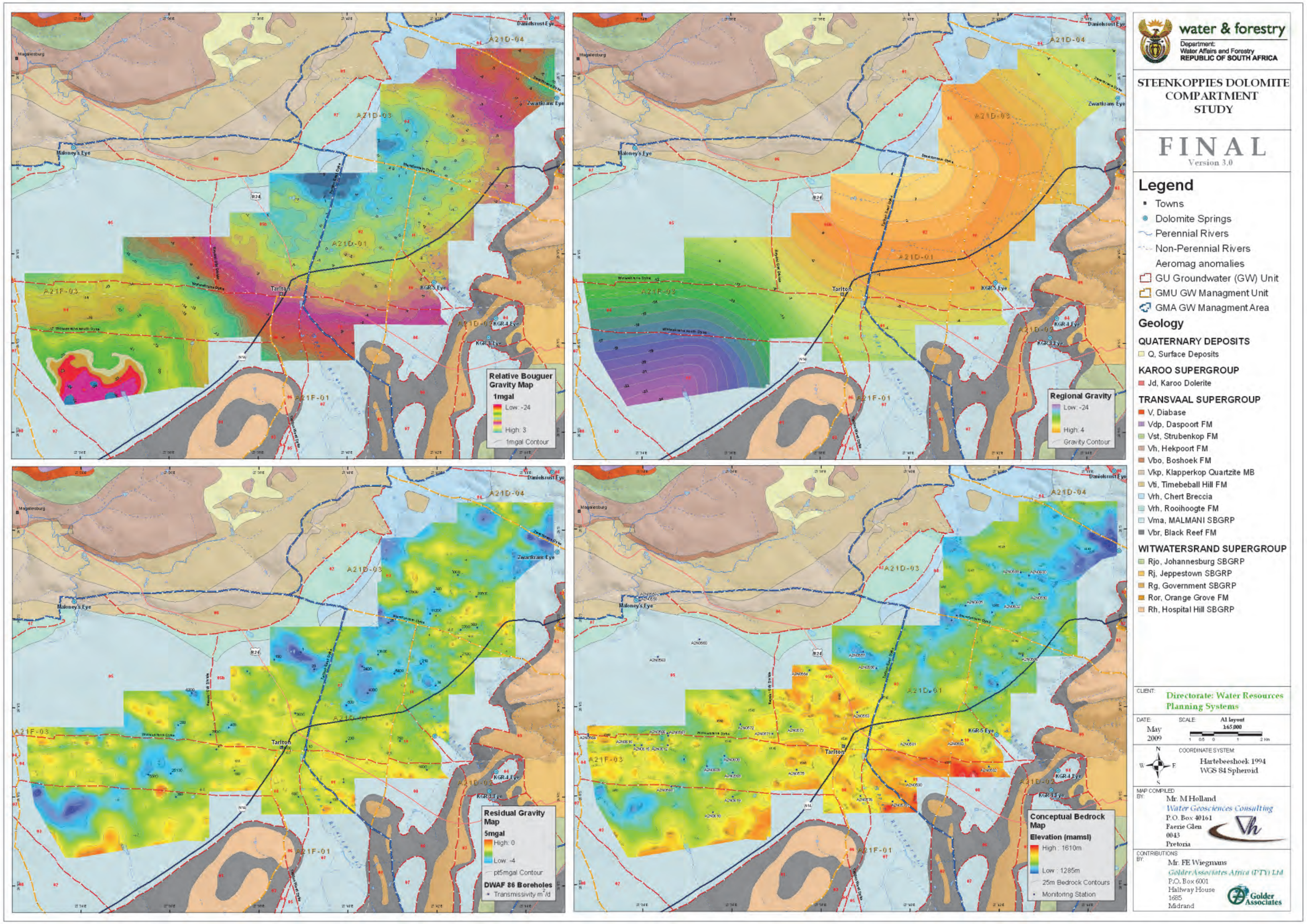


Figure 8.8. Re-worked gravity survey data of the Tarlton gravity survey of 1986.

- The Pretoria Group shales in the north (also a significant east-west trending dyke). The management boundary has been expanded slightly toward the north to incorporate minor surface run-off features.
- A clearly distinguishable positive magnetic anomaly known to as the Eigendom dyke forms a hydrogeological boundary towards the west (distinct N-S zigzag magnetic anomaly in Figure 8.7).
- Some controversy exists regarding the delineation of the eastern boundary and in previous investigation both the Tarlton west and Tarlton east dykes have been put forward as the main compartment boundary. In this investigation the delineated eastern boundary coincides closely with Barnard's, (1997) delineation of the boundaries of the Steenkoppies compartment.
  - This boundary extends southeast toward the town of Randfontein based on a less pronounced anomaly visible on the first vertical derivative of the total field aeromagnetic data (refer to Figure 8.7 insert map). In this study this boundary will form the major groundwater divide between the Zwartkrans and Steenkoppies compartments. The groundwater divide is based on water level elevations, simple chemistry distribution plots and residual gravity data, however, it is noted that further work is necessary to confirm this boundary as a hydraulic barrier.
- The southern boundary of the dolomites is represented by the Black Reef quartzites and shales. However, the catchment of the Maloney's Eye extends further south towards the sub-continental surface water divide discussed in section 8.2. This boundary will include the quartzites and shales of the Witwatersrand Supergroup. It is expected that a significant portion of surface run-off and to a lesser extent lateral groundwater inflow from these quartzites, will enter the underground network of the Steenkoppies dolomite compartment and therefore form part of the Maloney's eye catchment.

Holland (2011) combined potential groundwater units (GU) to form groundwater management units (GMU) where lateral hydraulic interdependence was evident and assumed. A GU can be defined as a groundwater body that has been delineated or grouped into a single significant water resource based on one or more characteristics that are similar across that unit. Delineated GMA, GMU and GUs are presented in Figure 8.9.

8.5.5 Groundwater Levels

The most comprehensive water level borehole survey in the study area was conducted by Barnard (1997). Although DWAF has monitored groundwater levels since 1985, only 31 of the 46 stations have data up to 2008 or more recent. Some of the stations have been consistently monitored (monthly) while others have relatively long gaps in between measurements. Holland (2011) could not prepare an updated groundwater level contour map due to the lack of a comprehensive borehole survey. However, a conceptual regional groundwater flow map was produced based on the borehole survey of 1997 as well as the limited current groundwater level data.

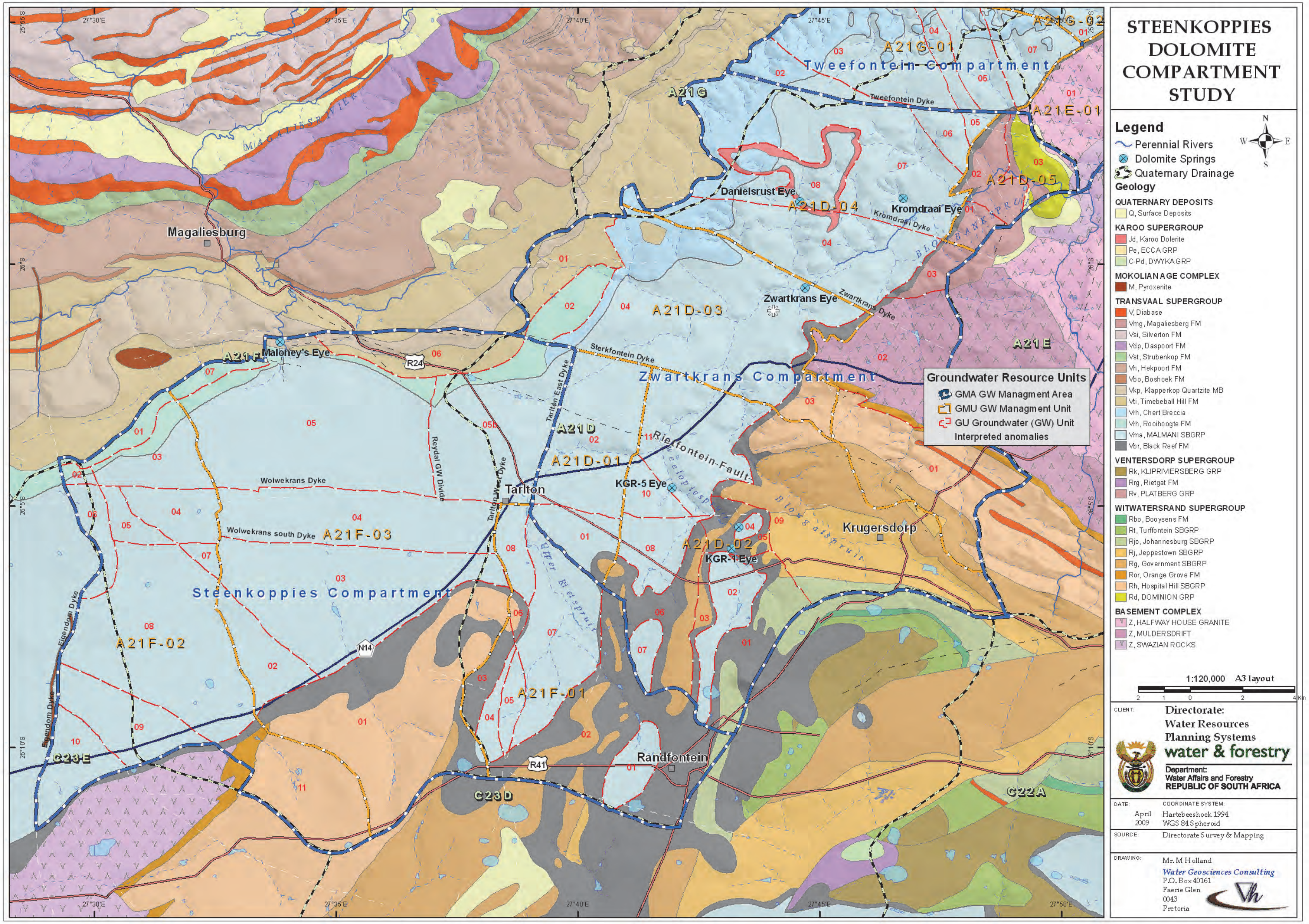


Figure 8.9. Delineated groundwater units.

8.5.5.1 Groundwater flow

Regional groundwater flow in the Zwartkrans compartment is directed to the north-east towards the Danielsrust and Kromdraai's Eyes, while in the Steenkoppies compartment it is to the north towards Maloney's Eye (Figure 8.10). GMU A21F-03 together with A21F-01 and A21F-02 represent the Maloney's Eye catchment. A21F-03 can be regarded as the main management unit of the Eye and consists of seven interdependent groundwater units. The first groundwater unit is the upper most catchment of the Maloney's Eye and consists of the Witwatersrand quartzites.

Table 8.6. Summary of groundwater level datasets (Based on NGDB; Bredenkamp *et al*., 1986; Barnard, 1997; Holland, 2007; Hobbs and Cobbing, 2007).

Compartment/ GMA	GMU	Area [Km^2]	GU No.	Area [Km^2]	Ad Hoc Water Levels (mbgl)				Ad Hoc Water Elevation (mamsl)		
					Count	Mean	Min.	Max.	Mean	Min.	Max.
Zwartkrans	A21D-01	22.9	01	5.5	20	41.3	13.9	84.1	1554.4	1480.7	1582.7
			02	17.4	23	54.9	21.5	84.1	1503.5	1482.6	1520.1
Steenkoppies	A21F-01	58.1	07	15.4	14	22.5	9.0	53.0	1576.8	1527.0	1590.6
			08	3.6	13	38.1	16.4	61.3	1551.4	1516.8	1581.6
	A21F-02	85.1	01	2.4	1	23.1	23.1	23.1	1571.9		
			03	7.7	1	121.4			1517.8		
			04	5.6	3	99.3	91.8	111.1	1513.7	1505.3	1519.7
			06	3.8	1	76.6			1578.4		
			08	30.6	8	57.2	42.2	80.8	1520.9	1506.5	1550.4
			10	6.8	1	40.0			1531.0		
	A21F-03	168.1	01	38.8	5	38.4	20.0	73.8	1566.4	1520.3	1601.6
			02	6.6	1	69.9			1504.0		
			03	29.4	10	80.9	65.1	96.6	1492.3	1490.4	1494.0
			04	19.9	16	74.8	63.6	90.4	1490.6	1487.5	1491.9
			05	62.1	30	63.9	7.9	92.1	1489.9	1487.5	1493.7
			05b		46	64.9	11.6	83.8	1505.3	1494.1	1565.6
			06	9.4	2	21.7	9.1	34.3	1524.3	1518.9	1529.6
			07	1.8	1	13.1			1567.0		

The other four groundwater units (GUs) are based on cross cutting dykes through the dolomite (e.g. east-west trending Wolwekrans dyke). Groundwater flow can be expected from A21F-02 and A21F-01 into A21F-03. A21F-01 can be regarded as the Upper Rietspruit valley dolomites. This area drains the artificial recharge component of the Randfontein WWTW effluent return flows. Groundwater is expected to flow northwards along the Tarlton west dyke across the Wolwekrans dyke and into the eastern-most edge of the Maloney's eye catchment. This area immediately north of the town of Tarlton has elevated groundwater levels and can be regarded as an additional groundwater unit (A21F-03(05b)). This is similar to the sub-unit defined by Bredenkamp et al. (1986) with the Reydal groundwater barrier acting as the unit boundary (Figure 8.10). This groundwater divide is not an impermeable barrier but the step in water levels of 5 m between the units suggest that this barrier might be due to more solid dolomite adjacent to a leached highly karstified unit (A21F-03(05)). It is significant to note the flat groundwater gradient in the centre of A21F-03 indicating a highly transmissive area. The area can be regarded the main drainage area of the Maloney's eye and the water level represents the discharge elevation of the spring. The sixth and seventh groundwater units consist of the Rooihoogte formation shales and part of the Timeball Formation quartzites immediately east and west of Maloney's Eye. The gravity lows based on Figure 8.8 are presented in the groundwater flow map (Figure 8.10) together with transmissivities from pumping tests conducted in the 1980s. Barnard (1997) similarly delineated six zones of different transmissivities values however, only some correlation exists between highly leached dolomite zones delineated in this study.

8.5.5.2 Groundwater hydrographs in relation to rainfall

Holland (2011) used the Cumulative Rainfall Departure (CRD) method to indicate the relationship between rainfall, groundwater fluctuations and spring flows. The monthly rainfall data used in the CRD-method is based on the rainfall time series dataset described earlier (Section 8.4.3). The CRD series is represented by the mathematical relationship given in Eq.3 and used extensively by Bredenkamp in his studies of dolomitic aquifers (Bredenkamp, *et al.*, 1995): The distribution of monitoring boreholes used in this analysis are shown in Figure 8.10.

$$ {}_{av}^{1}CRD_i = \sum_{n=1}^{i} R_n - k \sum_{n=1}^{i} R_{av} \, (i = 0,1,2,3.....N) \qquad (8\text{-}1) $$

Where R is rainfall values with subscript "$_i$" indicating i-th month and "$_{av}$" the average. $k = 1+(Q_p+Q_{out})/(AR_{av})$. If, according to the regression $k > 1$, which indicates that pumping or an external impact has affected the water level, the natural water levels could be simulated from equation (8-1) by setting $k = 1$. The equation was adjusted to consider the long-term water fluctuations and short-term delay from rainfall to groundwater recharge.

The hydrographs produced indicate a direct relationship between rainfall and groundwater level fluctuations within the Maloney's Eye catchment. A good correlation with the CRD graph was achieved with a short moving term average of 9 months and a long term moving average of 60 months for all other CRD-graphs (e.g. Figure 8.13). Two borehole hydrographs at the monitoring stations at the spring indicate the response of the aquifer to recharge (Figure 8.11). A decline is evident in station A2N558 since 2000 onwards despite a general increase in rainfall. This borehole is situated 30 m south of the Maloney's Eye dyke. A2N559 is located downstream of the Maloney's Eye and north of the Maloney's Eye dyke, which explains the difference of 2 meters between the groundwater level elevation. Both these boreholes are drilled into the shales and quartzites of the Pretoria Group overlying the dolomite.

Boreholes illustrated in Figure 8.12 are located in the main groundwater unit (A21F-03(05)) draining towards the Eye. Groundwater level responses to rainfall are similar to the stations at the Eye with maximum fluctuations of 2 meters. Despite a slight increase in the CRD-graph, groundwater levels of station A2N572 rapidly declined since 2000 (Figure 8.12).

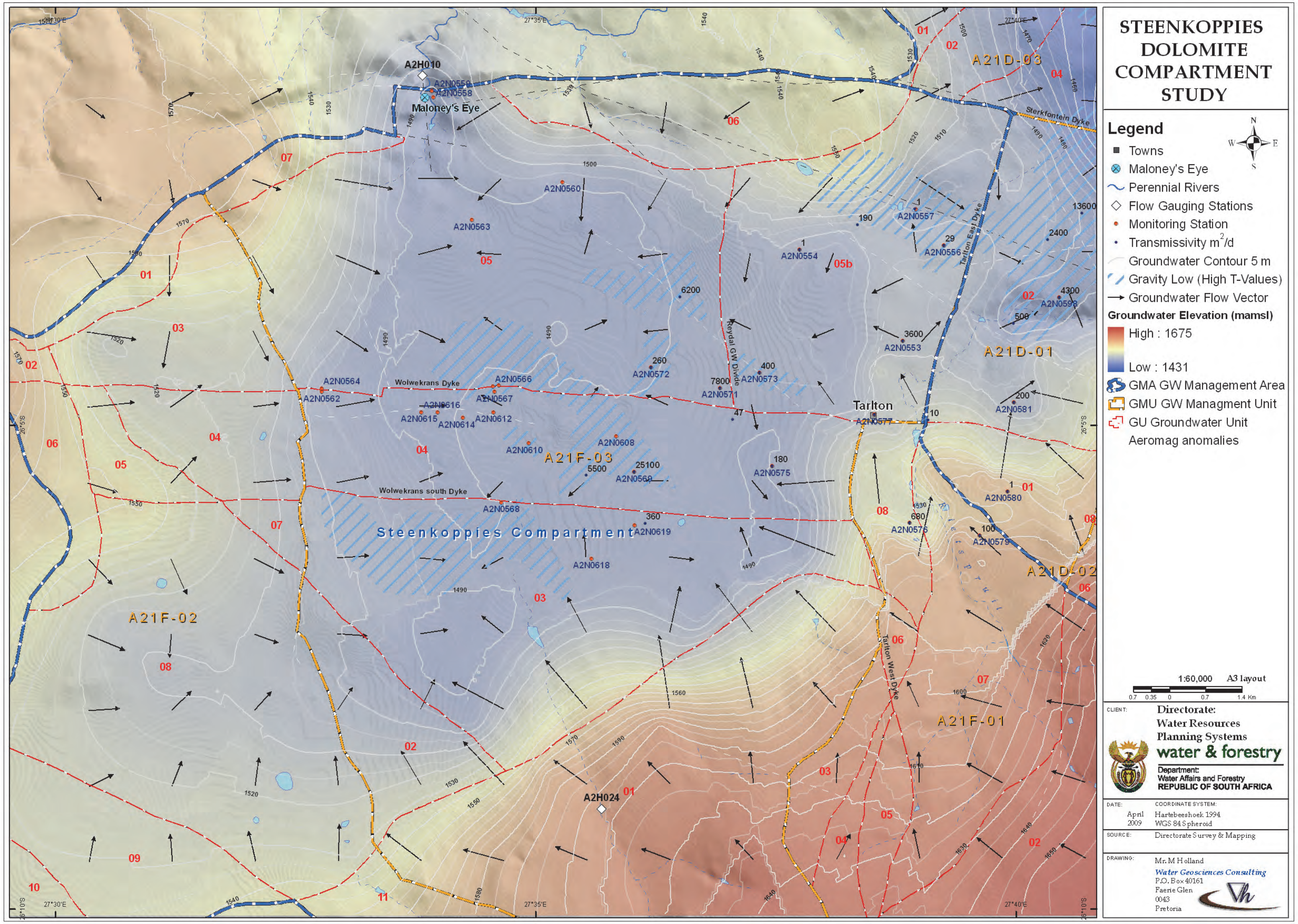


Figure 8.10 Regional groundwater flow.

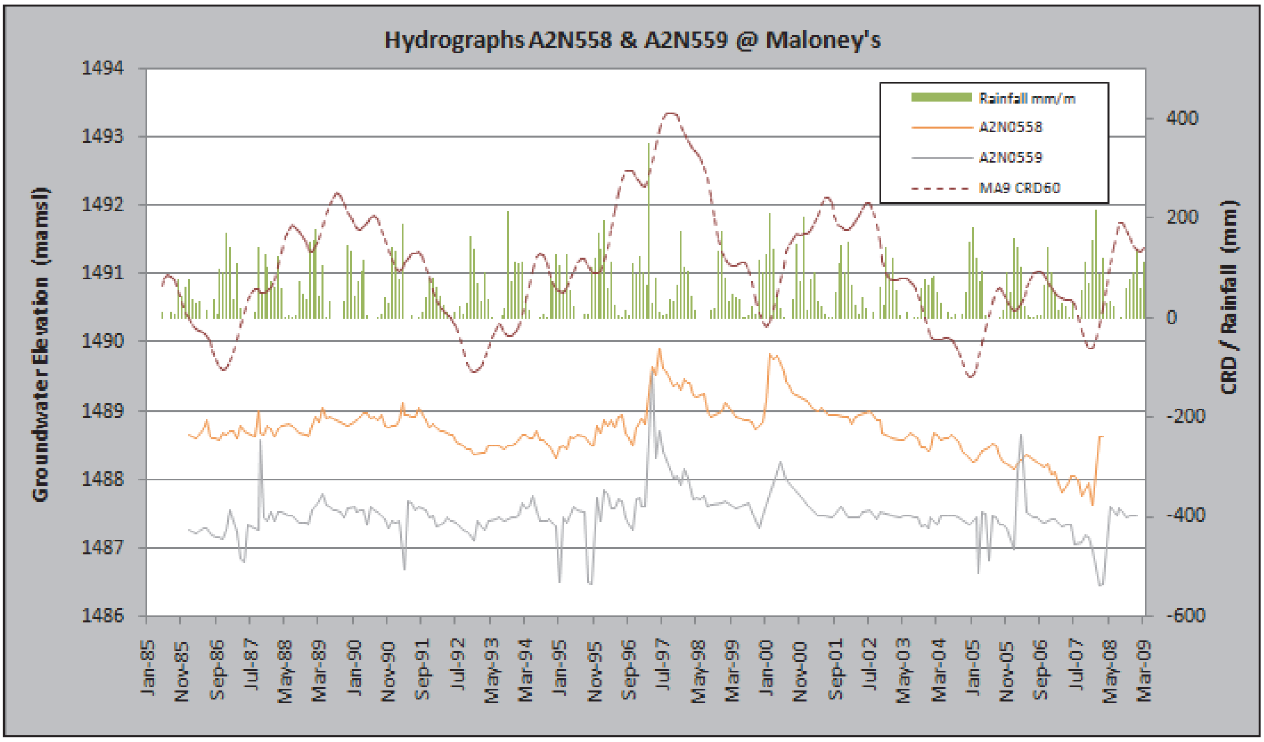


Figure 8.11. Borehole hydrographs for stations at Moloney's Eye.

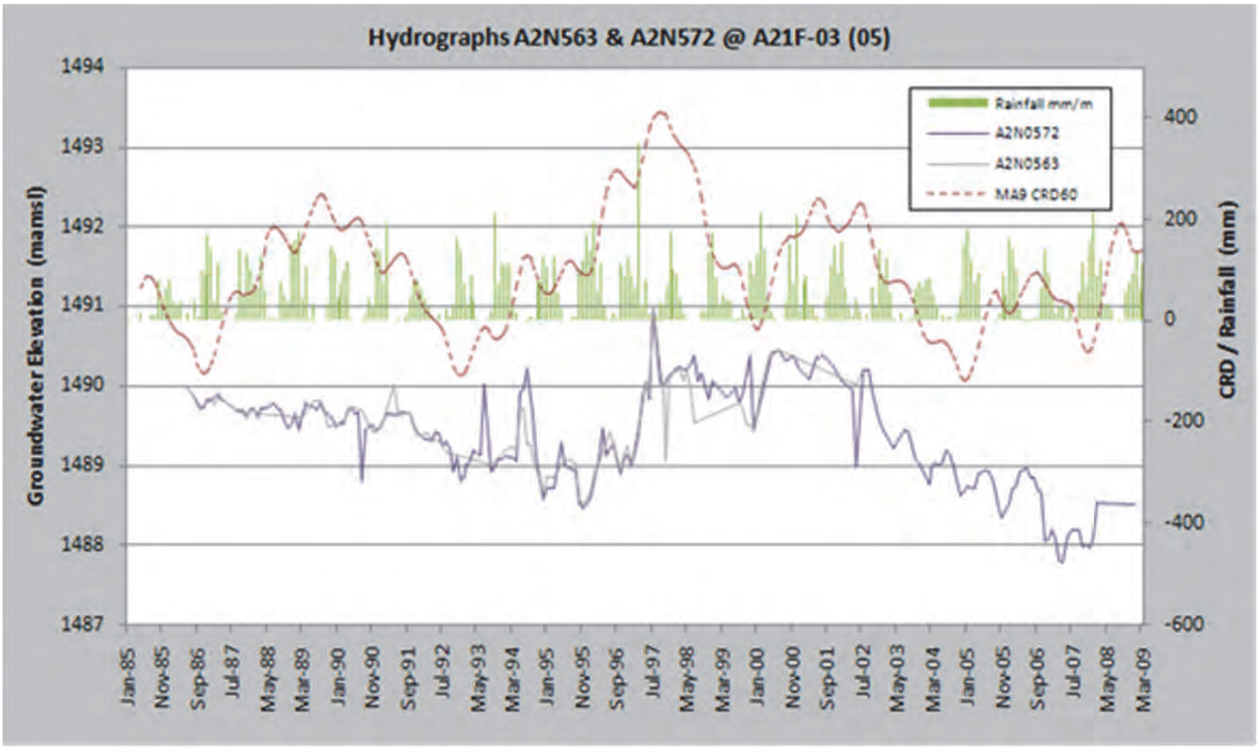


Figure 8.12. Borehole hydrographs for stations upstream of the Moloney's Eye.

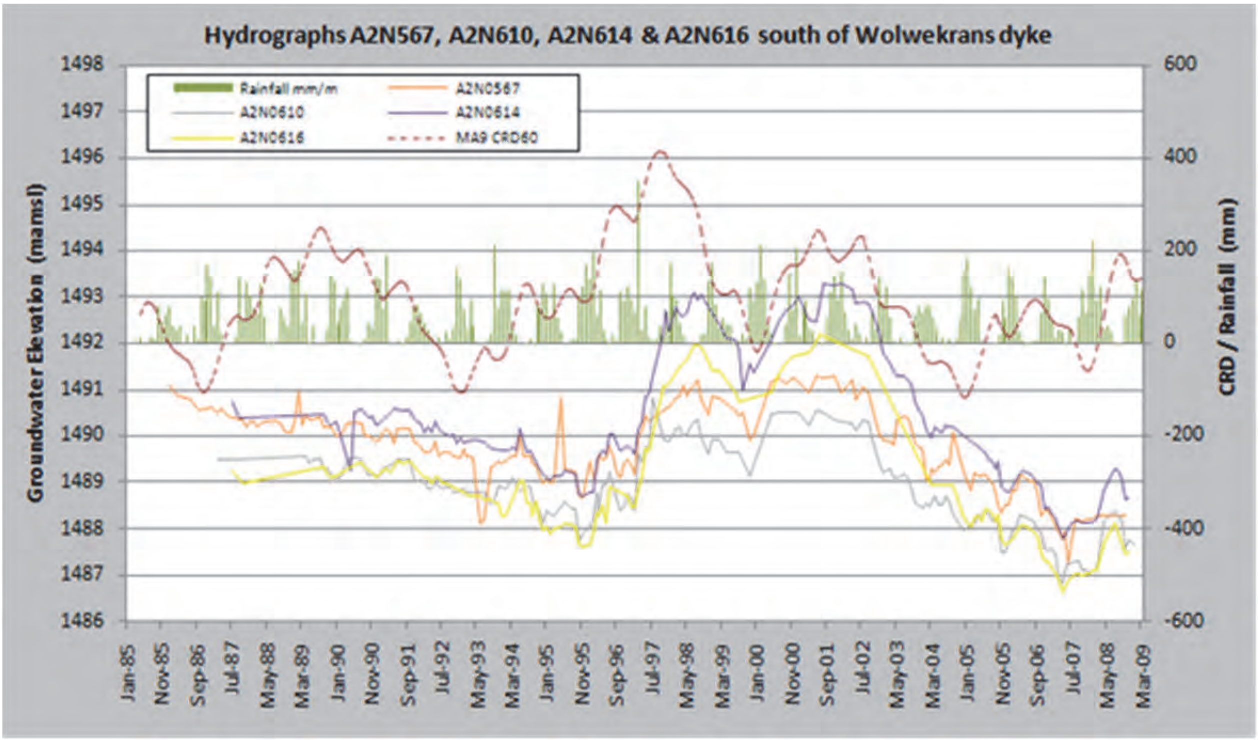


Figure 8.13. Borehole hydrographs for stations south of Wolwekrans dyke.

A good fit between the CRD-graph and groundwater level fluctuations in Figure 8.13 is possible especially between 1996 and 2005; thereafter declining water levels can be attributed to abstraction.

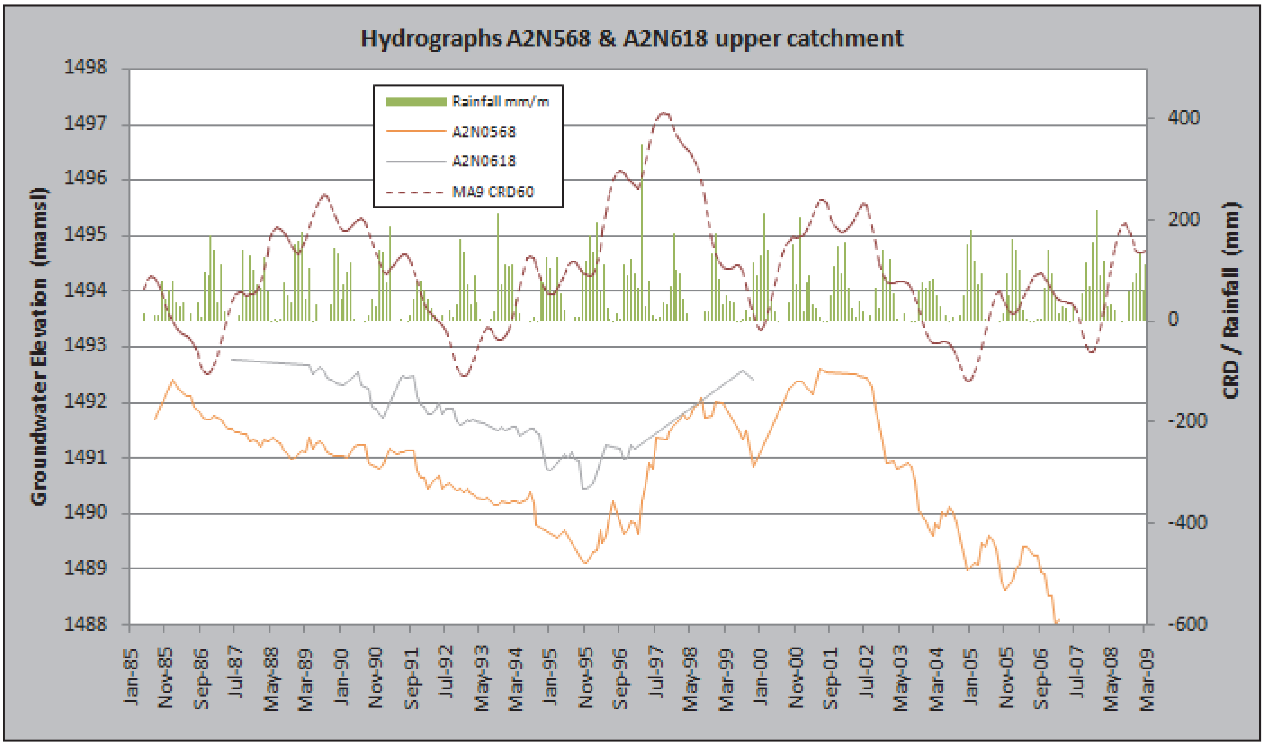


Figure 8.14. Borehole hydrographs for the upper catchment of the Maloney's Eye.

The k-factor component which indicates that pumping or an external impact has affected the water level has not been implemented in the CRD-graph. A slightly greater response (fluctuation) to rainfall is evident in all hydrographs in this resource unit. Similar responses are observed in the most southern dolomitic groundwater unit. Figure 8.14 indicates declining groundwater levels since the onset of monitoring all the way through to the late 1990s. Above average period of rainfall and higher recharge increased groundwater levels back to levels obtained in the early 1980s. However, another period of decline in water levels between 2000 and 2007 could be attributed to increases in abstraction.

The hydrographs presented in Figure 8.15 are from boreholes situated at the eastern boundary of the Maloney's Eye catchment. Based on the CRD-graph a very good correlation exists between rainfall and groundwater level response. It seems that these boreholes are not impacted by large scale abstraction and therefore also not part of the main groundwater system influencing the drainage of the spring directly. This Tarlton north area explained previously can be regarded as a sub-groundwater unit A21F-03(05b) (refer to Figure 8.17).

A summary of the monitoring stations and a correlation with the Maloney's Eye spring is given in Figure 8.16 and Table 8.7. Based on the previous discussions a good relationship between rainfall and groundwater level response was established. Similar relationships are observed with the discharge of the Maloney's Eye and a direct correlation is observed with groundwater levels in this region.

Table 8.7. Summary of borehole hydrograph data.

STATION	A2N0568	A2N0610	A2N0614	A2N0616	A2N0567	A2N0572	A2N0558	A2N0559
Start (monitor)	Aug-85	Mar-87	Jul-87	Jul-87	Jan-86	Jun-86	Jan-86	Jan-86
End (monitor)	Feb-07	Jan-09	Nov-08	Nov-08	Oct-08	Jan-09	Mar-08	Jan-09
Measurements	192	183	168	135	215	215	227	215
Mean (mamsl)	1490.6	1488.8	1490.2	1488.8	1489.8	1489.3	1488.7	1487.4
Min (mamsl)	1487.9	1486.8	1487.8	1486.6	1487.2	1487.7	1487.6	1486.4
Lowest record	Jan-07	Apr-07	Apr-07	Apr-07	Jun-07	Apr-07	Dec-07	Feb-08
Max (mamsl)	1492.6	1490.8	1493.2	1492.1	1491.2	1491	1489.9	1489.5
Fluctuation (m)	4.6	4.0	5.5	5.5	4.0	3.2	2.3	3.1
Mean-Min (m)	2.7	2.0	2.5	2.3	2.6	1.6	1.1	1.0
Environmental critical water level* (mamsl)	1489.5	1487.4	1489.2	1488.2	1489.1	1489.1	1488.2	1487.3
Latest water level (mamsl)	1488.09	1487.78	1488.65	1487.49	1488.26	1488.26	1488.51	1488.64

* – Used in this study to estimate groundwater levels for each station to maintain a flow rate of (6 Mm^3/a) or 0.2 m^3/s. This level has been regarded by some as the Maloney's Eye reserve.

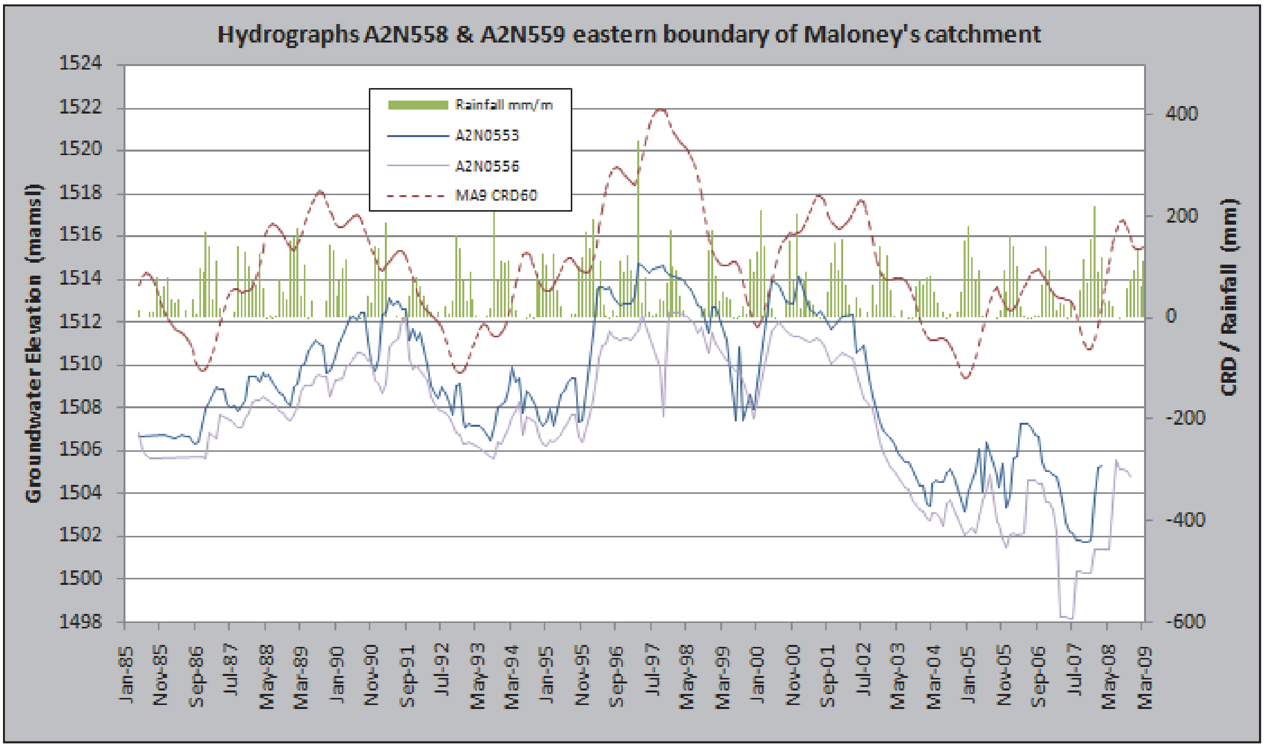


Figure 8.15. Borehole hydrographs of two stations near to the eastern boundary of the Maloney's Eye catchment.

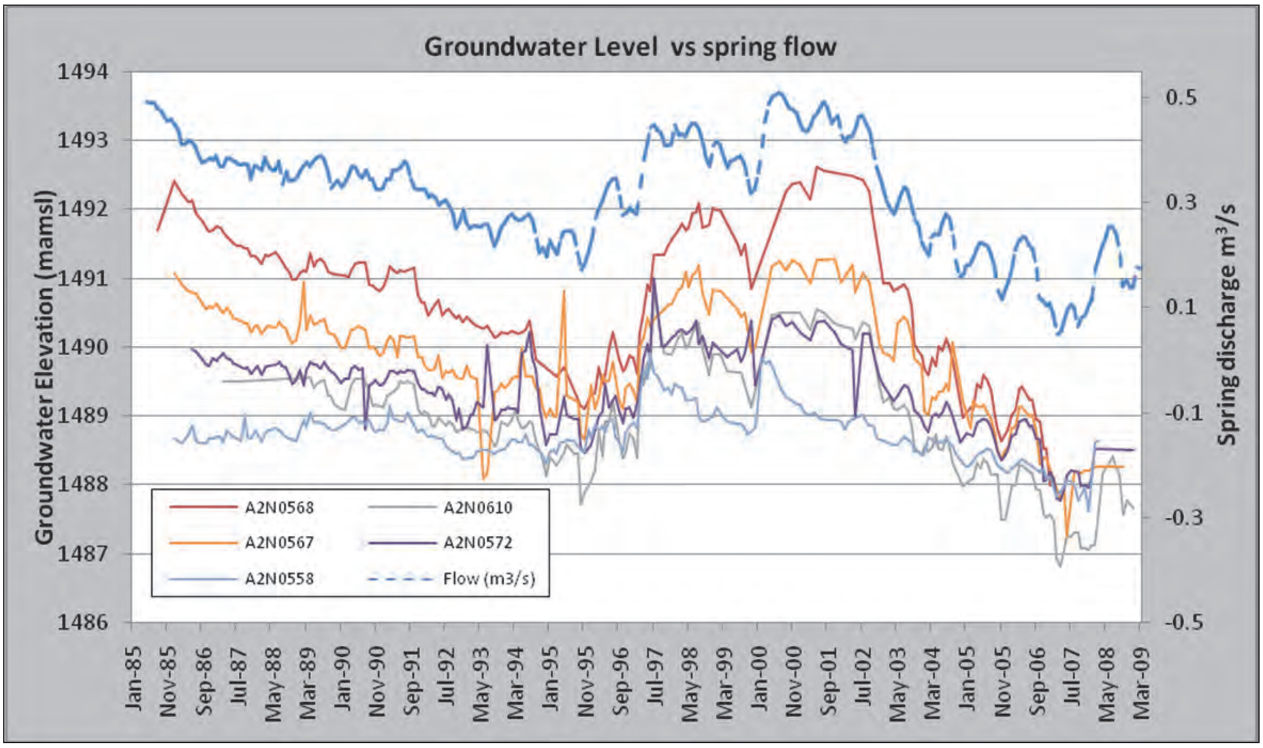


Figure 8.16. Spring flow plot vs. borehole hydrograph for the period 1985 to 2009.

The lowest groundwater levels recorded in the area corresponds closely to the lowest spring flow recorded March 2007 (0.05 m^3/s). Mean groundwater elevation in this area range from 1488 to 1491 m.a.m.s.l. and confirm the flat hydraulic gradient of this system attributed to high transmissivities and low topographic gradients. It is evident that only subtle groundwater fluctuations are necessary for a significant decline in spring discharge (e.g. an 84cm decline in water level in four years for A2N567 relates to a 3 Mm^3/a drop in flow at the spring). The accuracy of water levels measurements within this GMU is therefore critical and the surveying of monitoring stations and the spring discharge points will increase confidence levels of management decisions. This data could be useful for predicting decreases in spring flow based on the amount of groundwater level decline and modeling spring discharges. The speculative critical water level for each monitoring station is provided in Table 8.7. This critical water level can be regarded as the lowest water level to maintain a spring discharge of 6 Mm^3/a (0.2 m^3/s). The base level of the entire system should not decline below 1488.5 m.a.m.s.l. (need to be verified with surveyed collar elevations). The groundwater system directly influencing the spring discharge is depicted in the figure extent below.

8.5.6 Spring Discharge

The direct relationship between rainfall and groundwater level fluctuations in the Maloney's Eye enables the CRD method to be used as a mean to simulate or predict spring flow. A similar approach as described in the previous section was used to produce the CRD graph in the monthly spring flow versus rainfall graph depicted below.

Generally the CRD-graph mimics the spring discharge reasonably well except for the extremely high discharge obtained during the period between 1976 and 1985. Since 1987 a clear discrepancy exists between expected discharges and rainfall and is highlighted in Figure 8.18.

The effect of pumping can be incorporated by the k-factor as explained in equation 8-1. A cumulative plot of rainfall versus spring flow reveals the distinct increase in spring discharges for the period between 1976 and 1985 (Figure 8.19). This can be attributed to a period of successive high rainfall events (refer to Figure 8.5) indicating a cumulative effect on discharge.

This occurrence can be explained by the duality of the recharge process in karst where an early immediate response could be conceived as intake via fissures and fractures, and a late delayed phase which consist of water slowly percolating through soil and rock of lower permeability and greater thickness also known as the "Epikarst" zone.

A simulation of the spring flow was done with the following equation[1]:

Q(discharge) = %Recharge x (Rainfall – average for previous lag months) x Area – Q(abstraction) + Inflow – Outflow. (8-2)

[1] Personal Communication (16 April 2009). Professor Gerrit Van Tonder, Institute for Groundwater Studies, University of the Free State.

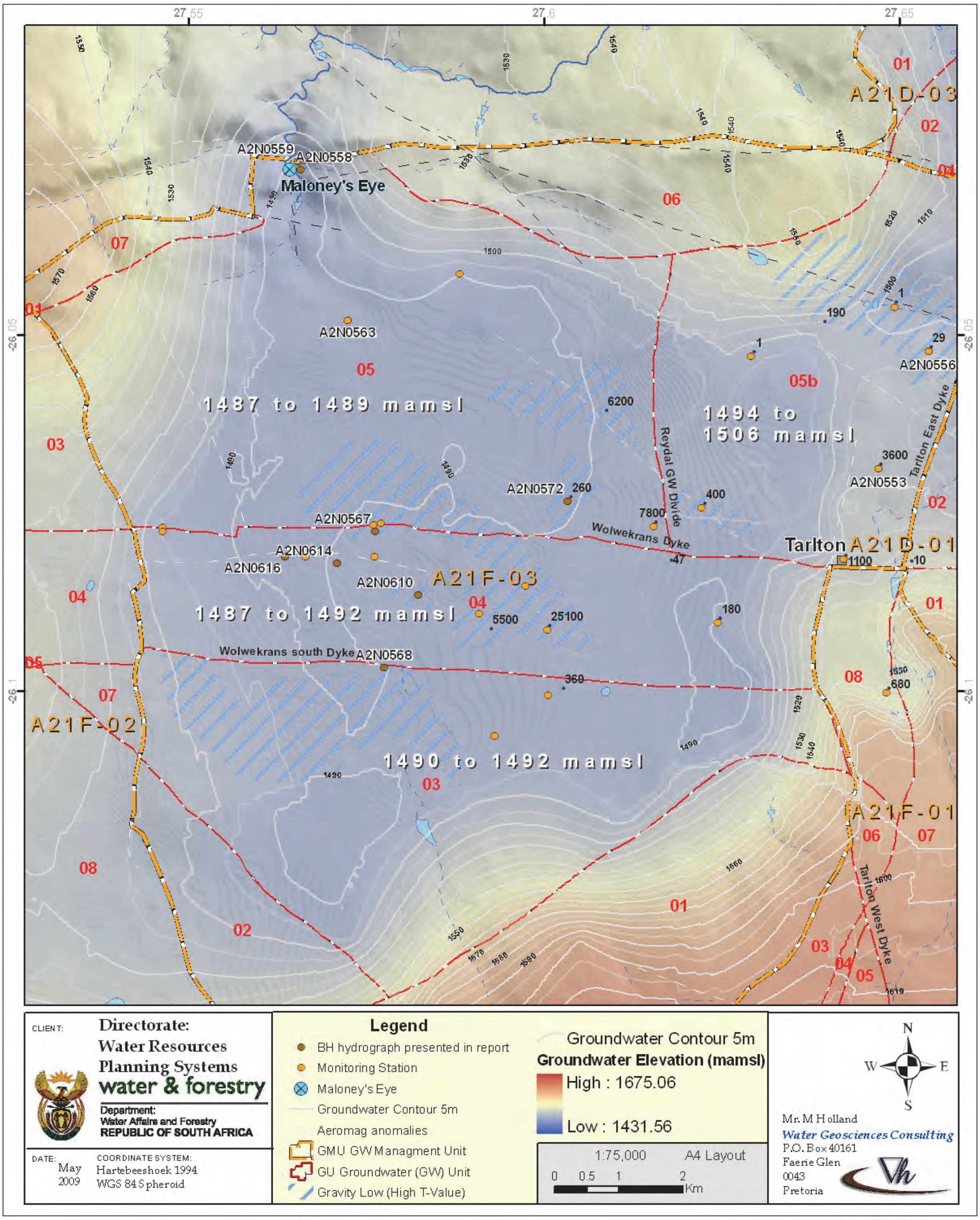


Figure 8.17. Maloney's Eye groundwater system.

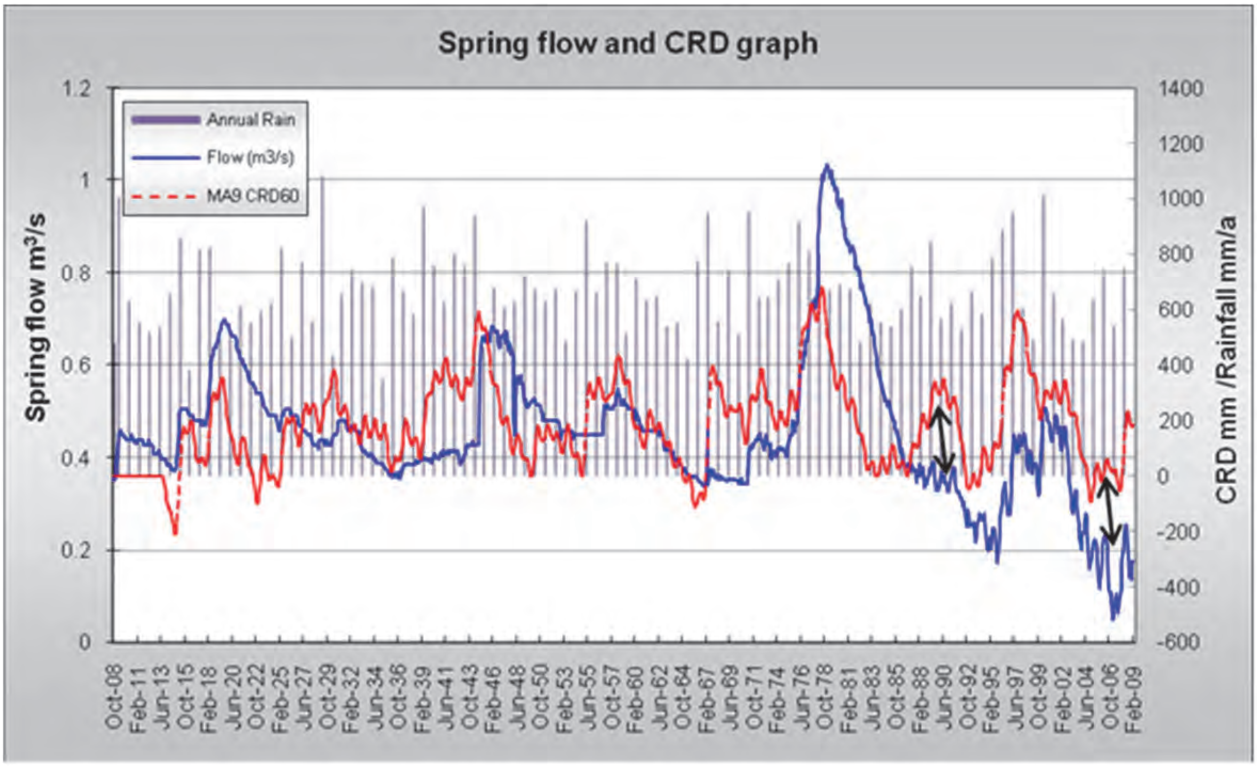


Figure 8.18. Monthly spring flow vs. CRD.

The area used in the simulation was 311 km^2 which can be regarded as the maximum extent of the Maloney's Eye catchment (A21F-03). A recharge value of 7% (best fitted value) was used over this area; however in many scenarios it is impossible to represent the total range with one average recharge value. In such a case a second recharge value could be applied by changing the recharge for a specified period. The period between 1976 and 1985 was simulated with a recharge value of 11%. Assigning higher recharge values for successive wet years are due to saturated soils conditions and the reduced demand by plants and therefore irrigation. The last part of the graph was fitted by assigning a monthly discharge volume to incorporate for pumping. The following abstraction rates were used to fit the latter stages of the discharge model (Figure 8.20).

- 1986 to 2002 – 10 000 m^3/d
- 2002 to 2007 – 15 000 m^3/d
- 2007 to 2009 – 20 000 m^3/d

8.5.7 Geochemical Description

The Zwartkrans compartment plays a major role in the assimilation or carrying of acid mine drainage, sewage effluent return flow and agricultural run-off. Anomalous high concentrations of sulphate, chloride and nitrate detected in this compartment and the extent thereof has been discussed by Holland and Witthüser (2008). Hobbs and Cobbing's (2007) hydrogeological assessment of the acid mine drainage south of the Zwartkrans compartment highlighted the threat of anthropogenic activities on the quality of groundwater. Both these investigations focused on the Zwartkrans compartment. The study by Barnard during 1995 was the most comprehensive groundwater quality study in the Steenkoppies compartment to date. This study emphasised the impact of the Randfontein WWTW effluent return flow on the groundwater quality in the compartment. This study was carried out by combining all groundwater and surface water datasets available for the study area, in addition to the 21 newly sampled locations. The water quality sampling was performed according to SABS/ISO 5667 standards and the samples were analysed in a SANAS accredited laboratory. Field measurements included pH, electrical conductivity (EC) and temperature. The distribution of water quality datasets within the Steenkoppies and Zwartkrans compartments are illustrated in Figure 8.21.

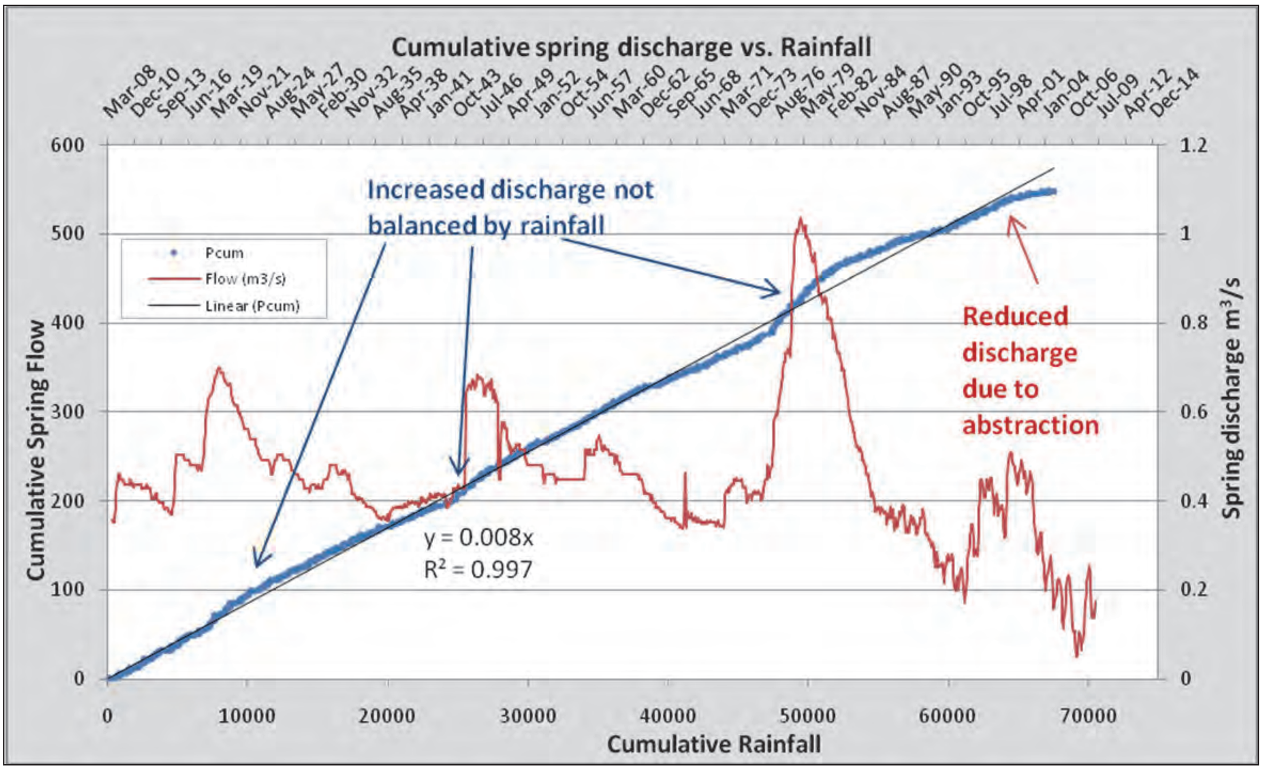


Figure 8.19. Cumulative spring flow vs rainfall plot.

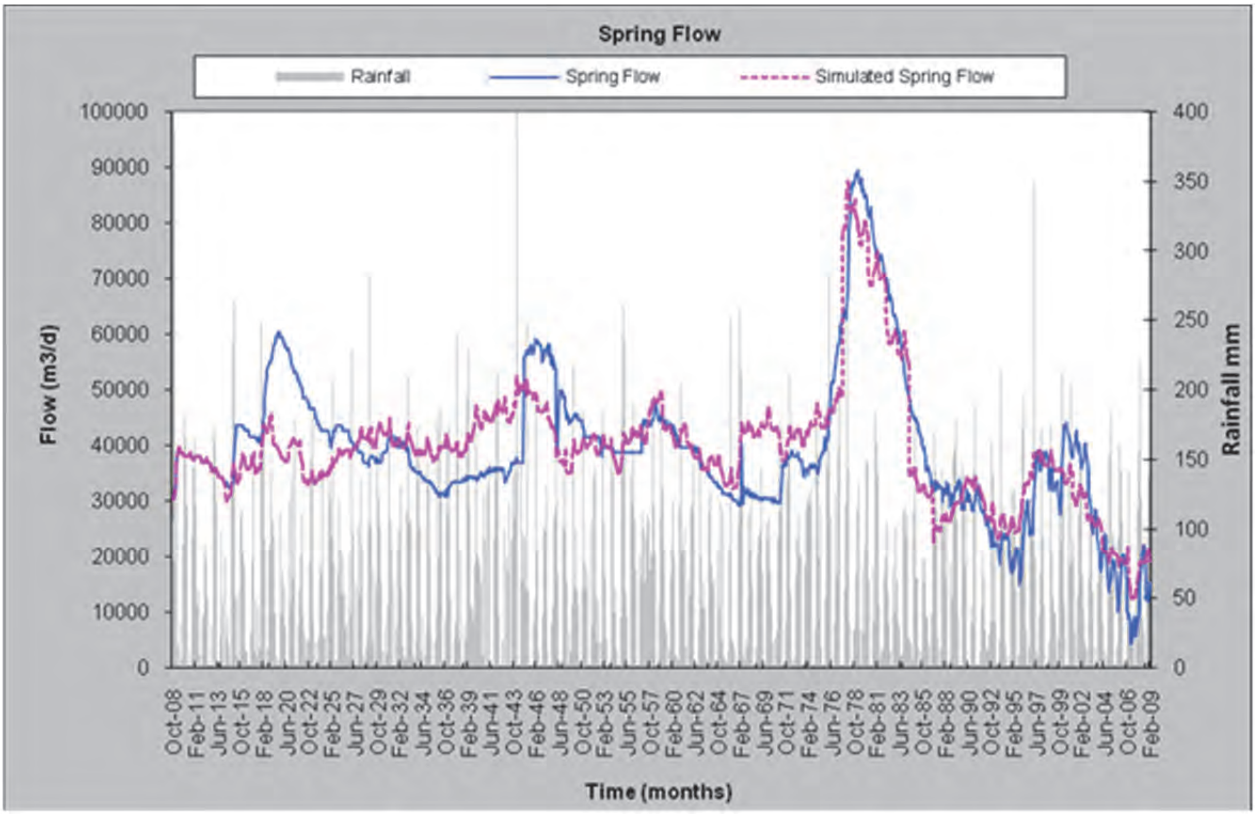


Figure 8.20. Spring discharge vs. simulated discharges.

8.5.7.1 *Water Quality Management system (WQMS) data – Time series data*

Long term water quality data for the Maloney's Eye (station 90163) was obtained from the DWAF. The location of this monitoring station is located at the Maloney's gauging station (A2H010) downstream of the Eye. This is also at the confluence of a stream draining the quartzites ridges towards the west of the Eye (Figure 8.21). The sampling location may have a distinct influence on the chemistry especially if the sample is taken after the confluence of the stream it will contain both a quartzite and dolomite water type signature. Clarification is needed regarding the location of sampling. The quality of surface water entering the upper reaches of the Steenkoppies compartment (station 90171) is mostly determined by the water quality from surface run-off from the quartzite hills of the Witwatersrand Supergroup (Figure 8.21). These station records contain major ions and selected trace elements since 1978. The Rietvlei valley which drains the Randfontein WWTW effluent return flows contains a number of monitoring stations, which monitor typical effluent elements (e.g. Cl, NO_3, PO_4, SO_4, Alkalinity, E. coli and faecal coliforms). These are represented by stations 10965, 101438, 101023 and 101024 on Figure 8.21. A summary of the WQMS datasets are presented in Table 8.8 and a plot of the major anions and cations of the Maloney's Eye versus flow are illustrated in Figure 8.22 and Figure 8.23 (units presented in mmol/L = mg/L/gram formula weight).

Comparing the Brandvlei (90171) sampling stations which can regarded as the recharge are of the Steenkoppies compartment with the discharging Maloney's Eye (90163) sampling station a distinct difference in chemical composition is evident. Samples taken from the Rietspruit indicate the impact of sewage effluent flows on the surface stream with elevated sulphate, chloride, nitrate and bicarbonate values compared to the Brandvlei and Maloney's sampling stations.

As discussed in section 8.4.2.1 the Rietspruit ceases to flow near the Tarlton intersection and it is expected that the entire volume of flow is either abstracted for irrigation purposes along the Rietspruit valley or enters the underground network through leaking river beds or swallow holes. During periods of high rainfall the Rietpsruit does flow into the adjacent Zwartkrans compartment up to a dam wall further downstream. At this location the Rietspruit disappears into the sub-surface and poor quality surface water will impact the groundwater quality of this system.

Table 8.9. Summary information of time series of surface water quality data. Concentration in mg/l.

Sample ID	Nr. of Samples	Ca	Mg	K	Na	Cl	SO_4	NO_3	HCO_3	pH-unit	PO_4-P	E.Coli/ 100 ml	Faecal Coliforms /100 ml
90163	191	26.5	16.3	0.7	2.8	3.3	5.7	1.3	155.3	7.8	0.03	-	-
90171	237	3.1	2.0	0.6	2.6	4.3	5.3	0.6	17.3	6.5	0.03	-	-
101438	21	-	-	-	-	35.4	65.1	9.9	144.2	7.3	1.03	2964.5	4428.7
10965	34	-	-	-	-	63.3	124.4	11.0	220.7	7.4	1.89	473.4	399.9
101023	21	-	-	-	-	65.5	113.8	16.5	289.4	7.4	3.42	39550.9	25806.8
101024	21	-	-	-	-	47.8	76.1	9.9	231.9	7.4	1.96	34657.0	35809.1
SANS Limits		*300*	*100*	*100*	*400*	*600*	*600*	*80*	-	*4-10*	*n/a*	*n/a*	*n/a*

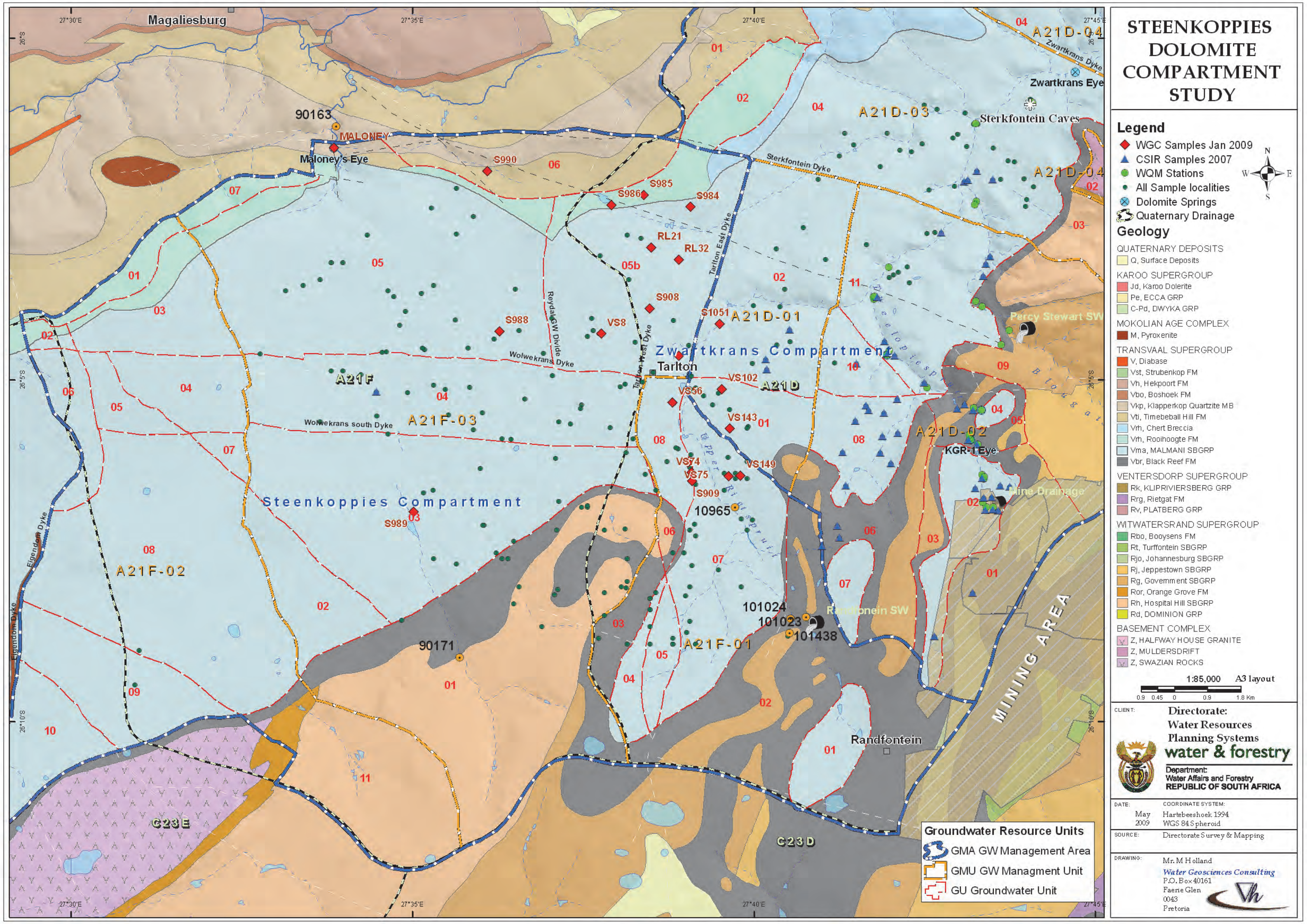


Figure 8.21. Distribution of water quality samples.

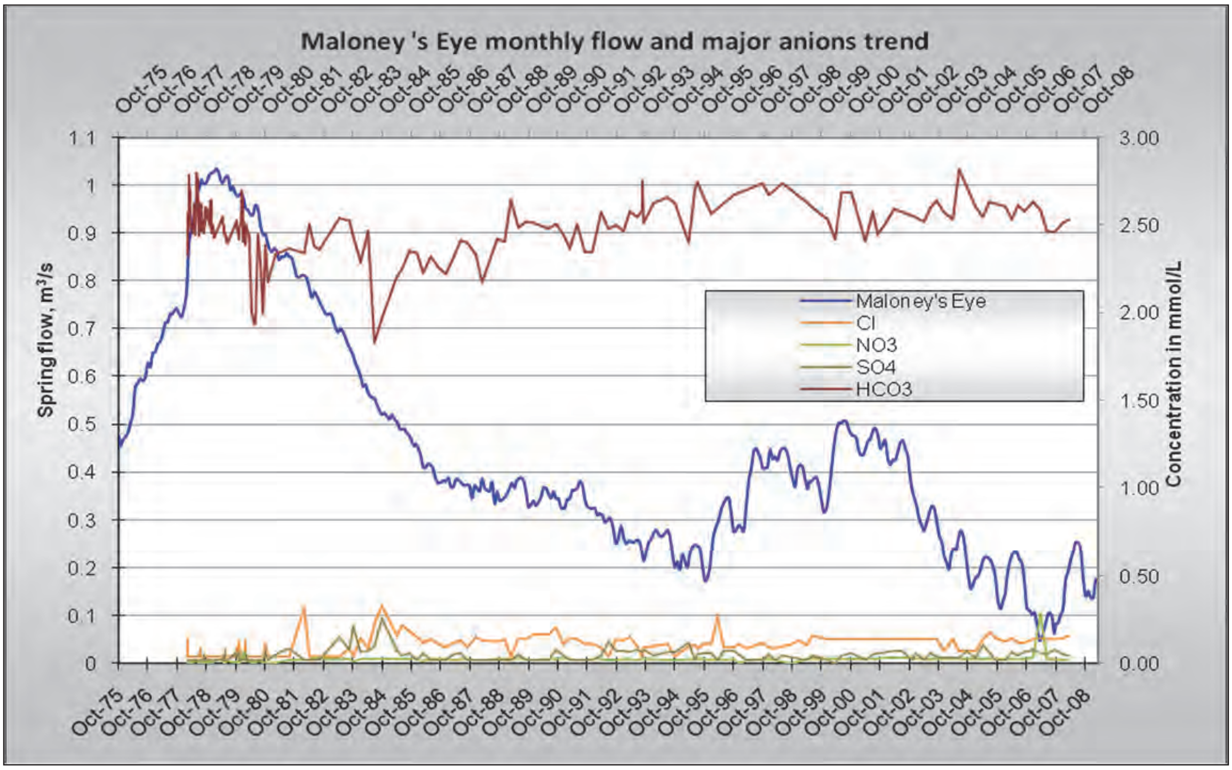


Figure 8.22. Chemical trend of major anions and spring discharge.

8.5.7.2 Spatial distribution of water quality

The distribution maps of selected elements assist in describing the chemistry spatially and determine the extent of pollution sources (Figure 8.24). In anthropogenically impacted environments, pollution sources typically have characteristic chemical signatures with selected element concentrations clearly elevated beyond their natural variability. The major ions with some trace elements based on groundwater management units (GMUs) are depicted in Table 8.9. Groundwater quality has been most impacted by anthropogenic activities in A21D-02. This is mostly attributed to the decanting of polluted groundwater from an abandoned mine area south of the Zwartkrans compartment. This water is treated in a modified old uranium settling plant; however, during periods of high rainfall significant volumes of untreated polluted mine water AMD has entered the Tweelopiespruit in the past. A21D-03 typically shows the distinct elevated chloride signature from the Percy Stewart WWTW effluent return flows. Elevated sodium, sulphate and nitrate levels are also characteristic of this GMU. A21D-01, which is directly east of the Steenkoppies compartment, contains samples with relatively pristine dolomitic signatures, which indicates that neither the mining nor either of the two effluent return flows sources has affected this groundwater unit to a large scale yet. Yet, in contrast A21F-01 shows elevated concentrations of Cl, SO_4 and NO_3, confirming the impact of the Randfontein WWTW on the groundwater system. The sub-unit A21F-03(05b) immediately north of Tarlton (refer to Figure 8.21), shows similar chemical constituents suggesting the flow of groundwater impacted by the Randfontein WWTW effluent discharges into this unit.

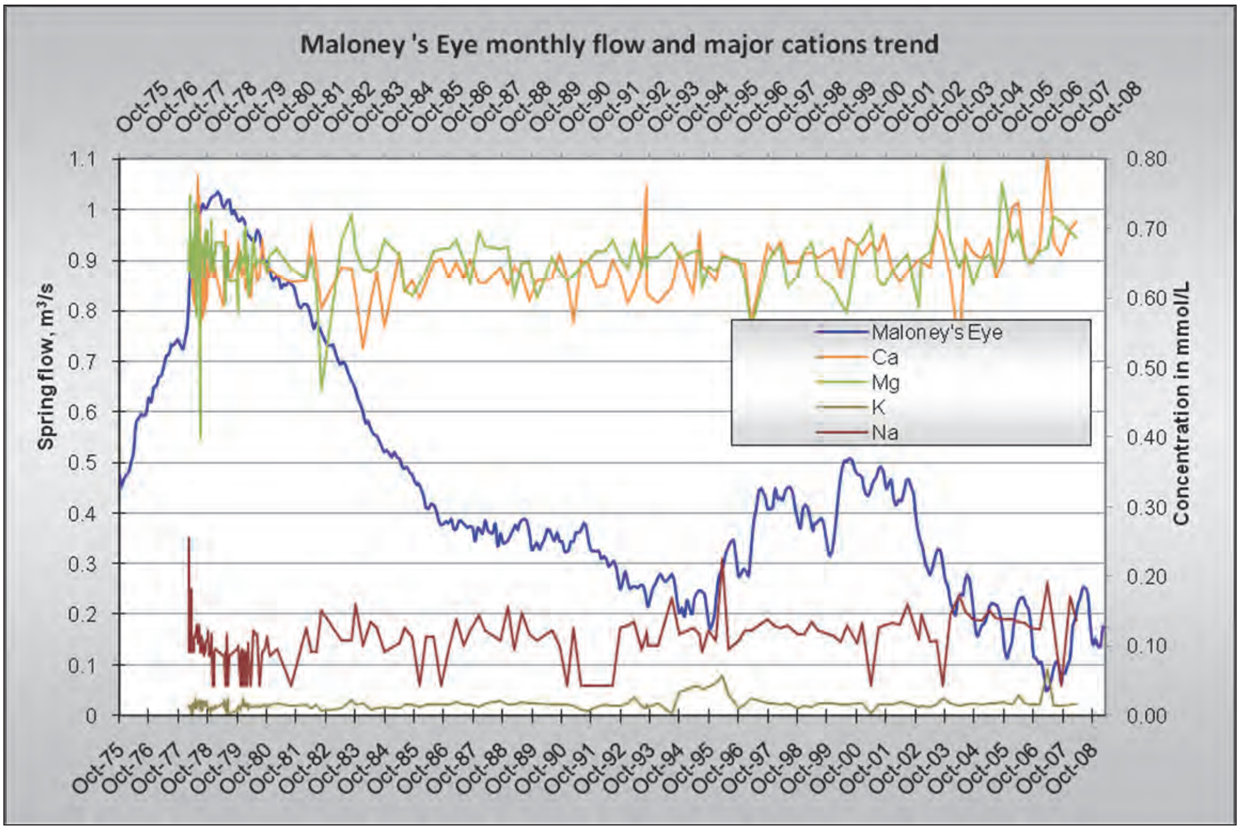


Figure 8.23. Chemical trend of major cations and spring discharge.

8.5.7.3 Hydrochemical Facies

Plotting the chemical dataset on a Piper diagram produces a visual presentation of water types as well as of the variability and trends in the water quality of the samples. Samples collected by the CSIR (Hobbs and Cobbing, 2007) and samples collected during this study are shown in (Figure 8.21). A summary of samples collected is attached in Appendix 8.A and displayed in Figure 8.25. Samples taken during this study focused on the Rietspruit valley and the eastern portion of the Steenkoppies compartment. Water chemistry in the catchment appears to evolve from a Ca–Mg to Na + K cation predominance and from a HCO_3 towards SO_4 or Cl anion predominance. The Ca–Mg–SO_4 facies samples in the upper corner of the diamond are influenced by acid mine drainage and represent the highly mineralized water samples from the mine water decanting source. The samples in the left corner of the diamond (Ca–Mg–HCO_3 facies) represent water not impacted by anthropogenic sources (pristine dolomitic water). Wastewater treatment return flow samples, as well as downstream surface water samples, plot towards the right corner of the diamond (Na–Cl facies).

Table 8.9. Mean water quality of major ions per GMU (Zwartkrans – highlighted blue and Steenkoppies – highlighted grey). EC in mS/m and all other concentrations in mg/l.

DGMU	Nr. of samples	pH	EC	Ca	Mg	K	Na	Cl	SO_4	NO_3	HCO_3	PO_4-P	Fe	Mn	NH_4-N
A21D-01	27	7.4	19.7	18.0	10.6	1.3	6.2	8.2	11.4	3.4	93.6	0.04	0.09	0.02	0.07
A21D-02	49	6.6	**135.9**	141.0	59.0	3.9	50.9	35.3	**784.0**	21.4	76.8	0.37	70.15	22.9	1.64
A21D-03	32	7.6	68.5	57.4	34.0	1.4	34.2	**49.3**	151.6	34.3	143.3	0.13	0.04	0.02	0.09
A21F-01	50	6.5	15.8	9.9	5.8	1.0	11.0	14.4	26.3	5.1	37.3	0.05	0.03	0.03	0.14
A21F-02	2	7.8	46.9	50.5	29.5	2.3	5.0	3.0	5.5	2.5	301.1	0.02			0.10
A21F-03(01)	19	6.1	4.7	3.0	2.3	0.5	2.6	3.1	8.7	0.6	15.8	0.01			0.04
A21F-03(03)	15	6.8	13.9	10.9	7.1	0.8	2.9	2.8	8.1	0.9	51.4	0.15	0.03	0.03	0.06
A21F-03(04)	27	7.1	19.0	17.5	11.0	0.6	5.3	6.5	9.4	1.1	103.7	0.02	0.13	0.01	0.04
A21F-03(05b)	22	7.6	33.0	25.5	17.7	1.2	18.0	20.3	29.4	5.7	128.8	0.02	0.09	0.03	0.21
A21F03-05	28	7.3	23.6	22.4	15.8	0.7	3.0	3.1	6.0	0.9	151.8	0.02	0.03	0.03	0.07

The WGC samples on a more detailed Piper diagram illustrates that the infiltration of large volumes of municipal wastewaters has changed the natural chemistry of the karst aquifer in this area (specifically samples VS75 and S1051). These samples do not show the typical SO_4 anion predominance suggesting that these waters aren't affected by significant AMD drainage.

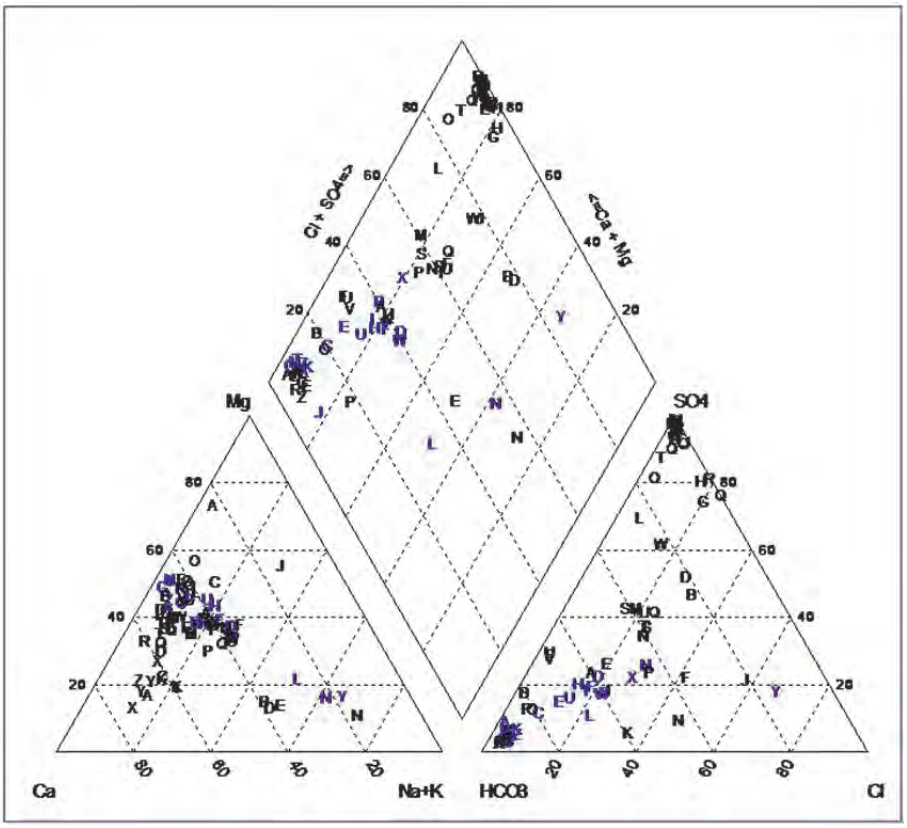


Figure 8.25. Piper diagram presenting the composition of 82 groundwater and surface water samples collected during 2007 and 2009 (WGC samples in blue and CSIR samples in black).

Figure 8.24. Spatial distribution of chloride, nitrate, sulphate and electrical conductivity.

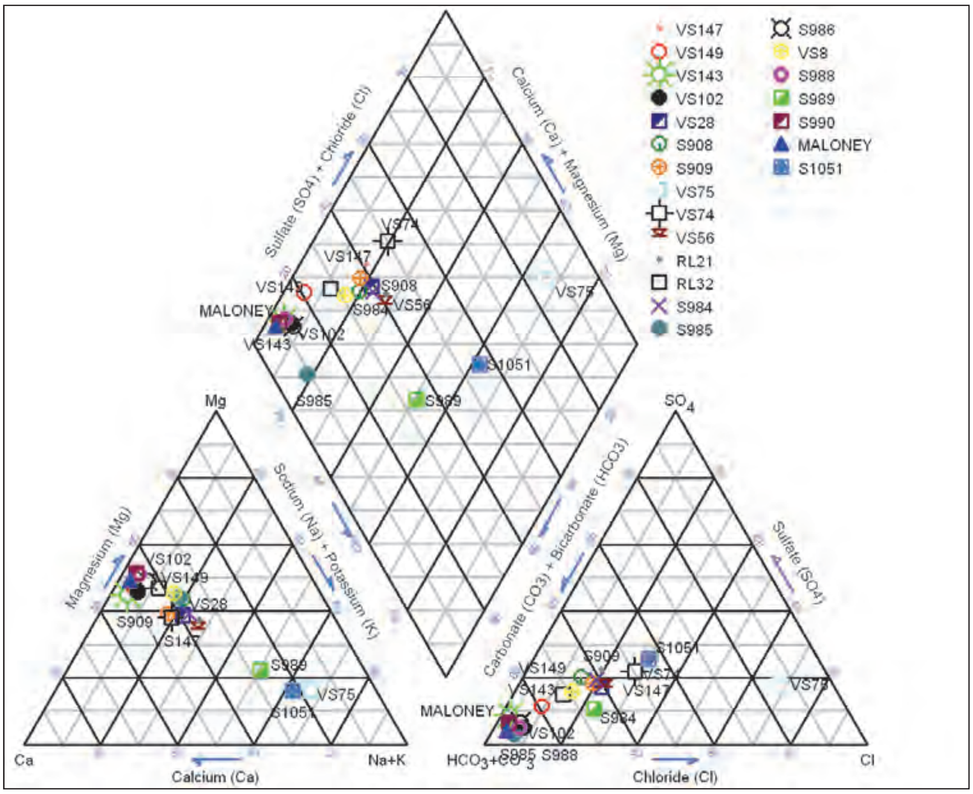


Figure 8.26. Piper diagram of the 21 WGC samples collected during January 2009.

8.5.7.4 *Environmental Isotopes*

The environmental isotopes deuterium (^2H), oxygen-18 (^{18}O) and tritium (^3H) are suitable for tracing the origin of the water in the hydrological cycle because they are constituents of the water molecule (Kranjc, 1997). When $\delta^2 H$ is plotted as a function of $\delta^{18} O$ for water found in continental precipitation, an experimental linear relationship is found that can be described by the equation (Craig, 1961). This is known as the global meteoric water line (GMWL).

$$\delta^2 H = 8\delta^{18} O + 10 \qquad (8\text{-}3)$$

Tritium

Tritium (^3H) is a radioactive isotope of hydrogen having mass 3 and half-life of 12.38 years. In Southern Africa, tritium levels in rainfall rose from initial (natural) values of about 5 TU to 60-80 TU as a result of fall-out of nuclear weapon testing in the early 1960s. Due to this tritium is an ideal isotope to be used for age dating of groundwater that recharged after 1952 (Pannatier *et al*, 2000). According to Weaver *et al*., (1999) tritium studies can provide semi-quantitative age determinations of groundwater:

- Water with zero tritium (<0.5TU) has a pre-1952 age.
- Water with significant tritium concentrations (>5TU in the southern hemisphere) is of post-1952 age.
- Water with little, but measurable, tritium (between 0.5 and 5 TU) seems to be a mixture of pre- and post-1952 water.

Results

Isotope samples were obtained in January 2009 from 19 boreholes, 1 spring (Maloney's Eye), a surface water sample and a rainfall event during 2006 (Figure 8.21). Only 10 samples were selected for tritium analysis. The analytical data are presented in Appendix 8A. The stable isotope data are plotted in Figure 8.27. The δD vs. $\delta^{18}O$ data points are shown relative to the Global Meteoric Water Line (GMWL, Craig, 1961). $\delta^{18}O$ ranges from -5.8‰ to -3.2‰ and δD from -30.6‰ to -15.8‰. The $\delta^{18}O$ and δD values of all samples are remarkably well correlated along an evaporation or mixing line. The long term isotopic data from the Pretoria GNIP (Global Network of Isotopes) station were used to obtain a more localised meteoric water line (PMWL, IAEA, 2004). A deuterium excess of 11.8% was assigned to this line and could hypothetically indicate the initial composition of the evaporated waters.

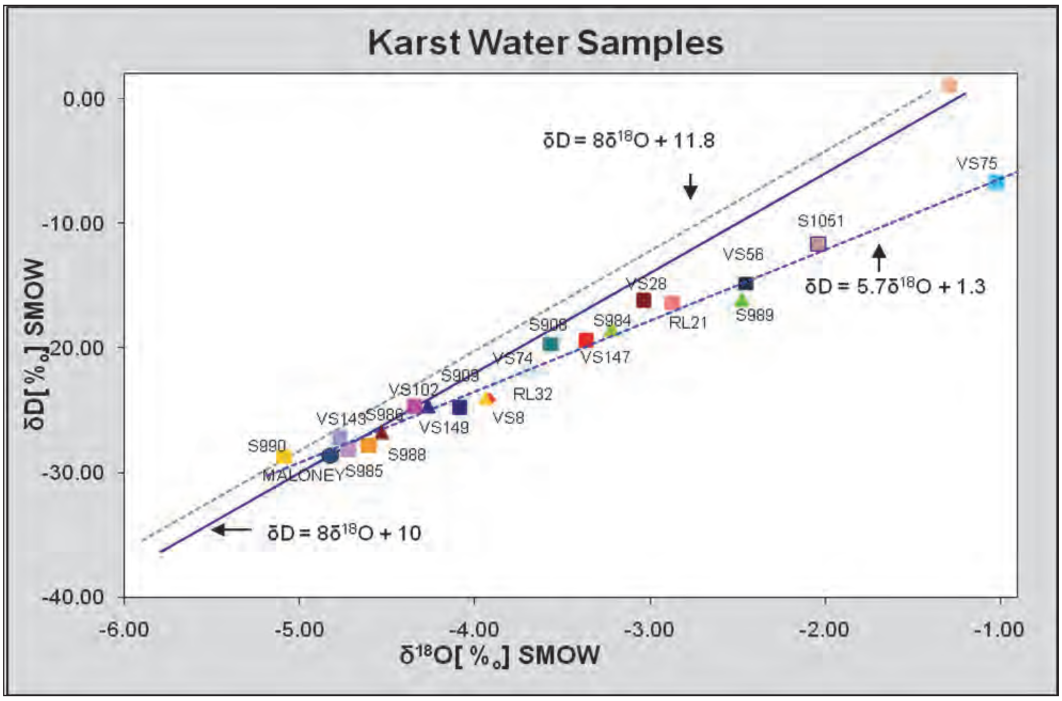


Figure 8.26. δ18O vs. δD of sample set relative to global meteoric water line (GMWL) (Craig, 1961) and long term Pretoria meteoric water line (PMWL).

Samples located in the upper Rietspruit valley (VS 56,VS74, VS147 and VS75), downstream of the Brandvlei gauging station (S989) and the unit directly north of Tarlton (S908, VS8, RL32 and RL21), has developed enrichment in their heavy isotopic content due to significant kinetic (non-equilibrium) evaporation. This can be explained by several mechanisms, one being the recharge of groundwater by surface water. Light isotopes are preferentially transferred to the vapour phase. The resulting surficial layer enriched in the heavily isotope is then readily mixed into the bulk of the water body through connective processes. This evolutionary enrichment produces $\delta^{18}O$ and δD values which lie to the right of the meteoric water line, and plot on an evaporation line of lesser slope and lower deuterium excess than the water meteoric water line. Groundwater derived through infiltration will carry this distinctive isotopic signal and could represent diffuse recharge in the area. All other samples plot on the meteoric water line or to the left of the PWML indicating a depleted isotopic composition, suggesting quick local recharging events typically of karst aquifers (VS149, Maloney and VS149).

The tritium value of the rainwater sample is unusually high at 13.9 *TU*, compared to about 3-4 *TU* normally found in ordinary rain water (Figure 8.28). Such values of between 10 and 14 *TU* are, however, observed occasionally in rain water sampled from the city area of Johannesburg[2]. The origin of these ^{3}H values could be attributed to Pelindaba nuclear technologies situated 30 km NE of the rainwater sample location.

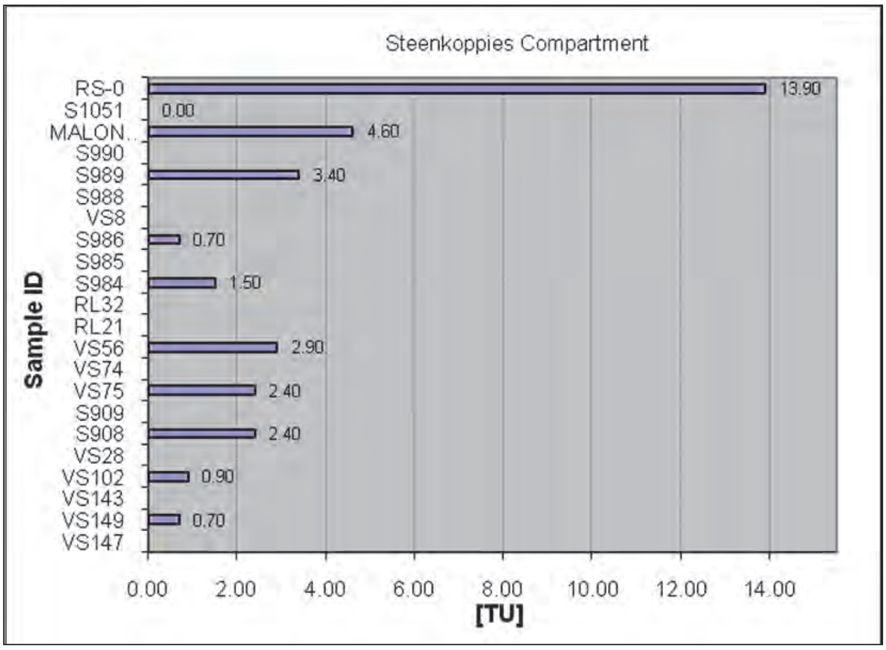


Figure 8.27. Tritium content of dataset in tritium units (TU).

Tritium is a radioactive isotope that follows a well-known law of disintegration. In this study three samples (Maloney's and S989) are set of from the rest of the samples which has values of around 3 *TU* indicating recent recharge and relatively fast percolation. Waters that originated from rainfall prior to nuclear-bomb testing would have maximum ^{3}H concentrations of 0.2 to 0.8 *TU* by the early 1990s. Samples with tritium values lower than 2 would account for residence times in order of several decades.

8.6 Water resource evaluation

8.6.1 Groundwater Use

The exact time period when large scale groundwater abstraction commenced is unclear, although according to the biggest commercial farmers in the Tarlton area irrigation started about 35 years ago. No readily available groundwater abstraction data is available for the area. Two borehole surveys conducted by Bredenkamp et al. (1986) and Barnard (1997) are perhaps the earliest indication of the volume of groundwater abstracted for irrigation purposes. Other indications of groundwater use can be obtained in the Water User Authorisation and Management system (WARMS). This system contains information on water users which are registered with the DWAF.

A recent water use verification project conducted by Schoeman & Associates on behalf of the DWAF aimed to determine existing lawful water use in the area prior to 1998 and was also used as an indication of current groundwater use in the area. Although some farmers have been

[2] Horstmann, U. (11 July 2007). Personal communication. Ithemba Laboratories, Johannesburg.

consulted in the process, the assessment of existing lawful use prior to 1998 required the interpretation of satellite images of this era[3]. The data was therefore produced by interpreting surface areas under irrigation and the respective types of crop irrigated. The two estimated water use datasets were produced for 1998 and 2004 with further verification and capturing of information during 2008/2009. The preliminary validation data has been forwarded to the farmers. Figure 8.29 indicates the distribution of pivots delineated by Schoeman & Associates as well as the registered water users (A more detailed groundwater management map is available as an A1 copy in the original report of Holland, 2011). The 21 Tarlton farmers who are in the process of forming a mini "water users association" (to be called the Steenkoppies Aquifer Management Association) are presented in a separate table (Table 8.10). All other registered water users within the Steenkoppies compartment are presented in Table 8.11.

Table 8.10. Summary of water use for irrigation by the 21 Tarlton Farmers (WARMS 2007).

Water User	Type of Crops	Irrigation History (Years)	Irrigation Area (Ha)	Water Volume registered (m^3/a)
A & J FARMS[#]	Vegetables	30	300	-
A.E.F. FERNANDES	Vegetables	32	56	253,125 (Zwartkrans)
CH BOUWER (Boerdery)	Vegetables, Grass, Lucerne etc.	21	5	22,918
CHADINHA BROTHERS FARMS	Potatoes, Lucerne, Maize	31	192	729,528
COPROSMA NURSERIES	Flowers, Instant Lawn	11+	34	62,478 (Zwartkrans)
DENNY MUSHROOMS*	Mushrooms	18	4	-
ETHADA BOERDERY*	Maize, Radish	30	58	-
F SUTIL	Vegetables	28	70	160,470
FLAMINGO FLOWERS	Flowers	25+	22	334,853
GREENACRES ORGANIC GROWERS	Organic Vegetables	7+	15	43,200
GREENWAY FARM PROPERTY	Carrots	19	750	1,114,880
HIGHVELD TURF[#]	Instant Lawn	30+	4	-
INTUITIONS QUALITY FLOWERS	Flowers	11+	15	147,150
J GROOT	Vegetables	22	95	851,030
KOPPENOL FAMILY TRUST	Vegetables	26	234	1,477,500
LIJANI TRUST	Vegetables, Dry land & Cattle	18	210	2,594,933
LILLY VALLEY	Flowers	18+	40	218,400
MAROLIEN BOERDERY[#]	Fresh Herbs	19	15	-
ROSALY BOERDERY	Vegetables, Dry land & Cattle	21+	362	1,487,250
SUN VALLEY AFRICA FLOWERS	Flowers	25	109	916,202
SUNPLANT	Flowers	8	2	26,000
TOTAL:			**2,592**	**9,457,264**

* – Are in the process of registration.

[#] – Could not locate in WARMS.

[3] Personal Communication (14 April 2009). Mr. Francois Joubert of Schoeman & Associates.

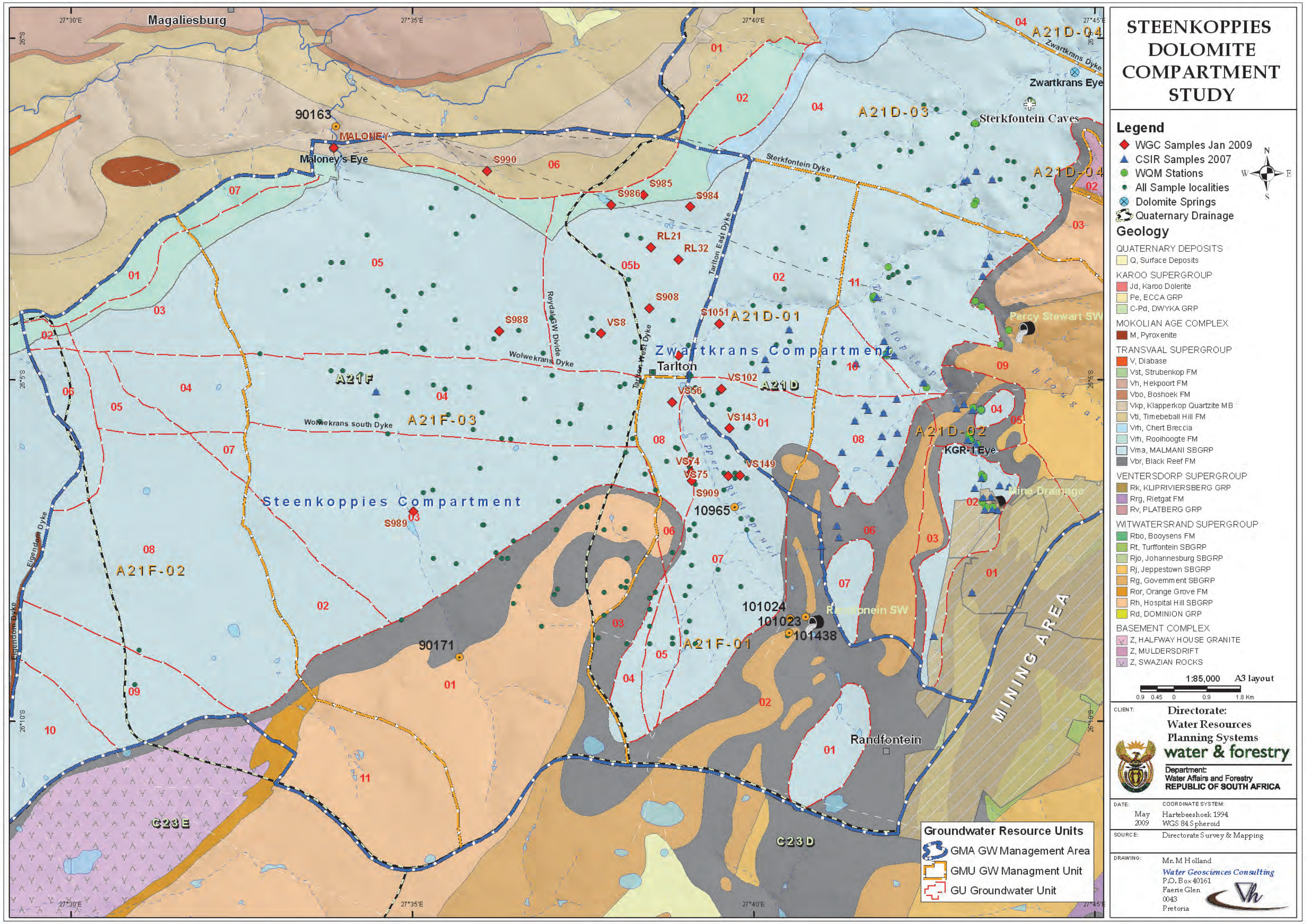


Figure 8.29. Locality of irrigation fields and pivots as well as registered water users (from Holland, 2011 sourced from Schoeman & Associates and WARMS).

Table 8.11. Summary of water users in the three delineated GMUs of Steenkoppies compartment (WARMS 2007).

GMU	Area Km^2	Register Water Users	Water Volume registered (m^3/a)	
			Surface water	Groundwater
A21F-01	58	22	1120981	2,735,003
A21F-02	85	9	-	2,907,428
A21F-03	168	40+	-	10,596,751
Sub-Total:	**311**			**16,239,182**
*Tarlton Farmers**		*21*		*9,141,661#*
TOTAL:			**1,120,981**	**25,380,843**

* Tarlton Farmers were listed separate in the preceding table and were listed separate from the other registered users.
# Excluding the Zwartkrans Compartment Farmers within Table 4.1.

A summary of the estimated water use from the Steenkoppies compartment based on the above mentioned sources is provided in **Error! Reference source not found.**. Based on this information it seems that the value obtained (34.9 Mm^3/a) from Schoeman & Associates during 1998, may be an over estimation of water use in the area comparing to Barnard's 1995 volume of only 20.7 Mm^3/a.

Table 8.12. Estimated groundwater use from the Steenkoppies compartment (Values in Mm3/a).

	Bredenkamp *et al.*	Barnard	WARMS	Schoeman & Associates	
Year	1986	1997	2007	1998	2004
Irrigation	13.5	19.0			
Households	3.9	1.7			
Total	**17.4**	**20.7**	**25.4**	**34.9**	**33.6**

8.6.2 Water Balance Information

The collated information during this investigation was used to develop a water balance for the Steenkoppies compartment. The total catchment area of the Maloney's Eye as delineated in section 3.3 is 311 km^2, which includes both the dolomite and, the quartzites and shales of the Pretoria Group and Witwatersrand Supergroup. Reasonable groundwater recharge estimates exist in the available literature and are summarised in Table 8.13.

Inflows into the compartment can be attributed to the following components:

- the artificial recharge component (Randfontein WWTW),
- irrigation return flows (agricultural run-off),
- and the surface water drainage system of the Brandvlei stream.

Outflows are mainly due to:

- artificial abstractions,
- and the natural discharging Maloney's Eye.

The water balance derived for the Steenkoppies compartment based on the 2008 hydrological year (Oct-07 to Sep-08) is summarised in Table 8.14. Average annual rainfall in this year amounts to 859 mm. Scenario 1 uses a recharge value of 11% for dolomite and groundwater use is based on registered WARMS users. Scenario 2 uses a recharge value of 13.1% on dolomite and based and groundwater use based on the preliminary water use validation data by Schoemann & Associates (2004). The percentage of irrigation return flows recharging the groundwater is estimated at 20% of the abstraction.

Table 8.13. Recharge estimations based on previous reports for Zwartkrans and Steenkoppies compartments (Rainfall = 670 mm/a).

Method	Recharge (mm/a)	Recharge %
Soil information	93.8	14.2%
Geology	58.9	8.9%
Vegter's Recharge Map (1995)	95	14.4%
Harvest Potential Map	69.5	10.5%
Specialist report: Bredenkamp et al. (1986)	99-120 (rainfall – 660 mm)	15-21%
Barnard, 1995*	105	15-17%
Holland (2007) (CRD-method and CMB)	113.6	17.2%
Average	89.3	13.1%

* – Barnard (1997) used recharge figures of 10% on dolomite and 6.5% on quartzites and shales in his groundwater model.

Table 8.14. Steenkoppies compartment water balance (Values in Mm^3/a).

Description	Scenario 1 (Low Recharge/WARMS Abstraction)			Scenario 2 (High Recharge/Schoemann Associates Abstraction)		
	Inflows	Outflows	Balance	Inflows	Outflows	Balance
			RECHARGE (Mm^3/a)			
Dolomite	20.19			24.05		
Pretoria	0.81			0.81		
Wits	4.63			4.63		
Sub-total	**25.63**			**29.49**		
			INFLOWS/OUTFLOWS (Mm^3/a)			
Brandvlei run-off	0.12			0.12		
R WWTW-Irrigation	2.61			2.61		
R WWTW-Rietspruit	0.52			0.52		
Maloney's		5.61			5.61	
Abstraction		25.40			33.58	
Abstraction returns	5.14			6.72		
Sub-total	**8.40**	**31.31**		**9.97**	**39.20**	
Balance TOTAL (M^3m/a)	**34.03**	**31.31**	**+2.72**	**39.47**	**39.20**	**+0.27**
Return flow component	9.2%			7.9%		

The Randfontein WWTW effluent return flow makes up 10% of the total inflows into the system if the entire component (see section 8.4.2.1) enters the groundwater system. Based on the information obtained from the Randfontein municipality only half of this volume is discharged into the Rietspruit and the other half is used for irrigation. Barnard (1997) noted the lack of effluent discharge monitoring from the Randfontein WWTW but nevertheless estimated the volume of effluent discharge data at 5.9 Mm^3/a for 1994. It was also stated that the Randfontein WWTW discharged 2.6 Mm^3/a in 1984, which corresponds more closely to current discharge rates. It is unclear how much was discharged into the Upper Rietspruit and how much was used for irrigation purposes. In this study, no evidence suggest that an increase in artificial recharge lead to an increase in water levels, an increase in spring flow nor an increase in chemical concentrations of the spring, during this period (refer to section 8.5.5.2 and 8.5.7.1). Therefore, if additional artificial inflows did occur, it might have much less of an impact on the system than expected. On the other hand, these alleged increased artificial inflows also occurred when abstraction did have a definitive influence on water levels and spring discharge consequently impulses of additional inflows might have been masked.

8.6.3 Conceptual Model

To illustrate the conceptualization, a section was drawn from south to north crossing the Steenkoppies dolomite compartment (Figure 8.30). The Maloney's Eye is situated at the intersection of the Maloney's Eye dyke and the east-west striking fault zone. Based on the digital elevation model the surface discharge site of the Eye is above the groundwater level of the dolomite drainage area. The Eye is situated within the shales/quartzites of the Rooihoogte/Timeball Hill Formations; therefore the existence of the Eye could be attributed to a dyke of low permeability and the cross cutting of the fault zone representing the main water conduit from the dolomite into the shales and quartzites.

The recharge area of the spring is expected to include the quartzites and shales of the Witwatersrand Group which extends further south than the Steenkoppies dolomites. Significant inflows from other sources (e.g. effluent return flows) and surface drainages (e.g. Brandvlei) forms the allergenic recharge component of the Steenkoppies compartment. Within A21F02 (Steenkoppies compartment) the Wolwekrans dyke and the Wolwekrans south dyke show little difference in water elevation and based on the high transmissivities identified through pumping tests and gravity lows it is expected that these dykes are fairly impermeable. Therefore large scale abstractions in groundwater unit (A21F02(03)) will also impact on the Maloney's Eye discharge due to the flat hydraulic gradient and interdependent groundwater units.

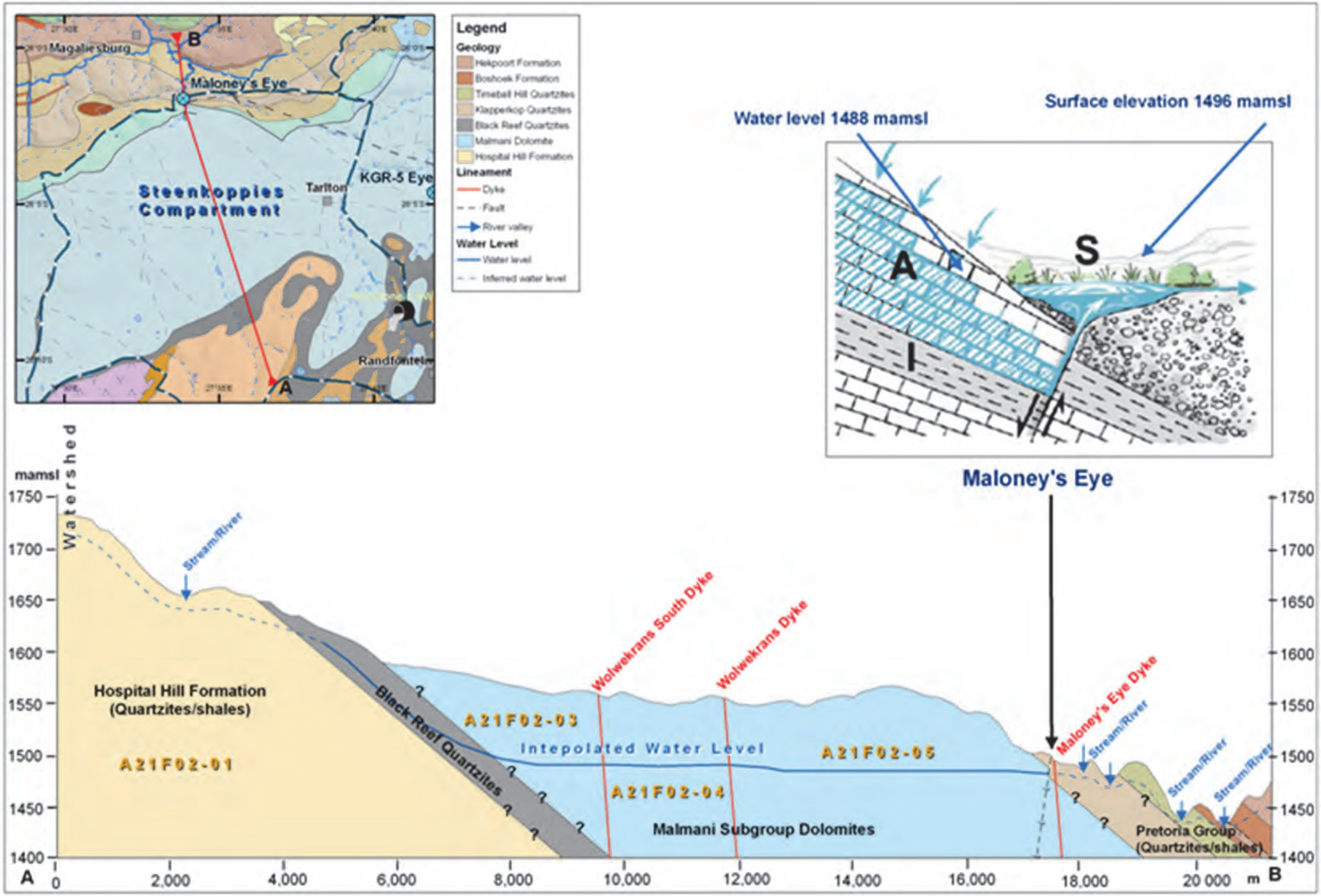


Figure 8.30. Conceptual model of the Maloney's Eye based on a south-north cross section.

8.7 Aquifer management

8.7.1 Background

Until the 1998 Water Act (DWAF, 1998) groundwater use was governed by the provisions of the 1956 Water Act. Groundwater abstraction appears to have grown steadily through the 1980s and 1990s, both in terms of volume and the number of boreholes. In 1994, following low flows in the Magalies River, DWAF ordered that abstraction of water from the Magalies River cease for an interim period, pending review of water allocations from the river. In 1997 a hydrogeological report concentrating on the Steenkoppies compartment was completed under the auspices of DWAF (Barnard, 1997). In September 2004 a group of concerned water users downstream of the Maloney's Eye formed the Magalies River Crisis Committee (MRCC) to “Address the problems associated with the flow of the [Magalies] River and to engage DWAF in seeking a solution to the problem and in following up on the promises that had been made”. In December 2004 DWAF issued a series of directives aimed at stopping unlawful water use in the Steenkoppies Compartment. In 2007 the MRCC was reconvened, and made a submission to the South African Presidency regarding the low flows at Maloney's Eye and the possible impact on the Magalies River, seeking amongst other things a temporary cessation of all groundwater abstractions from the Steenkoppies Compartment to allow the flow at the eye to recover (MRCC, 2007). The submission also emphasised the risk of sinkholes forming as a consequence of declining water levels in the compartment. Essentially, the 2007 submission by the MRCC states that the primary cause of low flows at Maloney's Eye is irrigation using groundwater by farmers in the Steenkoppies compartment, and that such irrigation needs to stop or be drastically reduced.

The 2007 submission by the MRCC to the Presidency led to a response by 21 groundwater users (the “Tarlton farmers”) in the Steenkoppies Compartment in the form of a submission to the Director-General of DWAF, dated November 2007 (Tarlton, 2007). The Tarlton farmers dispute that irrigation is to blame for the low flows at Maloney's Eye, although they agree that water resources in the greater Magalies area are under stress. They state that “No credible evidence has been put forward to show that the water difficulties in the Tarlton and Magalies River area is attributable to the existing lawful use of water by the Tarlton Farmers” (Tarlton, 2007). The Tarlton farmers therefore dispute the restrictions on groundwater irrigation contained in the DWAF directive of 2004. The Tarlton farmers commissioned and paid for a groundwater study by the environmental consultancy ERM (Pty) Ltd which supports their views (ERM, 2007). In particular, the ERM report states that changing rainfall patterns, changing sewage inputs to the compartment, changing water uses downstream of Maloney's Eye, alien vegetation along the banks of the Magalies River, mining activities and other factors are also to blame for the decline in flow at the eye and in the Magalies River (ERM, 2007). The study done by Barnard in 1997 estimated a catchment size (177 km^2) and a water balance for the Steenkoppies area (Barnard, 1997). The ERM report states that the catchment is in fact likely to be considerably larger (about 500 km^2) than stated by Barnard, based on geochemical evidence. The ERM report does however state that aquifer management needs to be instituted, and that a detailed hydrogeological study needs to be carried out.

In 2008 DWAF published a notice in the Government Gazette of 14 March 2008 restricting the use of irrigation water in the compartment to certain days and times, and dependent on the volume of flow at Maloney's Eye. When flows at the eye are less than 93 L/s, then all abstractions apart from Schedule 1 use are prohibited. The notice also called for the details of all irrigators to be submitted to DWAF within 21 days of publication of the notice.

The value of agricultural activities in the greater Tarlton area is very large, both in terms of money flowing into the area and in terms of employment. The Tarlton Farmers estimate that the activities are worth more than three quarters of a billion rand and employ 3500 people directly, as well as supporting large numbers of people and economic activities indirectly (Tarlton, 2007). Obviously any major reduction in farming activities could have severe economic and social consequences for the area.

In 2007 the Tarlton farmers started negotiations aimed at the establishment of a Water User Association (WUA) for the area, to be known as the Steenkoppies Aquifer Management Association, with the assistance of the Danish government aid organization DANIDA. The WUA is essentially aimed at furthering the joint interests of users of groundwater from the Steenkoppies Compartment, and a draft constitution for the WUA has been prepared.

A Water User Association (WUA) is "A statutory body established by the Minister of Water Affairs and Forestry under the National Water Act". A WUA is a co-operative association of individual water users who wish to undertake water-related activities for their mutual benefit." (DWAF, undated). A WUA enables water users to pool resources to "more effectively carry out water related activities" (DWAF, undated). A WUA is governed by the National Water Act (DWAF, 2008). It is regarded in law as a body corporate, and can borrow money, open bank accounts and enter into legal proceedings. WUAs may represent one sector (e.g. irrigating farmers promoting coordinated development of a resource), or many sectors (e.g. farmers, miners and forestry sharing a resource). The Minister of Water Affairs must establish a WUA, once he or she is satisfied that it is in the public interest and that wide public consultation has taken place. WUAs are generally funded through charges to their members, although in certain circumstances the state may assist with funding. Former subterranean water control boards are required to become WUAs, and this process must incorporate a measure of transformation in terms of management structure (DWAF, 2004). The final powers and functions of the WUA, once established, are delegated by the Minister, who may also remove functions and even dissolve the WUA under certain circumstances. The advantages of a WUA to the Tarlton irrigation farmers would include better control of joint finances and jointly owned equipment, simpler and more effective negotiation with regulators and other stakeholders, and the acknowledgement and consolidation by members and others of joint interests. A WUA would also provide a forum for discussion, and allow decisions to be jointly made and communicated.

Figure 8.31. Description of the Water User Association concept formulated in the Water Act.

8.7.2 Summary for management purposes

In summary, this study makes the following technical observations which are relevant to the management of the Steenkoppies Aquifer:

1. The flow at Maloney's Eye has indeed declined in recent years, to well below the long-term average.
2. The flow at Maloney's Eye correlates very well with rainfall over most of the record length. In the last fifteen or so years, the flow has declined further than rainfall records would suggest, (i.e. the flow and rainfall cumulative averages have diverged).

3. The water level data from boreholes in the area under irrigation show a clear correlation between water level in the compartment, and flow at the Eye.
4. Groundwater levels in the compartment have declined in recent years, to levels below what would be expected from rainfall decreases alone.
5. The response in groundwater levels and flow at the eye to extreme rainfall events is rapid (days or less) with a slight delay for average rainfall periods.
6. The area of aquifer as estimated by Barnard (1997) seems to be more or less correct (i.e. in the region of 177 km^2). There is little evidence to suggest that the groundwater catchment for Maloney's Eye extends far into the shales and quartzites to the north of the eye. There is a clear topographic decline from the eye towards the north, implying that groundwater in this area would move towards the north, not towards the eye. The shales immediately to the north of the eye are likely to form a groundwater barrier in any case. The hydraulic properties of the dolomite beneath the shales and quartzites are likely to be poor, with very little groundwater flow and storage.
7. Irrigation abstractions are likely to be a major cause of flows at Maloney's Eye being lower than would be expected due to rainfall variation alone. Other issues such as the variability in sewage inputs will play a part, but they cannot on their own explain the full extent of the declines in flow at the eye.

8.7.3 Proposed management interventions

This study makes the following observations with regard to management actions for the Steenkoppies compartment. These observations are based on available data, which is limited in some areas. However, it is considered that there is enough data to make certain fundamental recommendations.

1. Accurate estimates for **current irrigation abstraction amounts in the Steenkoppies compartment need to be made**, and the issue of abstraction licensing needs to be resolved. (This issue is addressed in the DWAF 2008 notice.)
2. A full inventory of all irrigation boreholes in the compartment needs to be made. This is linked to the licensing issue. (This issue is addressed in the DWAF 2008 notice.)
3. The decline in groundwater level monitoring infrastructure in the compartment needs to be reversed. If necessary new boreholes need to be drilled. **Several existing boreholes and the Maloney's discharge point need to be accurately surveyed** to determine absolute elevations above a common datum. Monitoring of groundwater levels is the basis for continued groundwater management in the compartment, and the "fine-tuning" of management interventions.
4. **Improved rainfall measurements** over the Steenkoppies compartment should be considered, which take into account both the total volume and the intensity of rainfall events (e.g. tipping-bucket rain gauge system).
5. Whilst it is difficult to agree on exact figures at present, it is very likely that over-abstraction by irrigators is at least partly to blame for declines in the flow at Maloney's Eye. **Measures to reduce groundwater abstractions need to be implemented**, although a gradual approach to implementation is suggested to ensure as little as possible disruption to this valuable industry.
6. As new groundwater data is collected, the technical and conceptual model of the compartment can be refined, and management interventions (such as irrigation abstraction restrictions) further developed. This is along the lines of the principles of "Adaptive Management" discussed by Seward et al. (2006).

7. Outstanding technical issues, which stand in the way of coordinated and united management actions, need to be resolved. These include estimating the rough size of the catchment for Maloney's Eye, and the relationship between declining flows at the eye and declining flows further downstream in the Magalies River.
8. Decisions made around the sustainability of the Steenkoppies groundwater resource and the flow at Maloney's Eye should be captured in local and regional planning documents. Water will be a growing factor in spatial planning in the area for various sectors.

8.7.4 Other management issues affecting the Steenkoppies compartment

Although the issue of the water "budget" for the compartment, and the associated flow of Maloney's Eye is the most important groundwater management issue that needs attention, there are several other technical groundwater issues that should also be considered, and which have a bearing on future management. These issues include:

- How is groundwater quality in the Steenkoppies compartment being affected by various practices, including the irrigation with treated wastewater, the application of fertilizers and biocides by commercial farming operations, and the potential impact of acid mine drainage from defunct mining operations in the vicinity?
- How "leaky" are the boundaries of the Steenkoppies compartment, and how might groundwater in the compartment be affected by changes in the quantity and quality of groundwater in adjoining compartments?
- What is the potential for artificial recharge in the compartment, perhaps using treated wastewater?
- Improved public participation in the management of groundwater in the Steenkoppies compartment is desirable. This would provide all stakeholders (e.g. farm employees, Magalies River water users, environmentalists, etc.) with information about on-going management, and also help to ensure that the concerns of all stakeholders are incorporated into management deliberations.

8.7.5 Management conclusions

The Steenkoppies compartment hosts one of the most valuable resources of groundwater in the country, key to an irrigated agricultural industry worth three quarters of a billion Rand and employing thousands of people. The flow of the Maloney's Eye spring also depends on the groundwater in the compartment. A steady increase in irrigation has taken place since the 1970s in the Steenkoppies compartment, and sporadic attempts to resolve the water crisis in the compartment before it occurred have not been successful.

The established DWAF approach to managing groundwater, as laid down in their document (DWAF, 2008), has not been followed in the case of the Steenkoppies compartment until recently. Assessment of the resource, whilst arguably never sufficient for such a valuable body of water, has in fact decreased in recent years – at exactly the time when declines in flow at Maloney's Eye have made national headlines (Business Day, 2007). Nobody knows exactly how much water is being used today for irrigation purposes, although DWAF is implementing steps to rectify this.

Planning, the second stage of the DWAF process depends on a sound interpretation of hydrogeological and other data. However, at present no single conceptual model of the aquifer is agreed upon by all parties, and no detailed reserve determination has been done. The total available resource is still under dispute.

The failures in assessment and planning have made it difficult to implement management actions. The 2008 directive to restrict groundwater abstraction based on observed flows at the eye is an improvement on the 2004 directive which sought to halt all groundwater use that did not fall under Schedule One of the National Water Act, since this threatened a valuable and long-established agricultural industry. However, without knowledge of what is currently being abstracted, and without the means to measure reductions, it will be difficult to implement this directive as intended.

The Tarlton farmers have stated that restrictions in irrigation amounts will have very serious consequences for their industry, and that even reductions of as little as 10% of irrigation volumes will need to be phased in slowly (Tarlton, 2007). Ideally the DWAF restrictions should be phased in slowly, as part of a process of dialogue with all stakeholders to avoid damage to the industry as far as possible. It may be possible to initiate smaller restrictions on abstraction, as more information is collected about the aquifer (adaptive management). The present situation has taken years to reach this point, and it may similarly need a substantial period of time to rectify. What should be undisputed is that the current situation cannot be allowed to continue – under the present circumstances, another dry spell will most likely see great reductions in flow at Maloney's Eye again.

Appendix 8.A: – Hydrochemical Samples (selected constituents, concentrations in mg/l unless otherwise indicated)

Sample Number	South (DD)	East (DD)	pH unit	EC mS/m	TDS	Ca	Mg	Na	K	Cl	SO_4	NO_3 as N	Alkalinity as CaCO3	NH_4 as N	F	Fe	Si	**δD [%o]**	**$\delta^{18}O$ [%o]**	**^{3}H [%o]**
VS147	-26.10697	27.66047	7.2	20.5	134.0	19.0	10.0	8.0	1.0	16.0	16.0	1.2	56.0	<0.2	<0.2	<0.025	6.800	-19.44	-3.37	
VS149	-26.10677	27.66324	7.1	9.7	62.0	10.0	6.0	<2	<1.0	3.0	5.0	0.8	36.0	<0.2	<0.2	<0.025	6.700	-24.61	-4.26	0.70
VS143	-26.09534	27.66075	7.3	11.7	72.0	13.0	7.0	<2	<1.0	1.0	5.0	0.3	52.0	<0.2	<0.2	<0.025	6.700	-27.25	-4.77	
VS102	-26.08567	27.65882	8.0	34.4	184.0	36.0	21.0	6.0	<1.0	8.0	7.0	9.1	124.0	<0.2	0.2	<0.025	7.900	-24.73	-4.35	0.90
VS28	-26.07759	27.64826	8.0	51.7	348.0	45.0	27.0	28.0	1.4	37.0	39.0	8.8	144.0	<0.2	<0.2	<0.025	9.700	-16.22	-3.04	
S908	-26.06598	27.64123	8.0	45.1	266.0	39.0	28.0	23.0	1.5	26.0	47.0	1.2	156.0	<0.2	<0.2	<0.025	8.400	-19.66	-3.56	2.40
S909	-26.10810	27.65147	6.9	10.6	74.0	9.0	5.0	4.0	<1.0	7.0	9.0	0.8	32.0	<0.2	<0.2	<0.025	6.000	-24.82	-4.09	
VS75	-26.10361	27.65046	6.6	58.9	358.0	19.0	11.0	84.0	1.4	96.0	34.0	18.0	28.0	<0.2	<0.2	<0.025	7.100	-6.74	-1.02	2.40
VS74	-26.10608	27.65140	7.2	24.7	154.0	22.0	12.0	11.0	1.0	21.0	22.0	4.5	52.0	<0.2	<0.2	<0.025	6.700	-21.85	-3.69	
VS56	-26.08892	27.64668	7.6	47.0	278.0	39.0	22.0	33.0	1.4	38.0	39.0	2.5	140.0	<0.2	<0.2	<0.025	9.300	-14.76	-2.45	2.90
RL21	-26.05110	27.64157	8.0	49.1	326.0	44.0	28.0	37.0	1.9	37.0	58.0	2.1	156.0	<02	<0.2	<0.025	8.980	-16.35	-2.87	
RL32	-26.05411	27.64825	8.4	30.2	170.0	32.0	22.0	10.0	<1.0	16.0	25.0	0.7	124.0	<0.2	<0.2	<0.025	9.910	-24.05	-3.92	
S984	-26.04123	27.65107	8.1	38.3	234.0	36.0	23.0	25.0	1.5	30.0	40.0	1.4	132.0	<0.2	<0.2	<0.025	7.640	-18.46	-3.21	1.50
S985	-26.03833	27.63968	7.4	14.5	94.0	14.0	10.0	7.0	1.6	4.0	<5	0.2	80.0	<0.2	0.9	0.132	7.260	-28.20	-4.72	
S986	-26.04078	27.63186	7.6	14.6	84.0	16.0	11.0	3.0	<1.0	4.0	6.0	0.4	80.0	<0.2	<0.2	0.164	7.070	-26.72	-4.53	0.70
VS8	-26.07214	27.62934	8.3	25.9	150.0	25.0	18.0	12.0	<1.0	16.0	23.0	0.8	104.0	<0.2	<0.2	0.296	8.930	-23.99	-3.94	
S988	-26.07155	27.60451	7.4	16.9	96.0	20.0	14.0	2.0	<1.0	5.0	5.0	0.5	92.0	<0.2	<0.2	0.029	6.910	-27.85	-4.60	
S989	-26.11558	27.58356	6.0	2.9	30.0	2.0	<2	4.0	<1.0	4.0	<5	0.6	16.0	<0.2	<0.2	0.033	11.200	-16.07	-2.47	3.40
S990	-26.03247	27.60162	7.5	20.6	112.0	26.0	18.0	2.0	<1.0	3.0	8.0	<0.2	116.0	<0.2	<0.2	2.680	6.130	-28.66	-5.08	
MALONEY	-26.02682	27.56410	8.0	24.7	140.0	32.0	20.0	2.0	<1.0	4.0	6.0	0.4	136.0	<0.2	<0.2	<0.025	7.590	-28.59	-4.82	4.60
S1051	-26.06975	27.65822	7.6	47.6	288	20	9	58	12.5	50	58	0.6	104	0.4	0.2	0.279	6.4	-11.71	-2.04	0.00

9 ASSESSMENT OF THE TARLTON DOLOMITIC AQUIFERS

9.1 Introduction

In this section the hydrogeology of the Tarlton dolomitic aquifers is described. The text is essentially taken from the recent report by Holland and Cobbing (2008) and formed part of a larger DWAF project in which guidelines for the development of the main dolomitic aquifer regions in South Africa were developed. The section of this document describing the Tarlton dolomitic aquifers was referred to as Activity 13 of the larger project.

9.1.1 Background

The Tarlton dolomitic aquifers are the only readily available water resource for many farms in the region and are also a vital component of the water resources needed for the expanding demand of the urban complexes of the Mogale City Local Municipality. The investigation and understanding of this complex compartmentalised karst aquifer has become crucial since the first mine water started to decant south of the area near Krugersdorp in August 2002. The rebounding water table has led to significant pollution of groundwater in the abandoned mining areas. Acid Mine Drainage (AMD) caused by the oxidation of sulphides, results in elevated heavy metal concentrations, a high sulphate content, an increased electrical conductivity and a lowering of the pH of the water in the mining area. In addition to the mining activities, two waste-water treatment plants (municipal sewage works) are located in the catchment, and intensive agricultural activities are carried out throughout the karst basin. The tributaries of the catchment play a major role in assimilating or carrying off the mining, industrial and municipal waste-water together with run-off from agricultural land. These waters enter the underground karst network through swallow holes, dolines and leakage from river beds. Such inflows are characteristic of karst terrain and pose a threat to existing surface and groundwater in the area. The area of decant is immediately south of the Cradle of Humankind World Heritage Site (COHWHS), which hosts a vast treasure chest of fossilized remains of past life forms, particularly hominids (humans, their ancestors and relatives) found in over 200 karst caves. To ensure its Heritage status the Cradle of Humankind requires a sustainable balance between utilisation and protection of the water resource.

9.1.2 Study Locality

The study area shown in Figure 9.1 is located approximately 40 km northwest of Johannesburg and includes the municipal areas of Mogale City and Randfontein. The aquifers under investigation are formed by the Malmani dolomite formations of the Chuniespoort Group. It is within this Group that karst formation has occurred. Dykes that form boundaries to groundwater flow cross the dolomites, creating isolated hydrogeological compartments. The investigation focuses on the Zwartkrans compartment to the east of Tarlton and the Steenkoppies compartment towards the west of Tarlton and includes the dolomitic outlier (footprint shape) towards the south of the main dolomite limb (Figure 9.1). The Zwartkrans compartment covers an area of 178 km^2 and contains the Sterkfontein and Wonder caves, and the major springs Danielrus, Kromdraai and Zwartkrans.

The Zwartkrans compartment's hydrogeological boundaries are:

- the Pretoria group in the north,

- the Tweefontein compartment in the north-east with the Rietfontein dykes as boundary,
- the Basement complex and Witwatersrand Super-Group in the east and south, and
- the Steenkoppies compartment in the west with the Tarlton west dyke as boundary.

The Steenkoppies compartment covers an area of 177 km^2 and is bounded by:

- the Pretoria group in the north, the Zwartkrans compartment in the east,
- the Witwatersrand Super-Group in the south, the Holfontein compartment in the west with the Eigendom dyke as boundary.
- The Maloney's eye drains this compartment and is a major source of water supply

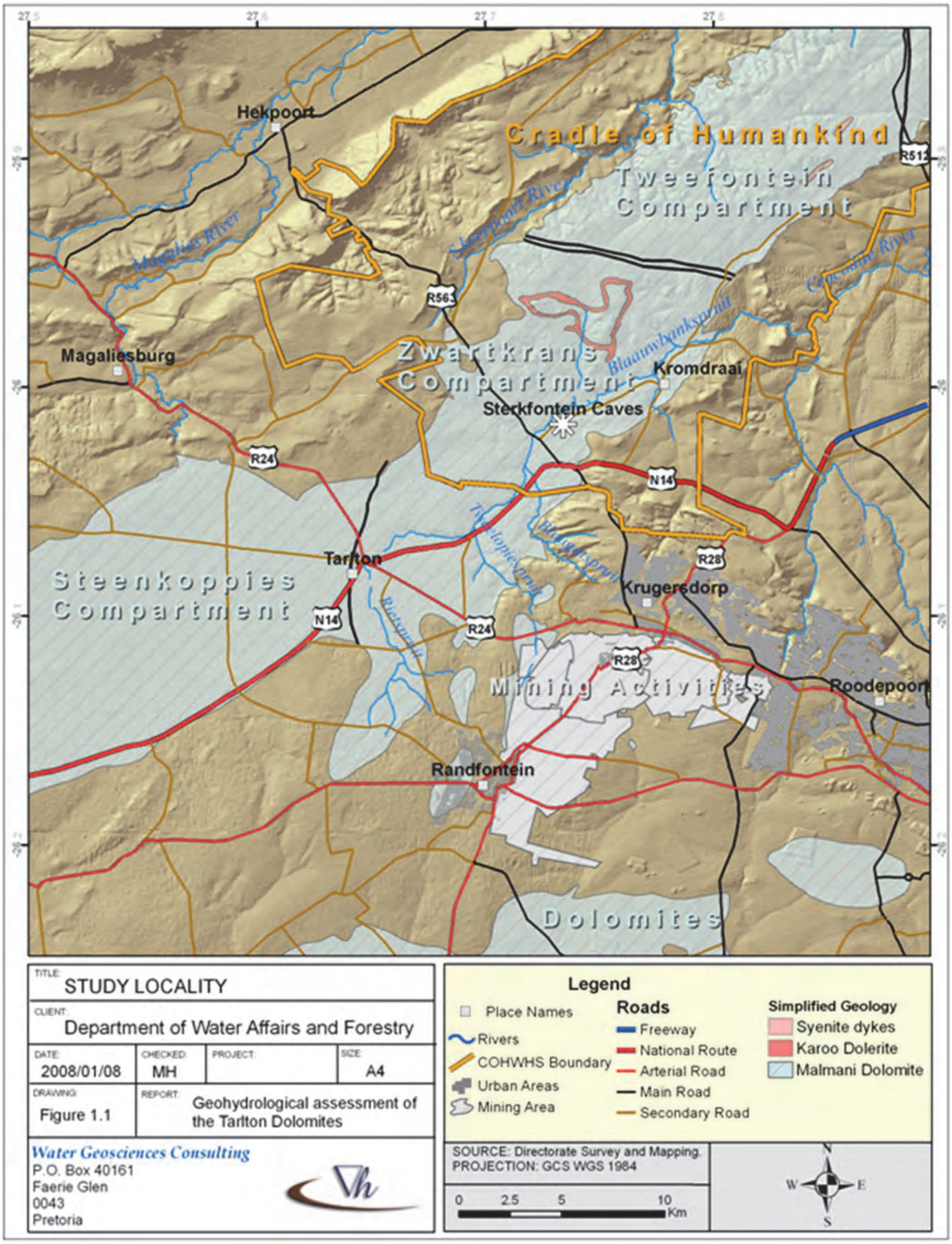


Figure 9.1: Locality map of the Tarlton dolomitic aquifer region.

Emphasis will be placed on the more impacted Zwartkrans compartment as most human activities occur within this compartment. However, the Steenkoppies compartment has received much more attention during the last year due to the declining flow of the Maloney's eye This will require at least an overview of the current status of the compartment.

9.1.3 Approach

This desktop geohydrological study is based on the processes and activities contained in Volume 3 of the Guideline for the Assessment, Planning and Management of Groundwater Resources within Dolomitic Areas in South Africa (DWAF, 2006), which will ensure that the deliverables are met. The desktop geohydrological assessment utilised the following information:

- the 1:250 000 scale geological maps 2526 Rustenburg and 2626 West Rand;
- the 1:500 000 scale hydrogeological map 2526 Johannesburg and its baseline data;
- aeromagnetic data for map sheets 2627BA, 2727BB, 2527DC and 2527DD;
- technical GH reports by DWAF's former Geohydrology directorate;
- water level monitoring data extracted from the National Groundwater Database (NGDB) managed by DWAF;
- groundwater quality data extracted from the NGDB;
- relevant and appropriate scientific reports commissioned by local authorities and developers.

9.1.4 Methodology

The objective of a desk study is the collation, scrutiny and evaluation of available and relevant meteorological, geographical, geological, hydrogeological and groundwater quality data. The primary task involved the gathering of information and data relevant to the dolomite aquifers in the delineated study area. The desktop assessment is based on the following information related to groundwater:

- Geological and hydrogeological maps,
- hydrogeological reports,
- geophysical profiles of exploration and/or monitoring boreholes previously drilled in the area,
- groundwater quality data, and
- other aspects, including information on land-use planning and potential water requirements.

This information is used to establish a background or baseline geological and hydrogeological reference for the identified study area, including possible boundaries for the dolomitic aquifer system associated with the distribution of compartmentalising dykes, together with any other potential aquifers within the catchment. The information obtained will be collated into a water balance, indicating water availability and water requirements.

9.2 Description of Study Area

9.2.1 Morphology and Drainage

The topography of the study area is generally flat to gently undulating, with plains, slopes and several scattered hill crests. The gently undulating landscape of the area is often interrupted by significant topographical differences which is attributed to different erosion and weathering characteristics of the band of dolomites and their associated breccias. The chert-poor units weather to a smooth topography covered by red silty type clayey soils devoid of chert. The chert-rich units weather to an uneven topography characterised by dissolution openings and a permeable chert residue with red silty and brown manganiferous soils (Obbes, 2001). The area is covered mainly by grass, with more dense vegetation along the rivers. The surface features of the Zwartkrans/Steenkoppies dolomites can often be related to the sub-surface bearing characteristics e.g. valleys of surface drainage coincide with fractured zones in karstified dolomite. The low density of runoff drainage suggests high recharge and a predominance of water flow underground, which eventually drains into surface streams at topographic lows or emanates as springs next to diabase dykes or formation contacts.

The study area extends over quaternary catchments A21D and A21F, and forms part of the upper Crocodile River sub-system located within the Crocodile (West) and Marico Water Management Area as described by the Department of Water Affairs (Figure 9.2). As shown in Figure 9.2, the Zwartkrans compartment is drained towards the north-east by the perennial Blaauwbankspruit Stream. The upper Blaauwbankspruit also termed the Rietspruit, drains storm water and surface run-off from the town of Randfontein in addition to some 8.16 Ml/day of treated sewage effluent (Krige, 2006) from the Randfontein Sewage Works facility. For some distance, stream flow remains constant, but disperses into the underground network as soon as it crosses the Rietfontein Wrench fault system.

Perhaps the most important and influential tributary on the karst hydrology, is the Tweelopiespruit. This stream originates approximately 4.5 Km to the south of the Krugersdorp Game reserve and traverses a distinct dolomitic outlier. This dolomite outlier is associated with the decanting of 15 Ml/day of polluted mine water from the old Black Reef incline mine shaft (Van Biljon, 2006). At the time of the study the polluted mine water was treated through a process of lime addition and aeration as well as secondary treatment through a wetland system. This facility, which includes a HDPE-lined containment dam and pumping stations downstream, struggles to contain the flow of decanting mine water during periods of high rainfall and significant amounts of mine water flows into the Tweelopiespruit. The second major tributary of the Blaauwbankspruit is the Blougatspruit which is responsible for the drainage of 19.3 Ml/day of treated sewage effluent in addition to surface run-off from the industrial area of Krugersdorp (Krige, 2006). This tributary flows through the quartzite hills, passes the Percy Stewart Sewage Works and after some 900 m, the stream flows off the Witwatersrand Quartzites and onto the Dolomite.

The Steenkoppies compartment is drained towards the north and forms the upper catchment of the Magalies River which originates at the Maloney's Eye (9.2). The Maloney's Eye dolomitic spring supports irrigation activities and domestic water supplies along the Magalies River. The compartment is typified by an almost flat undulating plain which is virtually devoid of surface drainage.

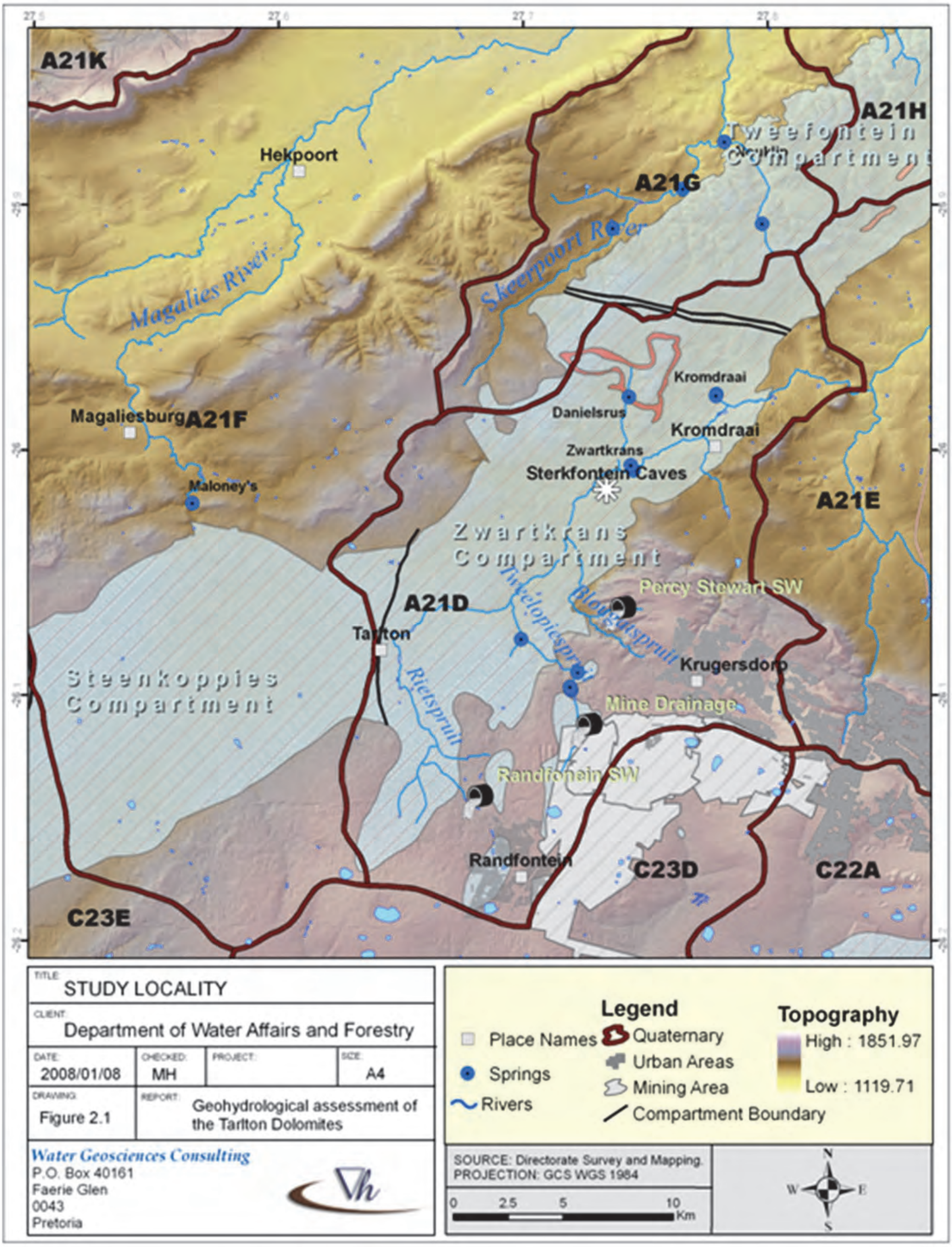


Figure 9.2. Surface water catchments of the study area.

9.2.2 Climate, Rainfall and Vegetation

The climate in the area is typical South African "Highveld", characterised by warm summers, when 80% of the rainfall is experienced as thunderstorms, and cool dry winters with cold nights.

Frosts are experienced for up to five months of the year and hail falls often. Climatic data of four meteorological stations closest to the study area is summarised in Table 9.1.

Table 9.1. Meteorological stations in the study area.

SAWS	Rainfall Record	Coordinates		Elevation (m.a.m.s.l.)	Rainfall (mm)
		Latitude	Longitude		
Krugersdorp	1969-current	-26.1000	27.7700	1 480	723
Randfontein	1955-current	-26.1300	27.7000	1 710	675

*- Data obtained from the South African Weather Services (Pretoria)

A very high potential evapotranspiration with a mean annual evaporation of about 1700 mm prevails (DWAF, 1992) which exceeds the average annual precipitation by a factor of 2.4. However, the actual evapotranspiration is much lower as the shallow soil cover limits availability of moisture to the plants, which causes excess soil water to infiltrate below the root zone, recharging the groundwater reservoir. Large parts of the study area comprises of small holdings (with greenhouses), cultivated land and built-up urban development. These land uses have removed the natural vegetation which was identified as Central Variation of the Bankenveld veld type by Acocks (1975).

9.2.3 Land-Use

Land-use in the study area encompasses a wide spectrum of activities, more specifically:

- Irrigation and dry land farming (mainly maize and vegetables) with numerous poultry farms (e.g. Sterkfontein poultry) and some stock farming along the Blaauwbankspruit.
- Quarrying for sand and for refractory clay and brick making.
- Agricultural holdings and smallholdings, e.g. Oaktree, Marabeth and Elandsvlei.
- Informal settlements, e.g. Botleng, Davyton and Etwatwa.
- Urban and industrial areas, e.g. Delporton.
- Conservation areas, e.g. the Krugersdorp Game Reserve.
- Waste Water Treatment Facilities, e.g. Randfontein and Percy Stewart.

9.2.4 Geology

9.2.4.1 Geomorphology

The present karst forms and geomorphology have been created by the interplay of ancient and recent erosion cycles on lithologies that have undergone many episodes of deformation. Subsequent to the break up of the super-continent of Gondwanaland (250 million years ago), the dolomites have been uplifted into a high interior plateau and the overlying Karoo cover rocks relatively rapidly stripped off by erosion to reveal a pre-Karoo palaeo-karst surface (King, 1963; Wilkins *et al*., 1987). An episode of quaternary regional up warping on an East Northeast trending transcontinental axis has caused significant drainage reversal over the whole karst region. The emergent plateau has tilted slightly towards the north and the younger streams have aggressively incised northward draining gorges, capturing the previous drainage pattern and exploiting zones of structural weakness. Renewed karstification of this rejuvenated surface has taken place over the Pleistocene period accompanied by climatic changes of the Highveld plateau pluvial cycles (Jamison *et al*., 2004). The dolomite is frequently concealed under a thick

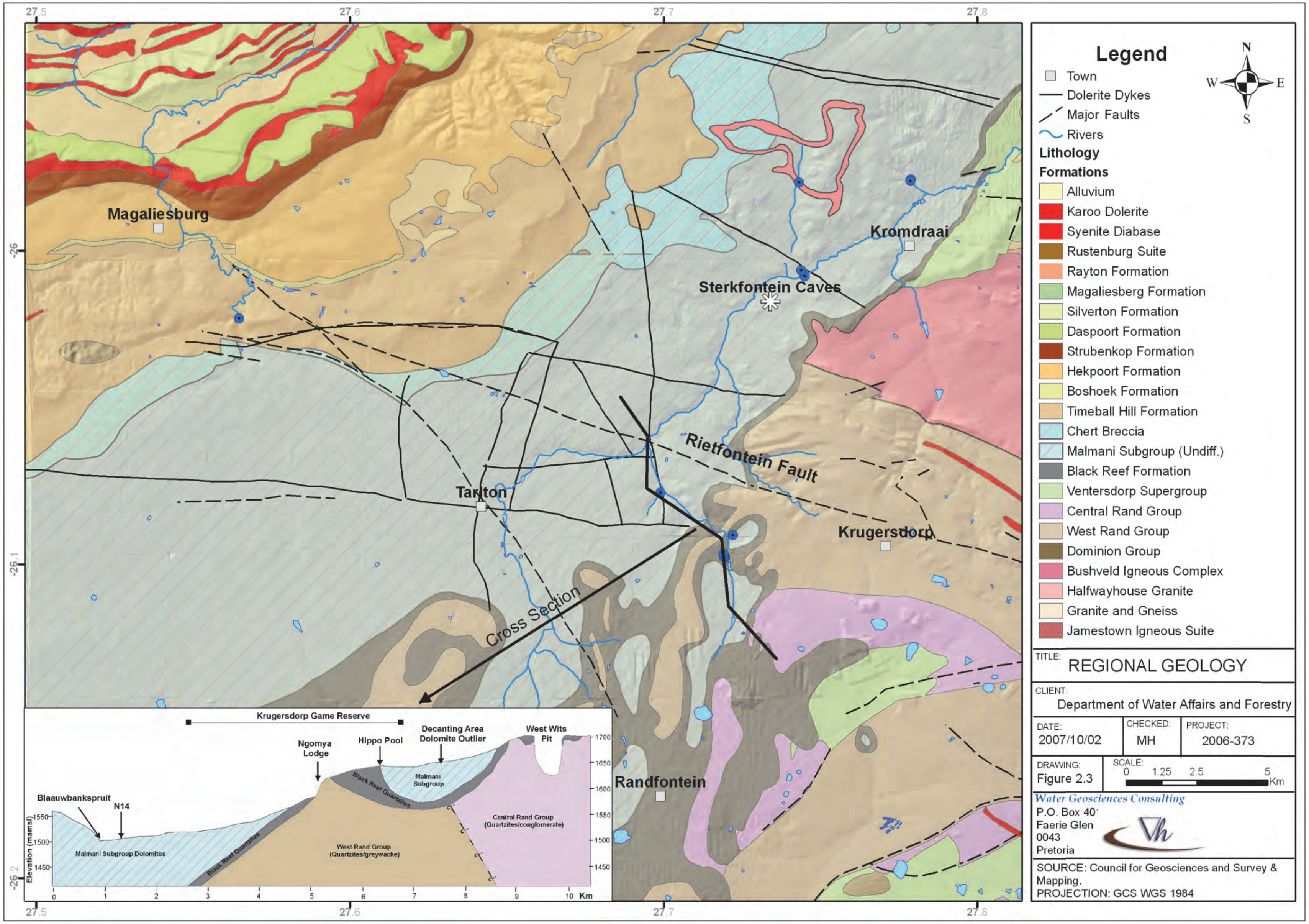


Figure 9.3. Regional geology of the area under investigation.

9.2.4.2 Geological Setting

The regional geology and stratigraphy in the study area show a variety of rock types. The North-western boundary of the Zwartkrans/Steenkoppies compartment runs along the crestal ridge of the Klapperkop quartzite of the Timeball Hill formation of the Pretoria Group. The South-eastern boundary runs over the Western part of the Johannesburg granite dome and its associated ridges of gold bearing Witwatersrand formations forming the faulted rim of the Witwatersrand basin. Dipping off the western flank of the Johannesburg Dome with a disconformable contact is the basal formation of the Transvaal Super-Group consisting of the Black Reef Quartzite formation underlying the Zwartkrans/Steenkoppies dolomitic compartments.

The Pretoria Group rocks in the northeast act as hydrogeological boundaries with numerous pre- and post-Karoo age impervious dykes subdividing the dolomite into ‘compartments’ isolated hydrogeologically from each other, especially in the centre portion of the study area (Figure 9.3). Based on the abundance of chert, the Malmani subgroup has been subdivided into five dolomitic formations. A generalised lithostratigraphy is presented in Table 9.2 and a short cross-section illustrating the dolomite outlier in its relation to the major dolomite compartment and the Witwatersrand Supergroup is illustrated in Figure 9.3. The geology pertaining to the study area is described in chronological order, from the oldest to the youngest formations.

9.2.4.3 Mafic Dykes and Lineaments

Aeromagnetic data sourced from the Council for Geoscience for the 1:50 000 map sheets 2527DC, 2527DD, 2627BA, and 2627BB was used for the identification of linear anomalies in the region (Figure 9.4). These magnetic anomalies was compared to the dykes mapped by Bredenkamp et al. (1986) and the two dyke sets mapped by Obbes, 2001. Obbes (2001) noted the negative aeromagnetic anomalies of the north-south trending dykes north of Tweefontein compartment and the positive aeromagnetic anomalies of the east-west trending dyke, which constitute the border between the Zwartkrans and Tweefontein compartments.

9.2.4.4 Regional Structure

Recent detailed mapping and analysis in the greater COHWHS has identified pre-Bushveld folding and late-Bushveld bedding consisting of sub-parallel ductile deformation mylonites which slice the stratigraphy into an imbricate stacked duplex (parts overlapping like roof-tiles) (Courtnage, 1995). Mylonites are formed as fine-grained laminated rock by extreme plastic deformation and milling of rocks during movement on faults, under high strain in deformation zones at depth. The dolomites and Pretoria Group have subsequently been folded and fractured by a re-activated left lateral WNW trending shear system which has imprinted sub-parallel deformation zones at +/-10 km intervals parallel to the Rietfontein Wrench Fault System as the principle control of cavern and karst form development upon the area (Holland *et al*., 2005) (Figure 9.5).

Table 9.2. Lithostratigraphy of the geology of the study area (SACS, 1980:205; Foster, 1984; Obbes, 2001).

Super Group	Group	Formation	Thickness (in m)	Lithology
		Diepkloof	?	(Karoo-age) Chert breccia with siliceous and ferruginous matrix.
TRANSVAAL	PRETORIA	Rayton	120	Shale, quartzite.
		Magaliesburg	300	Quartzite.
		Silverton	600	Shale.
		Daspoort	80-95	Quartzite.
		Strubenkop	105-120	Slate.
		Hekpoort	340-550	Andesite.
		Timeball Hill	270-660	Shale, Diamictite, Klapperkop Quartzite and ferruginous quartzite. Graphitic and sitly shale.
		Rooihoogte	10-150	Quartzite, Shale, Bevets Conglomerate Member and Breccia.
	CHUNIESPOORT	Frisco	30-158	Chert-free dolomite with some primary limestone and carbonaceous shale at the base.
		Eccles	490	Chert-rich dark dolomite with stromatolitic and oolitic bands. Chert increases to the top.
		Lyttelton	220-290	Chert-free dark dolomite with large stromatolites and sometimes with wad.
		Monte Christo	740	Alternate layers of chert-rich and chert-poor light coloured dolomite with stromatolites and oolites.
		Oaktree	190-330	Chert-poor dark dolomite with interbedded layers of carbonaceous shale at the base, decreasing to the top and sometimes with wad.
		Black Reef Quartzite	11-30	Shale and Quartzite. Arkosic Grit
VENTERS-DORP	Undifferentiated		?	Andesite tuff, conglomerate calcareous shale, sandstone.
WITWATERSRAND	CENTRAL RAND	Undifferentiated	2 880	Arenaceous, rudaceous rocks.
	WEST RAND		5 150	Quartzite, reddish and ferruginous magnetic shales.
	DOMINION		?	Quartzite, conglomerate, shale, interbedded lava.
BASEMENT COMPLEX				

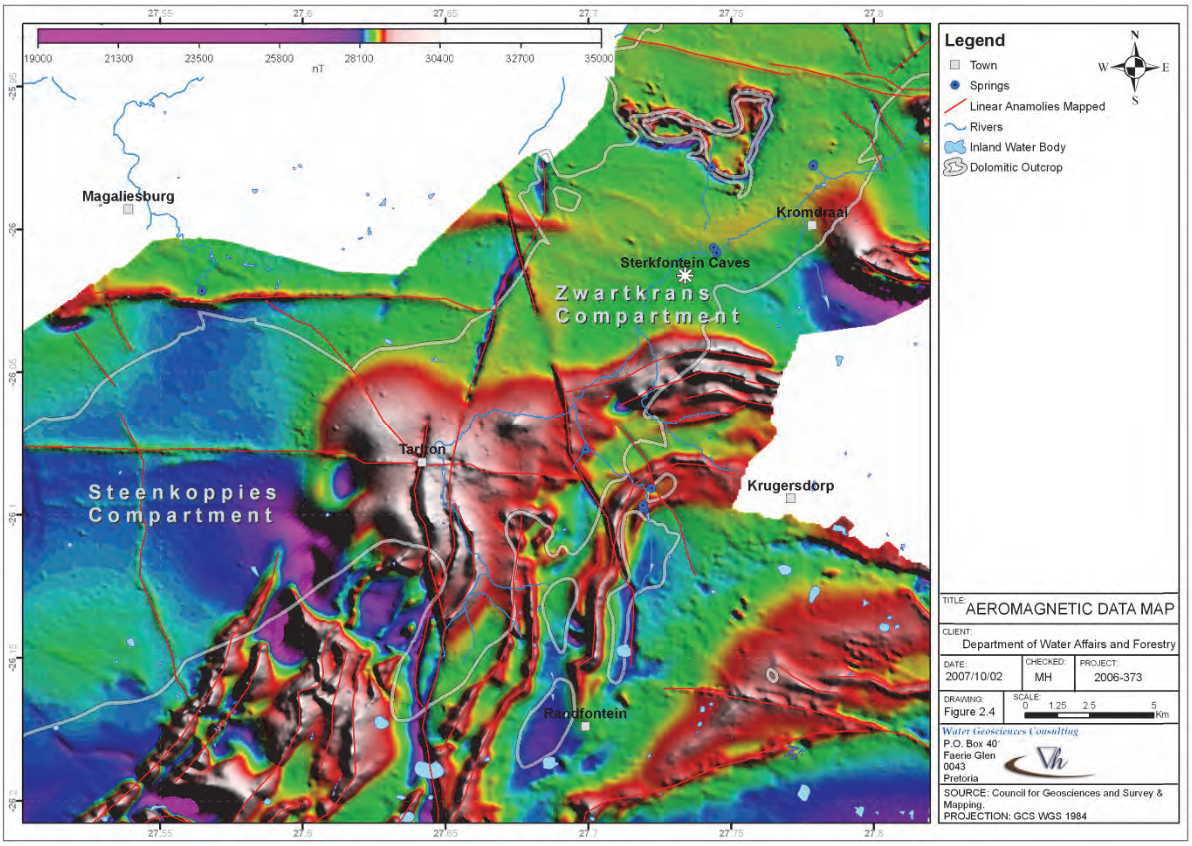


Figure 9.4. Aeromagnetic data interpretation (Sourced from: The Council for Geosciences).

Most of the caves, dolines, sinkholes and fissures are located on the WNW shear zones and in close relationship to impervious bedding of sub-parallel mylonitic cherty slate horizons (Jamison et al., 2004). The final phase of rejuvenating of these fractures occurred as a result of epeirogenic warping and uplift along the Griqualand-Transvaal axis (Partridge and Maud, 1987), during the late Cretaceous era, which initiated the present karst cycle on the Craton interior.

Therefore, the dolomites are not only compartmented by near vertical dykes and silicified faults but also by bedding sub-parallel ductile mylonitic thrust planes and refolded folds (Holland *et al.*, 2005). As a result of fracture reopening in the Tertiary epeirogenic warping of the dolomite plateau, solution along the WNW trending fracture zones was enhanced and a new cycle of karstification of the dolomite ensued. The present caves and karst features would thus be expected to occur as stacked perched water tables, and an inherited structural and lithological framework (Jamison et al., 2004) controls complex recharge and flow regimes within and between compartments.

9.3 Hydrogeological Overview

9.3.1 General

The low density of runoff drainage suggests high recharge and a predominance of water flow underground, which eventually drains into surface streams at topographic lows or emanates as springs next to dykes or lithologic/formation contacts. The formations of the dolomites are distinguishable based on their chert content. The chert poor formations weather evenly to produce a low storage potential residue of silty clay. The chert rich formations weather quite differently. The dolomite weathers faster than the chert leaving the rock supported by chert

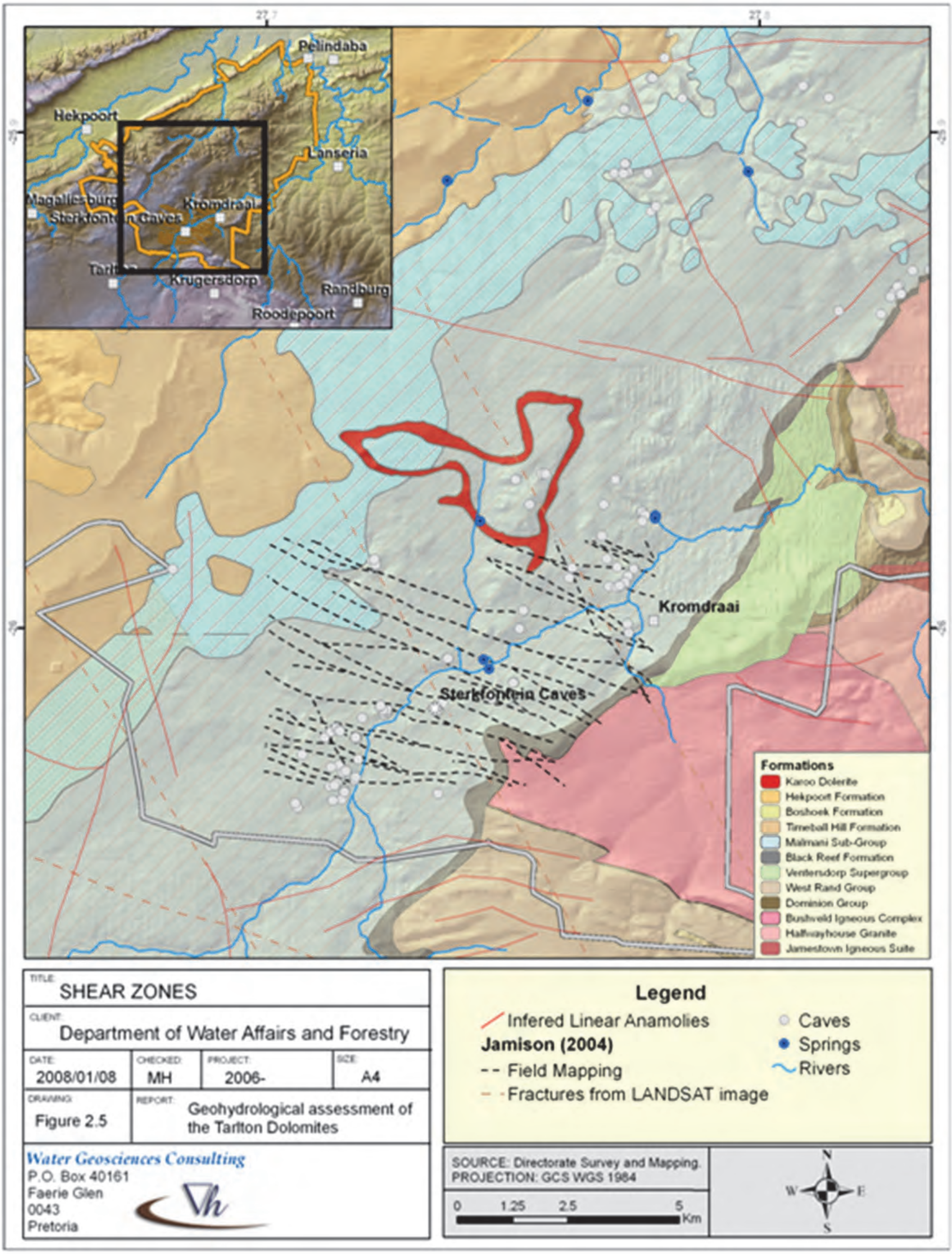


Figure 9.5. Locality of Caves in relation to major faults (data from Jamison et al., 2004).

structures. Eventually the chert will weather and collapse under its own weight leaving a permeable coarse chert breccia. Chert rich formations develop a greater concentration of fissures and fractures, which will enhance the process of weathering. These chert rich formations are generally favorable for large-scale development of groundwater. The overlying Pretoria group reveals very low primary permeabilities and signifies weakly developed secondary permeabilities along faults and fractures. Once the dolomite is exploited excessively it is expected that the Pretoria Group will contribute groundwater to the dolomite (Kuhn, 1989). The hydraulic connection between the dolomites and the underlying Witwatersrand and Basement rocks is poor due to low permeability values in these underlying rocks.

9.3.2 Compartmentalisation

Dolomitic compartments are formed by crosscutting dykes that act as barriers to groundwater flow, creating isolated hydrogeological compartments. The major compartments according to the various geohydrological studies conducted on the Tarlton dolomites by Foster (1984), Vegter (1986) and Bredenkamp et al. (1986) are the Steenkoppies, Zwartkrans, and Tweefontein compartments. The Zwartkrans and Steenkoppies compartment were subdivided into smaller sub-compartments by Bredenkamp et al. (1986) based on field surveys, aeromagnetic data, gravity measurements, and water level measurements. Recent studies by Holland (2007) clearly illustrated the role of the dyke structures in building compartments and sub-units in the Zwartkrans compartment, although the extent of leakage through the dykes was not established. It is important to note that these dykes are not totally impermeable and an extensive lowering of the water level through groundwater abstraction could clarify the extent of leakage through these boundaries.

9.3.2.1 Dolomitic Outlier

With regards to surface – groundwater interaction it is important to point out that the decanting area of polluted mine water is situated within a dolomite outlier that is separated from the Zwartkrans Compartment by the Black Reef Formation and sediments of the Witwatersrand Super-Group. The visible fracturing of these rock formations might suggest that this barrier might not be totally impermeable and sub-surface movement of contaminated water is possible. The dolomite outlier has similar characteristics as the dolomites discussed in the previous section but is dominated by residual products such as silica, iron and manganese oxides and hydroxides (wad) caused by the dissolution of the dolomite. This residual mass is also spongy, compressible, of low density and has a high void volume (Van Biljon, 2006). In an effort to identify groundwater flow paths from the mine workings a geophysical investigation was undertaken by Van Biljon (2006). The aim of the gravity survey was to determine preferential flow-paths along deeply weathered paleo-valleys (or grykes) in the dolomite bedrock. From the results three boreholes (RG1 to RG3) were drilled into the weathered zones to act as scavenger boreholes to create a sufficient drawdown to prevent contamination moving towards the Krugersdorp Game Reserve (KGR). It is unclear if this process has been started.

9.3.3 Groundwater Levels

The DWAF have maintained 37 continuous groundwater level monitoring stations up to 2005 with 26 of these stations monitored up to the latter part of 2007. All of these target the dolomitic groundwater resource of the Steenkoppies and Zwartkrans compartments. The monitoring stations with the most comprehensive datasets are presented in Appendix 9A. The statistical characteristics for each dolomitic groundwater compartment are presented in Table.

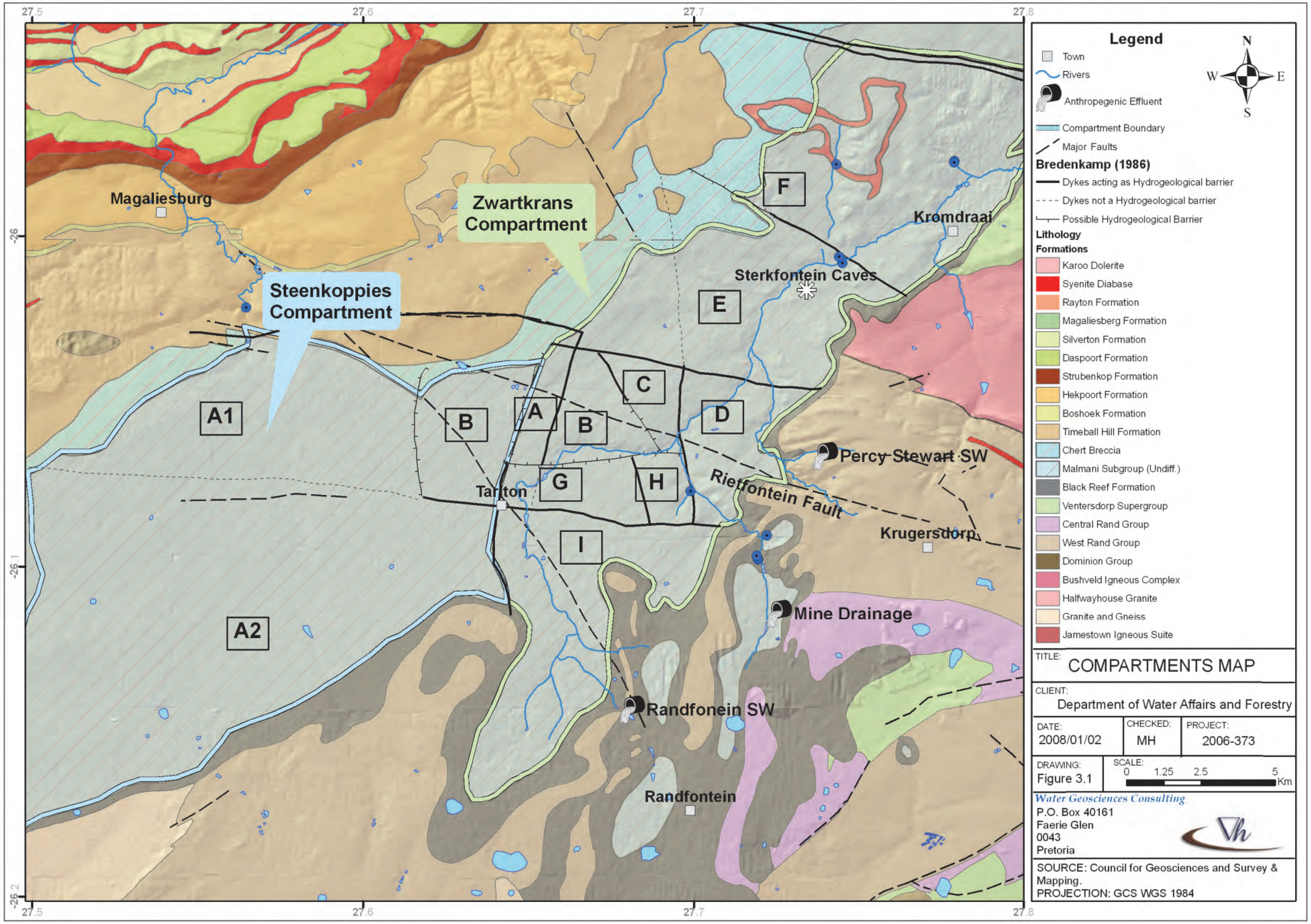


Figure 9.6. Dolomitic compartments map, inferred from previous investigations.

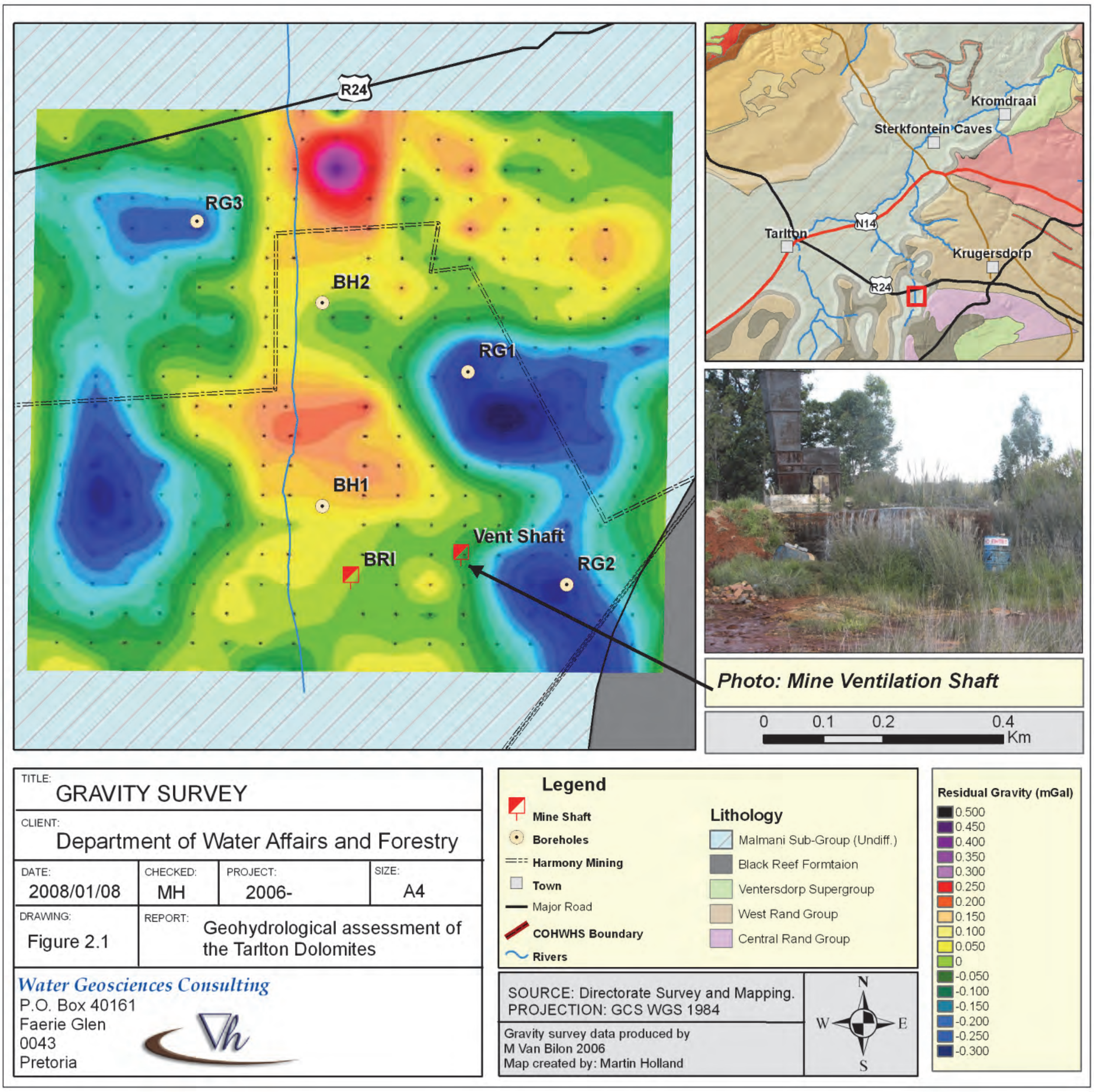


Figure 9.7. Gravity survey at the mine water decanting area on the dolomitic outlier (Holland, 2011; data obtained from Van Biljon, 2006).

Table 9.3. Groundwater level information for dolomitic compartments.

Compartment	Groundwater level depth (m.b.g.s)			Groundwater level elevation (m.a.m.s.l.)		
	10 percentile	Mean	90 percentile	10 percentile	Mean	90 percentile
Steenkoppies	9.44	54.24	70.99	1484.41	1487.94	1492.20
Zwartkrans	26.88	50.20	69.54	1439.01	1490.25	1561.19

9.3.3.1 Groundwater Fluctuations

The statistical analysis of the dolomitic hydrostatic behaviour since the mid-1980s is presented in Table Table 9.49.4. Although sub-units C, F and G do have a number of accessible boreholes, no long term monitoring records exist.

Table 9.4. Statistical analysis of long-term groundwater level data for selected boreholes in dolomitic aquifers.

Compartment	Sub-Unit	Station	Depth to Groundwater Level (m.b.g.s)				Change in Groundwater Levels 1980s to 2007	
			Min.	Mean	Median	Max.	Max Δh	Cumulative Δh
Zwartkrans	A	A2N553	58.30	64.12	64.24	71.24	12.94	-4.87
		A2N556	44.04	49.12	48.85	58.32	14.28	**-6.49**
	B	A2N598	56.43	60.36	60.03	64.17	7.74	**-7.13**
	D	A2N584	22.47	26.53	26.71	28.83	6.36	-3.92
		A2N586	24.65	27.39	27.35	29.35	4.7	-2.44
	E	A2N590	34.06	35.56	35.64	36.73	2.67	-2.25
		A2N592	75.46	77.51	77.52	78.85	3.39	-2.88
		A2N600	23.26	24.62	24.63	25.53	2.27	-1.41
		A2N602	53.10	55.02	55.13	56.49	3.39	-2.31
		A2N605	60.80	62.71	62.87	63.90	3.1	-2.07
		A2N607	64.35	67.91	67.53	71.93	7.58	2.28
	H	A2N583	44.00	44.96	44.86	45.84	1.84	-1.26
	I	A2N576	30.21	46.62	48.89	61.93	31.72	-2
		A2N579	23.06	26.70	26.85	30.00	6.94	-4.43
		A2N580	50.30	54.74	54.50	60.90	10.6	**-9.4**
		A2N582	34.90	39.88	39.96	43.43	8.53	-2.89
Steenkoppies	A1	A2N558	7.30	8.56	8.57	9.58	2.28	-0.89
		A2N559	5.82	7.89	7.94	8.92	3.1	-0.08
		A2N572	67.93	69.54	69.47	71.79	3.86	0.84
	A2	A2N566	56.90	58.86	58.91	61.72	4.82	-2.37
		A2N567	57.78	59.21	59.10	61.80	4.02	-2.91
		A2N610	58.80	60.66	60.70	62.79	3.99	-2.42
		A2N612	54.15	55.92	55.94	59.72	5.57	-2.39
		A2N614	64.93	67.79	68.05	70.40	5.47	-2.59
		A2N615	64.90	68.78	69.09	71.16	6.26	-2.72
		A2N616	65.73	68.90	69.14	71.27	5.54	-2.28

The resultant dataset only includes the longest and most up to date record of continuous groundwater level measurements in the study area. Irregular data and anomalous readings were removed from the water level series. Table 9.5 and Figure 9.8 summarises the results of the statistical analysis presented in Table 9.4.

A comprehensive indication of dolomitic aquifer hydrostatic response trends and behaviour is provided by the hydrographs presented in Appendix 9B. Initial observations made from the groundwater level trends and Table 9.4 was a notable decrease in cumulative water levels since the onset of monitoring. Considerable groundwater level fluctuations are observed in the Zwartkrans compartment with values exceeding 13 m. Observed natural groundwater level fluctuations are of the order of 5 m, reported by Hobbs (2004) and Holland (2007) for the Rietvlei, Witkoppies and Bapsfontein dolomitic aquifer located south-east of Pretoria. Considering the occurrence of extreme positive groundwater level responses to rainfall of up to several meters, any further fluctuations could be attributed to significant development and unsustainable utilisation of the groundwater resources in the region. This is clearly illustrated in the cumulative groundwater level change column in Table 9.5 with three stations in the Zwartkrans compartment showing a lowering of the water table of more than 6 m. Table 9.5 illustrates the average cumulative change in groundwater levels for the each sub-unit delineated. Sub-units A, B, D and I seem to have sustained the greatest decline in water levels since the start of monitoring in 1986. Natural groundwater level fluctuations of stations within the Steenkoppies compartment do not exceed 6.3 m, however, average groundwater level declines of 2.5 m were observed in the (A2) Steenkoppies compartment.

Table 9.5. Summary of dolomitic aquifer hydrostatic behaviour based on Table 9.4.

Compartment	Sub-Unit	No. of Stations	Groundwater Fluctuation (m)		
			Range of Fluctuation	Mean Fluctuation	Mean Cumulative ∆h change
Zwartkrans	**A**	2	12.94 to 14.28	13.61	-5.68
	B	1	-	7.74	-7.13
	D	2	4.7 to 6.36	5.53	-3.18
	E	6	2.27 to 7.58	3.73	-2.2
	H	1	-	1.84	-1.26
	I	4	8.53 to 31.72	12.19	4.68
Steenkoppies	**A1**	3	2.28 to 3.86	2.99	+0.04
	A2	7	3.99 to 6.26	5.1	-2.53

To elaborate further on the fluctuations observed in the tabulated information and in the preceding graph, a monthly rainfall plot versus monthly groundwater levels trends is illustrated in Figure 9.9. The groundwater level trends of three DWAF monitoring boreholes in the Zwartkrans and rainfall data from the Krugersdorp weather station were used.

The following observations are based on the preceding graphical information:

- A prolonged "positive" effect is evident in response to recharge from rainfall at stations A2N576 and A2N582 between 1993 and 2003; thereafter a steady decline is evident in groundwater levels.
- Both A2N580 and A2N582 indicate a less pronounced response to rainfall and suggest a significant storativity.
- Increasing rainfall during the mid-90s had a clear positive influence on groundwater levels up to the early 2000s. During the last couple of years it seems that high rainfall periods have little effect on the declining groundwater levels. This effect could be attributed to sustained groundwater abstraction throughout the year.

9.3.3.2 Groundwater Drainage

A sufficient body of material already exists to define the direction of groundwater movement in the Zwartkrans compartment. In contrast little or no information regarding groundwater levels exist for the Steenkoppies compartment. The general groundwater flow of the Steenkoppies compartment would be north towards Maloney's Eye. Figure 9.8 is used to visualize the variations in groundwater elevations across the study area based on 67 static water levels in the Zwartkrans compartment during the summer of 2006/2007 by the University of Pretoria (Holland, 2007) and 10 static water levels in the Steenkoppies compartment based on the NGDB dataset (Table 9.4).

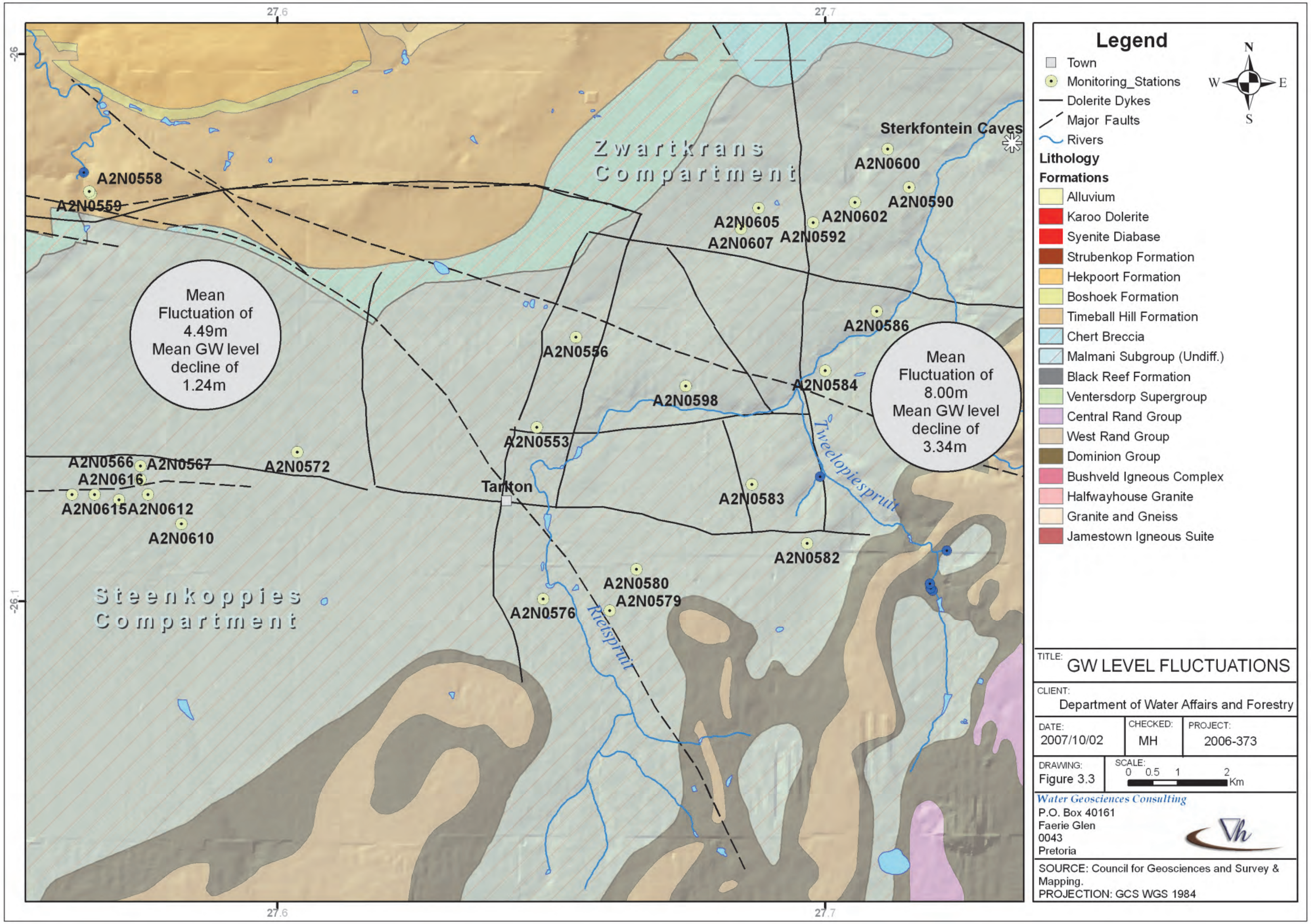


Figure 9.8. Spatial view of groundwater level monitoring stations and compartment fluctuations statistics.

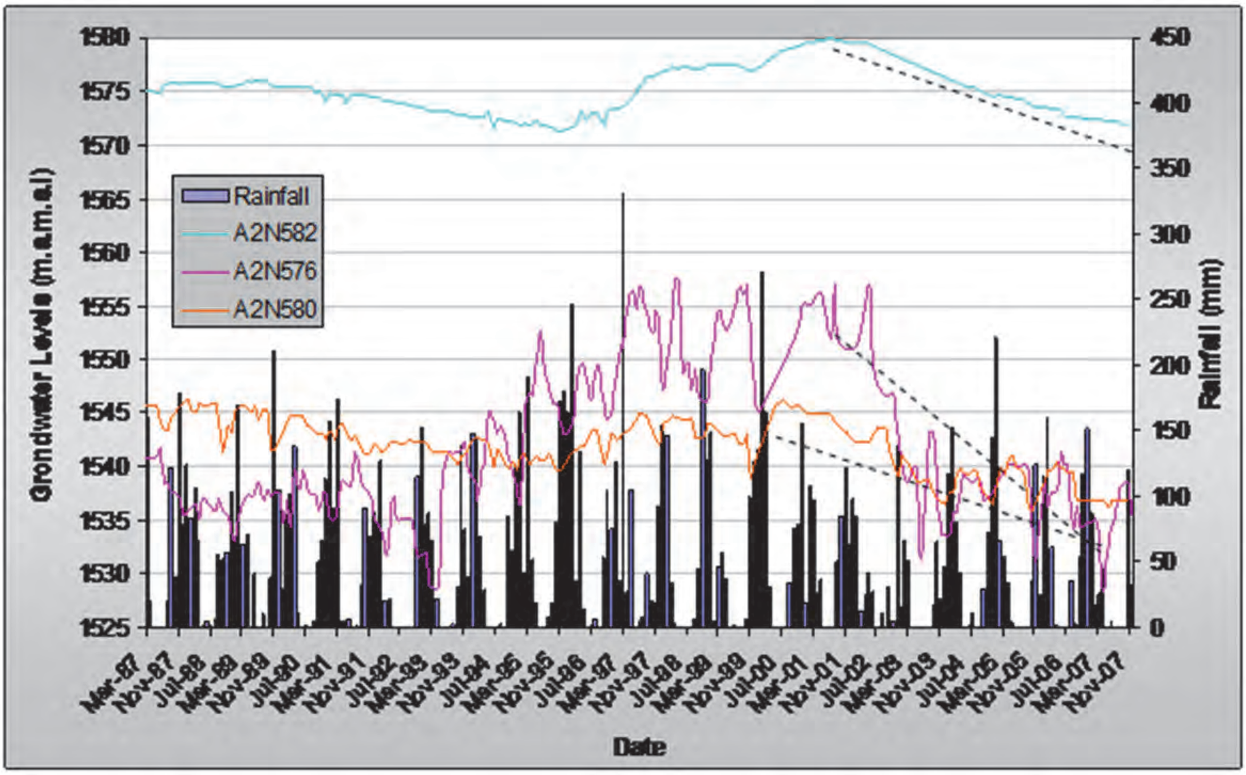


Figure 9.9. Monthly groundwater level trends versus monthly rainfall for the period 1987 to 2007.

The flow vectors were drawn tentatively based on the inverse distance weighting interpolated groundwater level data of Holland, (2007) and from specialist reports (Hobbs and Cobbing, 2007). Groundwater flow is predominantly from the south towards the Rietspruit, and after the confluence with the Blaauwbankspuit groundwater flow gently sweeps towards the SE to NW striking dyke in the northeast (Figure 9.10).

The following further interpretations were made from Figure 9.10:

- The most southerly EW striking dyke has a definite influence on groundwater elevation confirming the dyke as a hydrogeological barrier.
- Groundwater levels may have been impacted by large scale abstraction at certain places in the southern sub-compartment with a slight impact on flow direction.
- Several karst springs act as natural outflows for groundwater within the sub-compartments; this is especially evident in the most northerly sub-compartment.

9.3.4 Groundwater Recharge

High intensity rainfall during January and February commonly generates recharge. The absence of surface drainage channels and low surface run-off from the karst, suggests that most of the recharge emanates from rainfall infiltration. However, large amount of effluent return flow enters the underground network of the karst system via swallow holes and leaching beneath the riverbed. Bredenkamp et al. (1986) indicated that this artificial recharge significantly impacts the water balance estimation of the Zwartkrans compartment. Reasonable groundwater recharge estimations exist in the available literature for the Zwartkrans compartment with different methods showing general agreement. The results of all available and recharge calculations for the study area are summarised in Table 9.6.

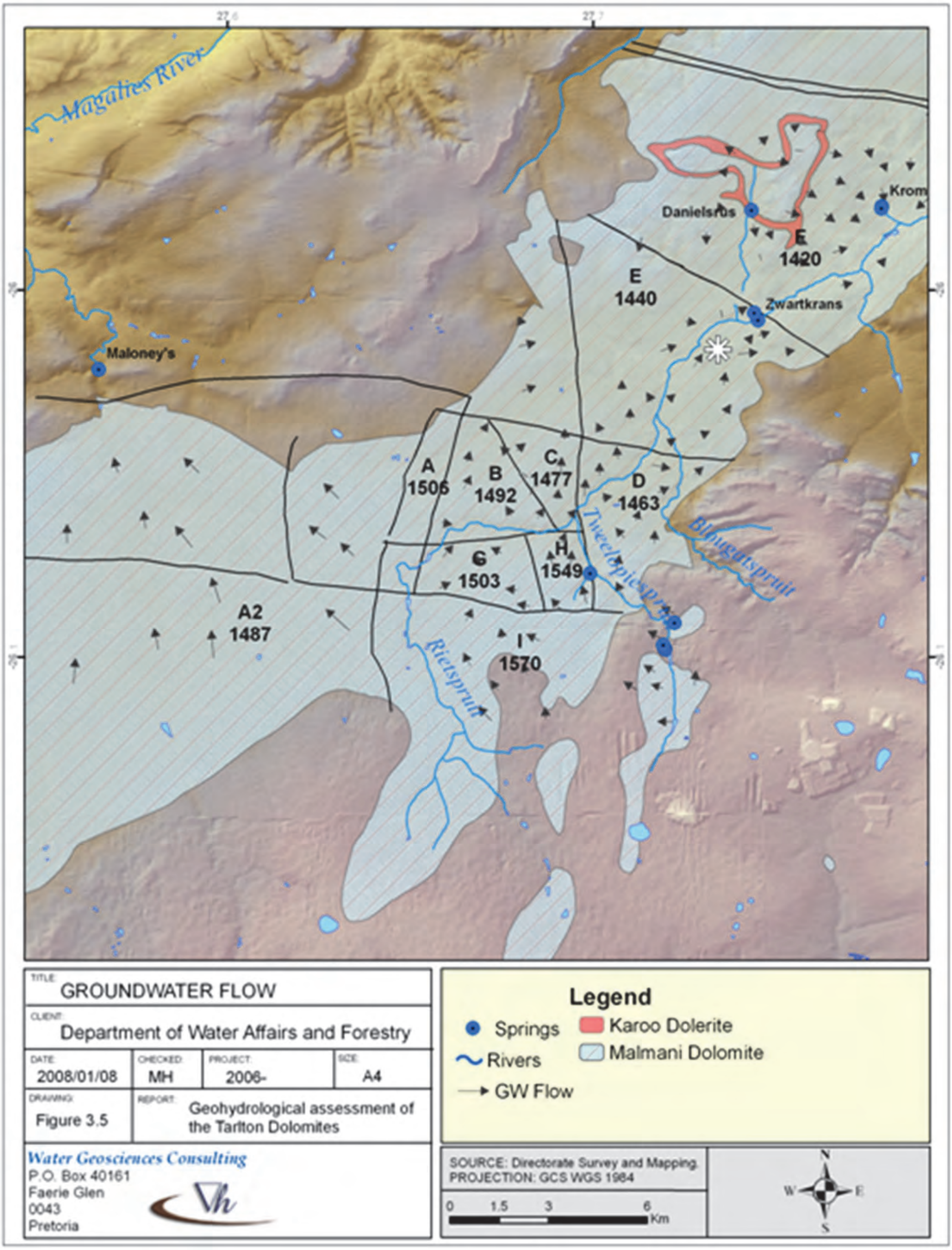


Figure 9.10. Groundwater drainage map (vectors drawn in tentatively) and representative mean groundwater elevation levels (mamsl).

Table 9.6. Recharge estimations based on qualified guesses and previous reports (Zwartkrans compartment).

Method	Recharge (mm/a) Rainfall=710.2 mm/a)	Recharge %
Soil information	93.8	13.2
Geology	58.9	8.3
Vegter's Recharge Map (1995)	95.0	13.4
Harvest Potential Map	69.5	9.8
Specialist report: Bredenkamp et al. (1986)	99-120 (rainfall – 660 mm)	15.0-21
Holland (2007) (CRD-method and CMB)	113.6	16
Average	85.64	11.94

Annual recharge estimations in the Steenkoppies compartment conducted by Bredenkamp et al. (1986) based on spring flow and rainfall-recharge relationships are between 13.9 and 14.5% of the average annual rainfall.

9.3.5 Aquifer Parameters

Bredenkamp et al. (1986) measured transmissivity values ranging from 1 to 25 100 m^2/day based on more than 30 pumping test analyses in the Zwartkrans compartment. The values are indicative of the highly anisotropic and heterogeneous character of the karst aquifer. Values obtained from slug test conducted by the University of Pretoria in the northern part Zwartkrans compartment vary between 37 and 7400 m^2/day. Holland (2007), as well as, Bredenkamp et al. (1986) have shown that the chert content in the aquifer has an influence on the transmissivity (*T*) values. The chert poor formations weather evenly to produce a low storage potential residue of silty clay. The chert rich formations weather quite differently and are more permeable. The dolomite weathers faster than the chert leaving the rock supported by chert structures. Eventually the chert will weather and collapse under its own weight leaving a permeable coarse chert breccia. Chert rich formations develop a greater concentration of fissures and fractures which will enhance the process of weathering. Transmissivity values in the thousands can be expected suggesting an excellent aquifer with high permeability.

9.3.6 Geochemical Description

The investigated karst aquifer demonstrates variations in the groundwater chemistry related anthropogenic activities. Degradation of groundwater quality is observed in most parts of the karst catchment more specifically the Zwartkrans compartment, where anomalous high concentrations of sulphate, chloride and nitrate were measured (Holland, 2007). Hobbs's (2007) hydrogeological assessment of the acid mine drainage south of the Cradle indicated the threat of anthropogenic activities on the quality of groundwater in especially the southern Zwartkrans compartment. Both these investigations focused on the Zwartkrans compartment.

The locations of the water quality monitoring points for the Zwartkrans and Steenkoppies compartment, available at the time of the study, are illustrated in Figure 9.11. The chemical dataset is based on three groundwater and surface water chemical datasets for the COHWHS. The first dataset was collected by the Department of Water Affairs and Forestry (DWAF) as part of the National Groundwater Database (NGDB, 1996 to 2007). Very few boreholes have been sampled on a continuous basis and the data are highly variable in content, reliability and periodicity of sampling. The second dataset is based on sampling conducted during 2005 by the

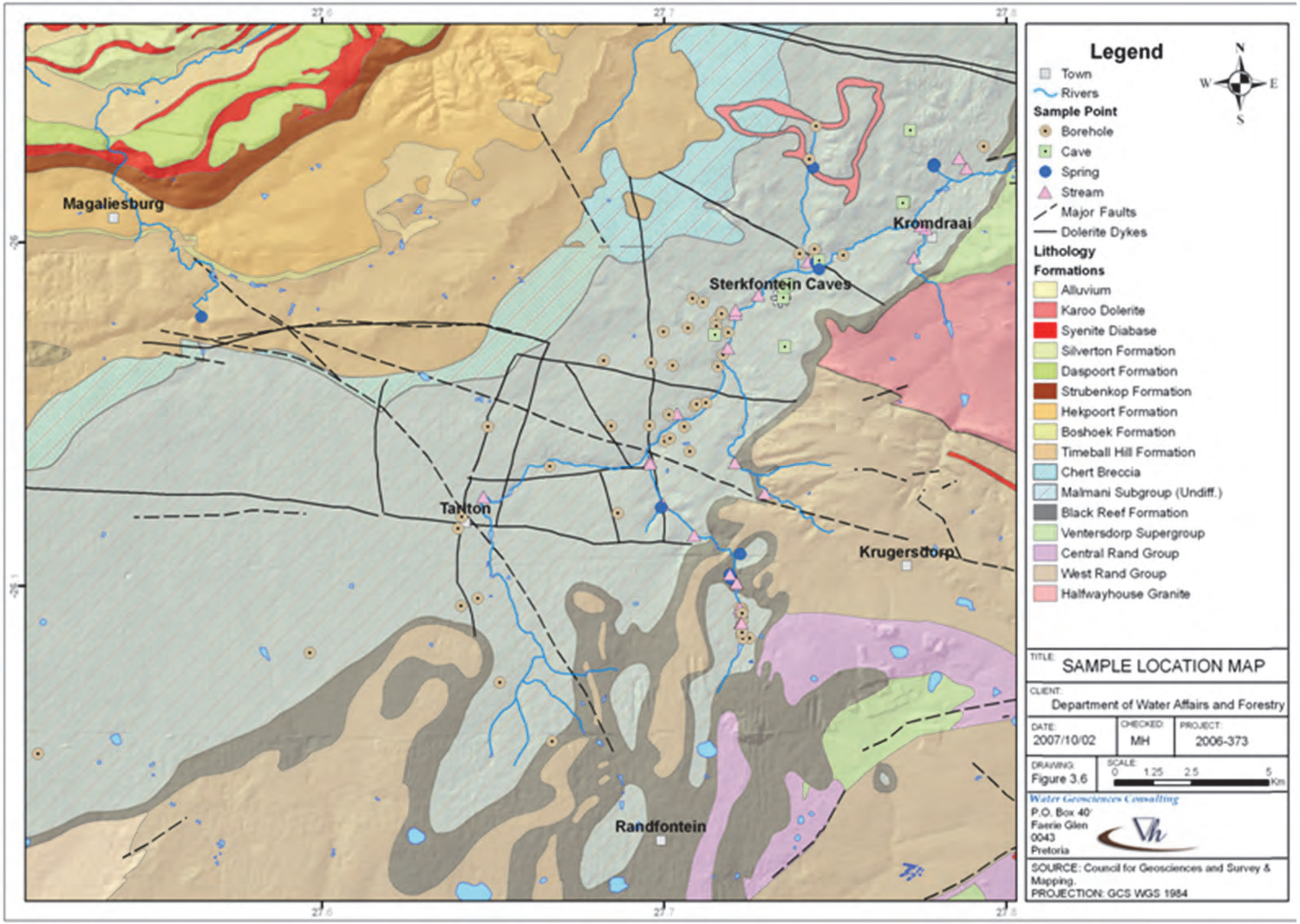


Figure 9.11. Surface water and groundwater quality sample locations.

Council for Geosciences (CGS) on behalf of Gauteng Department of Agriculture, Conservation and Environment. The dataset contains 56 samples retrieved from caves, boreholes, and streams throughout the karst system. The University of Pretoria (UP) sampled the source of the sewage effluent return flow, the decanting mine water, as well as a number of boreholes and springs during and after the rainy season (2005-2006).

From the onset it is apparent that there is a lack of monitoring data in the Steenkoppies compartment. Further, the three or four chemical data sampling points in the NGDB for the Steenkoppies compartment were only sampled up to 1996. This is similar to the NGDB chemical data observed for the Delmas/Bapsfontein dolomites, where good monitoring data exist prior to 2000 and inadequate monitoring from then onwards.

9.3.6.1 Water Quality

The Piper diagram presented in Figure 9.12 shows a schematic representation of the mixing that describes the development of the water quality in the karst catchment (Group "A" in Figure 9.12). The mixing derives from three end-members, 1) "pristine" dolomitic groundwater (Group "B"), 2) the grouping of surface and groundwater influenced by acid mine drainage (Group "C") and 3) Blougat Spruit surface water draining effluent returns flows from the Percy Stewart Sewage works (Group "D"). The chemical evolution from a Ca-Mg-HCO_3 water type toward a SO_4 type is the main chemical evolution trend with a lesser contribution of Na-rich type waters on the water chemistry slightly displacing water samples away from the Group B-C trend line (Figure 9.12).

The water samples have an equivalent mole ratio of Na/Cl larger than one, clearly deviating from ratios determined by Galloway et al. (1983) for Atlantic rainwater (0.81-0.90) or seawater (0.86). In the absence of chlorite bearing strata and based on observed high chloride concentrations at the outlet and downstream of the waste-water treatment plants the distinctively elevated chloride concentrations could be related to waste-water treatment return flows (Holland and Witthüser, 2007).

The Electrical Conductivity (EC) distribution map (Figure 9.13) confirms the direction of the evolving trends and is consistent with increasing specific conductance towards the anthropogenic sources. In the absence of other sulphate sources in the dolomites, the elevated sulphate concentrations indicates a strong anthropogenic signature which could be attributed to the hydrochemical influence of both the acid mine drainage and the effluent return flows on the water quality. Taking the sparse chemical dataset in the Steenkoppies compartment into account, it nevertheless seem that the extent of anthropogenic impacts is confined to the Zwartkrans compartment and more specifically along the flow paths of the Tweelopiespruit and Blougat Spruit (Figure 9.13). Swallow holes and diffuse leakage from rivers acts as one of the main contributors to recharge of the karst system and have altered the groundwater chemistry at significant distances from the pollution sources. Although the above information illustrates that the direct drainage of large volumes of municipal wastewaters and polluted mine water into the catchment's tributaries has changed the natural chemistry of the karst aquifer, the groundwater within the Zwartkrans compartment is still within the acceptable limits for drinking water in South Africa (SANS, 2011). However, at the source of mine drainage, sulphate, calcium and magnesium concentrations as well as EC far exceed the acceptable limits for drinking water in South Africa, which are 400 mg/l, 150 mg/l, 70 mg/l and 150 mS/m respectively (SANS, 2011). Chemical analysis of 223 samples consulted for the assessment of dolomitic groundwater quality from the Chuniespoort Group by Barnard (2000), revealed mean sulphate, chloride, magnesium and EC concentrations of 71 mg/l, 38 mg/l, 35 mg/l and 63 mS/m. These values could be a good indicator of the quality of South African dolomitic groundwater, which is slightly more mineralised than natural or pristine dolomitic groundwater due to prolonged mining activities in dolomite areas.

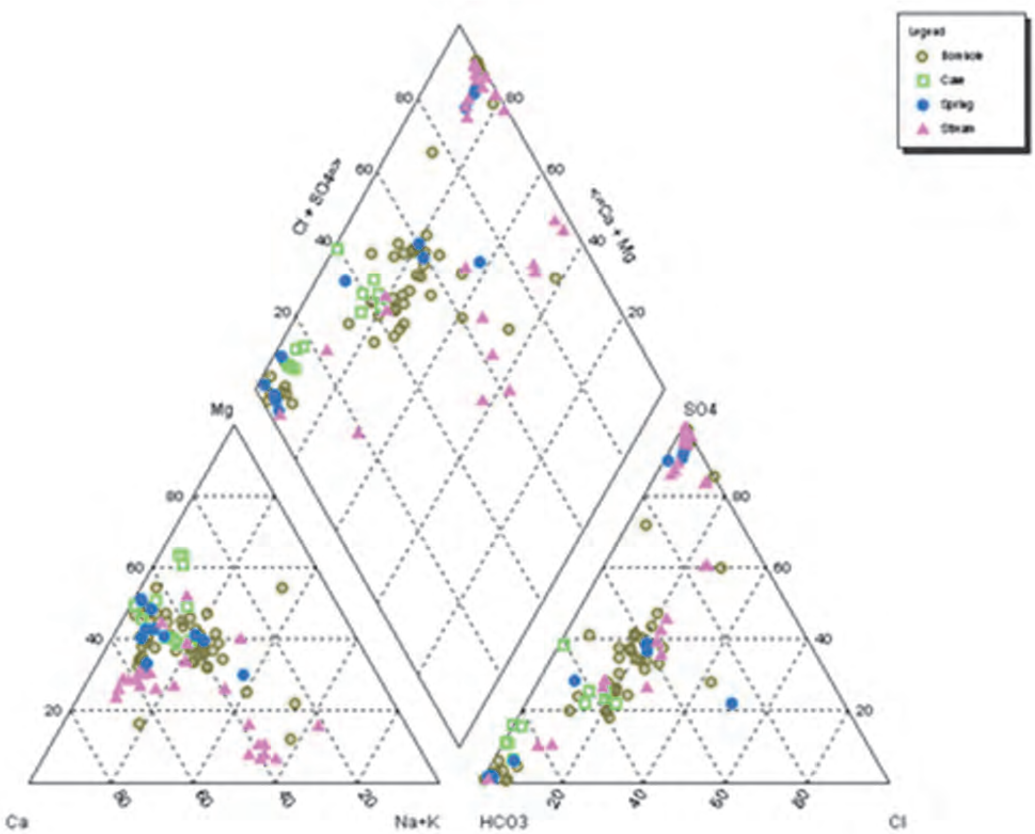


Figure 9.12. Piper diagram showing the main water types in the area under investigation.

9.3.6.2 Potential impacts on caves

Pollution can influence cave ecology in several different ways. Since many cave habitats are dependent on water, the pollution of water entering the karst system and recharging the natural caves reservoirs could have a devastating and long-term effect on cave ecosystems. In addition, Durand (2005) indicated that limestone and dolomite mining has damaged the cave structure in numerous caves in the Cradle of Humankind including Sterkfontein, Wonder Cave, Haasgat, Bolt's Farm and Gladysvale. The decanting of Acid Mine Drainage upstream of the caves threatens the structural stability of the karst system and there exist a real threat of excessive karstification in this area. In order to preserve the cave systems it is essential to identify the most sensitive areas and establish monitoring programmes accordingly. Recent chemical parameters obtained from the borehole at the Sterkfontein caves indicate sulphate, and chloride levels of 154 mg/l and 55 mg/l respectively, undoubtedly indicating anthropogenic impacts.

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9.4 Water Resources Evaluation

9.4.1 Groundwater Use

An evaluation of data sourced from the DWAF's Water Authorisation and Registration Management System (WARMS) yielded a good indication of groundwater use in the Tarlton dolomitic compartments (Table 9.7). It is important to note that this data has not been verified by DWAF's regional offices; therefore evaluation of both the groundwater water data should be done with this in mind.

Table 9.7. Summary of WARMS-based groundwater use information (2007).

Compartment/ Area	Sub-Unit	Area (km^2)	No. of Users	Registered Volume (m^3/annum)	Water Use Sector
Zwartkrans	A	4.3	6	276 326	Agriculture: irrigation/livestock
	B	7.4	6	253 780	
	C	5.3	3	215 458	Agriculture/Industrial
	D	14.4	1	12 280	Agriculture: irrigation
	E	46	15	1 538 438	Agriculture: irrigation/livestock
	F	60	5	44 321	Agriculture/Industrial
	G	7.2	25	1 048 384	Agriculture: irrigation
	H	2.8	-	-	-
	I	30.6	67	5 379 961	Agriculture/Industrial
	TOTAL:			**8 768 948**	
Steenkoppies	A1	43.8	21	1 768 943	Agriculture: irrigation
	A2	119.2	24	5 619 429	Agriculture: irrigation/livestock
	B	14	1	1 788 490	Agriculture: livestock
	TOTAL:			**9 176 862**	
Combined	GRAND TOTAL:			**17 945 810**	

The registered groundwater abstraction volumes and localities are indicated in Table 9.7. Taking the accuracy of the data into consideration, the information nevertheless indicates a large number of registered groundwater users in the both the Zwartkrans and Steenkoppies dolomitic compartments. Earlier reports by Vegter (1986) and Bredenkamp et al. (1986) suggested much higher groundwater abstraction rates for the Tarlton dolomites. Groundwater abstraction for irrigation was estimated at 15 Mm^3/a and 13 Mm^3/a for the Zwartkrans and Steenkoppies compartment respectively. More recent groundwater abstraction estimates by Schoeman & Associates (2006) for the Zwartkrans compartment was based on the amount of water required from the aquifer for irrigation from satellite images. This method revealed an estimated abstraction rate of 14.08 Mm^3/a. However, Krige (2006) estimated a value of 25.5 Mm^3/a and believed that Schoeman and associates did not include all areas under irrigation from satellite photographs. Without the validation of true abstraction rates in the compartment this component remains critically uncertain and should be addressed. Based on the decline in water levels (up to 3 m) in the preceding sections it is fair to assume a conservative groundwater abstraction rate of

18 Mm^3/a in the Zwartkrans compartment and 16 Mm^3/a in the Steenkoppies compartment. It is evident that numerous borehole owners are not registered groundwater users under Section 21(a), taking water from a resource.

9.4.2 Surface Water Use

An evaluation of data sourced from the DWAF's Water Authorisation and Registration Management System (WARMS) yielded the summary of surface water use information presented in Table 9.8.

Table 9.8. Summary of WARMS-based surface water use information (2007).

Compartment/Area	**Sub-Unit**	**Area (km^2)**	**No. of Users**	**Registered Volume (m^3/annum)**	**Water Use Sector**
Zwartkrans	D	14.4	1	23 100	Agriculture: irrigation
	E	46	2	97 662	
	F	60	5	813 540	
	G	7.2	1	253 125	Agriculture: irrigation/livestock
	I	30.6	24	2 266 983	Agriculture: irrigation
	TOTAL:			**3 454 410**	

In the absence of surface drainage channels abstraction from streams or rivers is not a complicating factor in the case of the Steenkoppies compartment. In contrast the Zwartkrans compartment's rivers do carry surface runoff and effluent disposal from both mining and waste water treatment activities. The dolomite aquifer contributes substantially to groundwater base flow, where there is direct hydraulic connection with the river and where springs comprise the source of streams (Holland, 2007). As a result large scale abstraction for irrigation activities occur along the Blaauwbankspruit river course (Table 9.8). The Danielsrus, Zwartkrans and Kromdraai springs discharges at about 0.1, 8.1 and 0.9 Mm^3/a respectively from sub-units E and F (Figure 9.14). Increased unsustainable groundwater utilization could reduce or even dry up spring flow, which will be detrimental to surface water users downstream. Monthly flow data from station A2H010 Maloney's Eye is illustrated in Figure 9.15 and clearly indicates the diminishing flow during the last couple of years. Monthly rainfall data is obtained from the Krugersdorp weather station. DWAF (2007) reported a decrease of the Maloney's Eye spring flow from 6.5 Mm^3/a to 4.5 Mm^3/a as a result of abstraction from boreholes in the dolomite aquifer near the spring. The decreasing flow of the Maloney's Eye and the diminishing flow further downstream has been a cause of great concern for both the authorities and registered water users. Detailed flow simulations of the Maloney's Eye by DWAF (2007) have revealed a negative water balance for the catchment and increased recharge occurs from the base of streams and rivers into the aquifer during dewatering. An immediate protection zone of 3.5 km and a secondary zone of 5 km for the spring flow have been delineated. Within these zones, abstraction rates are limited while compulsory licensing is essential as an immediate measure to protect the aquifer (DWAF, 2007).

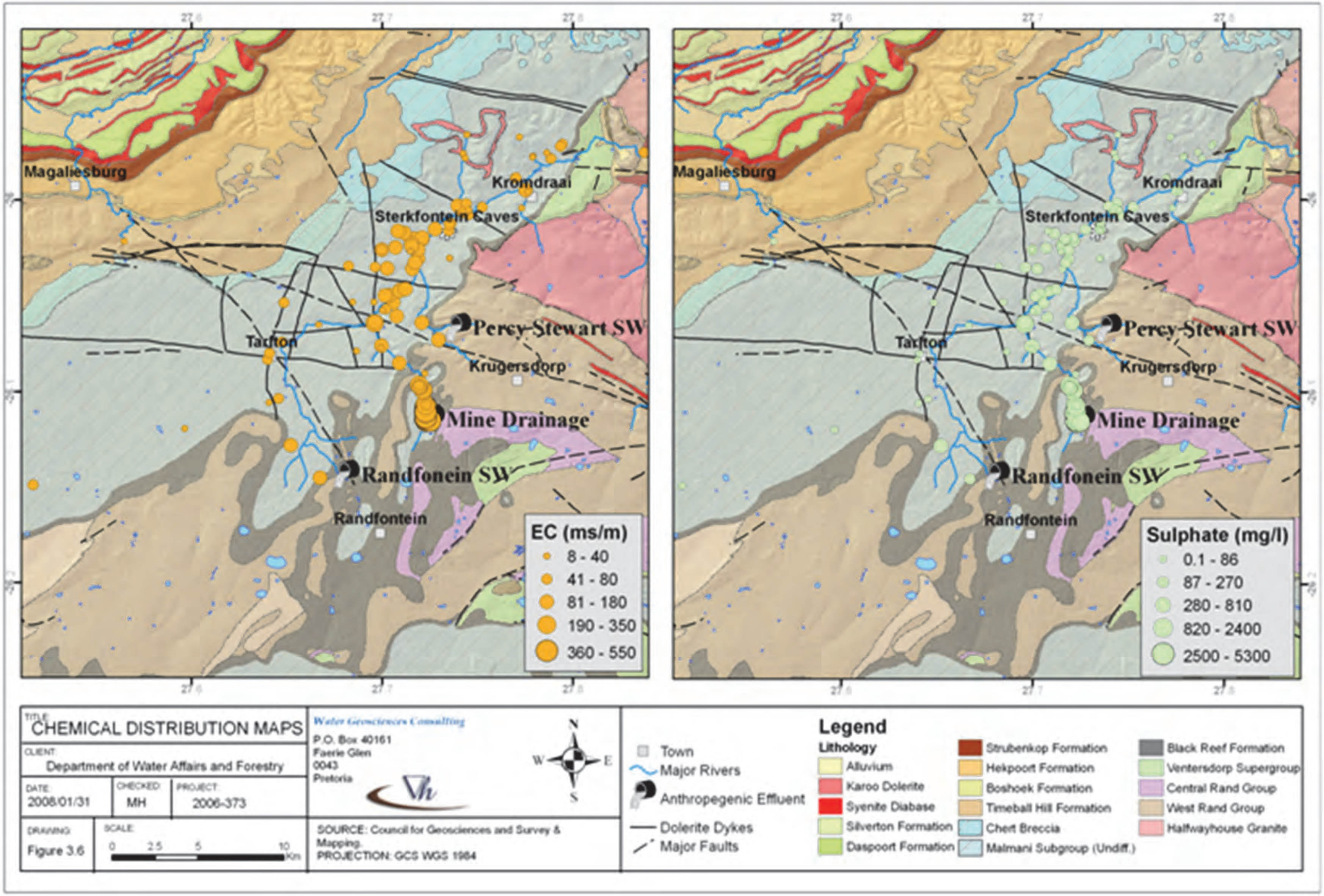


Figure 9.13. Electrical conductivity and sulphate distribution maps (Based on the last available chemical sample 1996-2007).

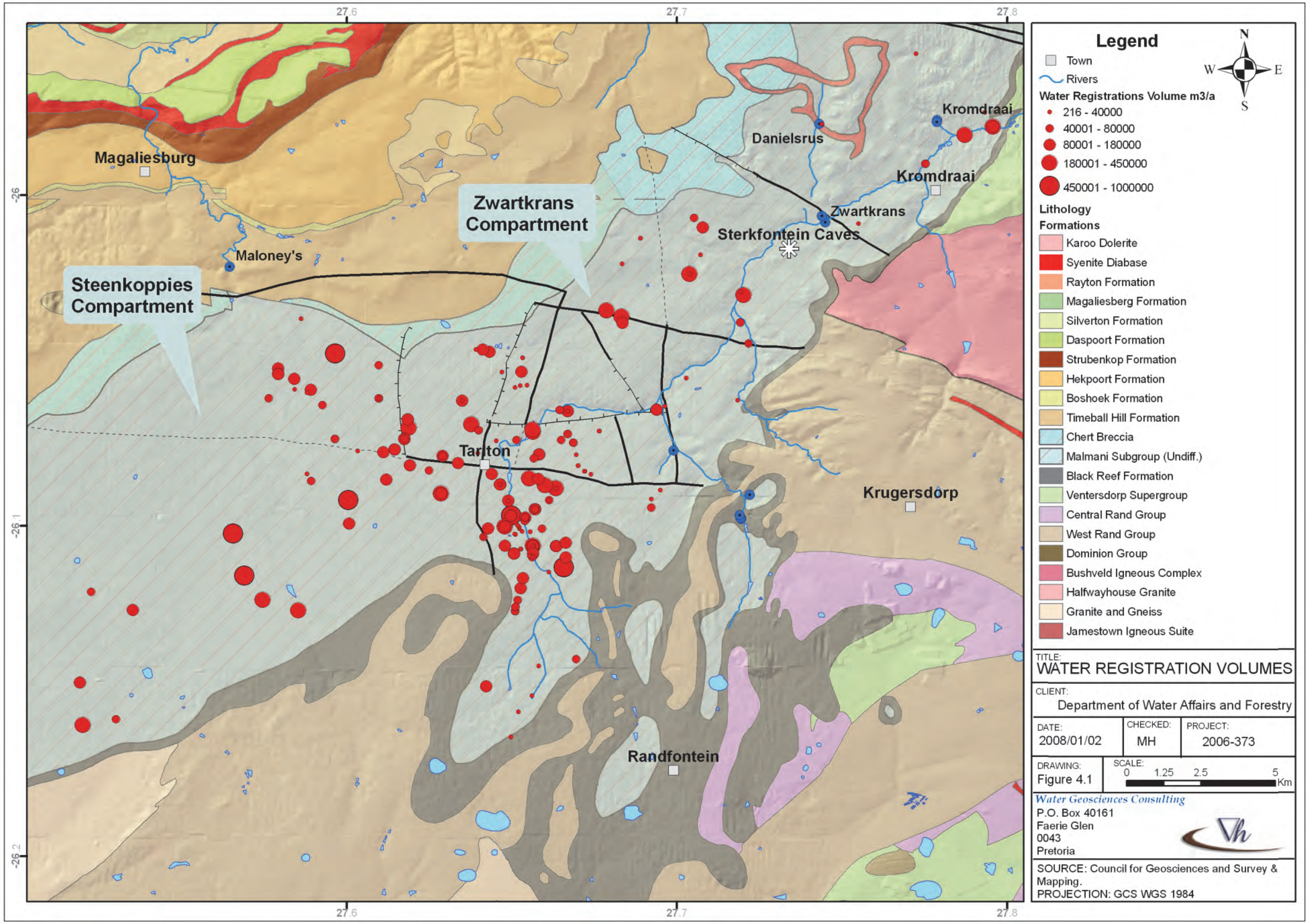


Figure 9.14. Location of annual groundwater authorisation abstraction volumes (Sourced from: WARMS).

9.4.3 Water Balance Information

9.4.3.1 Groundwater Resource Units

In dolomitic environments it has been shown that with the presence of sub-vertical dykes hydrogeologically isolated compartments can be identified which exhibit different hydrostatic response patterns. The identification of groundwater resource units is imperative in Reserve determination assessments and accurate water use licensing. In this study a conceptual understanding of the two dolomitic areas under investigation formed the basis for the identification of groundwater resource units.

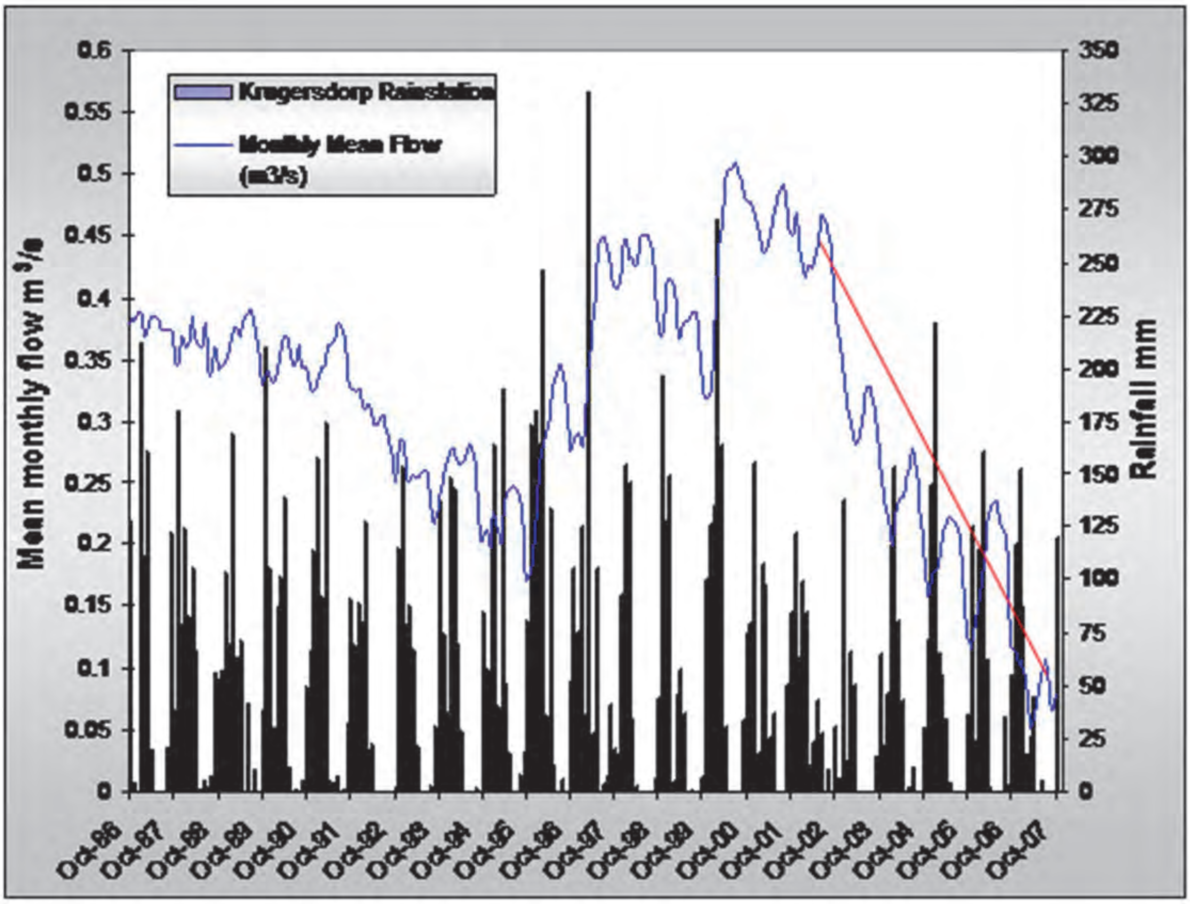


Figure 9.15. Long-term hydrograph for Maloney's eye flow gauge station.

The proposed groundwater resource units as depicted in this study include:

- Zwartkrans compartment (GRU 1)
- Steenkoppies compartment (GRU 2)

9.4.3.2 Groundwater Balance

It is beyond the scope of this investigation to provide a detailed account of all the groundwater inflows, outflows and groundwater contributions to baseflow in the mentioned resource units. However to assess the status of the resource unit under investigation it remains critical to provide some basic water balance information. This in return will assist in decision making regarding resource classification and setting of resource quality objectives which is imperative for Groundwater Resource Directed Measures (GRDM) assessments. A number of studies even as early as 1986 (Bredenkamp et al., 1986) have documented the lowering of the water level due to large scale irrigation and abstraction rates far exceeding the rate of groundwater recharge. Consequently any further exploitation relies exclusively on groundwater in storage in the various dolomitic compartments and sub-units. A summary of the groundwater units, use, availability and recharge is illustrated in Table 9.9. It takes into account storage potentials determined in the 1980s for the dolomitic aquifer and based on the decreasing water levels in Table 9.5 provides a reasonable indication of the amount of storage used since this period.

Table 9.9. Water balance information for resource units identified.

Resource Unit	Sub Unit	Area (km^2)	Potential Storage upper 5 m (Mm^3)*	Recharge (16% of Annual Rainfall) (Mm^3/a)	Groundwater Abstraction (Mm^3/a)	Spring Flow (Mm^3/a)	Potential Storage used based on water level decline (Mm^3)#
Zwartkrans GRU 1	A	4.3	2.15	16.8	18.0	9.0	2.4
	B	7.4	3.7				5.28
	C	5.3	2.65				-
	D	14.4	7.2				4.58
	E	46	23				10.12
	F	60	30				-
	G	7.2	3.6				-
	H	2.8	1.4				0.35
	I	30.6	15.3				14.32
	Total	178	89	16.8	18.0	9.0	37.05
Steenkoppies GRU 2	A1	2	21.9	15.9	16.0	15.5	0
	A2	119.2	59.6				30.15
	B	14	7				-
	Total	177	88.5				30.15

* As determined by Bredenkamp et al. (1986) for the emergency supply potential for dolomitic aquifers west of Krugersdorp. Aquifer porosity determined as a conservative 10%.

\# Based on the mean cumulative water level change within each sub-unit (Table9.5). Aquifer porosity determined as a conservative 10%.

\- No groundwater level measurements.

9.4.3.3 Emergency Supply Potential

The emergency supply potential investigation of the dolomitic compartments in 1986 indicated significant volumes of water available in the Tarlton dolomites and in particular sub-units A, B, C, D, E and A2. In most cases it was suggested to fully exploit only the upper five meters for emergency supply purposes. Accordingly only 74 Mm^3/a and 66 Mm^3/a were recommended as an emergency groundwater potential in the Zwartkrans and Steenkoppies compartments respectively. Based on Table 9.9 almost 50% of the available storage in the upper 5 m of both the dolomitic aquifers has been utilised. Any emergency supply exploitation will have to consider the upper 10 m of storage, however the risk for sinkhole development and subsidence will significantly increase and most springs in the area will dry up. The only reasonable emergency exploitation supply could be obtained from sub-unit A2 in the Steenkoppies compartment with and exploitable storage in the upper 10 m of 150.45 Mm^3 (Bredenkamp et al., 1986) However this amount may have decreased to 120.3 Mm^3 according to the exploited storage volumes in Table 9.9.

Considering the deficiency of data in some sub-units it remains clear that most of the dolomitic groundwater resource units of the Tarlton area are stressed aquifers. Any future groundwater allocation will rely heavily on our ability to accurately predict the responses and status of the resource unit under investigation. In some situations no further groundwater should be allocated and this will require enforced restrictions of abstraction. On the other hand increasing groundwater abstraction in certain sub-units (e.g. sub-unit H) could intercept the polluted mining water before it reaches neighbouring compartments. This will however require proper monitoring stations of both groundwater quality and groundwater levels.

9.5 Aquifer Management

9.5.1 Background

Due to the physical characteristics of the host rock, water resources in dolomitic areas are particularly vulnerable to over-exploitation, unsustainable practices and pollution. This vulnerability aggravates the potential impact of land use on the dolomitic groundwater resources. Assessment, planning and management as described within the Dolomite Guideline by DWAF (2006) provide three interrelated steps that will assist in the sustainable development, protection and management of the groundwater resources and will assist in achieving the overall goal of integrated water resources management (IWRM).

9.5.1.1 Management Issues

Recently, numerous geohydrological assessments have been undertaken on the Tarlton/Steenkoppies dolomites (Van Biljon, 2005; Krige, 2006; Hobbs and Cobbing, 2007; Holland and Witthüser, 2007). These assessments provide a valuable overview of the water resources (in terms of both water quantity and quality) within the Tarlton/Steenkoppies dolomites and present various challenges related to the management of these aquifers. The Tarlton/Steenkoppies dolomitic aquifers have been extensively impacted by mainly three anthropogenic sources 1) decanting of acidic mine water associated with gold mining activities in the nearby Witwatersrand sediments, 2) discharge of inadequately treated sewage from the two waste water treatment plants and 3) run-off of fertilizers and livestock excrement from the agricultural areas. In addition to the identified pollution risks, exploitation of the aquifer has resulted in declining groundwater levels in both the Zwartkrans and Steenkoppies compartments. The exploitation of the dolomitic aquifer has increased costs associated with irrigation as well as having a detrimental effect on springs and other groundwater-dependent features. The large spring known as Maloney's Eye in particular has significantly lower flow rates compared to the early 1980s. In terms of technical management of groundwater, particularly with respect to the accuracy of groundwater data on which key decisions are based, the following need to be addressed:

- Consistent and reliable groundwater level monitoring (more specifically in the Steenkoppies compartment).
- The spread of groundwater quality monitoring points need to be verified and updated.
- Reliable estimation of abstraction.

To improve the current conceptual understanding of the dolomitic aquifer, the following refinement of the following factors is needed:

- Groundwater drainage of the total area.

- Leakage between compartments (Steenkoppies/Zwartkrans) and outflow and inflow from adjacent geological formations.
- Leakage effects of dykes.
- Water Balance of the total area.
- Simulation of the aquifer response to different scenarios and proposed developments (e.g. location of a waste water treatment plant in the Steenkoppies compartment).

An issue related to all the aspects mentioned above, is the general lack of collaboration between stakeholders. There is a desperate need for closer cooperation with other national government departments (e.g. DEAT and DME) as well as with provincial and local authorities (e.g. Mogale Municipality). This would help with the burden of data collection and analysis, give warning of new developments and/or potential groundwater problems, and generally ensure that efforts are not duplicated.

9.5.1.2 Management Actions

Management is generally an iterative process that involves the setting of management objectives and then monitoring and reporting against these objectives. Immediate actions are to involve all participating stakeholders and public participants to represent the management objectives of the aquifer. Further actions must ensure,

- that the monitoring network is sufficient to provide effective coverage and accurate measurements for management purposes;
- data collection should be managed as part of a value chain and involves correct data collection, recording, handling, archiving and reporting according to an agreed data management system.
- monitoring data and generated information will be used to control water use within the site-specific environment (e.g. stressed Steenkoppies compartment) and provide support to licensing decisions and for future water use allocations.

9.6 Conclusion & Recommendations

The Cradle of Humankind requires a sustainable balance between utilisation and protection of the water resource, in order to protect its vast treasure chest of fossilized remains of past life forms, found in the numerous karst caves. Despite its importance, the ongoing exploitation of the karst aquifer and surrounding catchment has resulted in the deterioration of both the quality and quantity of the groundwater resource. The lowering of the hydrostatic head in the dolomites is evident in both the Zwartkrans and Steenkoppies compartment with abrupt and significant groundwater level fluctuations indicative of over utilization of the aquifers. The significant decrease in the spring flow of the Maloney's Eye is reason for concern and management of the Steenkoppies dolomitic aquifer immediate south of the eye is crucial. DWAF (2007) identified protection zones in the vicinity of the spring and clear recommendations including compulsory licensing was suggested, although it is unclear if these zones are implemented.

The decanting of some 15 Ml/day of polluted mine water in addition to a large volume of treated waste water remains a threat to the quality of groundwater in especially the Zwartkrans dolomitic compartment. The water facies in this compartment have changed due to infiltration of contaminated water from a Ca-Mg-HCO_3 type to an Mg-Ca-SO_4 or Na-SO_4 type. Three hydrochemically different regimes were identified. The karst aquifer receives recharge from tributaries carrying pollutants from acid mine drainage and treated sewage effluent. Inflows into the system occur via swallow holes and leakage through the river bed. The best indicators for the present pollution in the dataset are elevated electrical conductivity and increased concentrations of sulphate, chloride and nitrate. The greatest risk to the use of the groundwater resource is related to the polluted mine drainage, with ion concentrations exceeding the recommended values for drinking water.

Based on these outcomes the following recommendations are proposed:

1) To further elaborate on the groundwater level trends within the identified compartments, continuous, consistent and reliable monthly groundwater level measurements from identified monitoring stations should be conducted. More frequent monitoring is necessary in stressed groundwater resource units and where groundwater monitoring is lacking (e.g. sub-units F and G).
2) The current groundwater quality monitoring programme requires revision. Most monitoring is conducted along the streams and springs downstream of the decanting area with little or no continuous chemical monitoring being done further downstream or in the Steenkoppies compartment. Sub-units that require monitoring include sub-units A, B, G, A1 and A2.
3) The role of bounding dykes, faults and formation contacts on the groundwater flow and extent of lateral leakage of compartments should be clearly understood.
4) Isotope investigations which should include groundwater dating together with tracer tests have proven to be greatly successful in karst hydrogeological investigations (Kranjc, 1997; Trcek, 2003) and a monitoring programme should be initiated to build up long term data.
5) Capturing of abstraction rates from large scale irrigation points is vital;
    - to evaluate and if necessary regulate abstraction in the Steenkoppies compartment and,
    - to assess the role of groundwater fluctuations and changes.
6) There is an urgent need for all available existing data to be collated into a single data set that not only consolidates often duplicate sets, but also eliminates redundant monitoring stations.

APPENDIX 9A

GROUNDWATER LEVEL MONITORING STATIONS

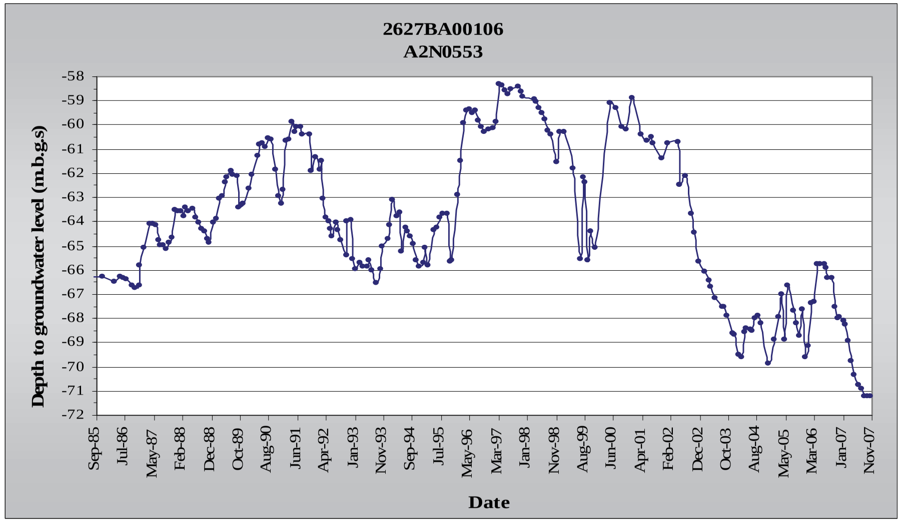
Monitoring Station	Coordinates		Groundwater Level		Length of Record	
	Latitude	Longitude	Depth (m.b.g.s.)	Elevation (m.a.m.s.l.)		
Zwartkrans Compartment						
A2N0553	27.64736	-26.06825	71.24	1501.90	1985/05/23	2007/10/24
A2N0556	27.65449	-26.05177	56.17	1500.19	1985/05/25	2007/10/24
A2N0576	27.64855	-26.09959	52.3	1535.44	1986/01/14	2007/10/09
A2N0579	27.66070	-26.10175	29.24	1575.30	1985/05/21	2007/10/09
A2N0580	27.66557	-26.09415	59.93	1536.84	1985/05/12	2007/10/09
A2N0582	27.69668	-26.08947	42.85	1571.88	1985/06/13	2007/10/09
A2N0583	27.68662	-26.07870	45.5	1550.50	1985/06/10	2007/10/09
A2N0584	27.70002	-26.05788	26.39	1467.85	1985/05/01	2007/09/19
A2N0586	27.70942	-26.04706	27.37	1461.20	1985/05/14	2007/10/10
A2N0590	27.71527	-26.02441	36.42	1441.25	1985/05/20	2007/06/20
A2N0592	27.69783	-26.03081	78.83	1439.08	1985/06/08	2007/10/10
A2N0598	27.67453	-26.06071	63.75	1500.81	1985/07/10	2007/10/10
A2N0600	27.71136	-26.01740	25.5	1438.94	1989/04/19	2007/10/10
A2N0602	27.70544	-26.02713	56.07	1444.47	1987/06/18	2007/10/10
A2N0605	27.68786	-26.02813	63.8	1438.20	1989/04/19	2007/10/10
A2N0607	27.68462	-26.03197	67.84	1440.16	1993/10/19	2007/10/10
Steenkoppies Compartment						
A2N0558	27.56597	-26.02556	9.58	1492.24	1986/01/15	2007/09/27
A2N0559	27.56572	-26.02517	8.19	1492.20	1986/01/15	2007/10/30
A2N0566	27.57500	-26.07528	60.53	1484.59	1985/09/05	2007/10/09
A2N0567	27.57500	-26.07778	60.9	1482.79	1986/01/15	2007/10/09
A2N0572	27.60365	-26.07280	70.95	1487.41	1985/06/26	2007/10/09
A2N0610	27.58253	-26.08589	62.52	1486.41	1987/03/24	2007/10/09
A2N0612	27.57639	-26.08056	57.47	1488.49	1987/06/17	2007/10/09
A2N0614	27.57111	-26.08150	70.04	1489.58	1987/07/15	2007/09/18
A2N0615	27.56667	-26.08056	71.3	1487.70	1987/07/15	2007/10/09
A2N0616	27.56250	-26.08056	70.91	1487.97	1987/07/27	2007/10/09

APPENDIX 9B

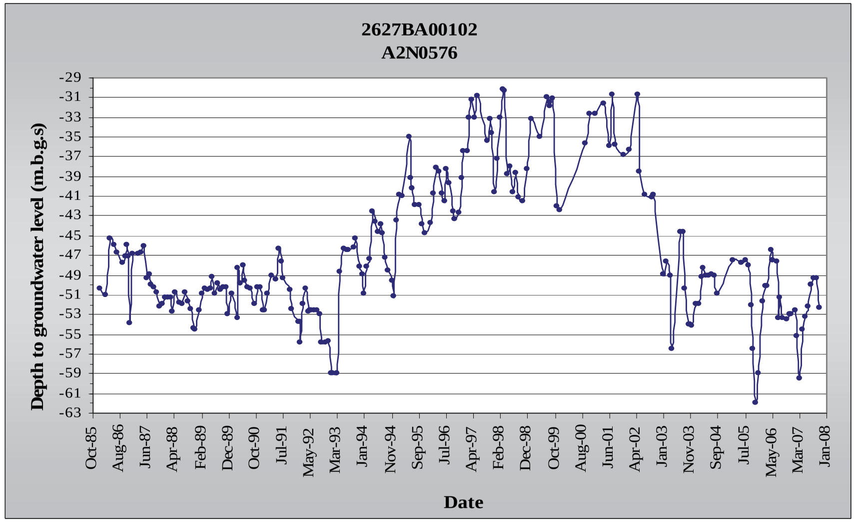
GROUNDWATER REST LEVEL TRENDS

9B.1: Zwartkrans Compartment

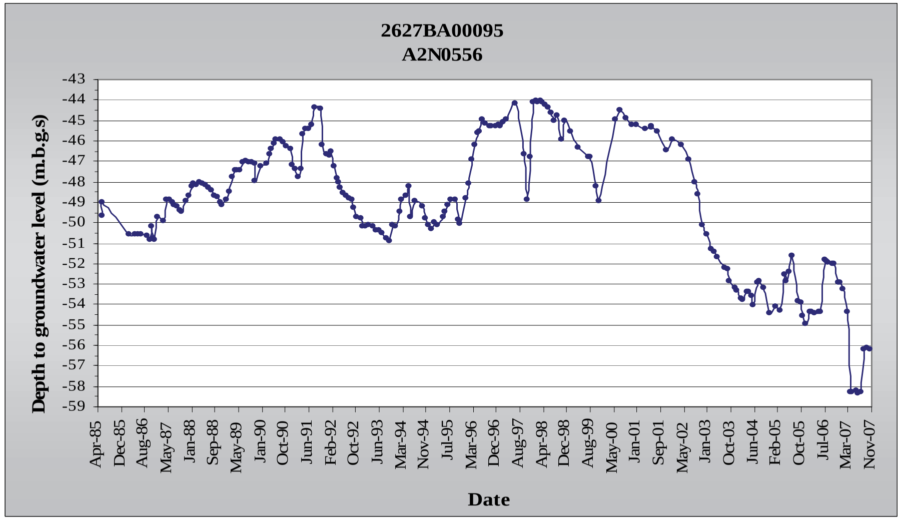
Station : A2N0553



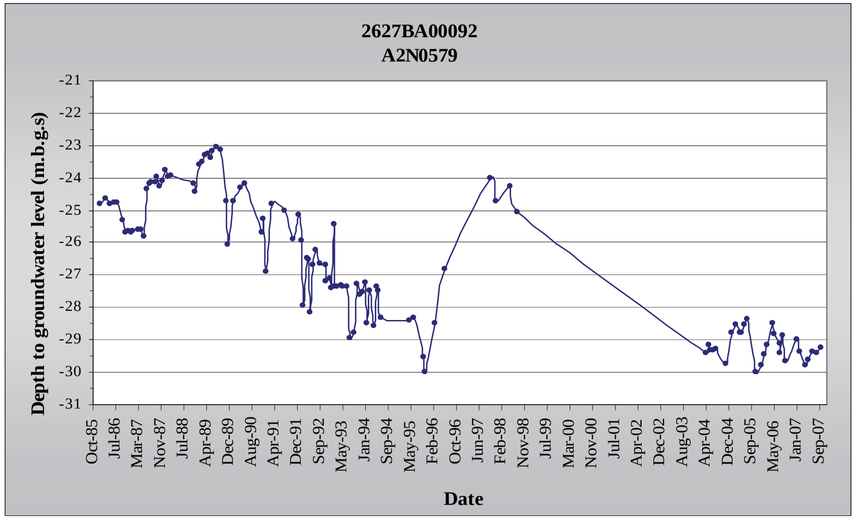
Station : A2N0576



Station : A2N0556

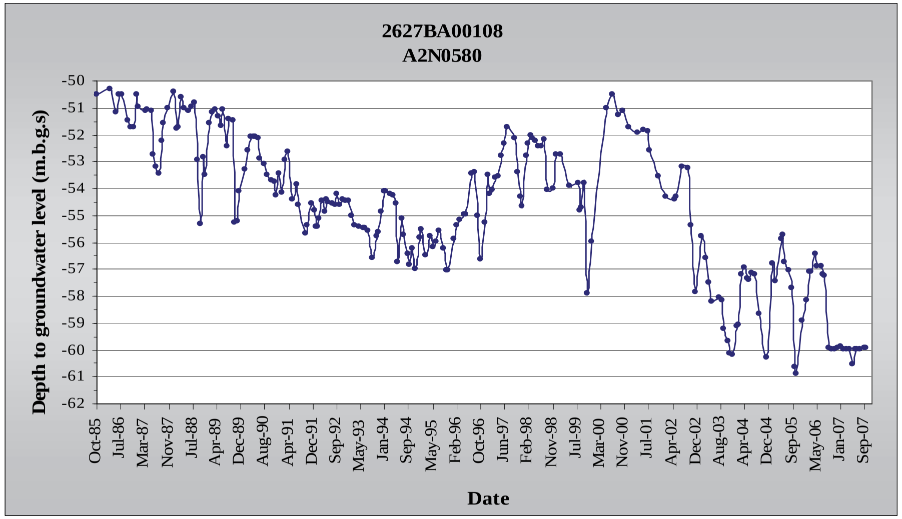


Station : A2N0579

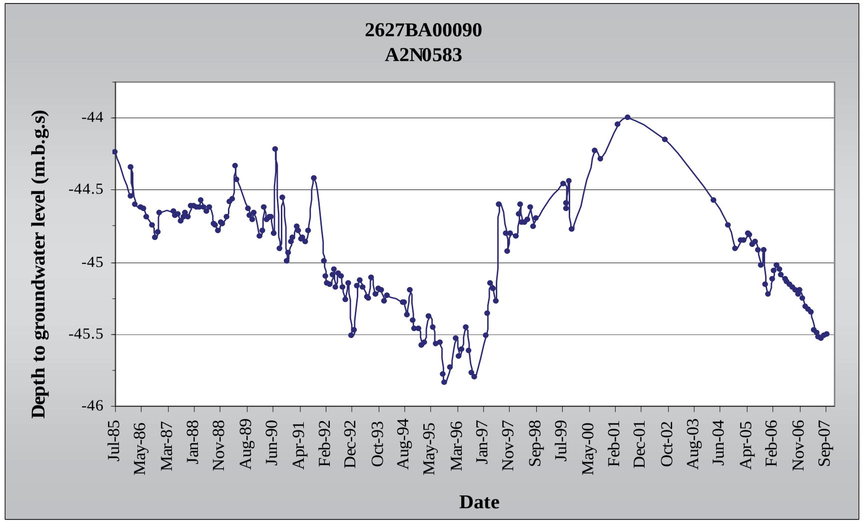


9B.1: Zwartkrans Compartment

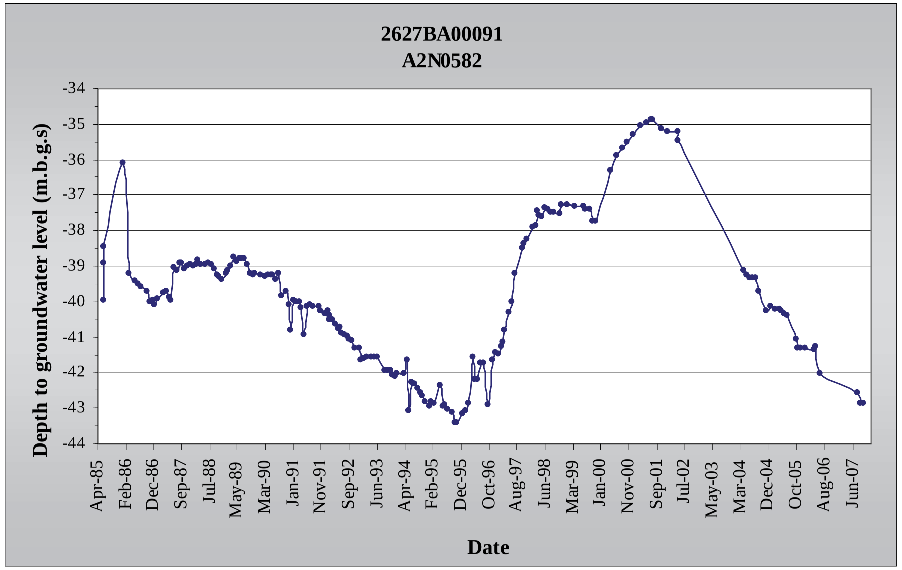
Station : A2N0580



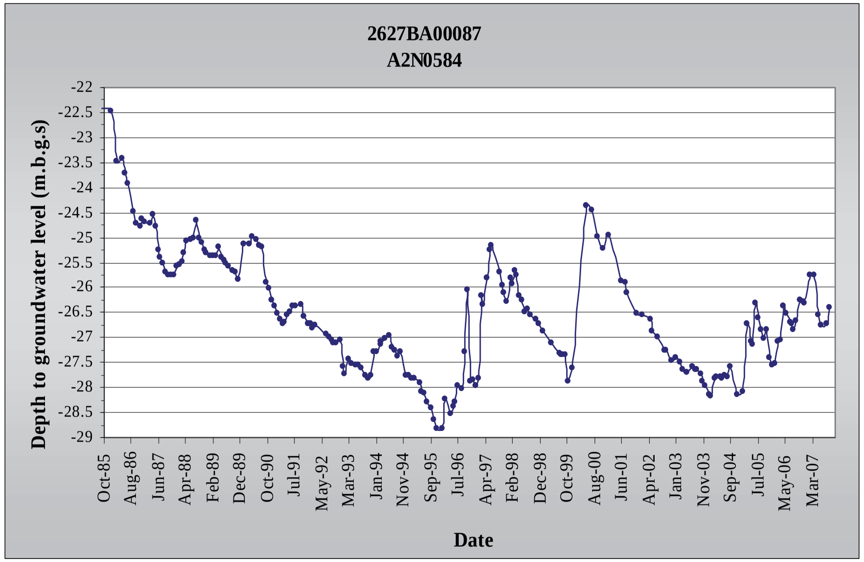
Station : A2N0583



Station : A2N0582

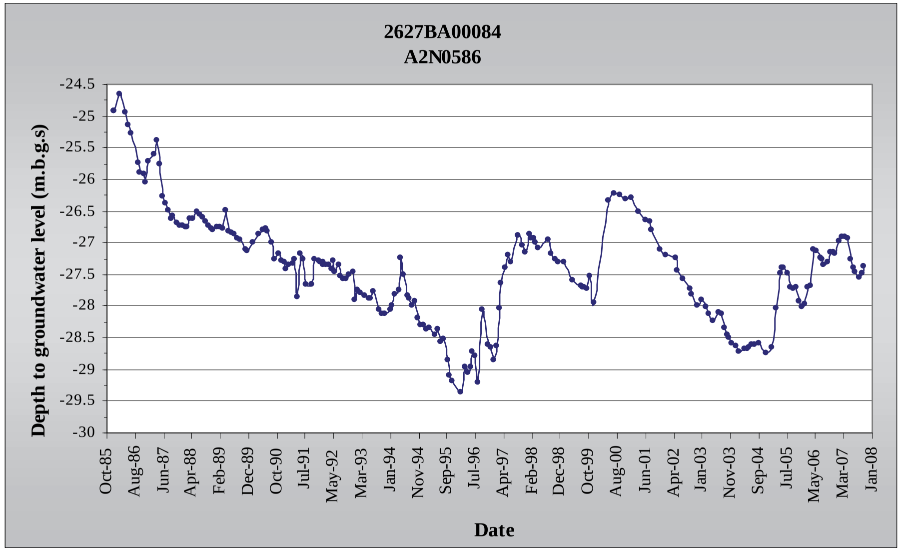


Station : A2N0584

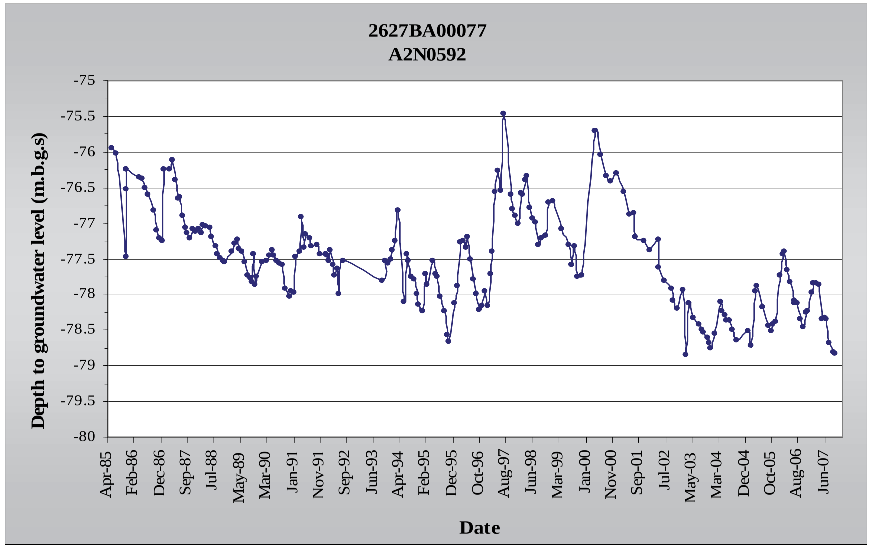


9B.1: Zwartkrans Compartment

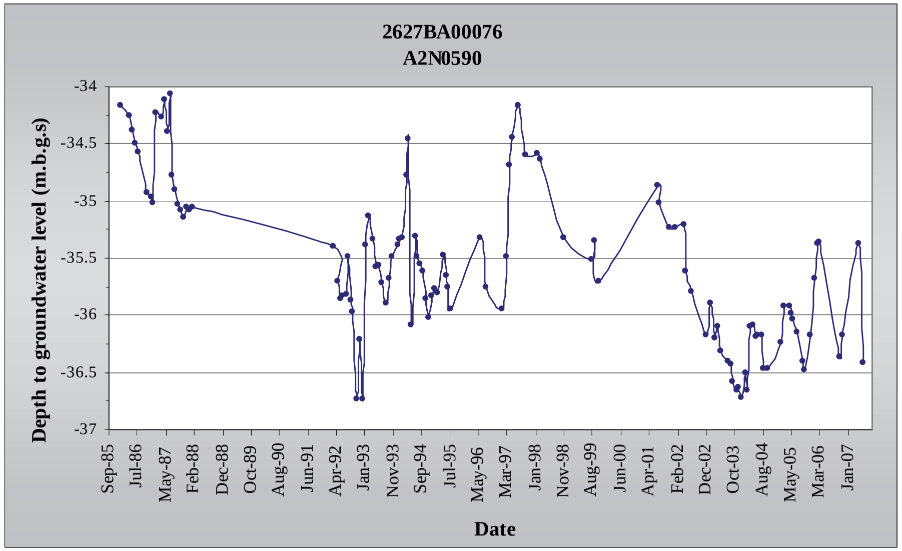
Station : A2N0586



Station : A2N0592



Station : A2N0590



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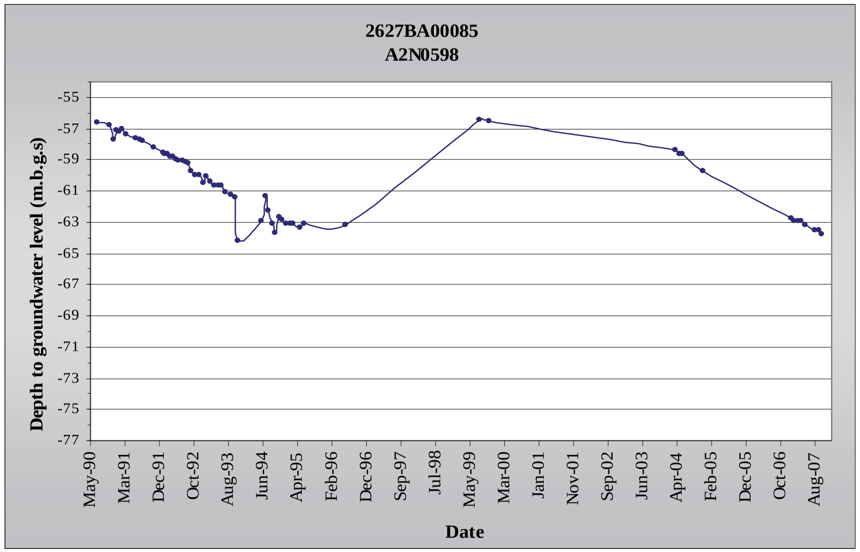

9B.1: Zwartkrans Compartment

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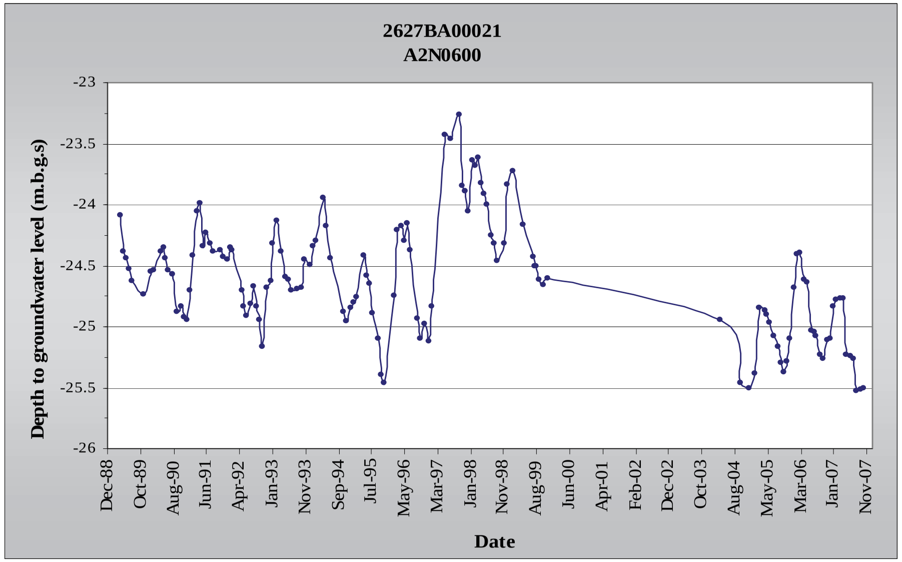
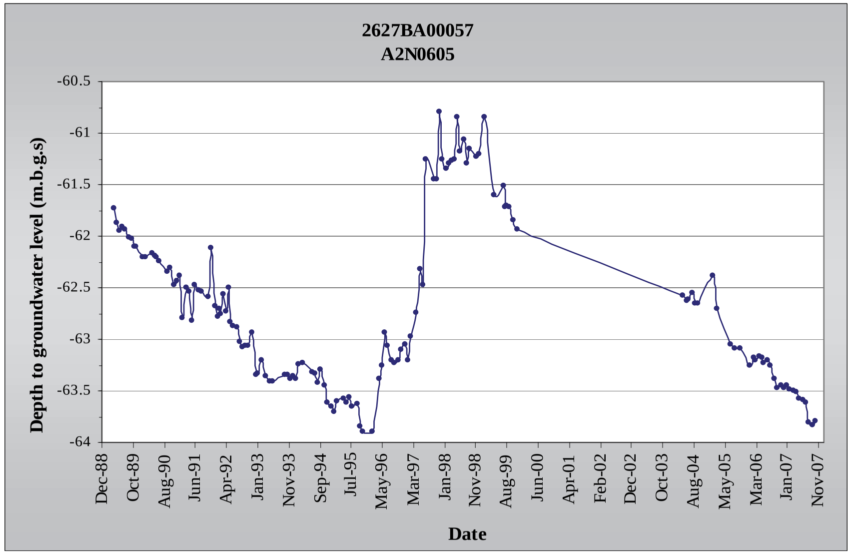
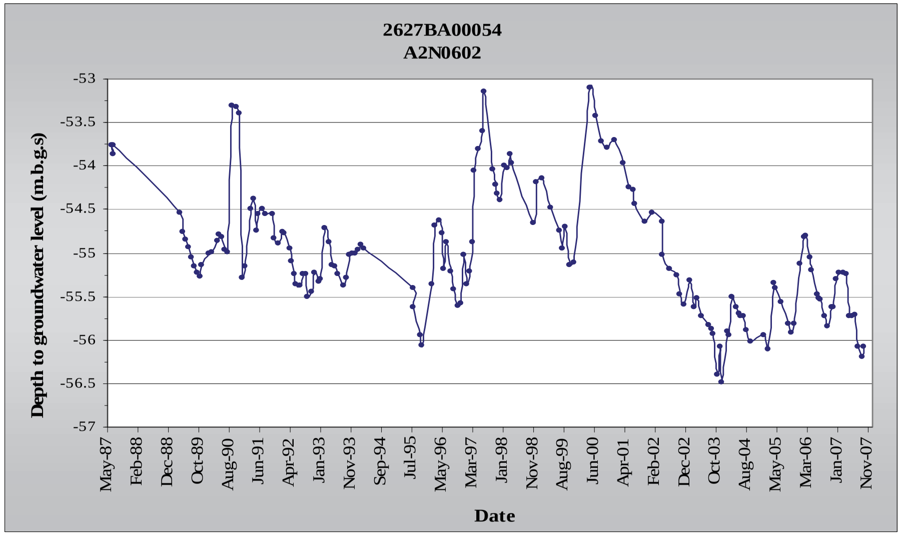


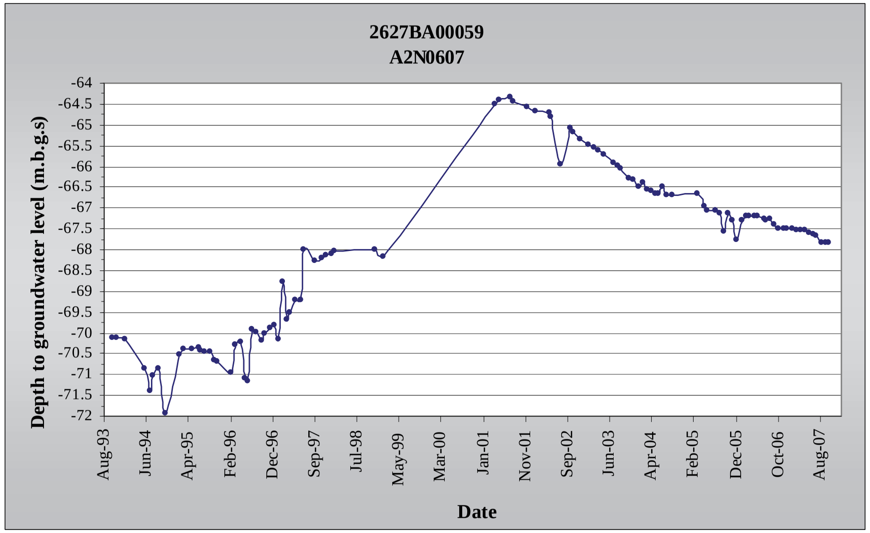
Station: A2N0605



Station: A2N0602

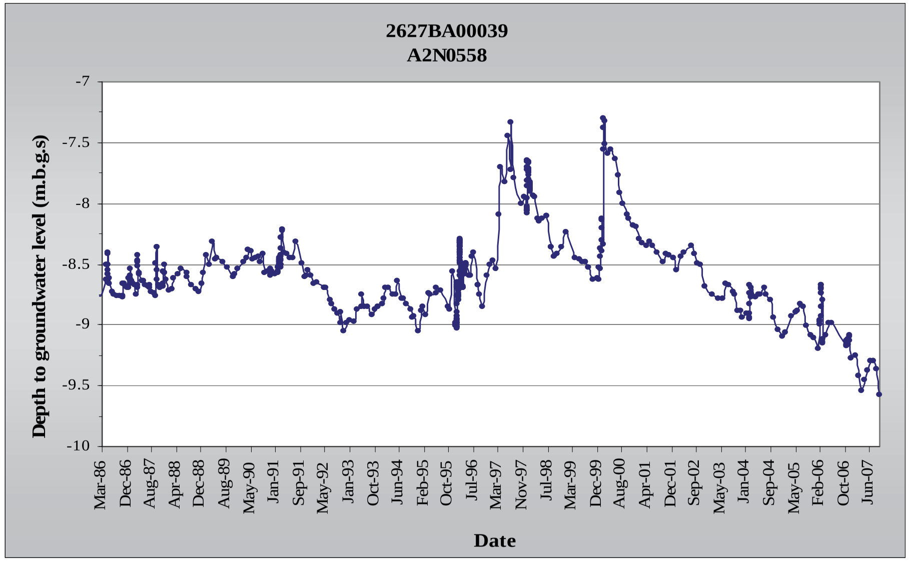


Station: A2N0607

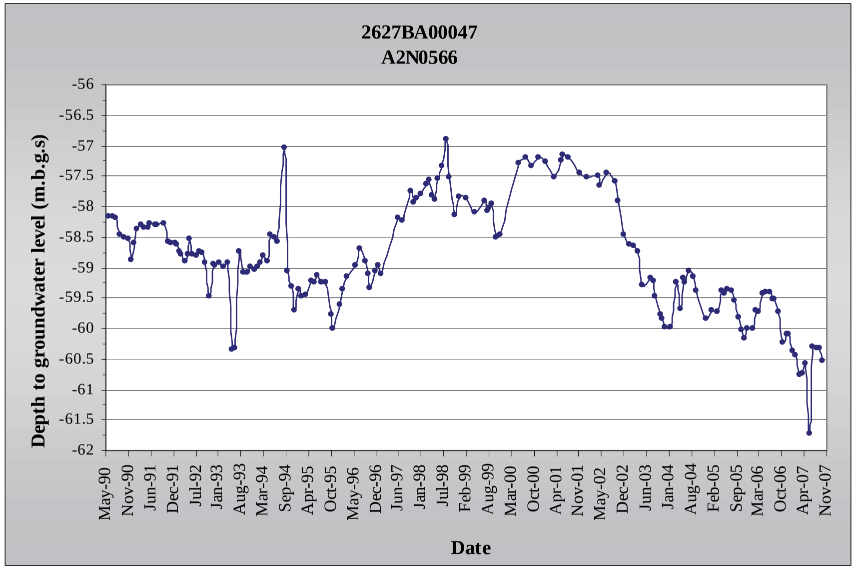


9B.2: Steenkoppies Compartment

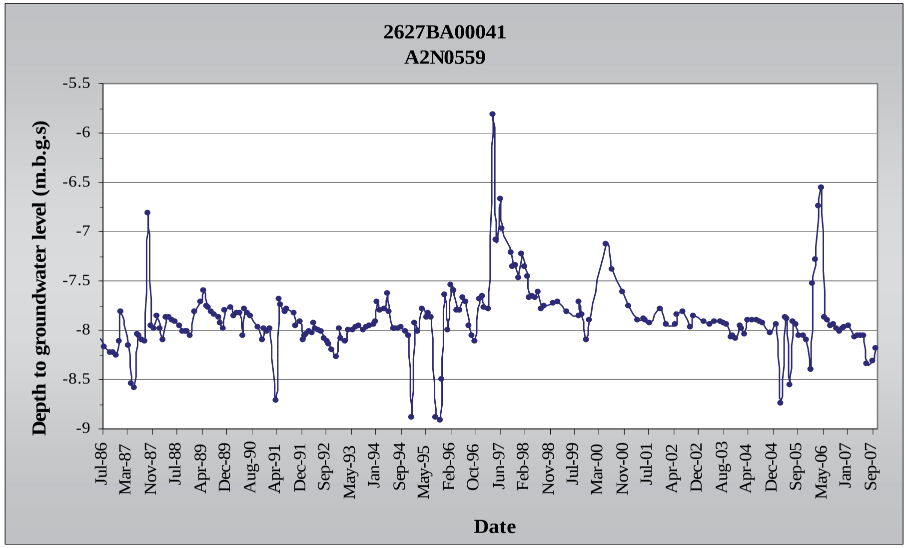
Station: A2N0558



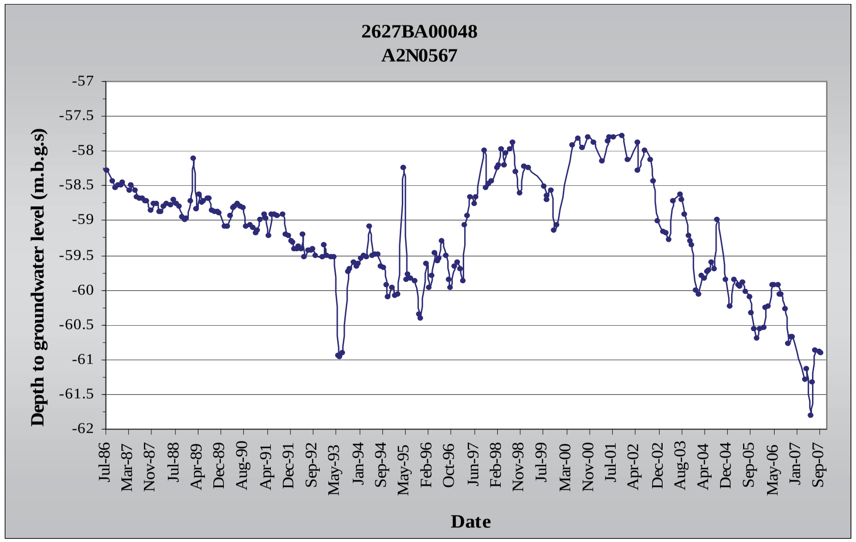
Station: A2N0566



Station: A2N0559

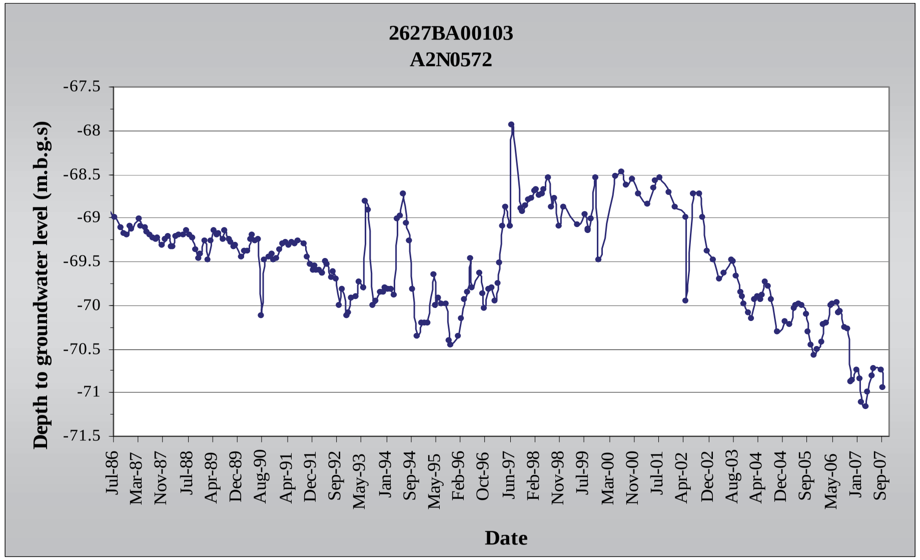


Station: A2N0567

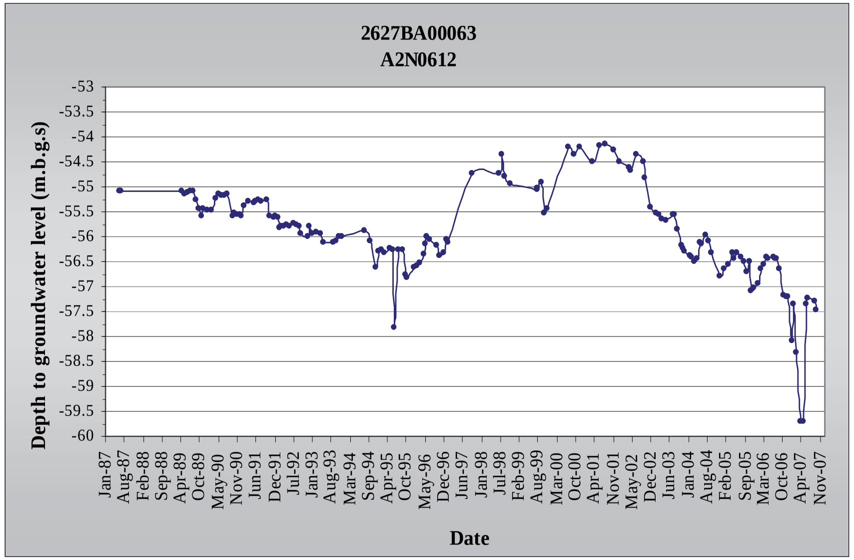


9B.2: Steenkoppies Compartment

Station: A2N0572



Station: A2N0612



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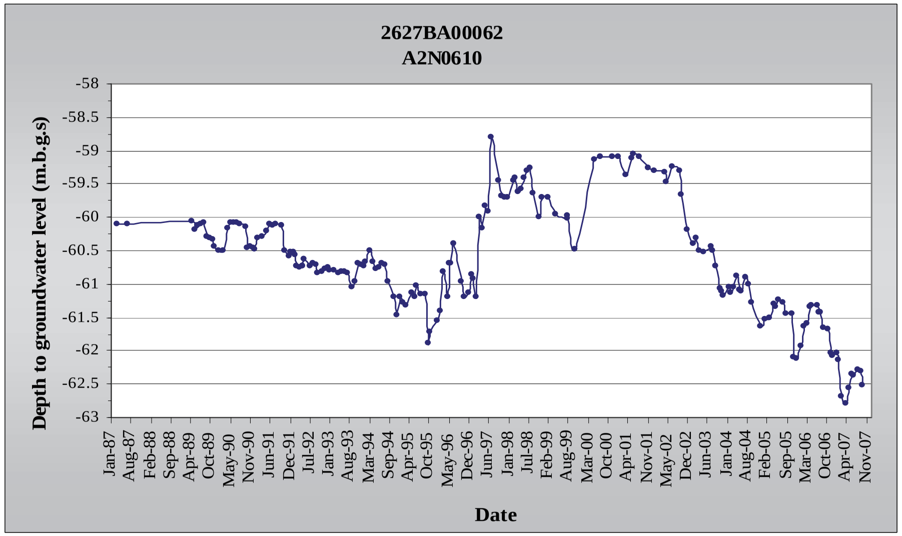

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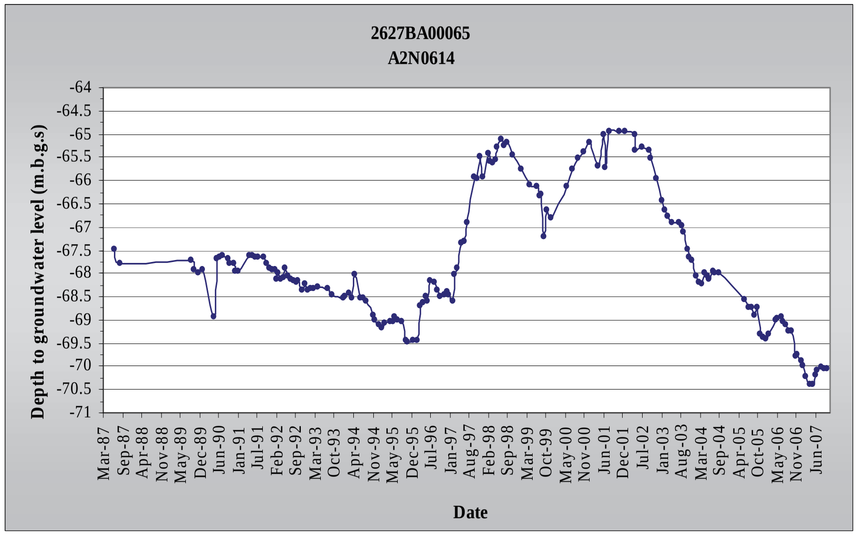
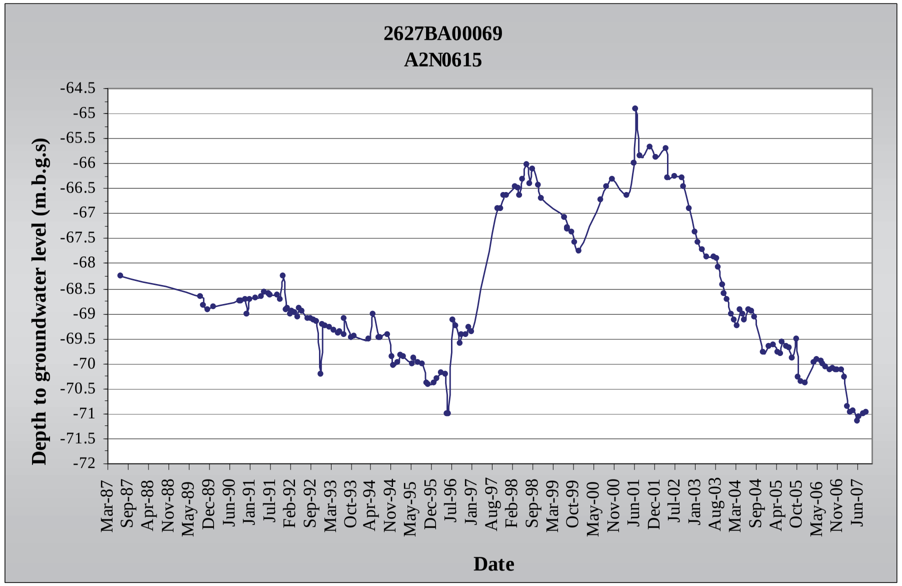


9B.2: Steenkoppies Compartment

Station: A2N0615



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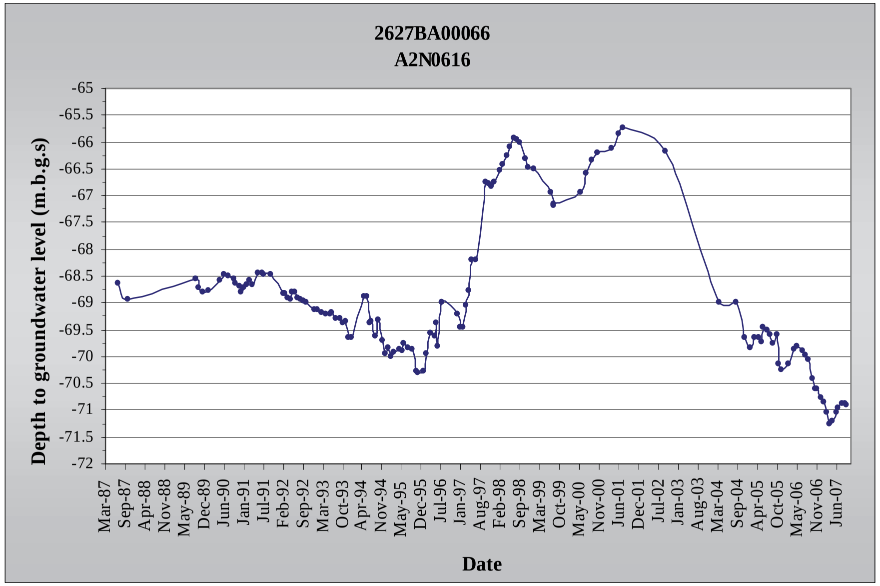


10 HYDROGEOLOGY OF THE PRETORIA-CENTURION AREA

In this section the hydrogeology of the Pretoria-Centurion dolomitic aquifers is described. The text is essentially taken from the recent report by Cobbing et al. (2008) and formed part of a larger DWAF project in which guidelines for the development of the main dolomitic aquifer regions in South Africa were developed. The section of this document describing the Pretoria-Centurion region was referred to as Activity 14 of the larger project.

10.1 Introduction

10.1.1 Background

The dolomite rocks of the Chuniespoort Group are considered to be South Africa's most important aquifer (Barnard, 2000). This is due to their high storage and high permeability, and to their proximity to major centres of population. More than half of the boreholes drilled into these rocks in the Gauteng area yield 5 l/s or more. They have been exploited for groundwater, via springs or "fountains", for many thousands of years. The Tshwane dolomites are both important to water supply, and vulnerable to over-abstraction and pollution. They also sustain ecological flows and are critical to the well-being of a variety of ecosystems. The dolomites can be divided into groundwater "compartments", separated by dykes or faults. Although movement of groundwater can occur from one compartment to the next, these compartments to a greater or lesser extent form separate groundwater units.

10.1.2 The 1980s "drought programme"

Although the groundwater resources of the dolomites in the Tshwane area have been studied for many years, many of the most important studies were carried out in the 1980s. This is because in the early 1980s drought caused levels in the Vaal Dam and other surface water sources supplying water to the Gauteng area to drop to very low levels. This prompted the authorities at the time to begin an investigation into the Chuniespoort dolomites as a possible source of water for the Gauteng area. The Directorate of Geohydrology of the Department of Water Affairs and Forestry carried out much of the subsequent hydrogeological work, which began towards the end of 1983. Vegter (1986) estimated that a sum of nearly R9 million was spent on groundwater investigations between the end of 1983 and the beginning of 1986. The work included geophysics, the drilling of 278 boreholes, and a considerable number of pumping tests. Boreholes were sited using the gravity method, which was confirmed as an effective geophysical method in such areas. An estimate of the exploitable storage of each dolomitic compartment was made, and production boreholes were drilled in the compartments for possible bulk water supply purposes. A hydrocensus was also carried out for each compartment to assess existing groundwater usage, and estimates were made of the impact of large-scale groundwater abstraction. Reports completed as a result of this "drought programme" include Vegter (1986), Kok (1985), Kok et al. (1985), Lieskiewicz (1986), and Kuhn (1989). Although the compartments of Vegter (1986) are slightly different to those delineated in this study (which follows those of Hobbs (2004)), the following table has been compiled from the data of Vegter (1986) to illustrate the considerable groundwater potential of the dolomites in the Tshwane area:

Table 10.1: Potential of Tshwane compartments (after Vegter, 1986)

Compartment	Area (km2)	Exploitable Storage (Mm3)	No. exploration boreholes drilled	Envisaged borehole pumping capacity (l/s)
Aalwynkop	15	4	4	130
Laudium	6	1.6	4	50
Erasmia/ Fountains West	92	14 to 23	23	1000
Fountains East	31	4.5 to 7.5	5	400

10.1.3 Study Locality

The study area is shown in Figure 10.1. The Sterkfontein Dyke has been chosen as the southern boundary of the study area; the dolomite rocks to the south of this dyke are considered to be the Midrand/Kempton Park dolomites. The area is bounded to the north and east by quartzites and shales of the Pretoria Group, and to the west and south-west by the Halfway House Granite.

The area is traversed by several major roads, including the N1 and the N14, and lies near to major centres of population, falling under the jurisdiction of the Johannesburg, Tshwane and Ekurhuleni Metropolitan Municipalities (see Figure 10.1).

10.1.4 Approach

This is a desktop study, and no new data has been collected by doing fieldwork. The following information was used in this study:

- the 1:250 000 scale geological maps 2528 Pretoria and 2628 East Rand;
- the 1:500 000 scale hydrogeological map 2526 Johannesburg and its baseline data;
- water level monitoring data extracted from the National Groundwater Database (NGDB) managed by DWAF;
- groundwater quality information extracted from the WMS;
- data from the WARMS database;
- technical reports by DWAF's Geohydrology directorate; and
- relevant and appropriate scientific reports commissioned by local authorities and developers.

10.1.5 Methodology

The available data was reviewed in order to develop an up-to-date assessment of the status of the Tshwane dolomites, both from a water quantity (water level) and a water quality perspective. Some of the important issues that emerge from the study are discussed in the conclusions.

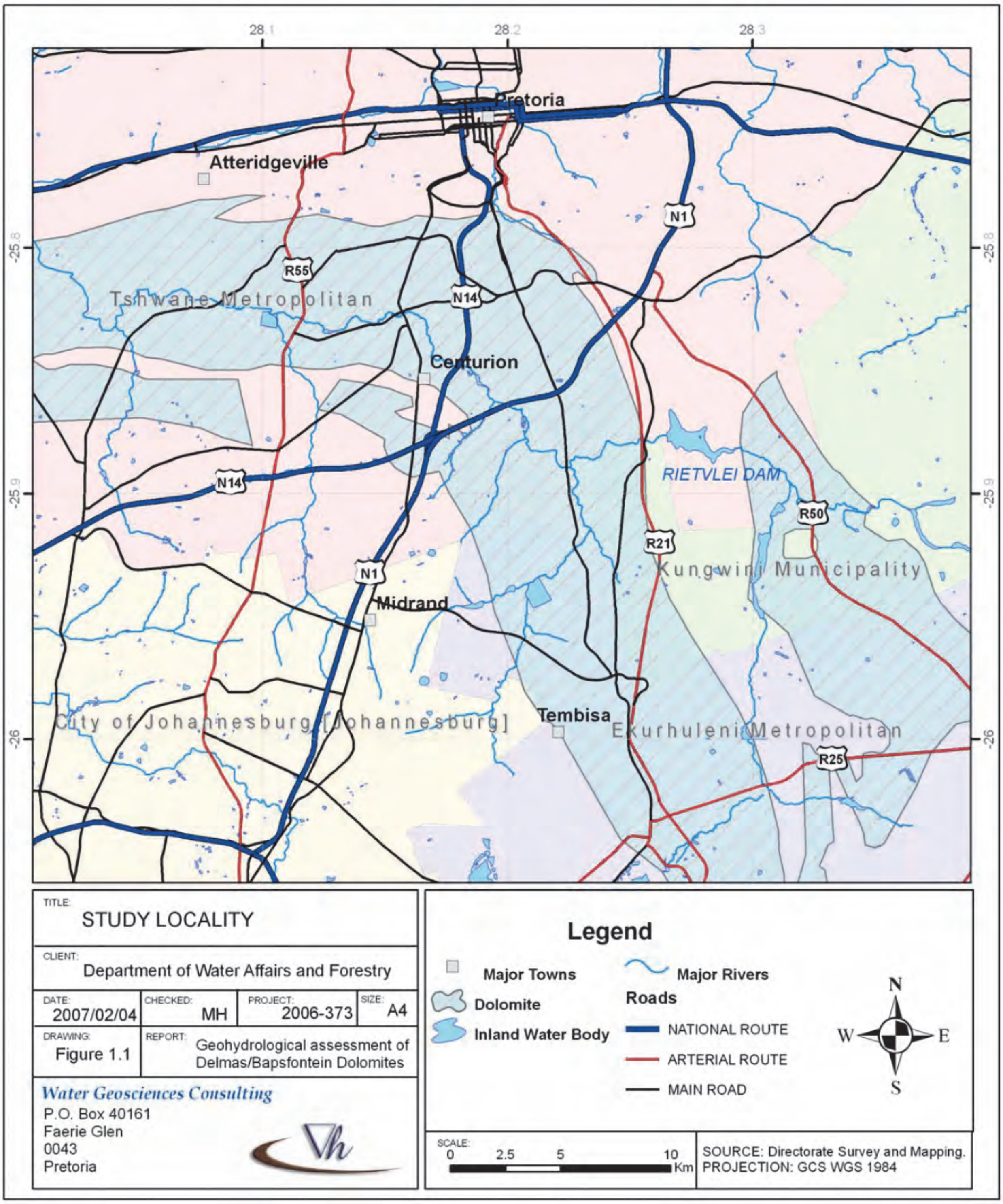


Figure 10.1: Locality of study area.

10.2 Description of Study Area

10.2.1 Morphology and Drainage

The topography of the study area is subdued, with a general drop in altitude from the south to the north. The dolomitic rocks tend to form flatter ground, with ridges being composed of the adjacent Pretoria Group quartzites. The study area is contained mainly within the quaternary catchment A21B, with small portions of A21H and A23D (see Figure 10.2). The area is drained by the Hennops River and its tributaries, including the Sesmylspruit, Olifantspruit, Kaalspruit and the Rietspruit. The Hennops River flows south from the Midrand area, via Centurion Lake, then turns towards the west where it flows into the Crocodile River. The flow of the Hennops River is sustained by springs and groundwater baseflow from the dolomites, and is augmented by effluent outfalls from the Olifantsfontein (close to the junction of the Kaalspruit and Olifantspruit) and Sunderland Ridge (close to the junction of the Rietspruit and Hennops River) wastewater treatment plants (see Figure 10.2). These plants have been estimated to discharge 38 Ml/day and 35 Ml/day respectively (Hobbs, 2004). As far as is known, no recent estimates of the proportional contributions of baseflow, runoff and wastewater to the flows in the Hennops and its tributaries are available, but these proportions vary seasonally, with baseflow and effluent making up the greater part of flows during the winter dry season. The rate at which the Hennops and its tributaries gain (or loose) groundwater will depend both on the exact location under consideration, as well as the time of year. In general, however, the surface water drainage system is likely to gain water on average in the study area.

10.2.2 Climate, Rainfall and Vegetation

The Tshwane area has a typical South African "Highveld" climate, with warm summers during which 80% of the rainfall falls as thunderstorms (often with hail) , and cool dry winters with cold nights (Holland, 2007). Much of the natural vegetation has been removed by human activities.

Hobbs (2004) has described the natural vegetation in the area as being of a false grassveld type, a "particularly sour wiry grassveld dotted with trees".

10.2.3 Land-Use

Land-use types include the following:

- Farming, both irrigated and non-irrigated. Some stock farming exists, and poultry farms are common.
- Agricultural holdings and small-holdings, such as Randjesfontein south of Rooihuiskraal, and Lyttleton and Raslouw near Centurion.
- Quarrying for sand and clay.
- Urban settlements (both formal and informal).
- Industrial areas.
- Conservation areas, such as the Zwartkop Nature Reserve adjacent to Valhalla.

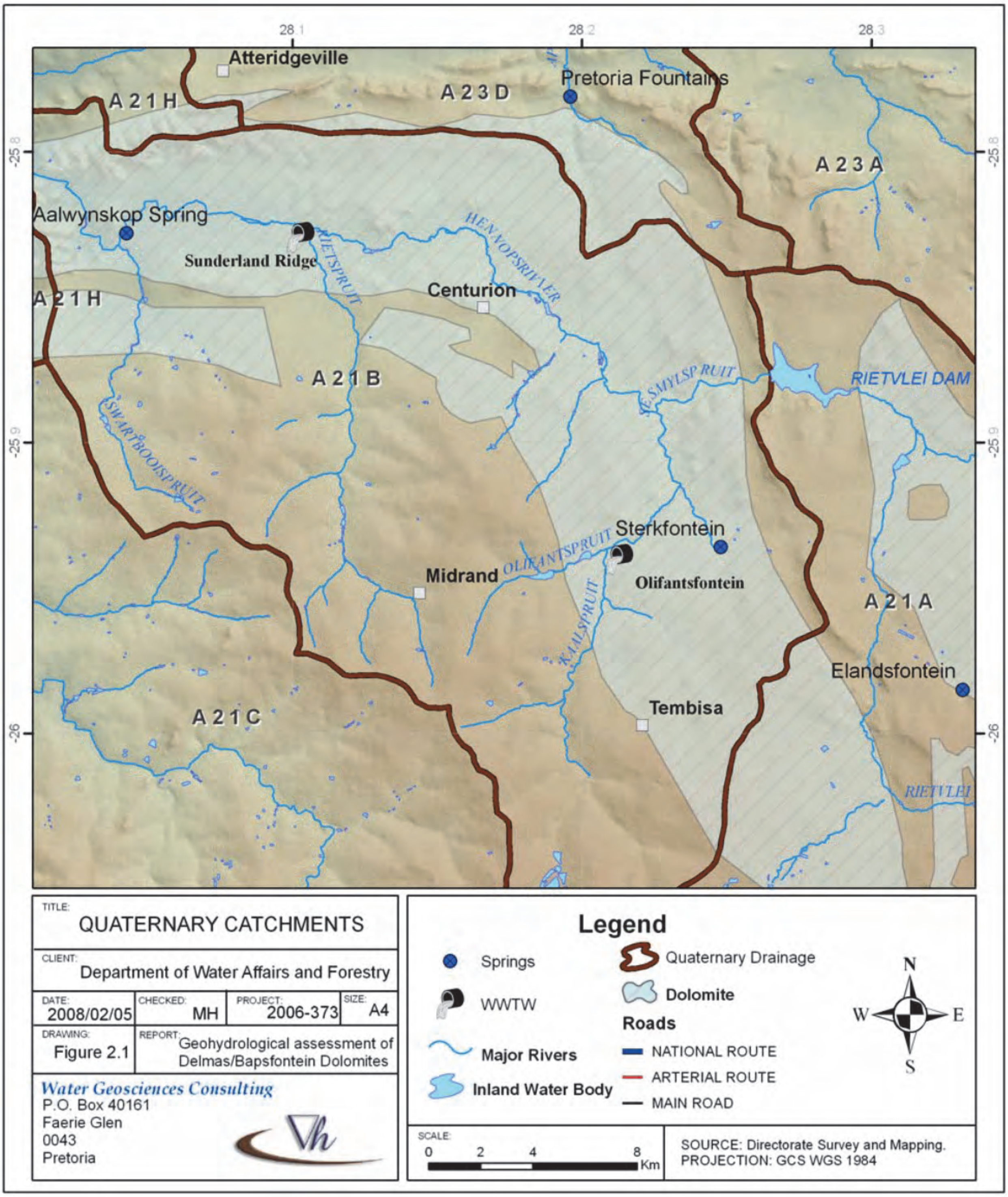


Figure 10.2: Surface drainage and quaternary catchment boundaries.

10.2.4 Geology

The oldest rock types in the study area are represented by various granites of Archaean age, together called the Basement Complex, and which include the Halfway House Granite in this area. The Witwatersrand and Ventersdorp Supergroups are not exposed in the study area, and rocks of the Transvaal Supergroup are the next oldest in the sequence. Quartzites of the Black Reef Formation overlie the Basement Complex, and are in turn overlain by dolomites and cherts of the Chuniespoort Group. The dolomites in the study area belong to the Malmani Subgroup of the Chuniespoort Group, and are dated between 2600 and 2500 Ma (Johnson et al, 2006). The Malmani Subgroup attains a thickness of up to 2000 m, and has been subdivided into five formations, depending on chert content, stromatolite morphology, and other features (Johnson et al, 2006). These boundaries of these formations are not always accurately known across the study area, and some maps do not differentiate between them. Overlying the dolomites are quartzites, shales and andesites of the Pretoria Group (Barnard, 2000).

A map showing the regional geological setting is shown in Figure 10.3.

Table 10.2: Geological sequence in the study area (after Holland, 2007)

BASIC LITHOLOGY	LITHOSTRATIGRAPHIC UNIT			ERA (age)	
dolerite / syenite	post-Karoo dyke / sill intrusive structures			early Mesozoic (150-190 Ma)	
sandstone / siltstone	Vryheid Formation	Ecca Group	Karoo Supergroup	early Mesozoic to late Palaeozoic (180-320 Ma)	
tillite / diamictite		Dwyka Group			
lava	Hekpoort Formation	Pretoria Group	Transvaal Supergroup	(2 225Ma)	Vaalian
shale / siltstone / quartzite	Timeball Hill Formation				
Dolomite	Malmani Subgroup	Chuniespoort Group		(2 430Ma)	
quartzite / shale	Black Reef Formation			(2 600Ma)	
Granite	Halfway House Granite Suite			Archaean (3 200±65Ma)	

10.3 Hydrogeological Overview

10.3.1 General

The dolomites of the Chuniespoort Group are classified as a karst aquifer (Barnard, 2000), which means that open cavities and even caves have developed below ground level due to the dissolution or chemical weathering of the dolomite. This gives the aquifer enhanced properties of groundwater storage and permeability, and is partly why borehole yields are high, and the Chuniespoort Group is considered so important (Barnard, 2000). Karst forms through the action of rainwater infiltrating into the aquifer, and reacting with carbon dioxide in the air and in the soil to produce a weak acid, carbonic acid. This acid then reacts with the dolomite rock to produce soluble ions of calcium, magnesium and bicarbonate, and these are carried away by the groundwater, leaving solution openings. Insoluble material in the dolomite such as chert and oxides of iron and manganese are left behind, and can form a dark-coloured, friable, porous material known as “wad”. The distribution of solution features in the dolomite is thought to be controlled by a variety of factors, including dolomite lithology, infiltration characteristics of soil or overburden, and existing zones of weakness or fractures in the dolomite. The different dolomite formations comprising the Chuniespoort Group have slightly different compositions, and the ratio of shales, cherts and breccias to “pure” dolomite varies. It can therefore be difficult to predict exactly where dolomite will be highly weathered and porous, and where its hydraulic

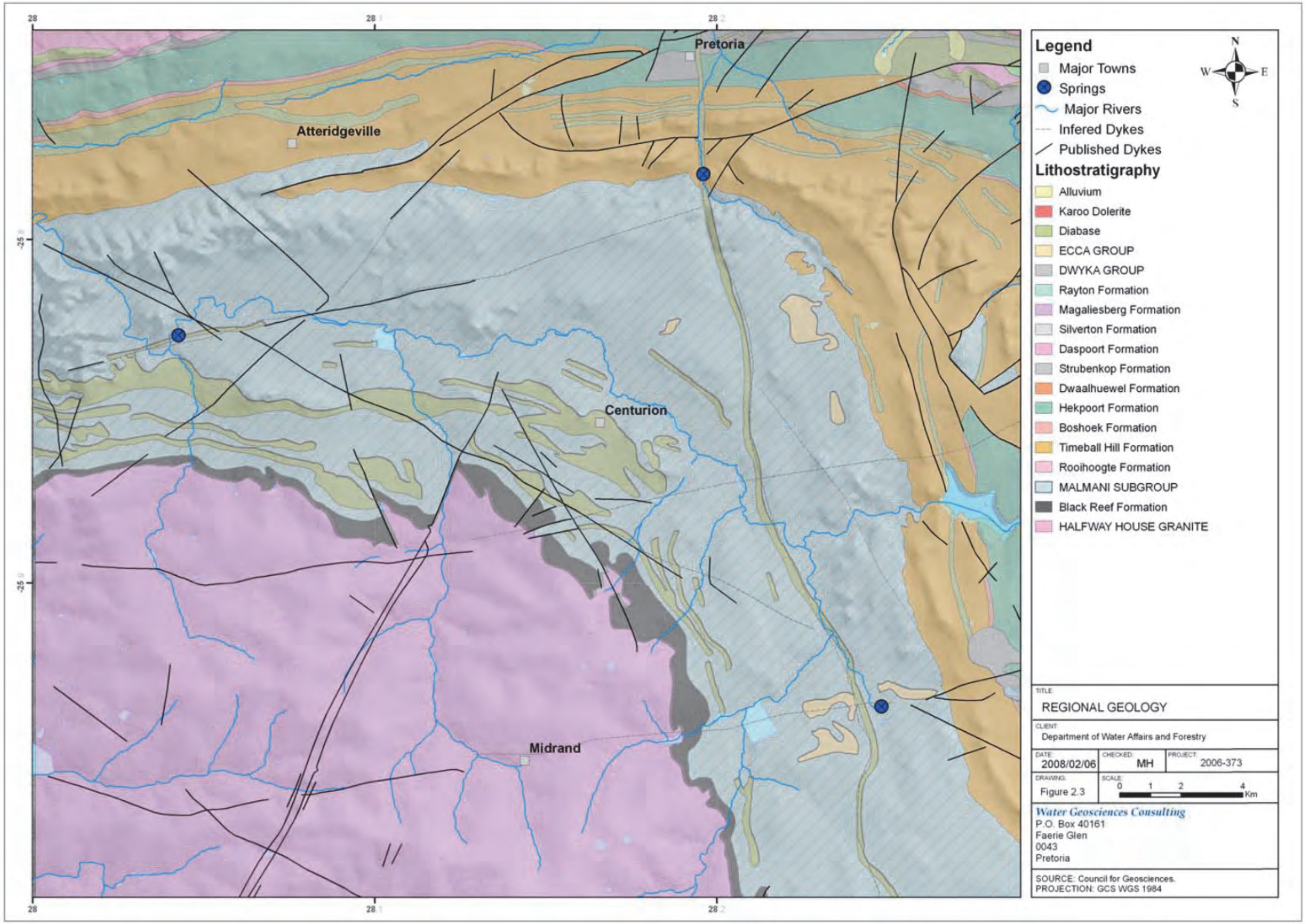


Figure 10.3: Regional geology of the area under investigation.

properties will be less favourable for borehole development. Solution-enhanced or karstified features in the dolomite are probably the major contributors to high values for permeability, but fractures in non-karstified dolomite are also important for groundwater flow (Barnard, 2000). In places where dissolution of dolomite below ground level has severely eroded the strength of the rock, sinkholes may form when the ground surface collapses down into the solution openings. Sinkholes are a serious concern for the planning of roads, buildings and other infrastructure. Factors such as groundwater over-exploitation, or leaks of water at the ground surface, can contribute to the formation of sub-surface voids, ground subsidence and even sinkholes.

10.3.2 Compartmentalisation

Unlike many other aquifers, natural groundwater levels in dolomite are not always closely related to surface topography, and the water table can be practically flat (Barnard, 2000, and Hobbs, 2004). This is due partly the relatively high permeability of dolomites. The groundwater resources in the Chuniespoort Group dolomites cannot however be considered as a single, interconnected resource. This is because the dolomites are divided into units or compartments by intrusive dykes and other structures, which form barriers to the flow of groundwater (the dykes are generally composed of post-Karoo age dolerite and syenite. Faults and topographic groundwater divides can also form compartment boundaries). Thus the study and management of groundwater resources in the dolomites is often based on the resources which exist in each compartment – pumping in one compartment may not substantially affect water levels in an adjacent compartment. Groundwater levels frequently vary from one dolomite compartment to another, and springs (some of substantial flow) can occur at the compartment boundaries. However, groundwater flow does occur between compartments, either through the dykes, or via a near-surface weathered zone where permeability has been enhanced. The compartment boundaries also do not always coincide with quaternary catchment boundaries (Hobbs, 2004).

Slightly different sub-divisions of the Tshwane dolomites into compartments have been proposed by different authors (e.g. Vegter, 1986, Barnard, 2000 and Hobbs, 2004). This is because the linear structures which form compartments are not always continuous, and the extent to which they prevent or allow groundwater flow is not always obvious. In some cases groundwater levels do not differ significantly from one compartment to the next, even where the compartments are separate. The compartments proposed by Hobbs (2004) have been adopted in this desk-top study, since they are based on recent water level and other observations. These compartments are: East Fountains, West Fountains, East Doornkloof, West Doornkloof and Erasmia (see Figure 10.4). Hobbs (2004) consolidated these compartments into three "groundwater management units" (GMUs), based on inferred connections between compartments (e.g. along the Sesmylspruit), and on similar water level changes (hydrostatic responses). These GMUs are as follows (Hobbs, 2004):

Table 10.3: Groundwater Management Units (after Hobbs, 2004)

GMU	Compartments
GMU 2a	Aalwynkop and Erasmia dolomitic compartments
GMU 2b	West Fountains and East and West Doornkloof compartments
GMU 2f	East Fountains compartment

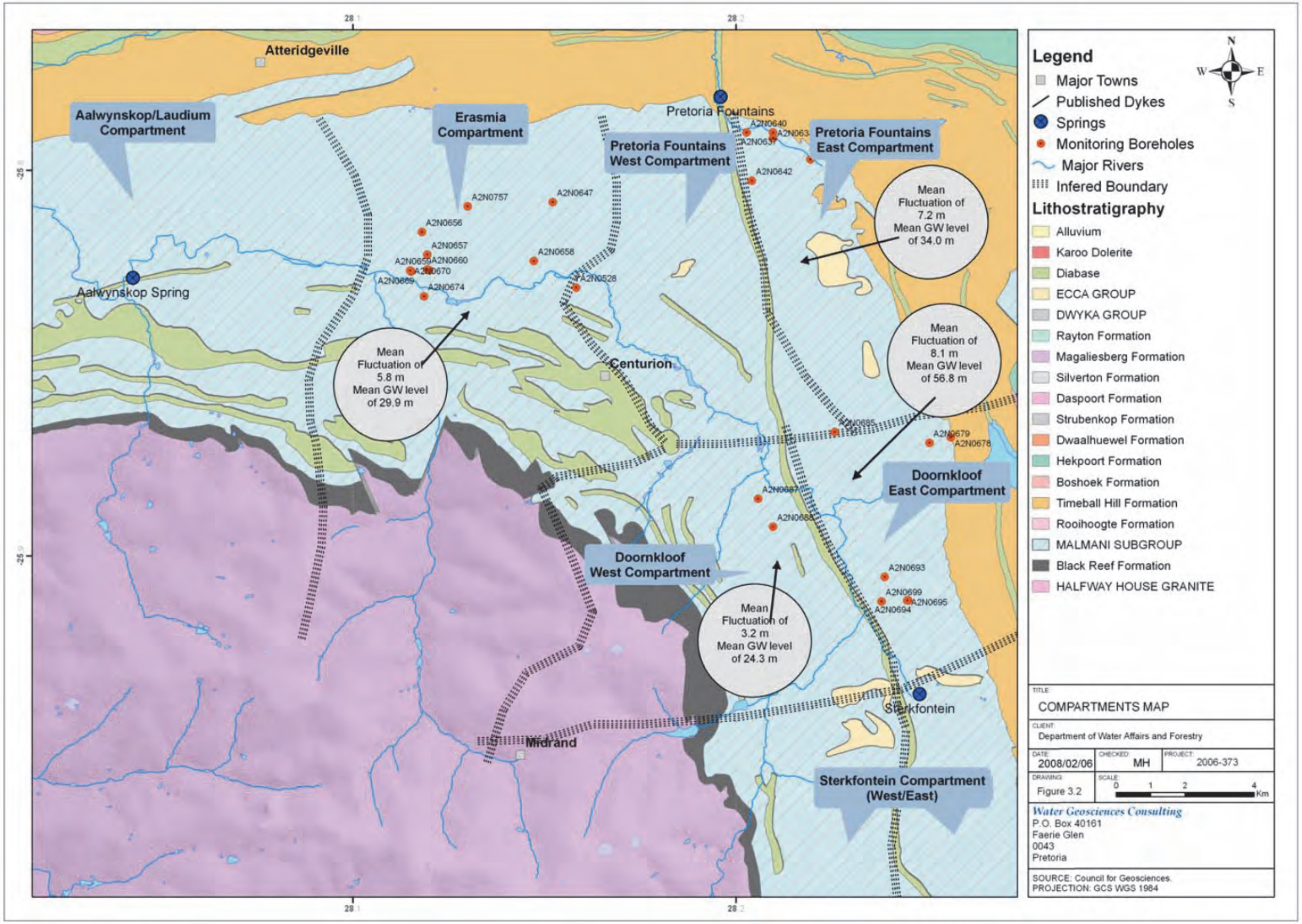


Figure 10.4: Dolomitic compartments map, inferred from previous investigations.

10.3.3 Groundwater Levels

The groundwater in the Tshwane dolomites has been extensively exploited for many years, and natural recharge and discharge mechanisms modified by people (such as altering river flows and capturing springs). It is therefore difficult to determine a “natural” groundwater state (Hobbs, 2004). The Department of Water Affairs and Forestry (DWAF) monitors water levels in the Tshwane dolomites using a network of boreholes. Not all of these boreholes are monitored regularly, and monitoring at some boreholes in recent years appears to have stopped, possibly due to access being restricted or boreholes being destroyed by construction work. The available DWAF NGDB data for the 1:50 000 map sheets 2528CC and 2528CD was examined, and twenty-five monitoring boreholes were identified which fall on dolomites in the study area, and which have recent water level data (up to 2006 or 2007). The borehole details are shown in Tables 10.4 and 10.5, and their locations on Figure 10.4. The data for the boreholes was examined, and a maximum, minimum, mean and median water level value was determined for each. The cumulative change in water level for each borehole’s dataset was also calculated, to determine whether there has been a general rise or decline in water levels over the period each borehole has been monitored.

The longest record available runs from October 1954 to the present (A2N0528), whilst the shortest begins in July 1999 (A2N0687). Sampling of water levels at the different sites is fairly irregular, and presumably depends both on access and on staff availability. This has resulted in gaps of fifteen years or more in some cases. Hobbs (2004) considered that the density of groundwater monitoring points was not adequate, particularly in some compartments such as the West Fountains Compartment, and that further monitoring points needed to be installed.

An examination of the available groundwater level data shows that, in general, groundwater levels in the Tshwane dolomites appear to have risen slightly. Only four monitoring boreholes show a decline in water levels since their monitoring records began (these are A2N0695, A2N0659, A2N0688, and A2N0757). The rest all show a rising water level or decreasing depth to water (mean rise about 2.4 m). This is likely to be due to the fact that 21 of the 25 borehole records examined start in the 1980s, either during or after the drought which occurred at that time. The rise could therefore represent a natural recovery of water levels as rainfall recovered. It should also be noted that the Gauteng area obtains a large proportion of its water from the Upper Vaal Water Management Area. (BKS (2003) reported that close to 50% of the water requirements of the Crocodile (West) and Marico WMA came from the Upper Vaal WMA). It is speculated that some part of the rise in groundwater levels in the dolomites could be due to increasing inputs from this source – either via mains leakage or waste-water returns. The study by Hobbs (2004) also found that groundwater levels in all of the compartments in quaternary catchment A21B (i.e. the present study area) had risen since the mid-1980s, and attributed this to increased rainfall recharge.

10.3.4 Groundwater Fluctuations

Natural groundwater level fluctuations in the Tshwane dolomites are thought to be small, most likely around 5 m or so (Hobbs, 2004). This is because groundwater storage in karstic dolomites is relatively large – in other words, a lot of water must be added or removed to obtain a fairly moderate change in water levels. This observation excludes fluctuations induced by pumping, which can of course be larger. This is supported by the data available to this study – the average (mean) difference between the minimum and maximum levels for each borehole is only 6.7 m – bearing in mind that the data in some cases spans more than 50 years. The maximum depth to water for the twenty-five borehole datasets examined was 100.6 m below datum (at A2N0678), whilst the shallowest water level was 1.5 m below datum (at A2N0687). The mean depth to water was 37.2 mbd. The statistical analysis of the dolomitic hydrostatic behaviour since the mid-1980s is presented in Table 10.4. Mean levels and fluctuations per compartment are shown on Figure 10.4.

Table 10.4: Statistical analysis of groundwater level data for boreholes in the study area.

LOCATION		**DEPTH TO GROUNDWATER (mbd)**			**CHANGE (m)**		**RECORD LENGTH**		
Compartment	**Station**	**Max.**	**Min.**	**Mean**	**Median**	**Cum. Δh**	**Max. Δh**	**Begin**	**End**
Doornkloof E	A2N0685	47.5	43.5	45.8	46.1	0.6	4.0	Jun-86	Oct-07
Doornkloof E	A2N0693	29.9	23.5	26.9	27.4	0.5	6.4	Jun-86	Oct-07
Doornkloof E	A2N0694	64.0	50.8	54.9	53.6	7.2	13.2	Aug-87	Oct-07
Doornkloof E	A2N0695	58.9	53.6	57.1	57.0	-0.6	5.2	Aug-87	Oct-07
Doornkloof E	A2N0699	31.6	23.7	28.9	29.6	2.0	7.9	Jun-86	Oct-07
Doornkloof E	A2N0678	100.6	89.2	95.5	96.0	2.4	11.4	May-87	Oct-06
Doornkloof E	A2N0679	91.0	82.5	88.6	89.2	1.2	8.5	Jun-86	Dec-05
Doornkloof W	A2N0687	2.8	1.5	2.6	2.6	0.1	1.3	Jul-99	Oct-07
Doornkloof W	A2N0688	49.1	43.9	46.0	45.9	-1.8	5.2	Jul-87	Oct-06
Erasmia	A2N0647	58.8	53.2	55.5	55.3	1.2	5.6	Oct-84	Oct-07
Erasmia	A2N0656	66.0	60.6	64.0	64.3	1.4	5.4	Jan-85	Oct-07
Erasmia	A2N0657	48.0	32.8	36.4	36.3	11.7	15.2	Jul-84	Oct-07
Erasmia	A2N0669	6.7	4.6	5.9	6.0	0.5	2.1	Jan-90	Oct-07
Erasmia	A2N0670	6.2	4.4	5.7	5.8	0.1	1.9	Aug-99	Oct-07
Erasmia	A2N0674	13.3	11.5	12.5	12.5	0.4	1.9	Apr-90	Oct-07
Erasmia	A2N0757	54.8	47.0	54.1	54.3	-7.7	7.8	Dec-89	Oct-07
Erasmia	A2N0658	36.3	24.0	32.3	32.7	1.2	12.3	Aug-86	Oct-07
Erasmia	A2N0659	24.8	21.2	23.6	23.9	-0.9	3.6	Apr-90	Oct-07
Erasmia	A2N0660	9.2	7.3	8.7	8.8	0.4	1.9	Sep-84	Oct-07
Pretoria East	A2N0637	32.1	20.4	23.6	23.4	4.1	11.7	Sep-84	Oct-07
Pretoria East	A2N0638	35.1	32.4	34.0	34.1	1.3	2.7	Sep-84	Oct-07
Pretoria East	A2N0640	11.1	8.1	9.5	9.6	0.8	3.0	Dec-84	Oct-07
Pretoria East	A2N0641	53.3	50.1	51.8	51.9	1.6	3.3	Dec-84	Oct-07
Pretoria East	A2N0642	62.7	47.3	51.3	48.1	6.1	15.4	Jan-85	Oct-07
Pretoria West	A2N0528	19.2	8.6	14.0	14.7	6.3	10.6	Oct-54	Oct-07

Table 10.5: Summary of water levels in each compartment

COMPARTMENT	**Water Level (mbd)**		
	mean	***median***	***range***
Doornkloof East	56.8	53.6	8.1
Doornkloof West	24.3	24.3	3.2
Erasmia	29.9	28.3	5.8
Pretoria East	34.0	34.1	7.2

10.3.5 Groundwater Drainage

A general groundwater gradient towards the north is found in the study area (following the general topography), with local exceptions. Groundwater crosses surface water quaternary catchment boundaries in the study area (e.g. between A21B and A23D) and these should not be regarded as barriers to groundwater flow. According to Hobbs (2004), water in the East and West Fountains compartments drains predominantly towards the north. The East and West Doornkloof compartments show groundwater flowing towards the divide between the compartments and the associated surface drainage, as well as north. Groundwater flow in the Erasmia and Aalwynkop compartments flows north and west towards the Tweefontein Compartment (not part of this study), with a component of southerly flow in the north of the Erasmia compartment. The flows at the major springs such as Pretoria Fountains and the Sterkfontein spring depend on this northerly flow of groundwater. It is likely that flow directions are modified locally by pumping, particularly considering the relatively flat groundwater surface, and average regional flow directions should not be relied on for defining local capture zones or protection zones.

10.3.6 Groundwater Recharge

Estimates for recharge to the dolomites in the Gauteng area vary between about 7% of mean annual precipitation (MAP) to about 15% of MAP (Bredenkamp et al, 1995, Kok et al, 1985, and Hobbs, 2004). Hobbs (2004) estimated figures of 14% and 11% for catchments A21A and A21B respectively. Recharge can be modified by changes to land-use, and may be lowered in areas of dense building development (due to impermeable roads, paving etc.) or raised due to leakage from water supply and sewage pipes. Further work needs to be done to quantify these effects.

10.3.7 Water Quality

An assessment of groundwater quality in the dolomites in the study area was carried out by examining data held by DWAF as part of their WMS database. The results for a total of 158 borehole water samples were obtained from the database. The network of boreholes from which water quality samples are taken is not the same as the borehole network used for water level sampling. The water quality sampling points are shown in Figure 10.5. All of the sample points fall into quaternary catchment A21B, apart from nine which are found in catchment A23D.

In general, only data for the concentrations of the major ions (Ca, Mg, HCO3, Na, Cl, NO3, K, SO4) plus F, PO4, NH4, pH and EC is available. Other minor ions, including possible pollution indicators such as B, are not routinely assessed. Hobbs (2004) described the chemical quality of the groundwater as generally good, with all but four of the sample sites having groundwater quality falling into the Class 0 (ideal) or class 1 (acceptable) category, according to the SANS 241 standard applicable at the time (SANS, 2001).

Groundwaters are predominantly of the calcium-magnesium-bicarbonate type, as expected for a dolomitic groundwater in which dissolution of the rock matrix is the major contributor to chemical quality. The mean pH value was found to be slightly alkaline at 7.62, probably reflecting the buffering capacity of the aquifer. (Barnard (2000) reported a mean pH of 7.6 for all of the samples considered for the study of the Chuniespoort Group for the entire Johannesburg hydrogeological map area.) The mean EC value for all of the samples was found to be 59.8 mS/m. A summary of the data is provided in Tables 10.6 and 10.7 below. All units are mg/l, except EC which is in mS/m. Durov and Piper diagrams illustrating aspects of the water quality of all samples are shown in Figures 10.6 and 10.7.

Table 10.6: Summary of major ion chemistry

	Ca	Cl	K	Mg	NO_3 as N	Na	SO_4	HCO_3
MEAN	52.1	28.0	1.7	34.2	0.83	18.2	33.7	254.4
MAX	162.8	154.1	39.3	102.4	4.71	121.1	633.6	682.8
MIN	0.5	1.5	0.2	1.0	0.00	1.0	2.0	61.9
MEDIAN	53.5	16.9	0.9	35.0	0.59	10.5	17.3	257.8
10th percentile	29.1	3.2	0.2	22.7	0.02	4.0	5.8	172.3
90th percentile	68.5	65.0	2.7	43.8	1.82	45.2	69.8	323.8

Table 10.7: Summary of pH, DMS, EC, and minor ions

	pH	DMS	EC	F	NH4	PO4	Si
MEAN	7.62	439	59.8	0.19	0.30	0.04	10.18
MAX	10.20	1205	144.0	2.20	38.25	4.44	30.23
MIN	6.35	95	13.7	0.05	0.02	0.00	2.22
MEDIAN	7.64	437	58.8	0.14	0.02	0.01	9.63
10th percentile	7.39	264	36.8	0.05	0.02	0.00	6.29
90th percentile	7.86	586	80.0	0.29	0.07	0.02	13.66

10.3.8 Pollution indicators

Whilst most of the samples were within acceptable limits, higher than expected salinity and raised concentrations of elements such as Cl, NH_4, SO_4 and NO_3 probably indicate pollution in certain of the samples. Pollution is most likely to come from surface water sources, in particular the discharge from sewage works and from urban run-off. Hobbs (2004) found that surface water in the study area was polluted and had poorer quality compared to natural dolomitic groundwater. In particular, the quality of water in the Sesmylspruit and Hennops River was poor and impacted on nearby boreholes. This poor quality is likely to be due to the presence of a sewage works upstream, and also due to leaking sewers and unserviced peri-urban areas. Possible groundwater pollution in the dolomite aquifer should be considered together with the surface water quality, since the two are closely linked. Hobbs (2004) reported that surface water quality at station A2H014 at the downstream end of the Hennops River shows a general decline in water quality (using the ratio of SO_4+Cl versus HCO_3 as an indicator of pollution) since records began in 1976, but a particular increase in pollution since about 2001. Hobbs (2004) found that measurements of salinity taken at the time of that study at the Sterkfontein Spring, and at the East and West Fountains springs, showed a slight rise. An improvement in water quality was noted following summer rainfall, due to dilution.

Although no microbiological water quality data was examined, the presence of e-coli and other indicators in groundwater indicates pollution by sewage, either from surface water courses or possibly from pit latrines in some areas. A study by Hoffman (1995) found bacteriological contamination of groundwater originating in the Tembisa area. Whilst this is to the south of the Tshwane dolomites, it is upstream of the study area.

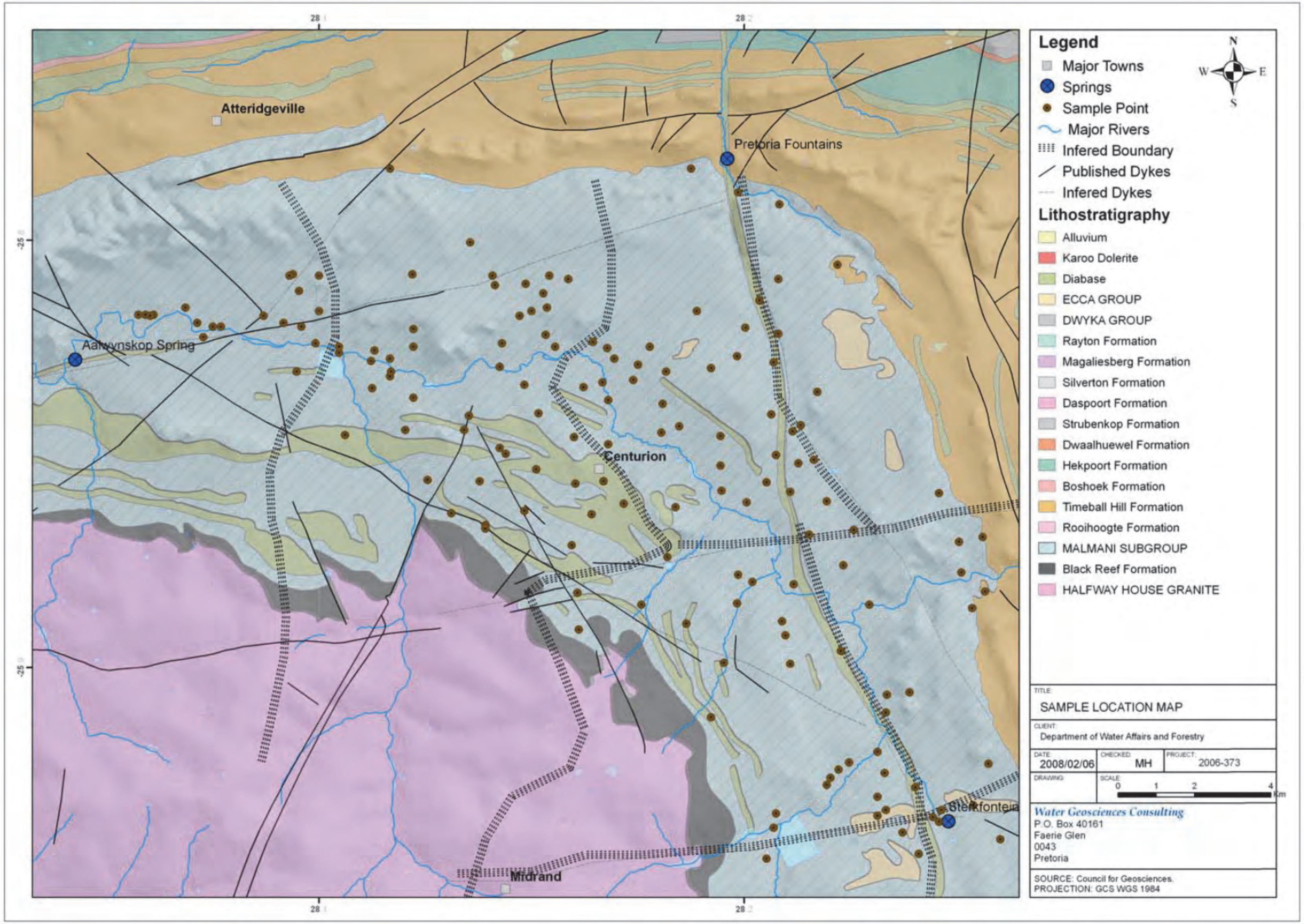


Figure 10.5: Groundwater quality sample locations.

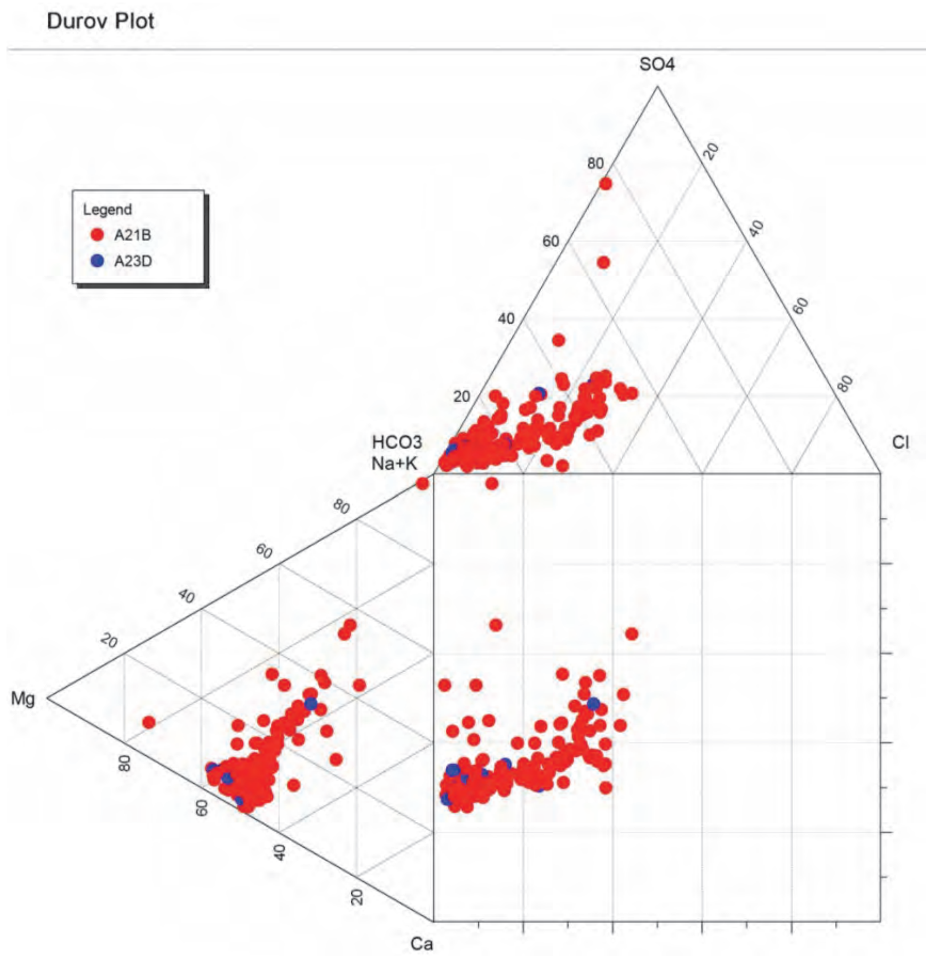


Figure 10.6: Durov plot of the water samples

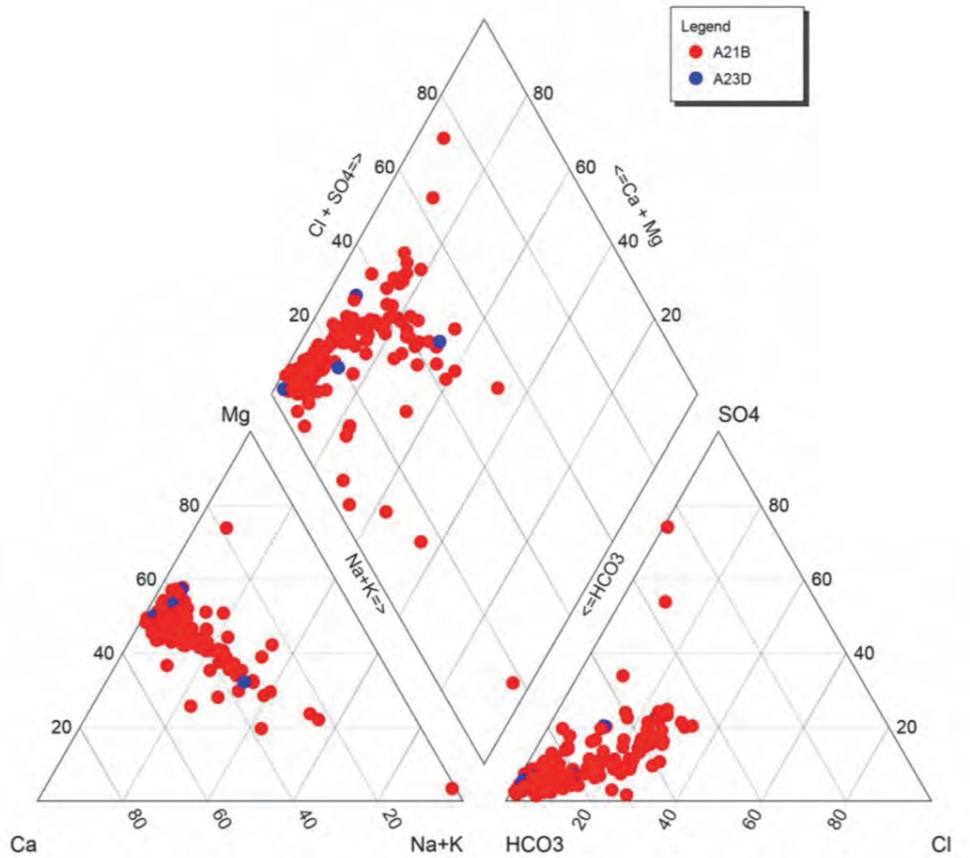


Figure 10.7: Piper plot of the water samples

10.3.9 Aquifer vulnerability

Dolomite aquifers are considered to be particularly vulnerable to surface pollution due to the relatively rapid rate of groundwater flow, often via fissures where little retardation of pollutants can occur (Barnard, 2000). In addition, sinkholes and other features in karstic environments provide direct routes for surface water into the subsurface (i.e. bypassing the soil zone). It is almost always much easier and cheaper to prevent groundwater pollution than it is to clean up or remediate such a problem. Hobbs (2004) confirmed that pollution of groundwater has already been detected in the study area, and future developments pose a further risk. In 2004, the three Groundwater Management Units which make up the present study area (2a, 2b and 2f, see above) were given water resource classifications as follows (Hobbs, 2004):

Table 10.8: Groundwater Management Units (after Hobbs, 2004)

Groundwater Management Unit	Relevant Compartments	Present Status Category	Present Management Class
GMU 2a	Aalwynkop and Erasmia	C	Fair
GMU 2b	West Fountains and East and West Doornkloof	D	Fair -
GMU 2f	East Fountains	C	Good

Particular attention was drawn to the impact of new property developments in the area, especially where French drains or septic tanks (on-site sanitation) were being considered as an alternative to connection to the sewerage system.

10.4 Water Resources Evaluation

10.4.1 Introduction

The data held in DWAF's Water Authorisation and Registration Management System (WARMS) was obtained for the quaternary catchments A21B and A23D. The WARMS system classifies water use by "resource type", which includes dams, rivers, boreholes and springs. All non-groundwater sources were first removed from the data, leaving only boreholes and springs/eyes. A GIS was then used to remove all data points not associated with the dolomites in the study area. The final data set consisted of 58 separate data points, 55 boreholes and 3 springs/eyes. All of the points fell into catchment A21B (Figure 10.8). The total licensed amount of water abstracted in the study area amounted to 3 882 218 m^3/year, or about 123 l/s if pumping continuously. Most of the water – about 3 285 589 m^3/year (about 104 l/s) of the total water use – is allocated for agricultural purposes (either irrigation or watering livestock). The three springs are all clustered together at Olifantsfontein in the far south of the study area, and together are registered to yield 1 063 500 m^3/year, or about 34 l/s, all for irrigation purposes. The mean yield for boreholes in the WARMS dataset (i.e. excluding the springs) was 2 l/s. This seems rather low for a dolomitic area in which most of the groundwater is used for agricultural purposes, in an area where the median yield of boreholes is expected to be more than double this amount (Barnard, 2000).

10.4.2 Discussion

The WARMS dataset has not yet been verified by DWAF's regional office, and in its present form it considerably underestimates the total groundwater use in the study area. For example, the water used for municipal supply purposes obtained from the Pretoria Fountains and the Sterkfontein Spring does not appear in the WARMS dataset. These two sources alone represent a usage of just less than 400 l/s. Hobbs (2004) found that the WARMS dataset did not include several significant groundwater sources, and also greatly underestimated the groundwater use at certain locations that did appear in the WARMS dataset. Hobbs (2004) estimated that the true groundwater use in the whole of catchment A21B was around 18 Mm/a (about 570 l/s), or almost five times the WARMS estimate. Although the study area for this study is not the entire A21B catchment, the large springs in this catchment do fall into the study area, and this estimate by Hobbs (2004) for groundwater use in the whole catchment is probably much closer to the true groundwater usage in the study area. The following table represents estimates by Hobbs (2004) of water use in catchment A21B:

Table 10.9: Summary of water use information in catchment A21B (after Hobbs, 2004).

WATER SOURCE	WARMS (m3/a)	OTHER (m3/a)
Boreholes	2 778 442	4 005 072
Springs	354 500	10 879 920
TOTAL GROUNDWATER	*3 132 942*	*14 884 992*
Rivers/streams	1 412 540	-
Dams	4 355 611	-
GRAND TOTAL	8 901 073	14 884 992

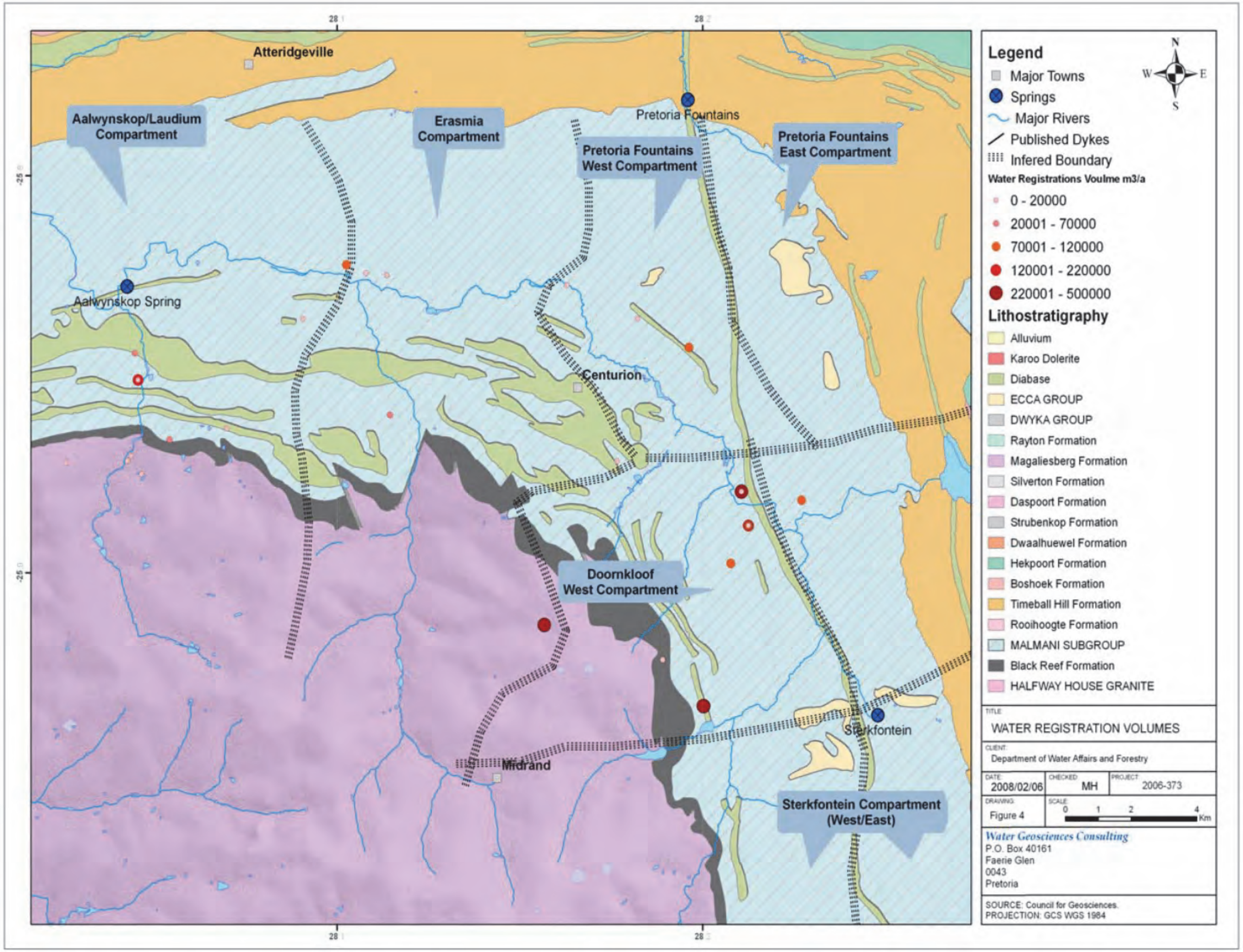


Figure 10.8. Locations of WARMS data points in the study area.

10.5 Tshwane Dolomites Assessment, Planning and Management

10.5.1 Introduction

10.5.1.1 The New DWAF Guideline

The Department of Water Affairs and Forestry (DWAF) has recently published the document "A Guideline for the Assessment, Planning and Management of Groundwater Resources in South Africa". The objectives of this document are as follows (DWAF, 2008):

To provide assistance and guidance to all role-players involved in the assessment, planning and management of the groundwater resources of South Africa, and
To ensure that all role-players in the management of groundwater resources of the country have clear guidance on the processes to follow.

Although the Tshwane Dolomites are certainly not a "new" area in terms of assessment, planning and management, it is desirable that these actions are aligned with the principles of this DWAF Guideline document. Whilst this chapter cannot give a comprehensive account of either the DWAF Guideline, or the various measures that might be needed to align activities in the Tshwane dolomite aquifer with the Guideline, it describes some of the issues that have been identified in the Activity 14 Study that have an important bearing on the assessment, planning and management of the aquifer.

The Guideline describes Assessment, Planning and Management as related steps, each one of which has a bearing on the others. The three steps can be seen to a certain extent as part of an iterative process which broadly seeks to ensure that groundwater resources are managed in accordance with new national environmental legislation (Figure 10.9). Whilst elements of all three steps are currently being carried out in the Tshwane dolomites, the challenge is to ensure that the process is implemented more fully to ensure the best possible management outcomes.

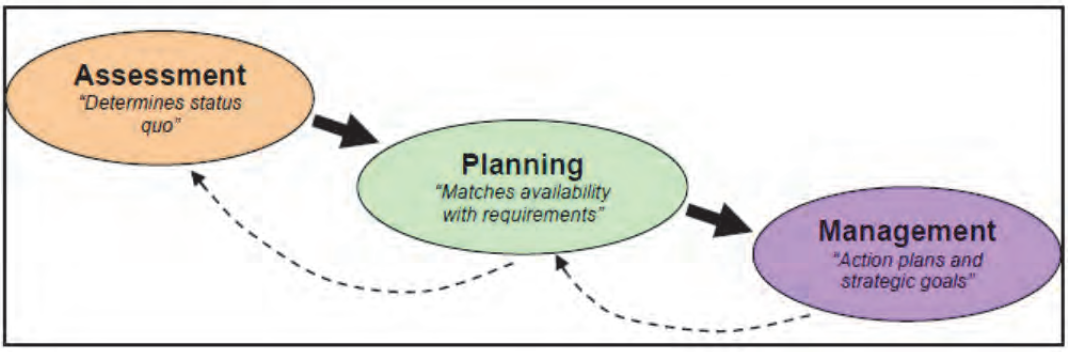


Figure 10.9: The basic aquifer management steps, after DWAF (2008)

"Assessment that is undertaken poorly can lead to poor planning. In turn, poor planning can lead to the adoption of unsuitable options and hence the unsustainable use of the groundwater resource" (DWAF, 2008)

10.5.1.2 Introduction to managing the Tshwane dolomites

The Tshwane dolomites are an important groundwater resource, with a possible critical value in terms of water supply to the surrounding large metropolitan areas in times of severe drought. The aquifer is therefore both an economic and strategic asset of considerable importance. The dolomites also have valuable functions in terms of supporting ecosystems and supplying basic water supplies to farms, smallholdings and other users, all of which are protected in terms of the National Water Act and other environmental legislation.

The Tshwane dolomites are intrinsically vulnerable to pollution from surface sources. In common with other karstic aquifers, groundwater flows rapidly through these rocks, often via fractures and fissures which have been enhanced by solution, and very little “filtering” or other retardation of pollutants takes place. In many places the soil zone (which could inhibit the downward movement of pollutants) is thin, or even absent. Sinkholes and other surface openings also present a direct pathway for groundwater contaminants to the water table. The fact that the dolomites are divided into compartments, which may be more or less separate from each other, can complicate the assessment, planning and management. Compartmentalisation also increases the need for good quality data.

Sound management of the dolomites is the key to both the protection and the sustainable use of the resource. The aquifers are located close to the most densely populated urban areas in the country, and the potential for pollution and over-abstraction is consequently high. Management of the resource may require decisive interventions from time to time – a “hands-off” policy in such a populated area will only result in the long-term degradation of the resource. Urban development in the area is currently proceeding at a rapid pace, which is likely to increase both the risk of pollution and the need for upgraded management. The scope and scale of the necessary management intervention in the Tshwane dolomites is likely to be growing.

The need for groundwater assessment, planning and management is now recognised as vital, and is summarised in the DWAF “Guideline for the Assessment, Planning and Management of Groundwater Resources in South Africa” (2008) as follows:

“Past experiences have indicated that a lack of effective assessment, planning and management of the resource can result in significant detrimental impacts on the aquifer systems. For example, unmanaged and uncontrolled abstraction and/or dewatering of the aquifers can lead to boreholes, wetlands and springs drying up; and in the case of karst aquifers, sinkhole formation.” (DWAF, 2008).

10.5.2 Management issues specific to the Tshwane Dolomites

10.5.2.1 High rates of development and population growth

The area underlain by the Tshwane dolomites is subject to increasing pressure from new housing and industrial developments, and a general increase in the numbers of people. Each new development which converts farmland, smallholdings or other low-density areas to higher density land use presents a potential risk of groundwater pollution, and also constitutes a possible new groundwater user. (The other groundwater-related risk associated with new development on the dolomites, sinkhole development, can also be considerable.) New developments therefore need to take groundwater into consideration at the planning stage, and ensure that accepted South African standards of development on karst aquifers are adhered to. It is possible that regulations regarding on-site sanitation, and even groundwater abstraction, are not always being adhered to in some new developments.

10.5.2.2 Inadequate monitoring network

According to the DWAF Guidelines, the Assessment step "enables the Planning and Management functions". Crucial to assessment are the tasks of determining water availability and water use requirements. The assessment of any aquifer depends on an adequate monitoring network of boreholes and other geosites. The current monitoring network in the Tshwane dolomites is likely to be inadequate for the early identification of pollutants, and also for the proper identification of water level trends. For example, the Pretoria West compartment has only one water level monitoring point whose record extends up to 2007/08, and the Doornkloof West compartment has only two such monitoring points. The total number of groundwater level monitoring points that were assessed for this study (i.e. those with records extending to 2006 or later) is only 25. Water quality monitoring points have a better coverage, but these tend to be visited less frequently. They are also not always in the optimum position in regard to potential pollution sources. As far as is known, there is no automated system at any of the water quality monitoring points for the "early warning" of water quality problems.

There appears to have been a marked decline in the number of active groundwater level monitoring points in the last ten years or so, and this trend may also apply to water quality monitoring points. Whilst the loss of some of these points may be unavoidable (i.e. due to building activities at borehole sites), lost points are not being replaced. At a time when the population in the area is expanding greatly, with a similar increase in building activities and associated risk of pollution from new sources, it is of concern that the monitoring network, rather than expanding, appears to be shrinking. There is also evidence that the WARMS database of groundwater users significantly underestimates the amount of groundwater being used, as well as the number of abstraction points, which makes it difficult to plan for further abstractions and to assess the true economic value of the resource.

Monitoring on its own is not adequate for aquifer assessment. Monitoring data needs to be collated, processed and presented regularly, in order to assess the "status quo" or current state of the aquifer (DWAF, 2008). It appears that there is not a routine system of collation and interpretation of monitoring data at present, and it is recommended that a regular report (every six months or every year) could be produced which gives a "state of the aquifer" snapshot for those tasked with planning and management. This report need not be long or complicated, and can be based on a standard template – but it will be able to give the non-specialist information about the state of the aquifer "at a glance". (This issue is also naturally connected with the broader one of groundwater capacity at DWAF more generally.) At present it appears that water levels in the Tshwane area are not declining, but incidences of pollution may be rising – although this assessment is based on limited information.

10.5.2.3 Pollution risks

Microbiological pollution of the aquifer has already been identified in parts of the study area (Hobbs, 2004). This is likely to be associated with the surface water courses crossing the aquifer, which are used for the discharge of treated sewage, as well as with discrete point sources (French drains, leaking sewers, etc.). In addition, there are informal settlements in the study area which are not yet linked to the sewerage system. A comprehensive assessment of microbiological pollution is beyond the scope of this study, but the trends need to be understood in order to assess the risk. Borehole sites where microbiological pollution is identified ideally need further investigation, in order to establish the causes. The quality of treated sewage discharge needs to be tracked (assessed), since this water can eventually end up in the aquifer. Microbiological pollution of the aquifer has the potential to place abstraction boreholes at risk, and sometimes the least expensive solution is then to withdraw the borehole from supply.

Inorganic pollution in the study area appears to be less prevalent than microbiological pollution, although the water quality monitoring network and the range of determinants assessed are probably not adequate for a comprehensive picture at this stage. Certain inorganic contaminants (fuels and solvents, for example) are notoriously difficult to remove from the aquifer once pollution has taken place, and can cause health problems in even small concentrations. It is likely that there are at least several discrete incidences of inorganic pollution (such as leaking fuel storage tanks at garages) that have not yet been detected in the Tshwane dolomites. A basic assessment of land-use activities would enable a broad assessment of risk to be done, and would allow for the most efficient siting of further water quality monitoring points (this is identified as Steps 4 and 5 of the DWAF (2008) Assessment process).

Several major roads also cross the dolomites, and consideration should be given to the potential groundwater contamination that would be associated with an accident involving vehicles with loads which could pollute the groundwater (e.g. a tanker carrying fuel). Whilst unlikely, consideration of this issue could form part of a general protection zone strategy. This issue would form part of the Planning stage in the DWAF process (2008).

10.5.3 Recommended actions

The actions recommended below have a bearing on assessment, planning and management of the Tshwane aquifer, and arise from observations made during the Activity 14 desk-top study.

10.5.3.1 Better monitoring systems

The current monitoring network for both groundwater levels and groundwater quality is probably inadequate for assessment purposes, and this compromises planning and management. The network should be reviewed, and a programme of adding to the network be instituted. Automated groundwater data collection would help to reduce the fieldwork burden, and would also allow for a higher frequency of data collection. Field visits could be combined (e.g. water level monitoring and water sample collection) in order to increase efficiency, where this is possible. It is also likely that efficiency gains could be made by targeting those areas most vulnerable to a change in groundwater circumstances. For example, the “source – pathway – receptor” conceptual model should be kept in mind when planning for pollution monitoring, and potential sources (sewage treatment works, garages, feedlots, etc.) and pathways (e.g. known fracture systems) should be given a higher priority.

10.5.3.2 Closer cooperation with other government agencies and official bodies.

There is probably a need for closer cooperation with other national government departments (e.g. DEAT and DME) as well as with provincial and local authorities. This would help with the task of data collection and analysis, give warning of new developments and/or potential groundwater problems, and help to ensure that efforts are not duplicated. Many authorities have a vested interest in better groundwater management, and some kind of cross-departmental forum would help to streamline work, and increase the uptake of research. The research councils (the Council for Geoscience and the CSIR) also have considerable expertise in dolomitic groundwater, and are both currently engaged on dolomite projects. Both research councils have publicly funded research budgets, and have the potential to work closely with DWAF on matters of technical importance.

The DWAF document (2008) lays out the requirement to incorporate assessment activities into the relevant water planning documents, including the Catchment level Internal Strategic Perspectives (ISPs), Water Services Development Plans (WSDPs) and the Catchment Management Strategies (CMSs). This implies close cooperation with the relevant Catchment Management Agencies (where formed), Water Services Authorities, Water User Associations and Water Service Providers.

10.5.3.3 Public participation

The DWAF document (2008) emphasises the importance not only of public participation, but also of genuinely taking the needs and opinions of all stakeholders into account in adapting a groundwater management strategy. The document describes various ways of raising awareness, consulting with the public, and communicating results. Good stakeholder participation is important to a successful management strategy, partly because it helps to ensure cooperation, and partly because a successful management strategy is by definition one which endeavours to meet the needs of all stakeholders (including environmental groups). Regular and broad stakeholder consultation and participation needs to be instituted in the Tshwane area, and needs to be addressed in terms of the detailed requirements in the DWAF document (2008).

10.5.3.4 Protection zone policy

At present source protection zones are not part of groundwater planning or management in the Tshwane dolomites. A source protection zone is a zone or area which can be defined around an important borehole or other groundwater source. The size and shape of the zone is based on the time it would take for a groundwater contaminant to reach the source from any given point. Three zones are commonly defined, 50 days (or ten metres, whichever is closer), 400 days, and the entire catchment. Potentially polluting activities can then be monitored or controlled (managed) within these zones. The size and shape of source protection zones depends on the groundwater flow, local topography, geology, and other factors, and can be challenging to do in karstic aquifers such as the Tshwane dolomites. They can be defined using simple “rule of thumb” criteria, or in a more accurate way using more complex models and/or tracer tests – possibly in collaboration with the research councils. A planning strategy incorporating source protection zones would essentially do four things in the case of the Tshwane dolomites:

- Help sensitive sources and areas (e.g. the Pretoria Fountains area) to be assessed and prioritised.
- Help to protect those sources, by focusing attention on potentially polluting activities within the zones.
- Through the process of defining the source protection zones, help to increase understanding of groundwater flow dynamics in the vicinity of sensitive sources.
- Assist with public awareness and participation with regard to groundwater protection.

Defining protection zones would put sensitive groundwater sources such as large public water supplies on a more "formal" basis, in alignment with international best practice.

10.5.3.5 Capacity building at DWAF

Capacity building in terms of groundwater staff and hydrogeological systems at DWAF is a "cross-cutting" issue that impacts on most of what has been discussed thus far. Insufficient human resources mean that it is more difficult to carry out the tasks which are needed, and it is intrinsic to all three management steps – assessment, planning and management. However, work such as the expansion of the monitoring network, increased frequency of monitoring, and the compilation of regular "state of the aquifer" reports presents an opportunity for the orientation and training of staff, particularly with regard to field data collection. It may be possible for part of the necessary work to form part of DWAF's capacity building and training efforts, and management according to the DWAF guideline should not therefore be seen as a "net drain" on staff capacity.

10.6 Conclusions & Recommendations

The dolomite aquifers in the Tshwane area are a very important source of water supply, both to farmers (agricultural use) and other individuals, and for urban water supply. The Pretoria Fountains and Sterkfontein springs alone supply just less than 400 l/s of good quality water to the municipal system, and a significant proportion of the water supply to the Tshwane Municipal area is therefore derived from dolomitic groundwater in the study area. The reader is referred to Hobbs (2004) for a more detailed description of many of the issues covered in this report.

Dolomite aquifers are highly vulnerable to pollution from surface sources, and this situation is made more serious by the proximity of large urban areas, roads, railways and other infrastructure. Although this desktop study was not able to address all of the groundwater issues in detail, the following issues have emerged:

- The quantity of groundwater in the Tshwane dolomites appears not to be declining. Most boreholes in fact show a slight rise in groundwater level. The reasons for this are most likely to be due to changing recharge conditions in response to rainfall.
- The quality of groundwater in the Tshwane dolomites may be getting worse. In particular, boreholes close to surface water courses such as the Hennops River are vulnerable to pollution from waste water. Groundwater pollution is difficult and expensive to remediate.
- Monitoring of groundwater, both groundwater levels and groundwater quality, is at present probably not comprehensive enough to provide a picture of changing trends in the aquifers. Monitoring appears to have declined in the last ten or so years, possibly due to restricted access to boreholes, or boreholes being destroyed.

- The WARMS dataset does not give an accurate picture of groundwater use in the study area. Important abstractions and water sources such as the Pretoria Fountains are absent from the dataset and it is likely that the licensed amounts for abstractions in the dataset are being exceeded in some cases. It is therefore difficult to know exactly how much groundwater is being used in the study area. It is recommended that DWAF and Tshwane Metropolitan Municipality cooperate in monitoring activities, to mutual advantage. In general, cooperation between the various stakeholders and holders of knowledge with regard to the Tshwane dolomites appears to be fairly poor.
- The area is under pressure from a number of development initiatives, including new housing developments. This increases the risk of groundwater pollution, and it is recommended that special consideration be given to this issue, particularly where on-site disposal of waste water is proposed. It is probably desirable to re-examine the issue of protection zones around public water supply sources, in the light of new developments.
- The risk of sinkholes in karstic dolomite areas can be serious. An activity of the current DWAF project of which this activity is a part is examining this risk in the Tshwane area, and will be developing generic guidelines. This risk should form an important consideration in approving new developments. It is likely that the final risk assessment guidelines will rely on accurate water level data, and this is another reason for improving the monitoring system.

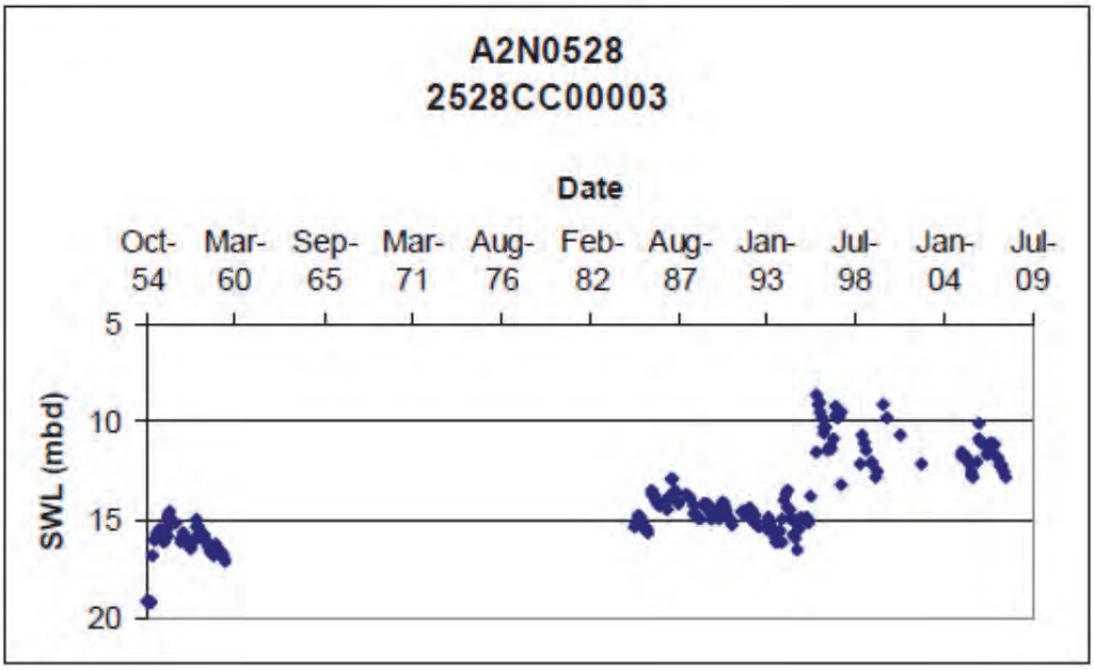
APPENDIX 10A

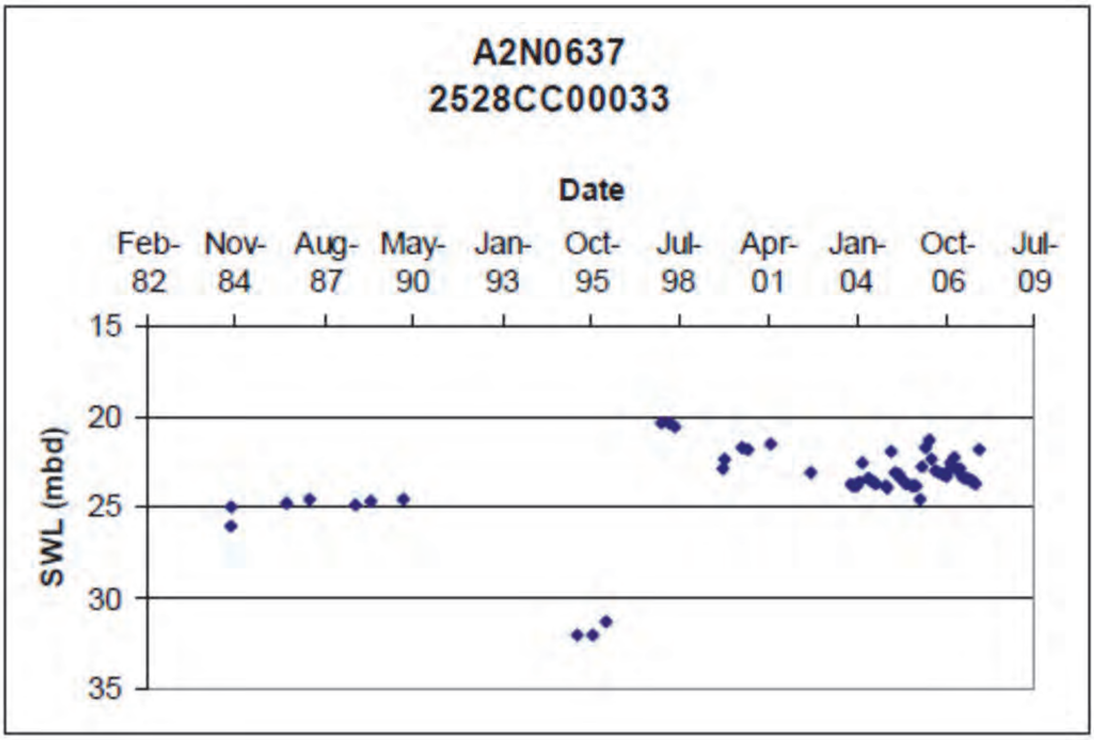
LOCATIONS AND IDENTIFIERS AND WATER LEVEL MONITORING STATIONS

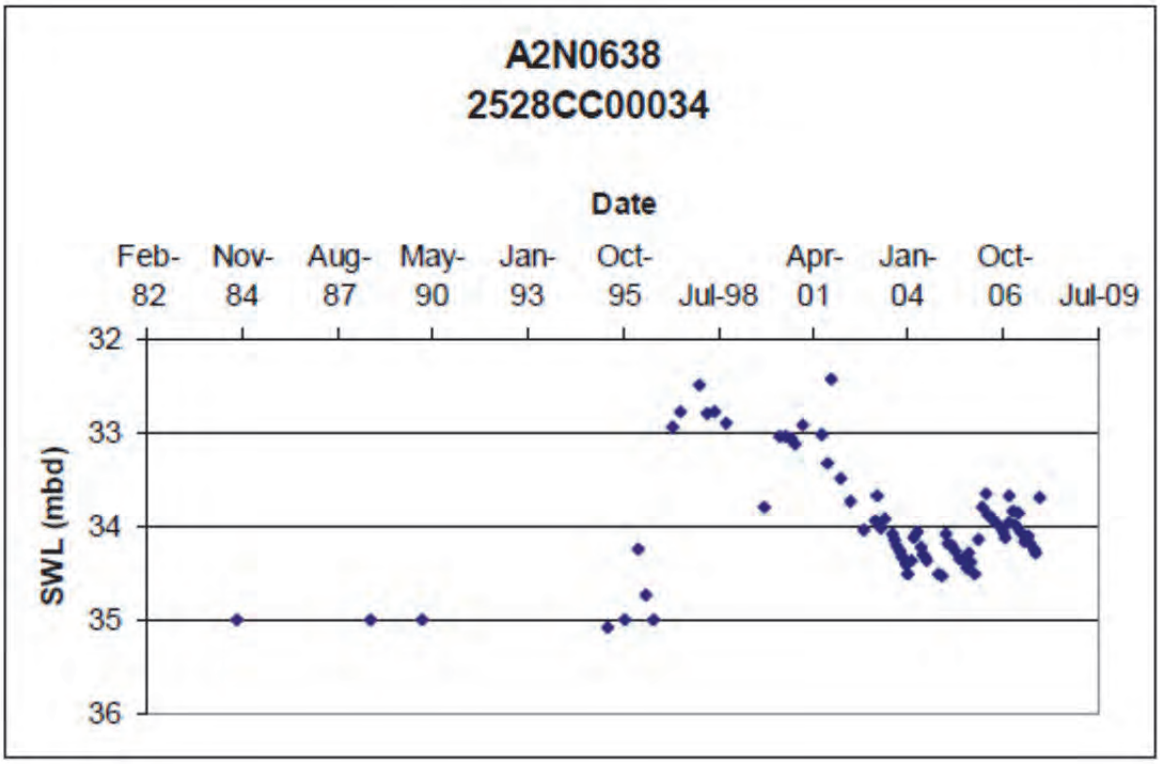
Compartment	ID	Other ID	Latitude	Longitude
Doornkloof E	A2N0685	2528CC00015	-25.86806	28.22583
Doornkloof E	A2N0693	2528CC00023	-25.90556	28.23888
Doornkloof E	A2N0694	2528CC00024	-25.91167	28.24500
Doornkloof E	A2N0695	2528CC00025	-25.91166	28.24472
Doornkloof E	A2N0699	2528CC00028	-25.91194	28.23805
Doornkloof E	A2N0678	2528CD00080	-25.86944	28.25611
Doornkloof E	A2N0679	2528CD00081	-25.87084	28.25056
Doornkloof W	A2N0687	2528CC00017	-25.88527	28.20583
Doornkloof W	A2N0688	2528CC00018	-25.89250	28.20972
Erasmia	A2N0647	2528CC00042	-25.80833	28.15222
Erasmia	A2N0656	2528CC00046	-25.81611	28.11806
Erasmia	A2N0657	2528CC00047	-25.82195	28.11945
Erasmia	A2N0669	2528CC00049	-25.82639	28.11528
Erasmia	A2N0670	2528CC00050	-25.82611	28.11500
Erasmia	A2N0674	2528CC00054	-25.83278	28.11861
Erasmia	A2N0757	2528CC00066	-25.80944	28.13000
Erasmia	A2N0658	2528CC00245	-25.82361	28.14730
Erasmia	A2N0659	2528CC00246	-25.82611	28.12000
Erasmia	A2N0660	2528CC00247	-25.82584	28.11945
Pretoria East	A2N0637	2528CC00033	-25.79027	28.20972
Pretoria East	A2N0638	2528CC00034	-25.79166	28.20972
Pretoria East	A2N0640	2528CC00036	-25.79027	28.20278
Pretoria East	A2N0641	2528CC00037	-25.79722	28.21945
Pretoria East	A2N0642	2528CC00038	-25.80278	28.20417
Pretoria West	A2N0528	2528CC00003	-25.83056	28.15833

APPENDIX 10B

GROUNDWATER REST LEVEL TRENDS



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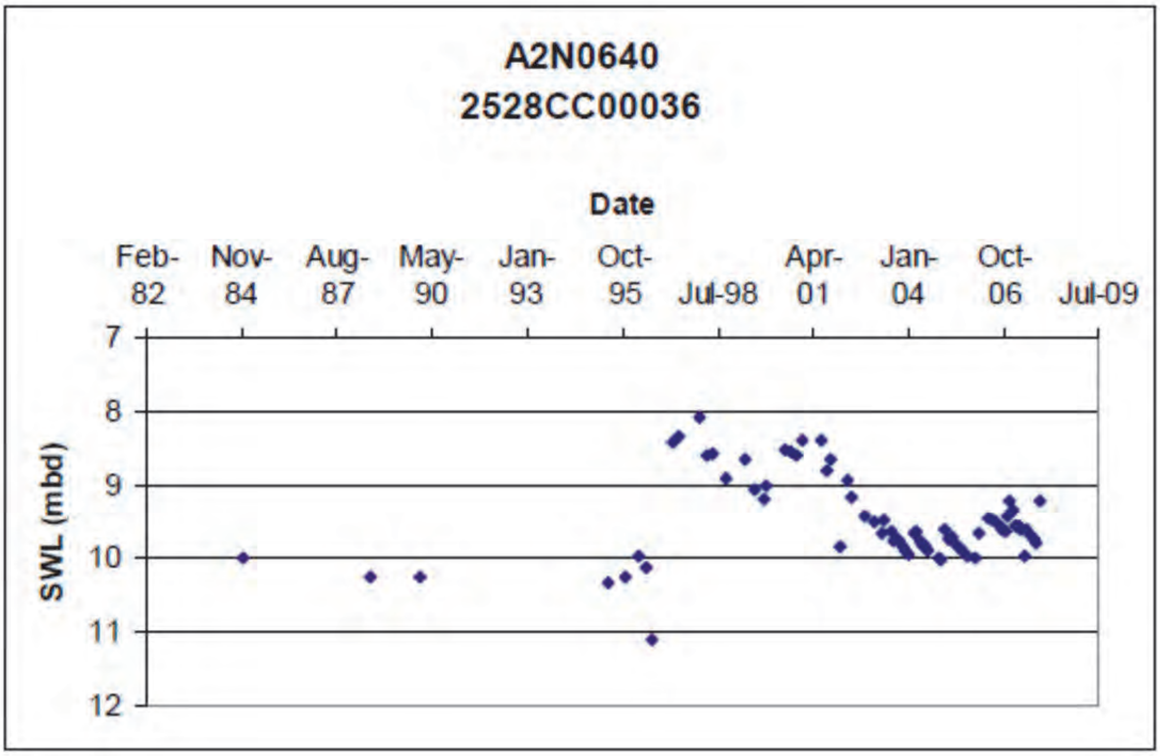
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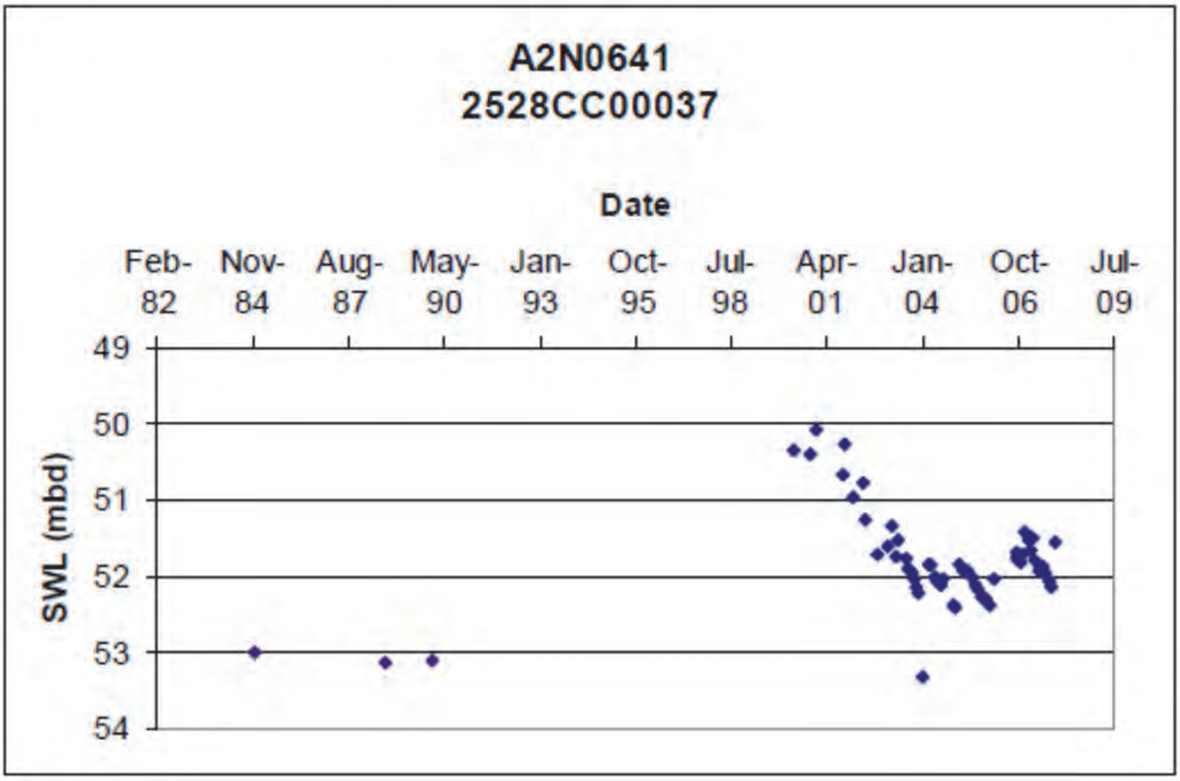
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SWL (mbd)
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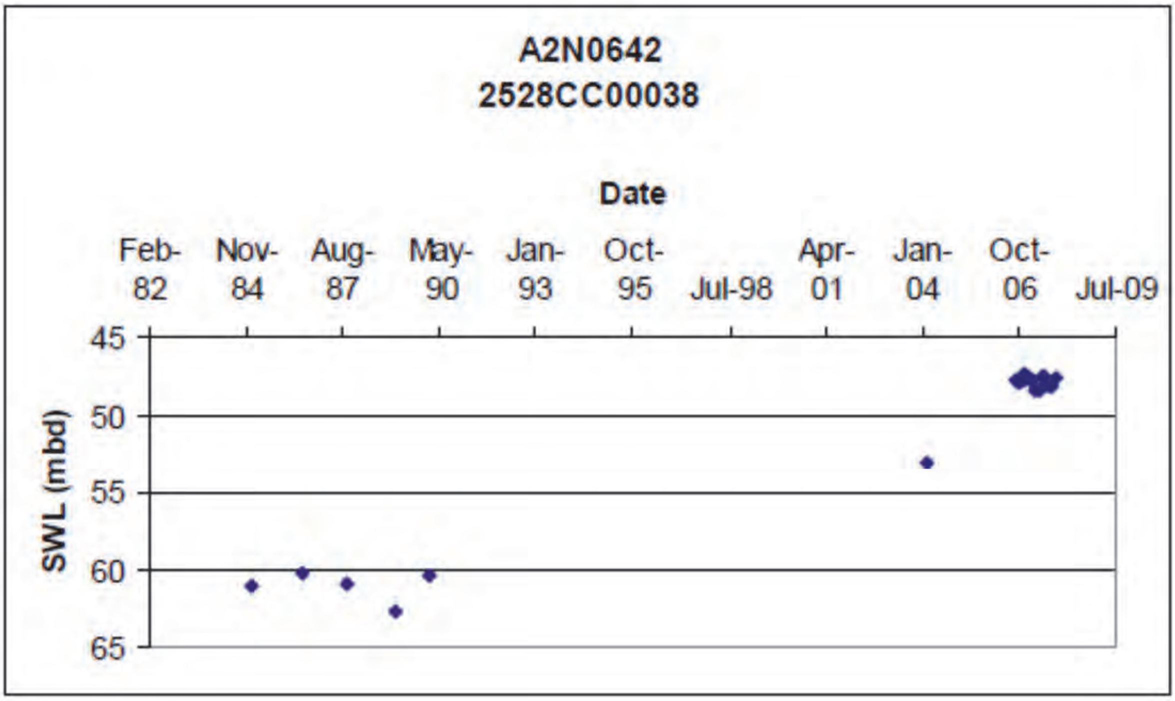
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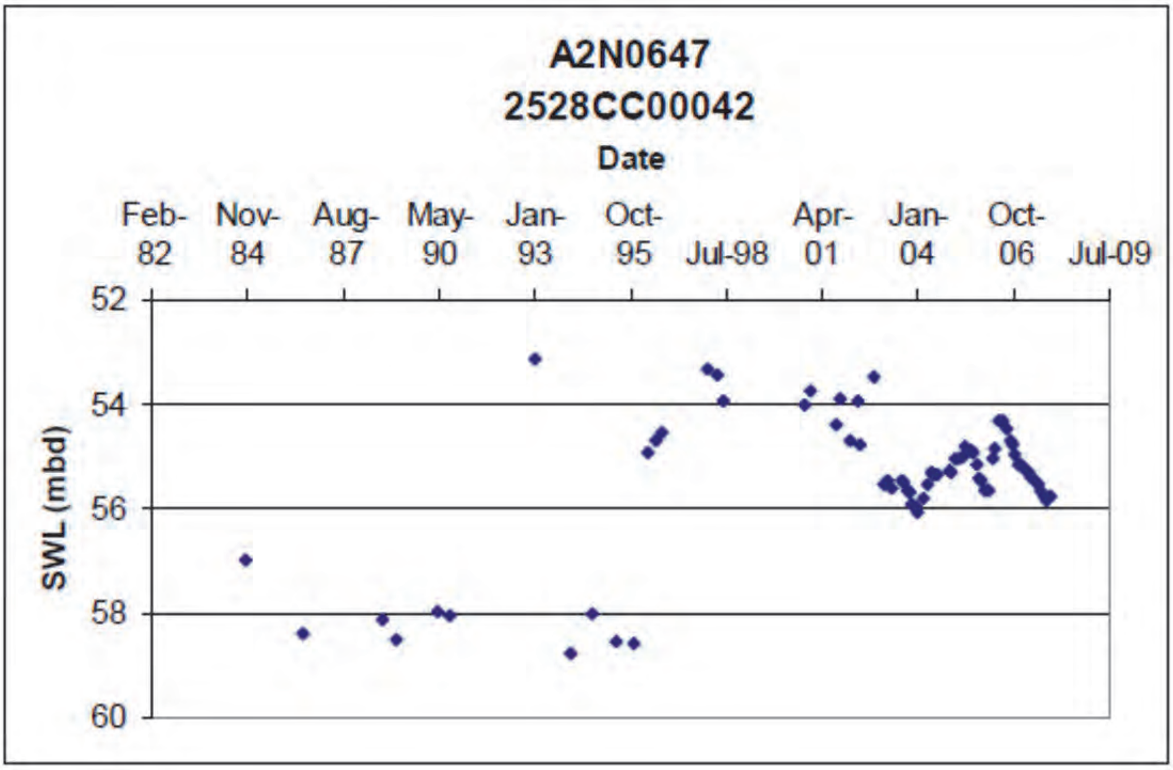

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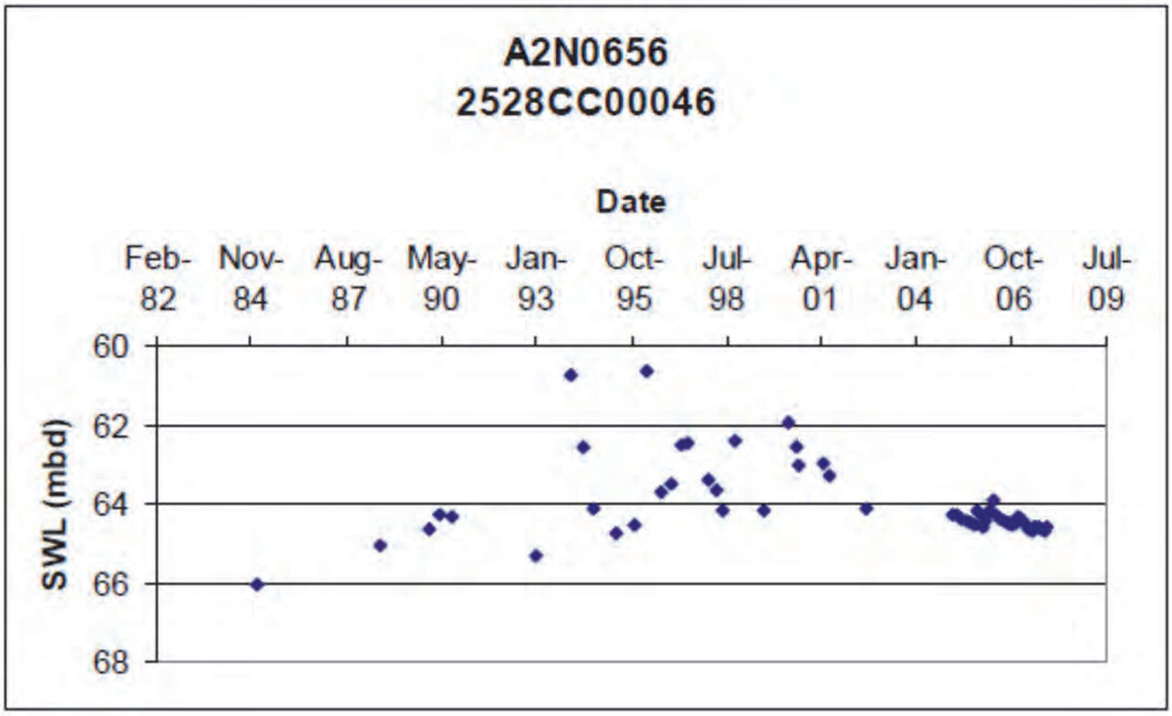

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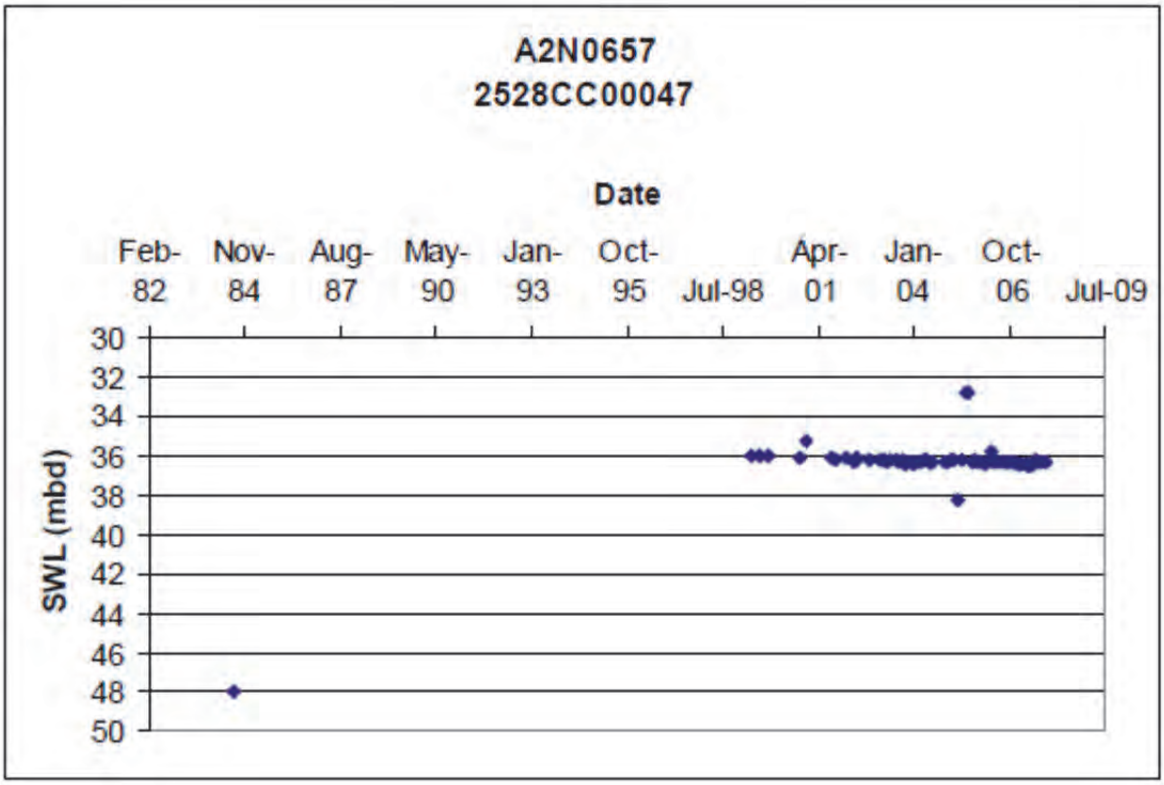
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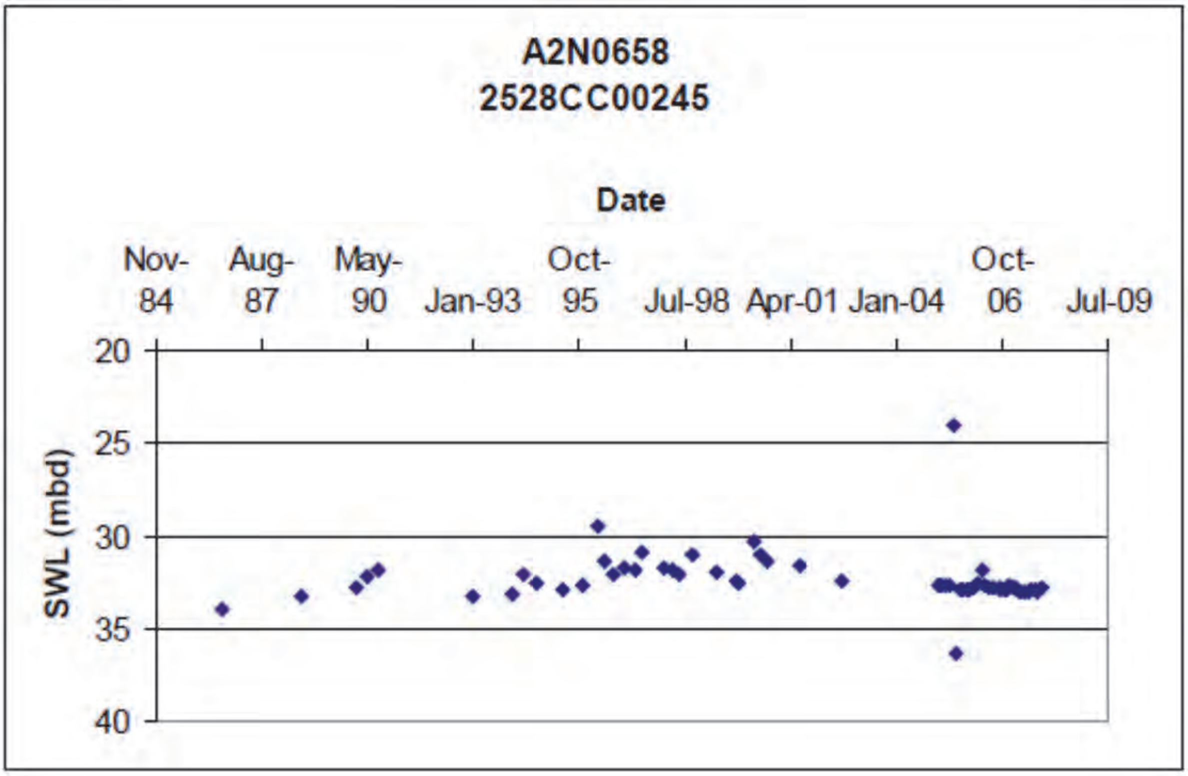
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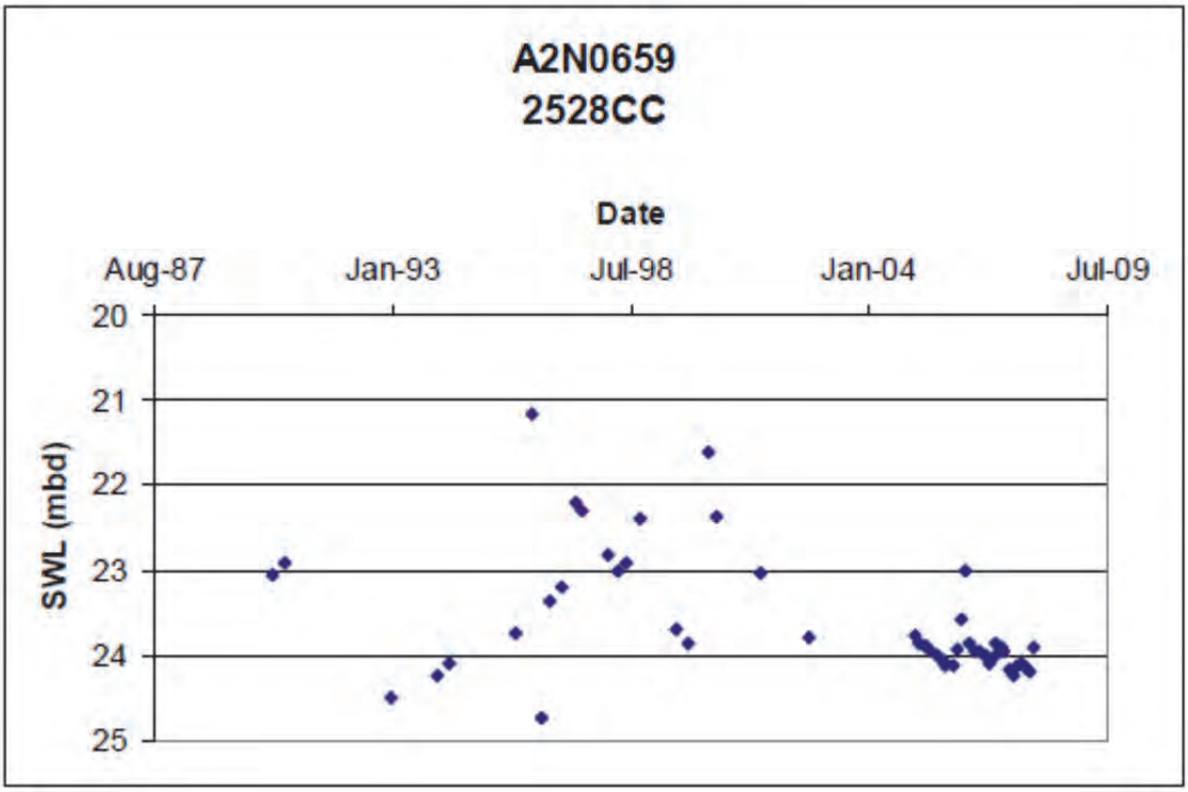
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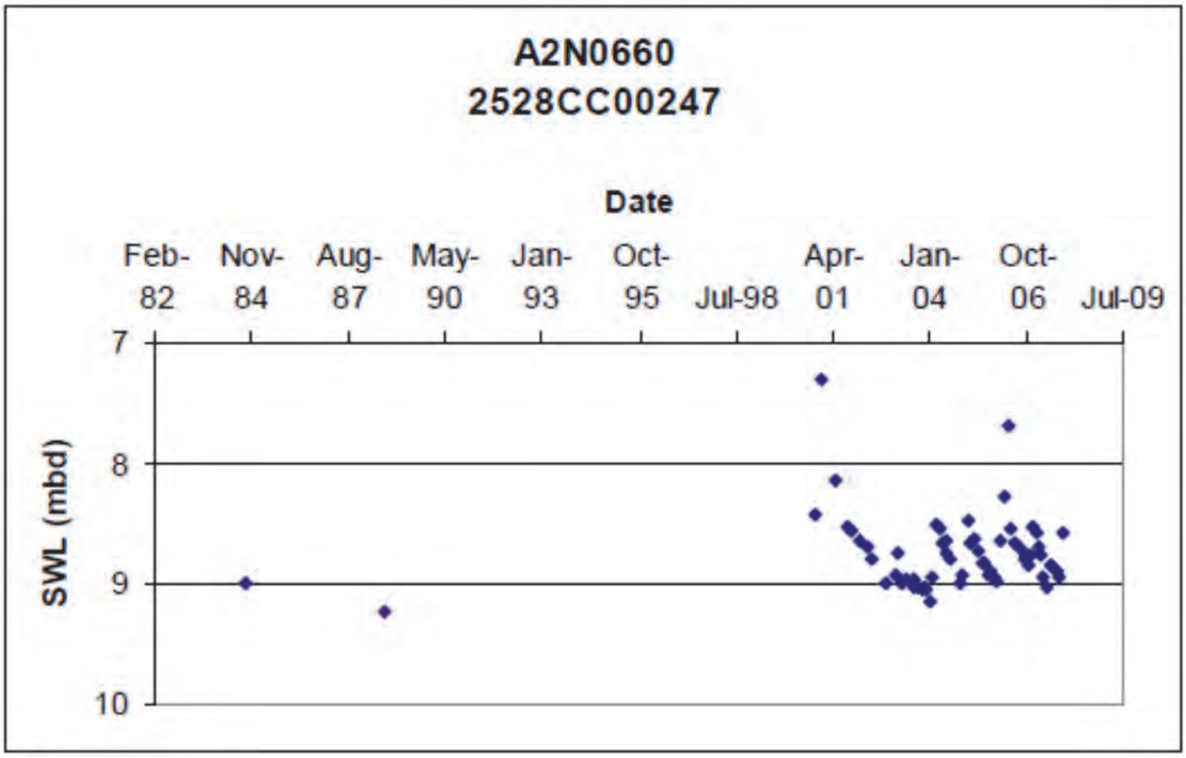
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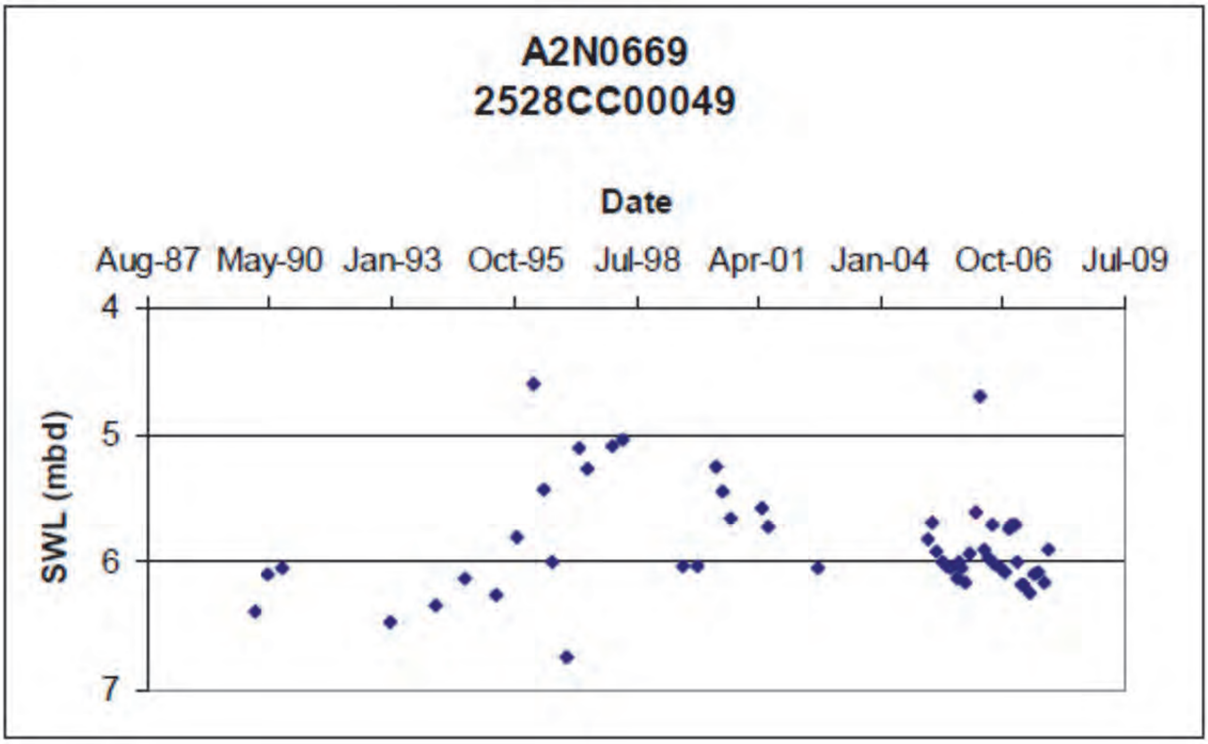
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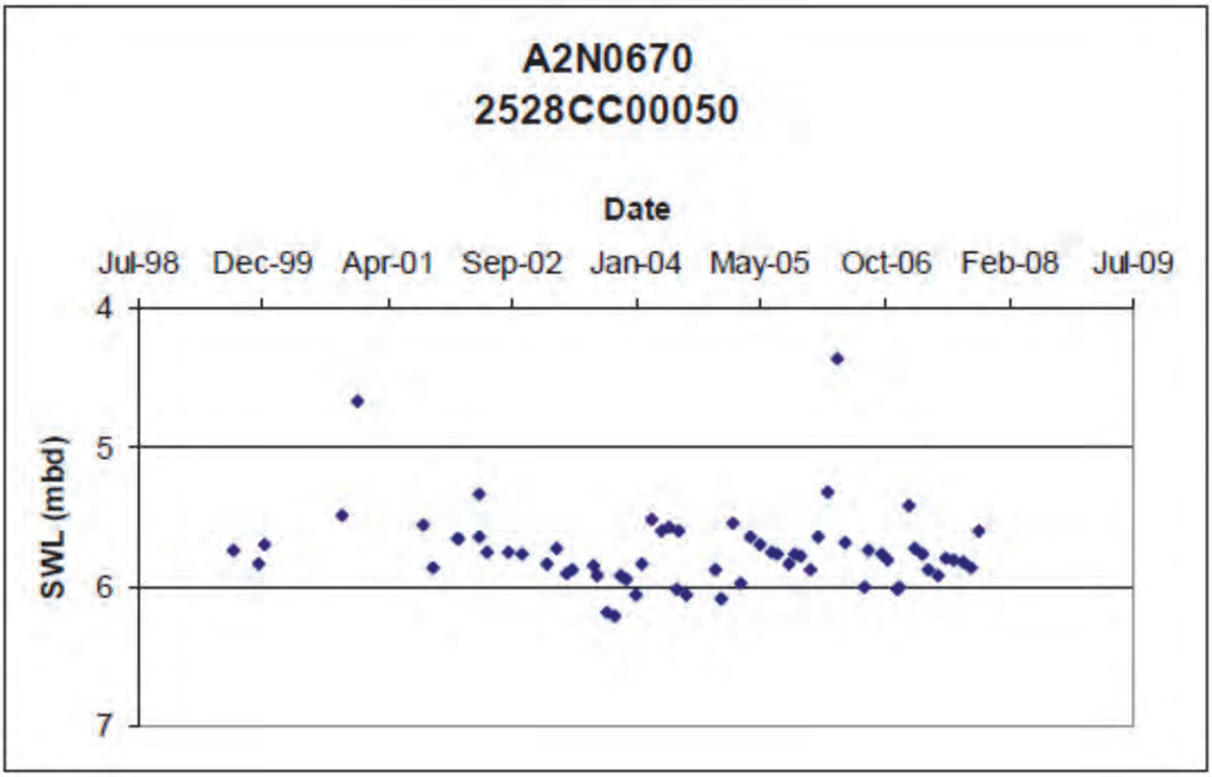
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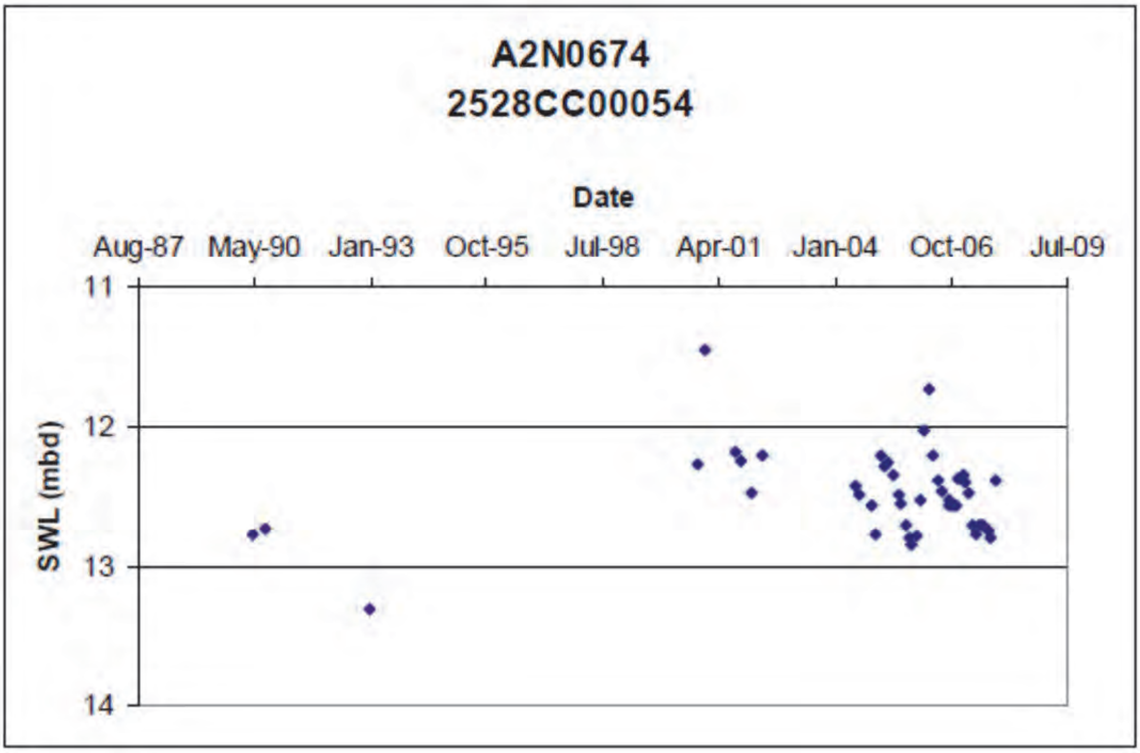
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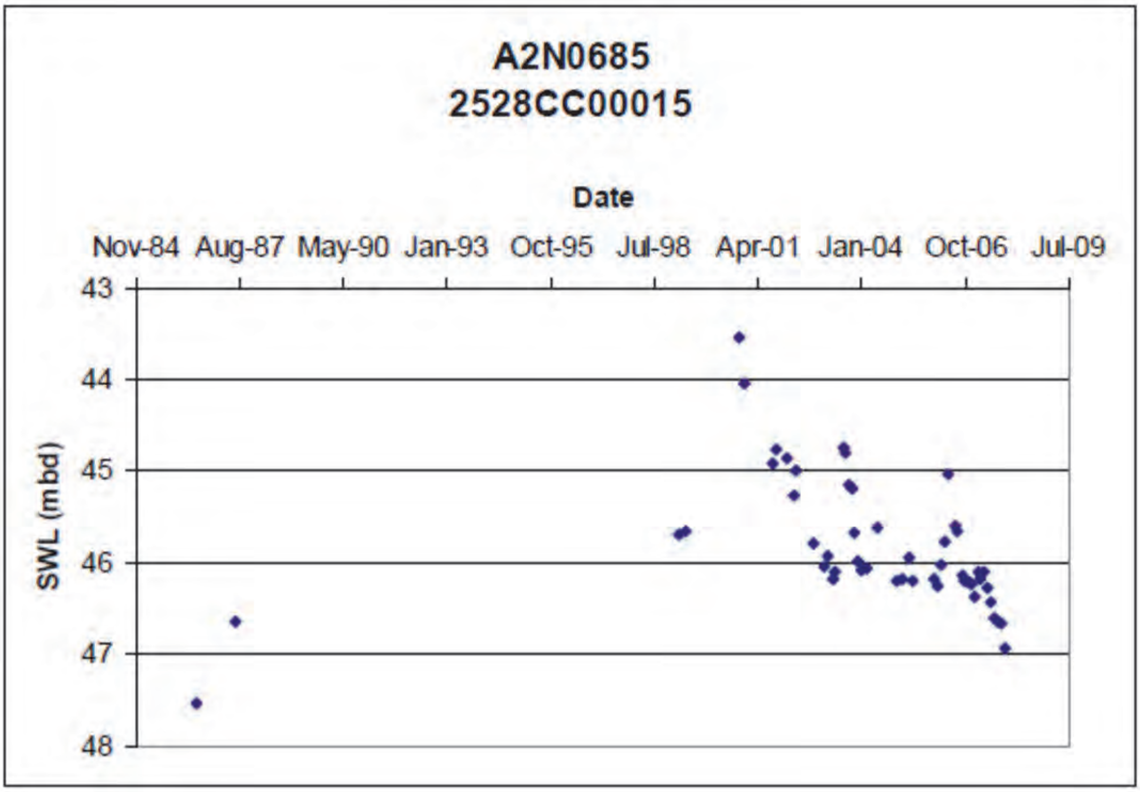
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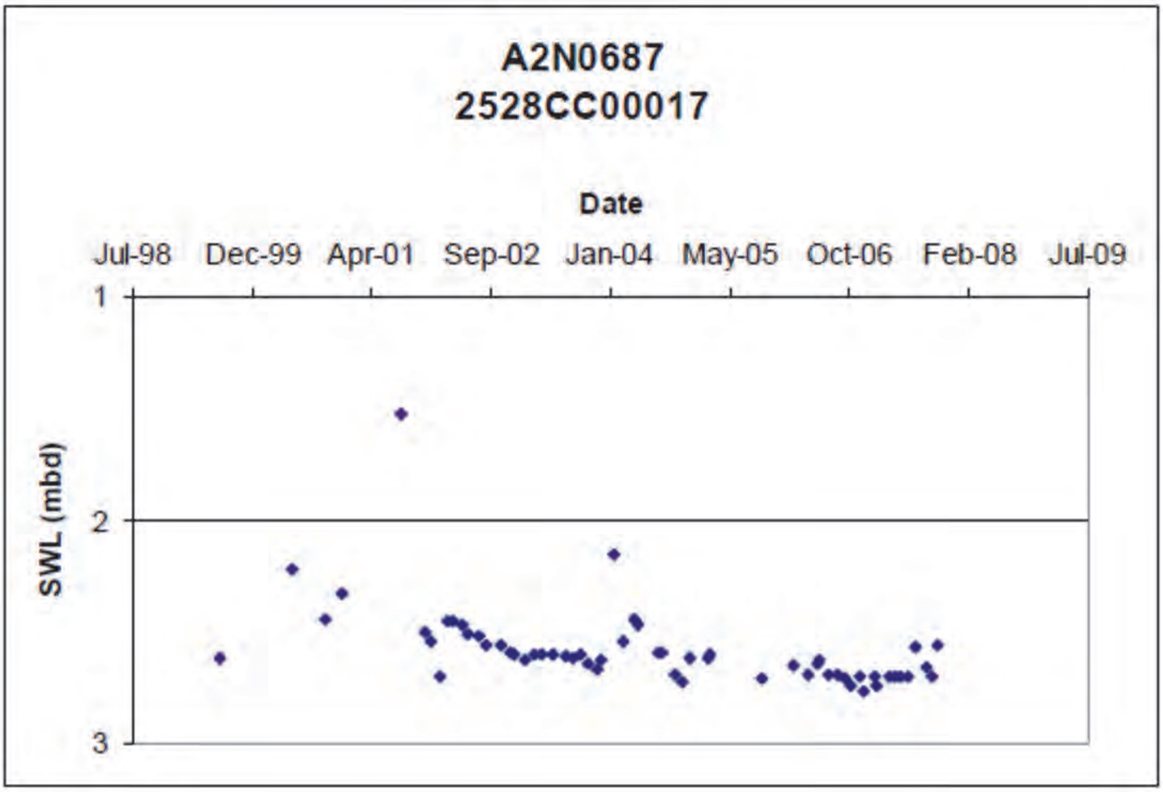
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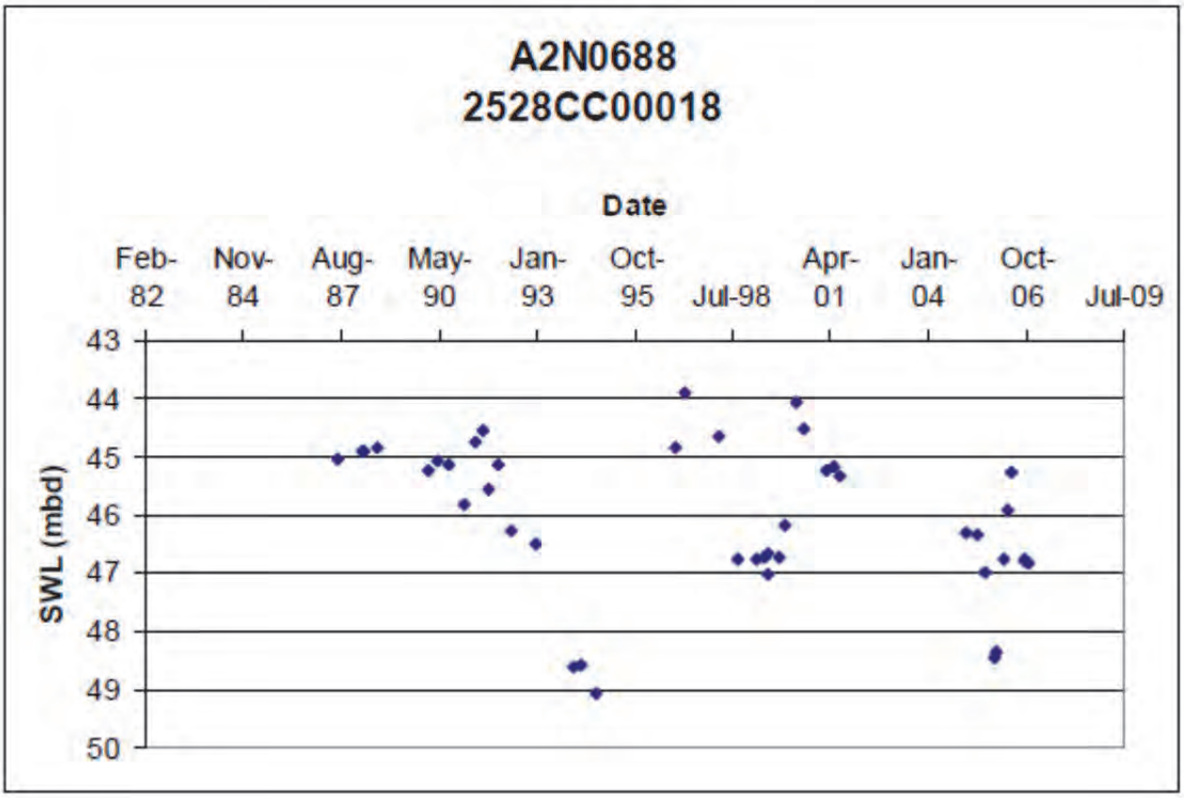
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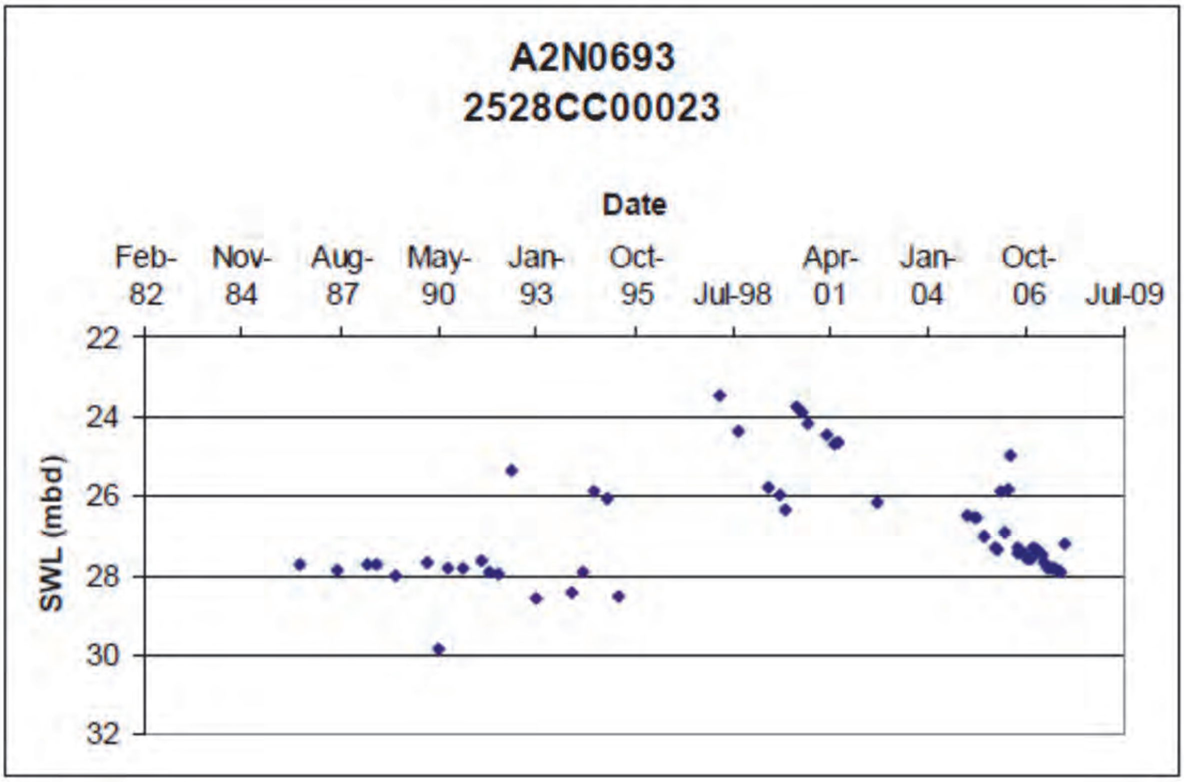
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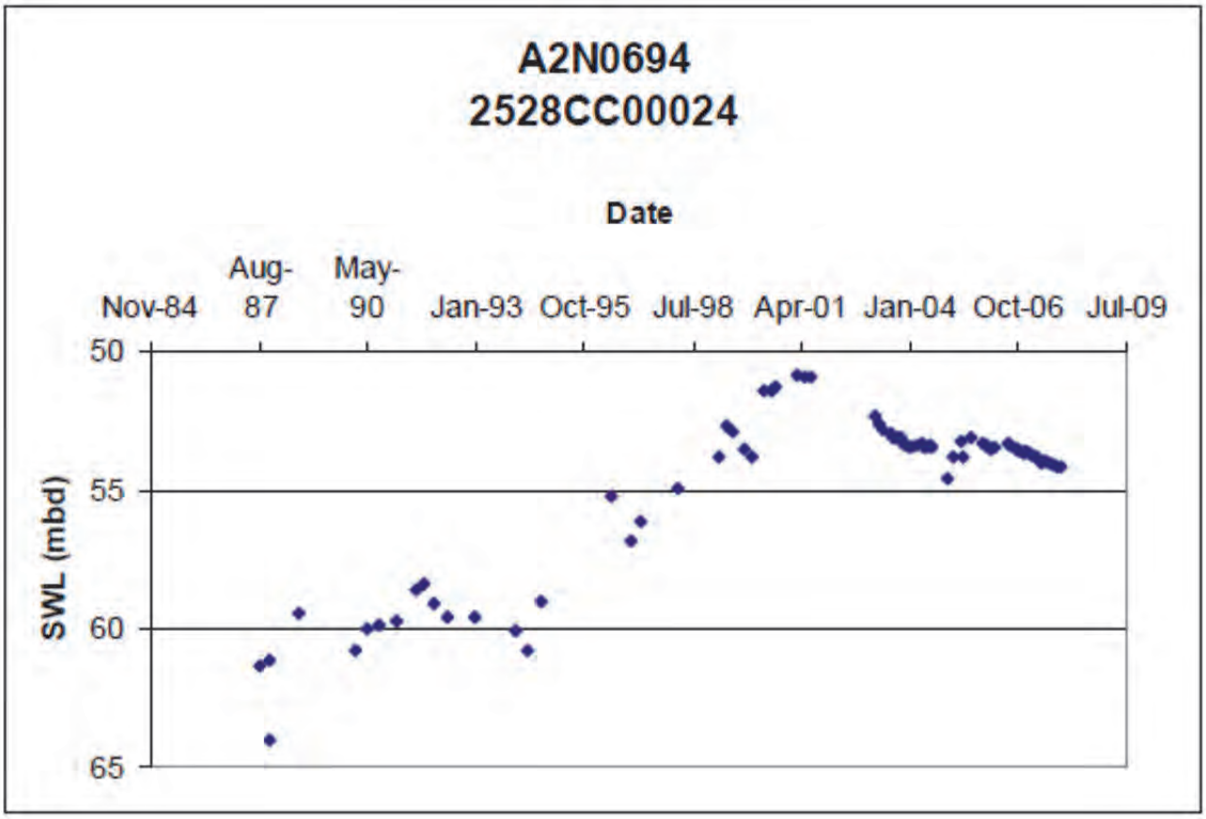
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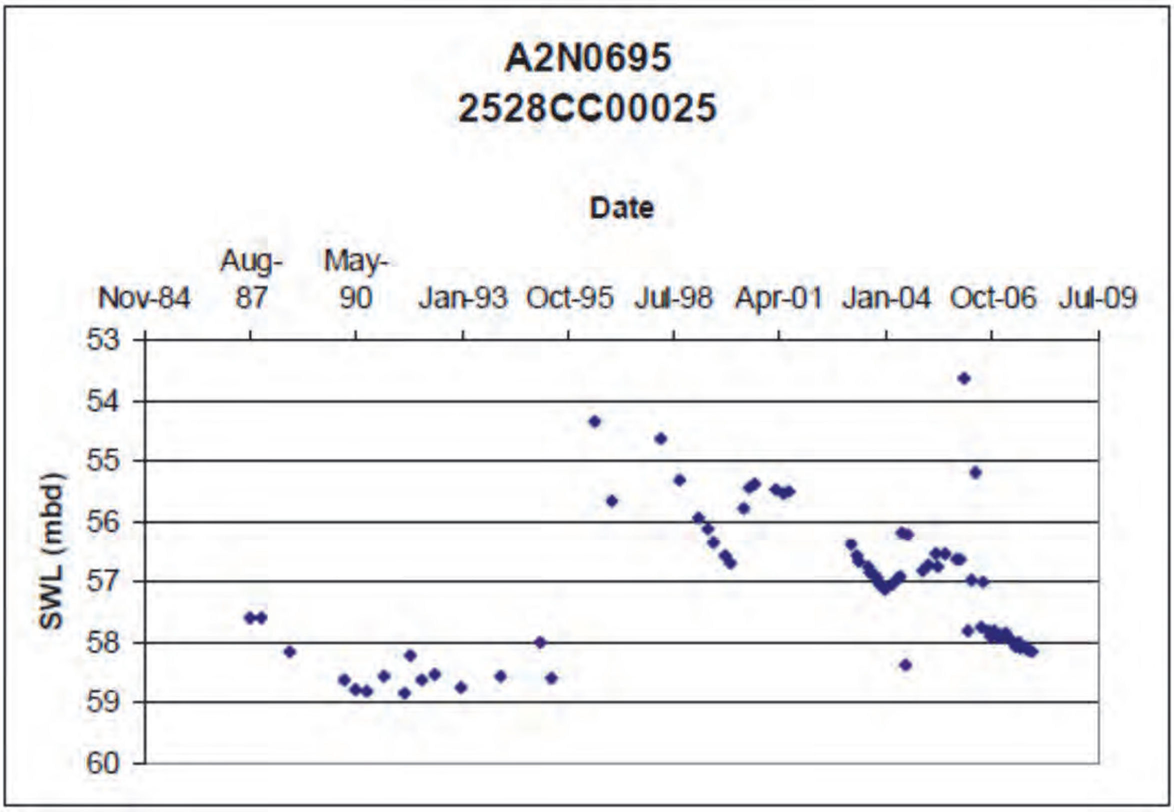
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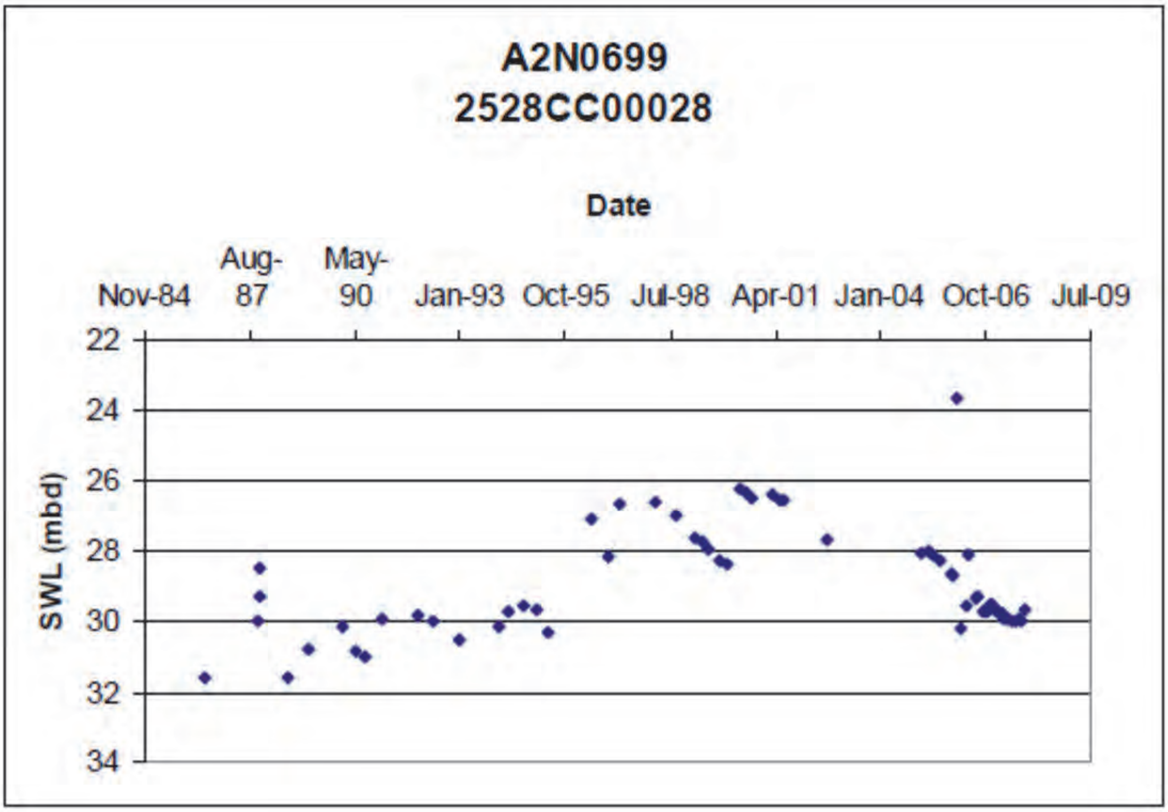
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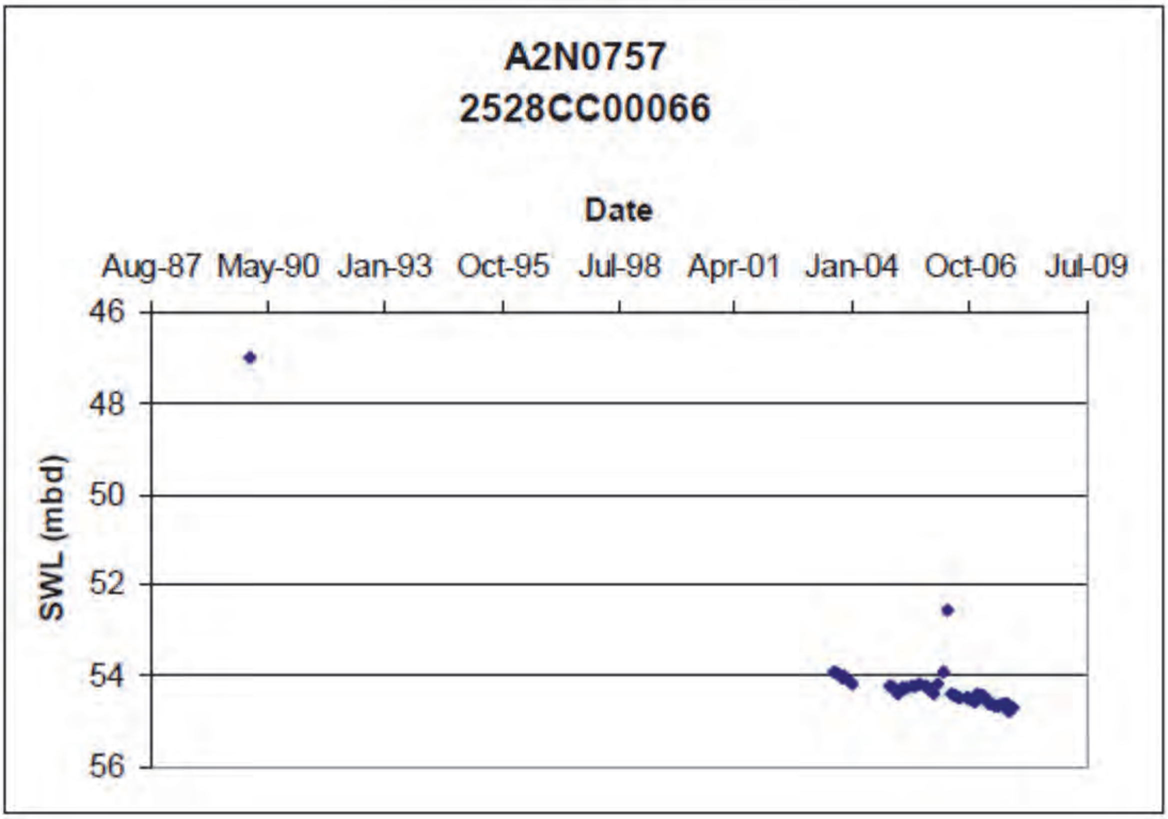
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11 HYDROGEOLOGY OF THE BAPSFONTEIN-DELMAS AREA

In this section the hydrogeology of the Bapsfontein-Delmas dolomitic aquifers is described. The text is essentially taken from the recent report by Holland and Titus (2007) and formed part of a larger DWAF project in which guidelines for the development of the main dolomitic aquifer regions in South Africa were developed. The section of this document describing the hydrogeology of the Bapsfontein-Delmas region was referred to as Activity 6 of the larger project.

11.1 Introduction

11.1.1 Background

The Delmas-Bapsfontein dolomitic aquifers southeast of Pretoria represent important water resources that are relied on by many. Water users include urban and rural dwellers, irrigation and livestock farmers, industry and mining. The aquifer also sustains the ecology where wetland areas around dolomitic springs and surface water flowing from the dolomite groundwater, create an ideal habitat for plant and animal species. The investigation and understanding of this complex compartmentalised karst aquifer has become crucial since the manifestation of numerous sinkholes in the Bapsfontein area. This desktop geohydrological study is based on the processes and activities contained in Volume 3 of the Guideline for the Assessment, Planning and Management of Groundwater Resources within Dolomitic Areas in South Africa (DWAF, 2006).

11.1.2 Study Locality

The study area shown in Figure 11.1 is located east of Johannesburg and includes the municipal areas of Delmas, Greater East Rand Metro, part of Kungwini and Tshwane Metropolitan. The aquifers under investigation are formed by the Malmani dolomite formations of the Chuniespoort Group. The study area centres on the Delmas-Bapsfontein dolomites extending from Rietvlei dam east of Pretoria to beyond the town of Delmas in the southeast, a distance of 64km.

11.1.3 Approach

The desktop geohydrological assessment utilised the following information:

- the 1:250 000 scale geological maps 2528 Pretoria and 2628 East Rand,
- the 1:500 000 scale hydrogeological map 2526 Johannesburg and its baseline data,
- Delmas-Bapsfontein aeromagnetic survey,
- technical GH reports by DWAF's Geohydrology directorate,
- water level monitoring data extracted from the National Groundwater Database (NGDB, now the NGA) managed by DWAF,
- groundwater quality extracted from the NGA, relevant and appropriate scientific reports commissioned by local authorities and developers.

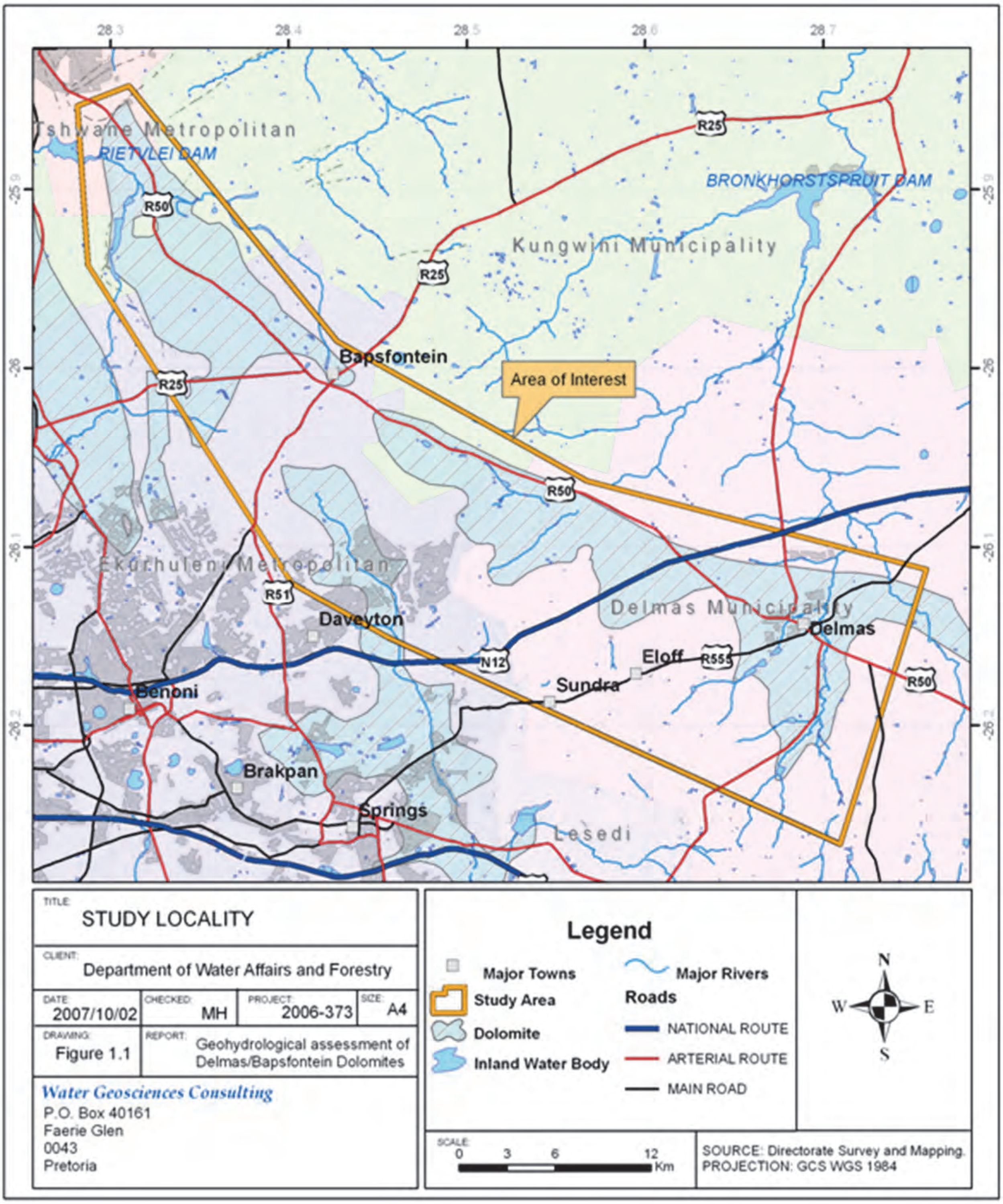


Figure 11.1. Locality of study area.

11.1.4 Methodology

The objective of a desk study is the collation, scrutiny and evaluation of available and relevant meteorological, geographical, geological, hydrogeological and groundwater quality data. The primary task involved the gathering of information and data relevant to the dolomite aquifers in the delineated study area. The desktop assessment is based on the following information related to groundwater:

- Geological and hydrogeological maps,
- hydrogeological reports,
- borehole logs,
- geophysical profiles of exploration and/or monitoring boreholes previously drilled in the area,
- groundwater quality data, and
- other aspects, including land-use planning and potential water requirements.

This information is used to establish a background or baseline geological and hydrogeological reference for the identified study area, including possible boundaries for the dolomitic aquifer system associated with the distribution of compartmentalising dykes, together with any other potential aquifers within the catchment. The information obtained will be collated into a water balance, indicating water availability and water requirements.

11.2 Description of Study Area

11.2.1 Morphology and Drainage

The topography of the study area is generally flat to gently undulating, with plains, slopes and several scattered hill crests. A prominent ridge crest capped with resistant quartzite (striking northwest to southeast) is situated along the northern part of the study area north of the R50. The dolomite dips regionally north-northeast beneath the Pretoria Group.

The study area extends over quaternary catchments A21A, C21D, B20B and B20A of the Crocodile (West) and Marico, and Olifants Water Management Area (WMA) respectively (Figure 11.2). As shown in Figure 11.2, the main surface drainage in the northern part of the study area is the Rietvlei system which originates to the west of Bapsfontein and eventually flows into the Rietvlei dam. To the east of the Rietvlei system the area is practically devoid of surface drainage features, which is typical for dolomite areas with rapid recharge taking place. To the southeast of Bapsfontein non-perennial streams drains the dolomite in an easterly direction which eventually flows north into the perennial Koffiespruit stream. Surface drainage of the Delmas region is drained towards the north by the Bronkhorstspruit River which feeds the Bronkhorstspruit Dam. Numerous perennial and non-perennial pans and dams are scattered throughout the area. Several dolomitic springs in the area support irrigation activity and domestic supplies (Figure 11.2).

11.2.2 Climate, Rainfall and Vegetation

The climate in the area is typical South African “Highveld”, characterised by warm summers, when 80% of the rainfall is experienced as thunderstorms, and cool dry winters with cold nights. Frosts are experienced for up to five months of the year and hail falls often. Climatic data of three meteorological stations (1985-2007) closest to the study area is summarised in Table 11.1.

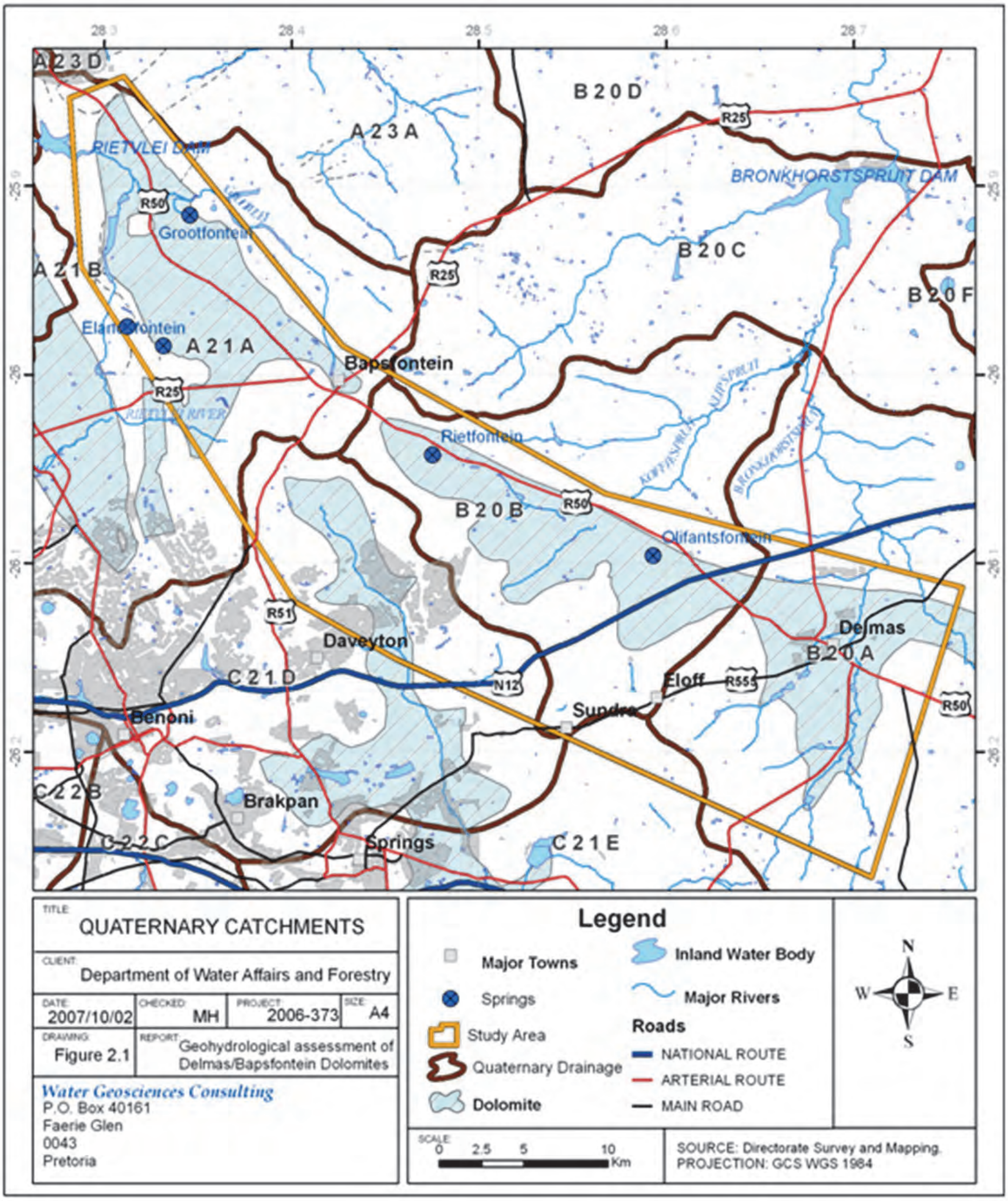


Figure 11.2. Surface water catchments of the study area.

Table 11.1. Meteorological stations in the study area.

Meteorological Station*	Coordinates		Elevation m.a.m.s.l.	Mean daily max. temp (°C)	Mean daily min. temp (°C)	Mean annual rainfall (mm)
	Longitude	Latitude				
Jan Smuts (O R Tambo Int. Airport)	28.2330	-26.1330	1694	22.2	9.8	721
Delmas (Witklip)	28.6800	-26.1500	1571	24.0	8.6	629.5
Irene	28.2110	-25.9100	1526	24.1	10.8	684.5

*- Data obtained from the South African Weather Services (Pretoria)

A very high potential evapotranspiration with a mean annual evaporation of about 1700 mm prevails (DWAF, 1992) and exceeds the average annual precipitation by a factor of 2.4. However, the actual evapotranspiration is much lower as the shallow soil cover limits availability of moisture to the plants, which causes excess soil water to infiltrate below the root zone, recharging the groundwater reservoir. Most of the study area comprises of small holdings (with greenhouses), large areas of cultivated land and built-up urban development. These land uses has removed the natural vegetation which was identified as Central Variation of the Bankenveld veld type by Acocks (1975).

11.2.3 Land-Use

The geographic locations of the various land-use activities are shown in Figure 11.3. Land-use in the study area encompasses a wide spectrum of activities, more specifically:

- Irrigation and dry land farming (mainly maize and vegetables) with numerous poultry farms (e.g. Hy-Line and Earlybird) and some stock farming in much of the south-eastern portion.
- Quarrying for sand, e.g. Tweefontein Quarry on Tweefontein 19IR and for refractory clay and brick making, e.g. Corobrik and Nova Bricks on Witkoppies 393JR and Apollo Bricks on Elandsfontein 412JR.
- Agricultural holdings and smallholdings, e.g. Elandsfontein, Bapsfontein and Modder East.
- Informal settlements, e.g. Botleng, Davyton and Etwatwa.
- Urban and industrial areas, e.g. Delmas and Bapsfontein.
- Conservation areas, e.g. the Rietvlei Nature Reserve.
- Holfontein Landfill site situated on Portion 24, Farm Holfontein 71 IR, Springs.
- Railway marshalling area known as Sentrarand belonging to the South African Transport Services.

11.2.4 Geology

11.2.4.1 Geomorphology

The present karst forms and geomorphology have been created by the interplay of ancient and recent erosion cycles on lithologies that have undergone many episodes of deformation. Subsequent to the break-up of the super-continent of Gondwanaland (250 million years ago), the dolomites have been uplifted into a high interior plateau and the overlying Karoo cover rocks relatively rapidly stripped off by erosion to reveal a pre-Karoo palaeo-karst surface (King, 1963; Wilkins *et al*., 1987). The surface karst features include natural springs, sinkholes, dolines and shallow depressions.

11.2.4.2 Geological Setting

The regional geology and stratigraphy in the study area show a variety of rock types. Igneous rocks, the oldest at about 3 200Ma (million years) old, are represented by the granite associated with the Halfway House Granite Suite found in the western portion of the study area. This geological basement is known as the Kaapvaal Craton. On the Kaapvaal Craton unmetamorphosed sequences ranging in age from 3 000 to 1 750 million years have accumulated in basins from oldest to youngest (Truswell, 1977). In this study such sequences are the less exposed Witwatersrand and Ventersdorp Supergroup with the widespread

Transvaal Sequence occurring elongated on the eastern side of the granitic basement. The sedimentary strata (tillite, sandstone, shale and clay) associated with the Dwyka Group and Vryheid Formation within the Karoo Supergroup cover the southeastern portion of the study area. The youngest geological deposits are represented by unconsolidated alluvium and colluvium of Quaternary age. A generalised lithostratigraphy is presented in Table 11.2 and the regional geological setting is illustrated in Figure 11.4.

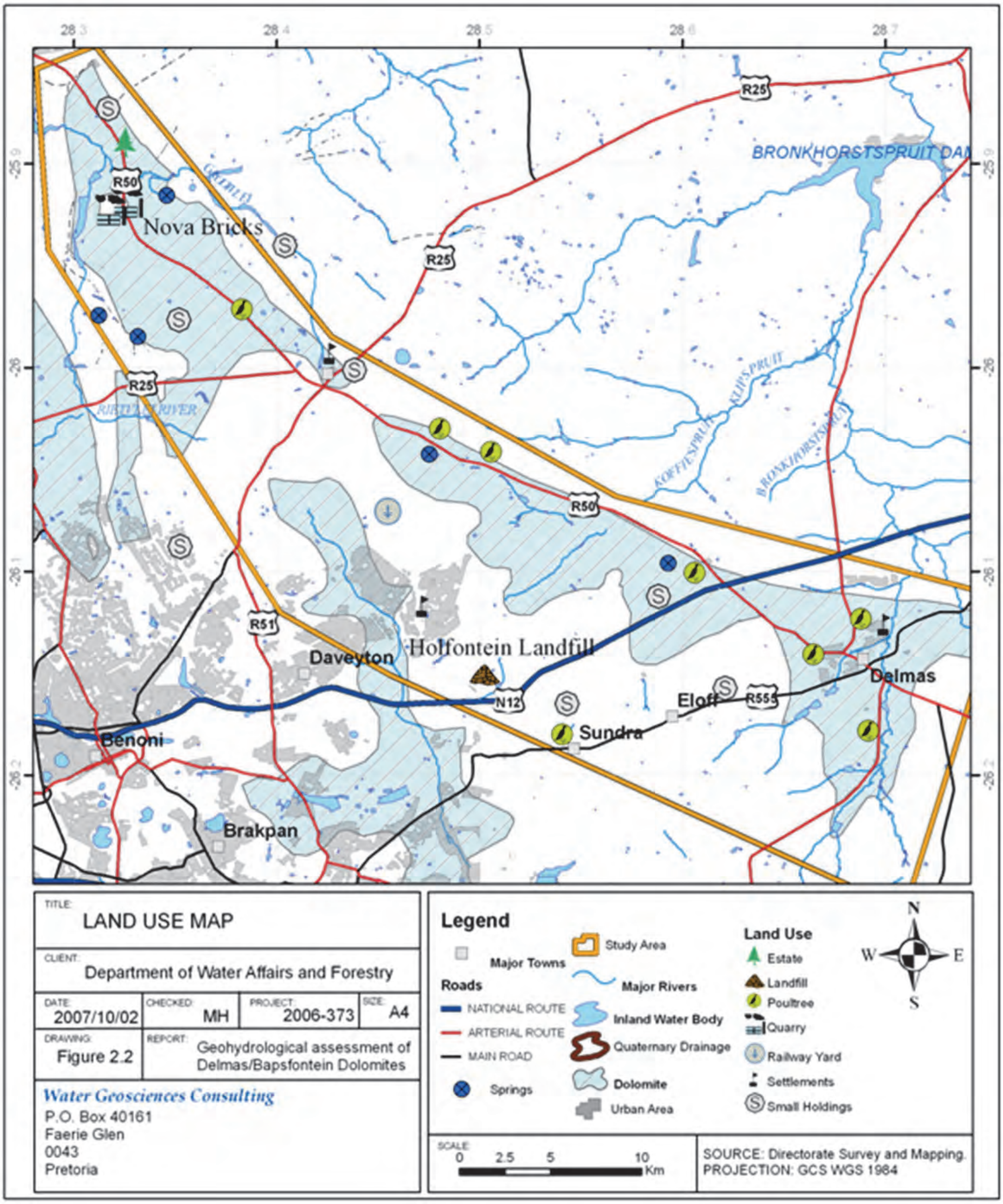


Figure 11.3. Geographic location of land-use features.

Table11.2. Lithostratigraphy of the geology of the study area (SACS, 1980:205 and Hobbs, 2004).

<table>
<tr><th>BASIC LITHOLOGY</th><th colspan="3">LITHOSTRATIGRAPHIC UNIT</th><th colspan="2">ERA (age)</th></tr>
<tr><td>alluvium / colluvium</td><td colspan="3">Quaternary sediments</td><td colspan="2">late Cenozoic (<10 000yrs)</td></tr>
<tr><td>dolerite / syenite</td><td colspan="3">post-Karoo dyke / sill intrusive structures</td><td colspan="2">early Mesozoic (150-190Ma)</td></tr>
<tr><td>sandstone / siltstone</td><td>Vryheid Formation</td><td>Ecca Group</td><td rowspan="2">Karoo Supergroup</td><td colspan="2" rowspan="2">early Mesozoic to late Palaeozoic (180-320Ma)</td></tr>
<tr><td>tillite / diamictite</td><td colspan="2">Dwyka Group</td></tr>
<tr><td>lava</td><td>Hekpoort Formation</td><td rowspan="2">Pretoria Group</td><td rowspan="4">Transvaal Supergroup</td><td rowspan="3">(2 225Ma)
(2 430Ma)</td><td rowspan="4">Vaalian</td></tr>
<tr><td>shale / siltstone / quartzite</td><td>Timeball Hill Formation</td></tr>
<tr><td>Dolomite</td><td>Malmani Subgroup</td><td>Chuniespoort Group</td></tr>
<tr><td>quartzite / shale</td><td colspan="2">Black Reef Formation</td><td>(2 600Ma)</td></tr>
<tr><td>breccia / conglomerate</td><td colspan="2">Klipriviersberg Group</td><td>Ventersdorp Supergroup</td><td colspan="2">Randian (2 700Ma)</td></tr>
<tr><td>Granite</td><td colspan="3">Halfway House Granite Suite</td><td colspan="2">Archaean (3 200±65Ma)</td></tr>
</table>

The dolomite occurring in the study area is part of the Malmani subgroup overlying the Black Reef formation and underlying the Timeball Hill Formation of the Pretoria Group. The Pretoria Group rocks in the northeast act as hydrogeological boundaries with numerous pre- and post-Karoo age impervious dykes subdividing the dolomite into 'compartments' isolated hydrogeologically from each other, especially north-west of the study area (Figure 11.4). Further, the sedimentary karst strata are intruded by sub-horizontal sill intrusions. These are comprised mainly of syenite and occur predominantly in the Midrand-Kempton Park dolomites to the west of the study area. The area south of the dolomitic outcrops is extensively covered by the younger Karoo sediments. The thickness of the Karoo sediments in the vicinity of Bapsfontein attains a maximum thickness of roughly 110 m.

11.2.4.3 Mafic Dykes and Lineaments

Aeromagnetic data sourced from the Council for Geosciences was used for the identification of linear anomalies in the region (Figure 11.5). These magnetic anomalies were compared to the dykes from published geological maps (2528 Pretoria and 2628 East Rand) and dykes identified by specialist studies. Dykes displayed two different magnetic signatures (positive and negative). Day (1980) characterised three dyke systems based on magnetic signature, direction and age relative to the Karoo Sequence:

- a negative magnetic signature, is assigned a pre-Karoo Sequence (Pilanesberg age),
- a positive magnetic signature (N-S), is characterized as a pre-Karoo Sequence, and
- a positive magnetic signature (E-W), is of Karoo age.

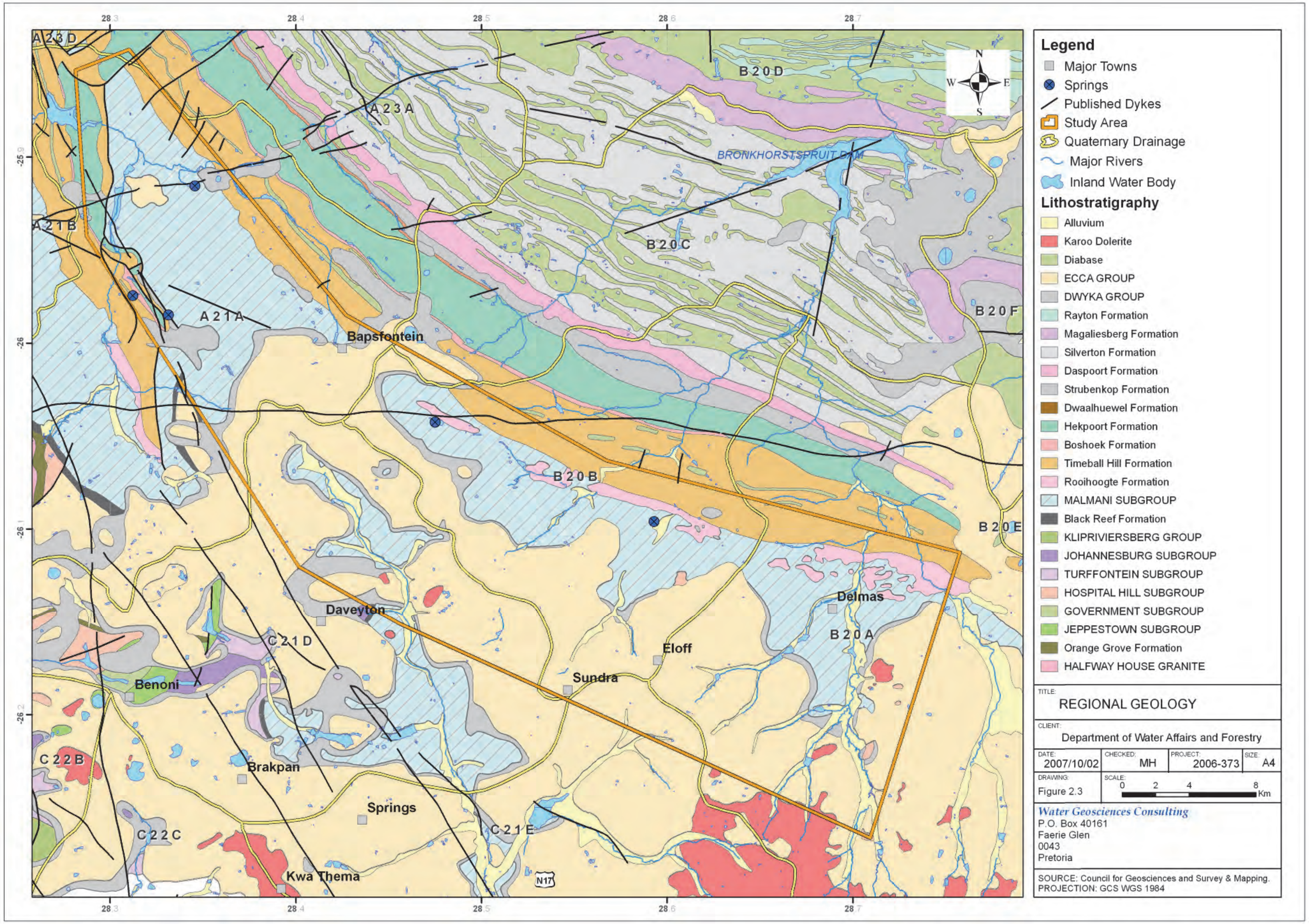


Figure 11.4. Regional geology of the area under investigation.

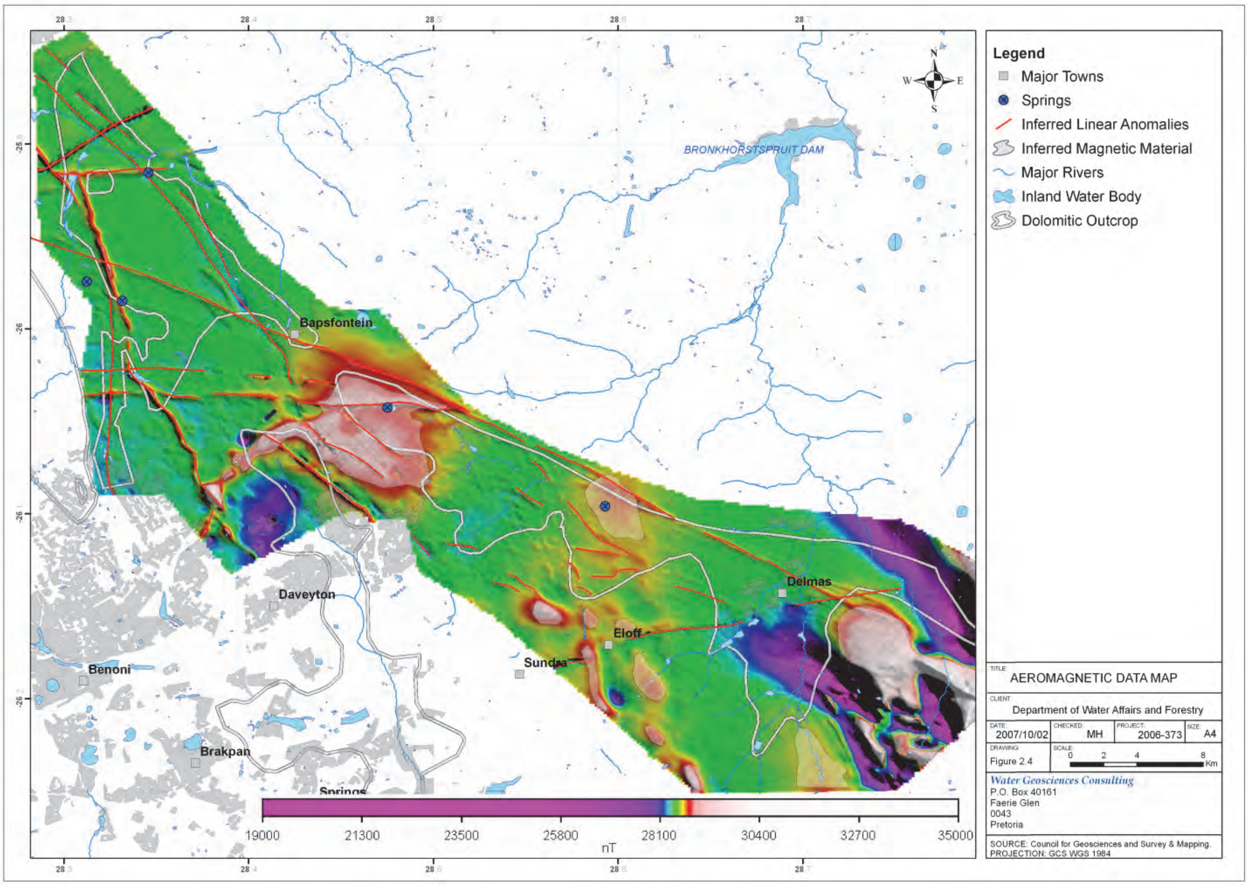


Figure 11.5. Aeromagnetic data interpretation (Sourced from: The Council for Geosciences).

11.3 Hydrogeological Overview

11.3.1 General

The hydrogeological properties of the dolomite are determined by geologic and geomorphological controls such as structure, stratigraphy and morphology. The water-bearing properties of the dolomite stem from carbonate dissolution along structural and lithological discontinuities such as faults, fractures, joints and bedding planes. The surface features of the dolomites can often be related to their sub-surface characteristics e.g. valleys of surface drainage coincide with fractured zones in karstified dolomite. The low density of runoff drainage suggests high recharge and a predominance of water flow underground, which eventually drains into surface streams at topographic lows or emanates as springs next to dykes or lithologic/formation contacts. Perched water levels are usually associated with Karoo outliers. The formations of the dolomites are distinguishable based on their chert content. The chert poor formations weather evenly to produce a low storage potential residue of silty clay. The chert rich formations weather quite differently. The dolomite weathers faster than the chert leaving the rock supported by chert structures. Eventually the chert will weather and collapse under its own weight leaving a permeable coarse chert breccia. Chert rich formations develop a greater concentration of fissures and fractures which will enhance the process of weathering. These chert rich formations are generally favorable for large-scale development of groundwater. The overlying Pretoria group reveals very low primary permeabilities and signifies weakly developed secondary permeabilities along faults and fractures. The Rooihoogte Formation is in hydraulic equilibrium with the dolomite due to numerous faults and fractures. Once the dolomite is exploited excessively it is expected that the Pretoria Group will contribute groundwater to the dolomite (Kuhn, 1989).

11.3.2 Compartmentalisation

Dolomitic compartments are formed by cross-cutting dykes that act as barriers to groundwater flow, creating isolated hydrogeological compartments. The major compartments according to the various geohydrological studies conducted on the Delmas-Bapsfontein-Springs dolomites by Kok (1985), Leskiewicz (1986), Vegter (1986) and Kuhn (1989) are the Rietvlei, Witkoppies, and Elandsfontein compartments. Further dolomitic areas delineated by these investigations include the Bapsfontein-Delmas area, Varkfontein-Knoppiesfontein area and the East Rand Basin. Figure 11.6 indicates the dolomitic compartments and areas as delineated by previous investigations. Recent work by Jasper Muller and Associates (2005) focused on the Bapsfontein compartment which was established as an isolated compartment southeast of the Witkoppies compartment. The Bapsfontein compartment is bounded by a major NW-SE striking dyke, suggesting an individual compartment of approximately 8.98km^2 (Van der Walt, 2005).

Further compartmentalisation of the Elandsfontein compartment immediately south of the Bapsfontein compartment seem plausible, considering the linear anomaly striking NW to SW. However, no evidence for its sub-division exists in the literature available and will for the purpose of the study be investigated as a whole. A significant amount of work was conducted on the Rietvlei, Witkoppies and Elandsfontein compartments in the late 1980s, by Leskiewicz (1986) and Kuhn (1989). Recently, a groundwater Reserve determination report by Hobbs (2004) for catchments A21A and A21B included the above mentioned dolomitic compartments northwest of Bapsfontein. The study identified geohydrological response units based on the dolomitic compartments and also gave a detailed evaluation of these aquifers (or dolomitic compartments) in terms of groundwater level fluctuations, water quality and use.

11.3.3 Groundwater Levels

The DWAF operates and maintains 129 groundwater level monitoring stations in the study area. All of these target the dolomitic groundwater resource. The monitoring stations with groundwater level data up to the last three years (2004-2007) and relevant to the study area is presented in Appendix 11A. The statistical characteristics for each dolomitic groundwater compartment or area are presented in Table 11.3.

Table 11.3. Groundwater level information for dolomitic compartments.

Compartment	Groundwater level depth (m.b.g.s)			Groundwater level elevation (m.a.m.s.l.)		
	10 percentile	Mean	90 percentile	10 percentile	Mean	90 percentile
Rietvlei	9.66	16.44	36.74	1478.40	1483.50	1489.91
Witkoppies	1.73	37.30	71.77	1500.20	1505.62	1517.61
Elandsfontein	27.09	43.56	64.95	1544.44	1580.82	1603.73
Bapsfontein	49.12	79.20	79.94	1528.33	1559.57	1559.95
Varkfontein-Knoppiesfontein	6.03	9.65	18.51	1605.03	1610.35	1621.51
Delmas	5.53	17.29	44.97	1539.02	1560.45	1583.90
East Rand	50.13	51.81	53.49	1568.29	1569.29	1570.28

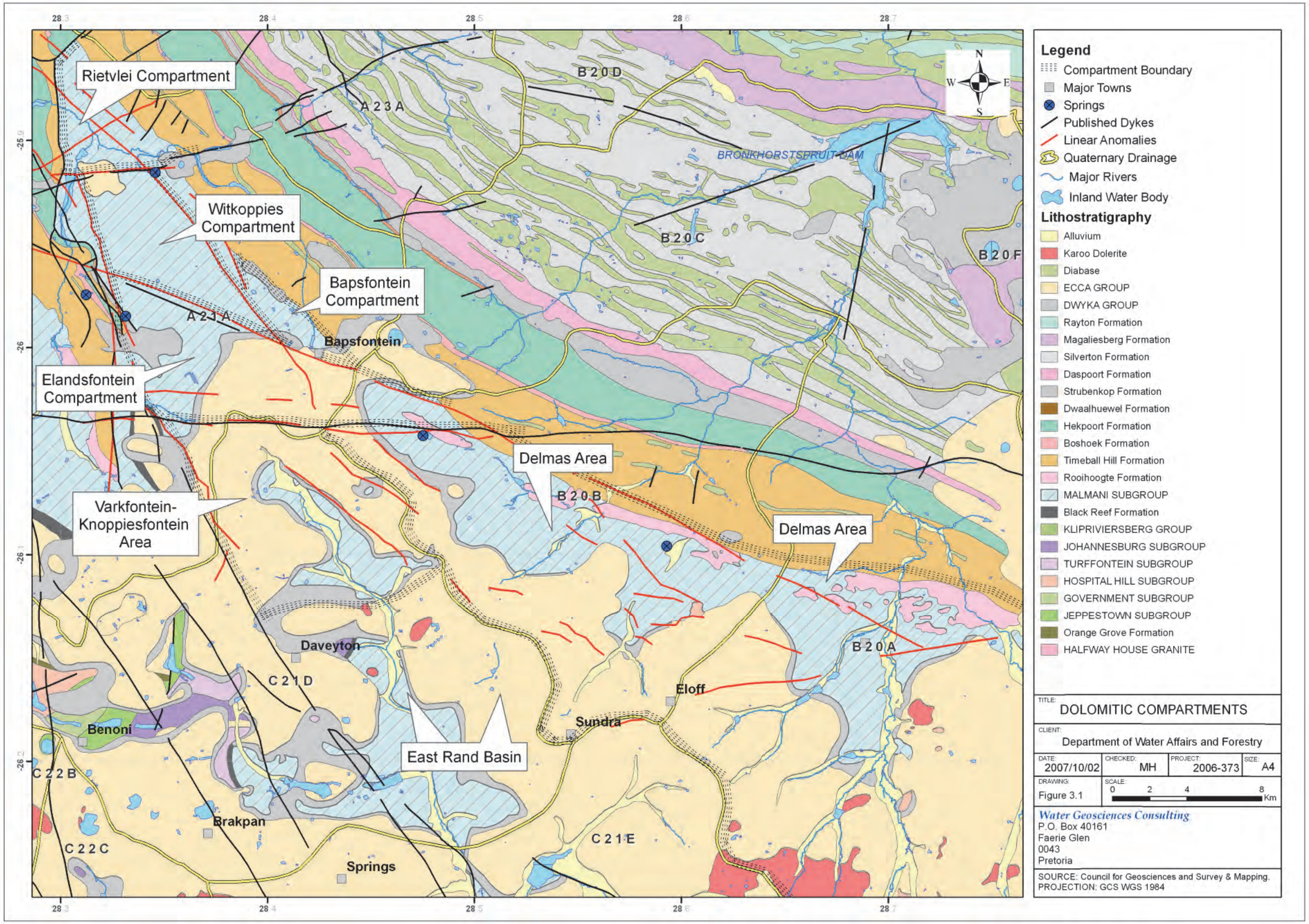


Figure 11.6. Dolomitic compartments map, inferred from previous investigations.

11.3.3.1 Groundwater Fluctuations

Natural hydrostatic fluctuations of the dolomitic groundwater levels have been comprehensively discussed by Temperley (1978). The study provides an excellent reference framework for establishing historical trends or patterns in this regard and shows a maximum water level fluctuation of approximately 2.5 m with respect to rest water level depths. The results of the Temperley study (1978) was re-examined by Hobbs (2004) by comparing various groundwater contour maps produced by Temperley (1978) with those produced by Leskiewicz (1986), Kok (1985), Hobbs (1988) and Kuhn (1989). The investigation suggested that the natural hydrostatic fluctuation in the dolomitic groundwater environment of the studied area might be adjusted to 5 m, which should be kept in mind when assessing long term groundwater level trends. Hobbs (2004) further provided a detailed account for groundwater levels and hydrostatic fluctuations in the Rietvlei compartment towards the northwest of the study area. The study revealed mean groundwater level fluctuations of up to 12.7 m indicating excessive groundwater abstraction from the production boreholes in the Rietvlei well field in the mid-1990s. This desktop investigation will follow a similar approach used by Hobbs (2004) to assess the hydrostatic behaviour of the dolomitic compartments to the east of Rietvlei. Due to the large number of groundwater level data available, the resultant dataset only included the longest and most up to date record of continuous groundwater level measurements in the study area. Irregular data and anomalous readings were removed from the water level series. The information presented in Table 11.4 summarises the results of the statistical analysis of dolomitic hydrostatic behaviour since the mid-1980s.

Table 11.4. Statistical analysis of long-term groundwater level data for selected boreholes in dolomitic aquifers.

Compartment/ Area	**Station**	**Depth to Groundwater Level (m.b.g.s)**				**Change in Groundwater Levels**		
						1980s to 2007		**1997 to 2007**
		Min.	**Mean**	**Median**	**Max.**	**Max Δh**	**Cumulative Δh**	**Cumulative Δh**
Witkoppies	A2N713	16.80	18.49	18.71	19.94	3.14	-2.2	-1.43
	A2N708	29.24	32.62	33.09	34.36	5.12	+0.32	-2.23
	A2N714	1.29	1.65	1.72	1.87	0.58	-0.03	-0.36
	A2N707	70.34	71.42	72.76	71.45	2.42	-0.27	-0.48
	A2N709	34.37	37.18	38.91	37.39	4.54	+1.05	-1.41
	A2N702	61.32	62.35	62.34	63.17	1.85	-0.32	-0.20
	A2N705	70.00	71.35	71.37	72.68	2.68	+0.07	-1.53
	A2N704	66.50	67.96	68.03	68.96	2.46	-1.68	-1.44
	A2N706	72.71	74.16	74.22	75.16	2.45	-0.63	-1.67
	A2N777*	1.12	1.44	1.41	2.22	1.10	-	-0.30
Elandsfontein	A2N715	19.44	24.16	21.85	35.48	16.04	**-13.88**	-15.04
	A2N710	20.61	29.95	30.16	37.95	17.34	-4.24	-11.43
	B2N021	38.12	47.72	47.08	66.58	28.46	**-23.98**	-21.58
	B2N717	10.00	14.09	14.24	17.13	7.13	+2.58	-3.41
	A2N711	19.69	30.78	32.42	38.64	18.95	+7.69	+11.78
	A2N781*	62.49	63.65	63.60	64.77	2.28	-	+2.28
	A2N782*	42.82	48.52	48.78	54.30	11.48	-	+2.80
Bapsfontein	B2N722*	79.80	82.24	82.61	87.74	4.74	-	+3.07
	A2N779*	77.89	82.99	82.85	87.56	9.67	-	+3.02
	A2N780*	39.54	40.64	40.65	42.69	3.15	-	-1.46

Compartment/ Area	Station	Depth to Groundwater Level (m.b.g.s)				Complete Record Late 1980s to 2007		Selected Record 1997 to 2007
		Min.	Mean	Median	Max.	Max Δh	Cumulative Δh	Cumalitive Δh
Varkfontein-Knoppies-fontein	C2N891	6.70	8.87	9.06	10.75	4.05	-0.20	-2.18
	C2N893	2.29	4.84	4.57	8.47	6.18	+2.88	-1.38
	A2N0783*	16.20	18.93	18.96	20.76	4.56	-	-2.56
East Rand Basin	C2N1113*	42.52	52.08	53.23	54.27	11.75	-	4.32
	C2N1114*	51.03	55.92	56.79	58.36	7.33	-	-0.25
Delmas	B2N068	1.68	8.25	7.39	23.28	21.6	**-13.91**	-14.39
	B2N066	16.89	26.19	26.21	32.84	15.95	**-11.43**	-5.01
	B2N041	1.66	11.03	10.16	21.46	19.8	**-8.78**	-9.56
	B2N044	1.76	12.67	9.7	41.51	39.75	-4.21	-5.91
	B2N043$	10.90	15.07	14.02	23.63	12.73	*-5.69*	-3.97
	B2N050#	2.81	17.54	22.26	34.39	31.85	*+14.08*	-
	B2N049#	19.62	28.60	28.76	39.97	20.35	*-6.31*	-
	B2N056#	2.45	22.96	21.13	43.23	40.78	*-16.71*	-
	B2N061	0.62	3.8	2.96	7.94	7.32	-4.87	-6.12
	B2N060	0.45	4.34	3.62	11.56	11.1	-1.31	-3.37
	B2N057	66.56	84.17	84.75	92.67	26.11	-5.75	-12.80
	B2N073	19.66	30.87	25.98	47.51	27.85	**-26.46**	-24.83
	B2N071	5.6	13.79	13.6	22.11	16.51	+6.7	-0.01
	B2N081	31.17	47.38	42.84	77.62	46.45	**-37.84**	-44.67
	B2N053	39.55	46.49	46.3	55.86	16.31	**-8.37**	-14.17
	B2N032	16.55	20.42	20.43	23.2	6.65	-1.31	-3.03
	B2N031	25.1	29.08	29.19	32.09	6.99	-1.37	-2.22
Delmas	B2N039$	4.09	11.83	11.02	28.20	24.11	*-21.24*	-17.41
	B2N063$	0.43	3.84	2.91	13.05	12.62	*-6.84*	-5.77
	B2N037$	0.36	5.46	5.47	15.05	14.69	*-9.55*	-6.74
	B2N038$	0.17	5.56	5.34	15.21	15.04	*-6.05*	-6.67
	B2N001	0.73	2.79	2.84	5.63	4.9	-1.28	-3.18
	B2N003	0.12	1.65	1.6	4.26	4.14	-1.25	-1.98
	B2N506	1.89	7.27	7.31	10.84	8.95	-0.49	-3.33
	B2N034	11.58	14.11	14.21	16.68	5.1	-0.63	-1.94

* – Only monitored since 2005 $ – Large data gaps # – Some irregularities in dataset

Table 11.5 and Figure 11.7 summarises the results of the statistical analysis presented in Table 11.4. Monitoring stations with certain irregularities or missing datasets identified in Table 11.4 were excluded from further analysis.

Table 11.5. Summary of dolomitic aquifer hydrostatic behaviour based on Table 11.4.

Compartment/ Area	No. of Stations	Groundwater Fluctuation (m)		
		Range of Fluctuation	Mean Fluctuation	Mean Cumulative Δh change
Witkoppies	10	0.58 to 5.12	2.63	-0.41
Elandsfontein	6	2.28 to 28.46	14.52	-4.94
Bapsfontein	3	3.15 to 9.67	5.85	1.54
Varkfontein-Knoppiesfontein	3	4.05 to 6.18	4.93	-2.04
East Rand Basin	2	7.33 to 11.75	9.54	2.03
Delmas-Bapsfontein	17	4.14 to 46.45	17.13	-7.2

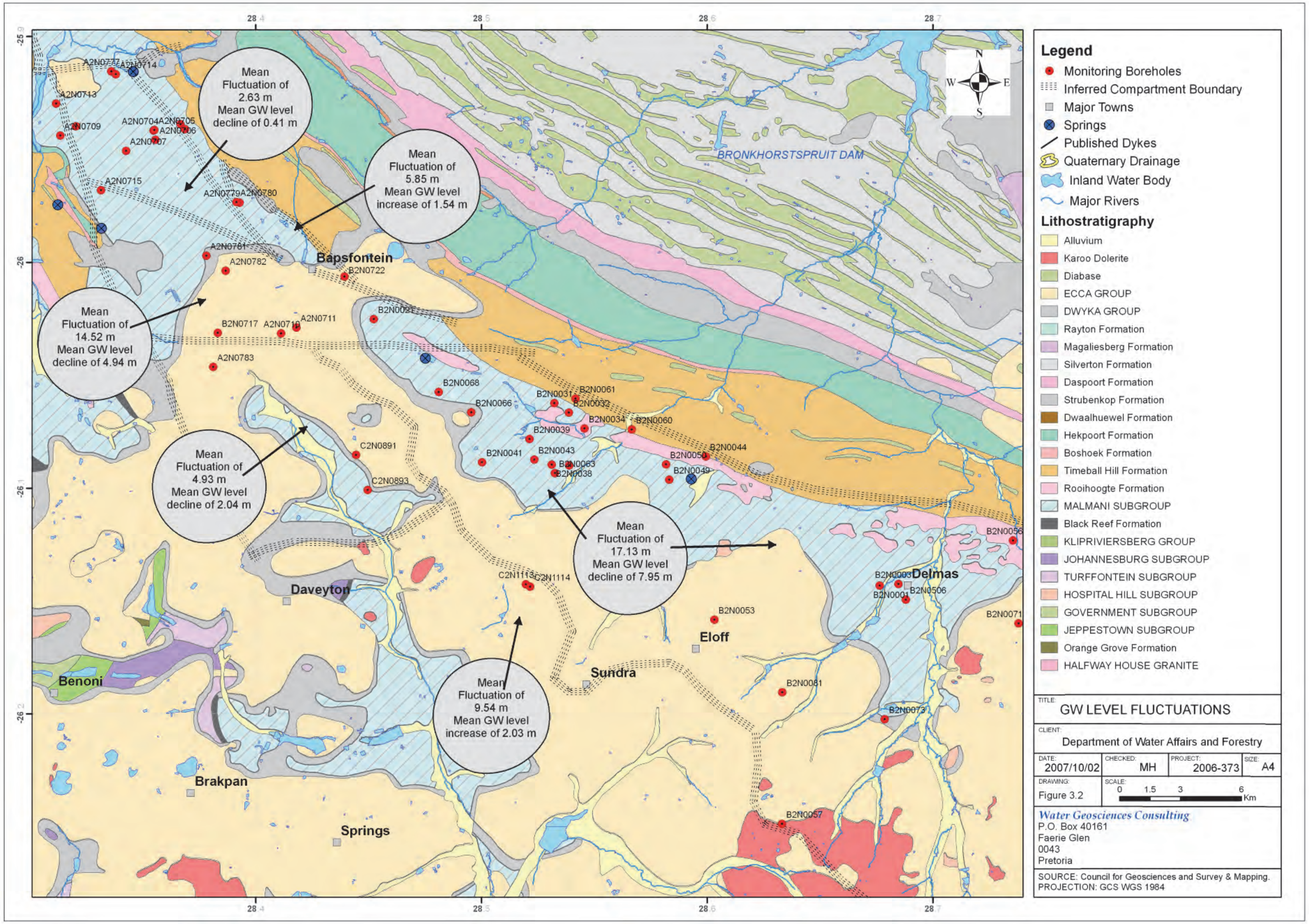


Figure 11.7. Spatial view of groundwater level fluctuations statistics.

A comprehensive indication of dolomitic aquifer hydrostatic response trends and behaviour is provided by the hydrographs presented in Appendix 11B. Initial observations made from the groundwater level trends and Table 11.4 was a notable decrease in rest water levels from the late 1990s onward. Figure11.8 better illustrates the change (positive) of groundwater water levels from the late 80s to 1996 compared to the change (negative) in groundwater levels for the last decade (1997 to 2007).

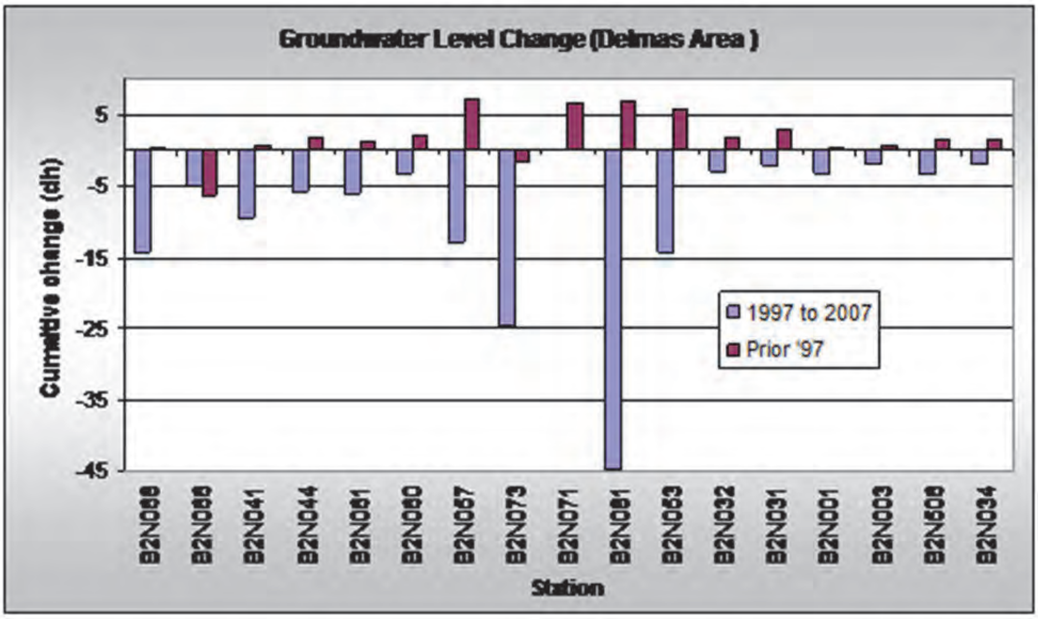


Figure 11.8. Groundwater level change during the last decade compared to prior 1997.

To elaborate further on the fluctuations observed in the tabulated information and in the preceding graph, a monthly rainfall plot versus monthly groundwater levels trends is illustrated in Figure 11.9. The groundwater level trends of three monitoring boreholes in the Delmas area and rainfall data from the Delmas (Witklip) weather station were used.

The following observations are based on the preceding tabulated and graphical information.

- From the onset considerable groundwater level fluctuations are observed throughout the monitoring stations in the greater Delmas-Bapsfontein dolomitic area (Table 11.3).
    - o The greatest cumulative groundwater level decline for a single station since the start of monitoring in the late 1980s is borehole B2N081 with a hydrostatic change of 37.84 m. The station has been drilled into the dolomitic aquifer underlying the Karoo formation of the Delmas area which is about 75 m thick (NGDB logs). Numerous other stations located in the Delmas and Elandsfontein compartment/area experienced negative cumulative groundwater level changes of more than 5 m since the start of monitoring.
- Mean hydrostatic fluctuation of the various compartments falls in the range of 2.63 to 17.13 m (Table 11.4). The upper value of this range represents the Delmas area. Further noteworthy mean fluctuations are observed in the Elandvlei, East Rand and Bapsfontein compartments with values of 14.52, 9.54 and 5.85 m respectively.
- Perhaps the most significant observation evident from the hydrographs in Appendix 11B and the tabulated information is an increasing trend in groundwater levels from the late 1980s to the late 1990s and a declining groundwater level trend after the late

1990s. This trend was clearly observed in Figure 11.8 where almost all negative cumulative groundwater level changes were observed after 1997. The influence of periods of exceptional rainfall is evident from Figure 11.9 from March 1987 to March 1996. Rainfall had a clear influence on groundwater levels which increased substantially during 1996 and 1997. After this period groundwater levels lowered once again which could be attributed to periods of lower rainfall. However, further lowering of groundwater levels indicate large scale abstractions and are observed in both B2N066 and B2N044. Monitoring station B2N032 represents a very small cumulative change in groundwater levels over time and suggests a borehole not influenced by excessive groundwater abstraction. It is important to note that the accuracy of weather station data is vital to determine natural groundwater level fluctuations, which is currently lacking in the study area.

- It is critical to note that based on the analysis above it might seem that the sinkhole prone Bapsfontein compartment experiences an increase in groundwater level of 1.54 m for the past three years (2005-2007 data) (Figure 11.7). However, there is not enough historical information in the Bapsfontein compartment to substantiate this observation. Investigations by Jasper Muller and Associates have reported that significant number of boreholes have dried up during 2000 to 2004.
- Taking the natural fluctuations of up to 5 m into account the magnitude of fluctuations and the decline in hydrostatic head confirms the significant development and unsustainable utilisation of the groundwater resources in the region, especially in the Delmas area.

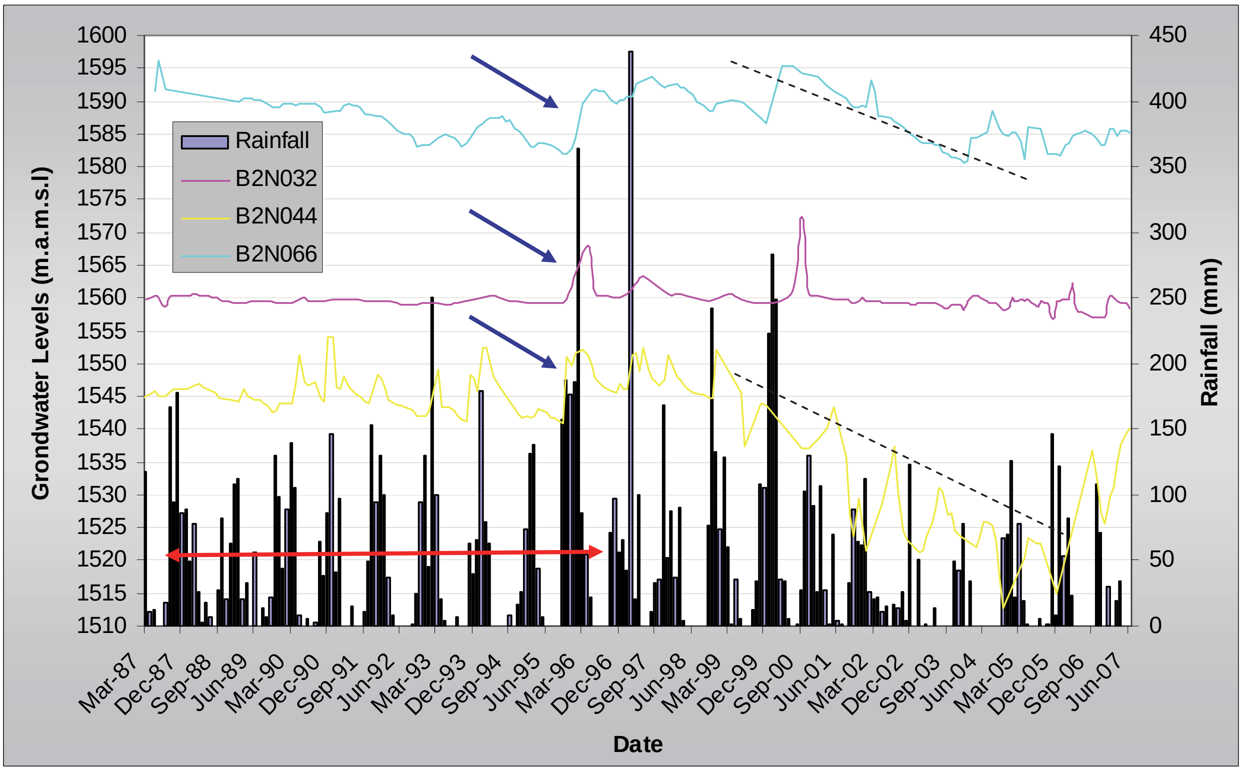


Figure 11.9. Monthly groundwater level trends versus monthly rainfall for the period 1987 to 2007.

11.3.3.2 Groundwater Drainage

The representative mean groundwater levels based on Table 11.3Table is illustrated spatially in Figure 11.8 and is used to visualize the variations in groundwater elevations across the study area. On a regional scale the mean groundwater levels indicate clear differences from inferred compartments depicted in section 11.3.1. These compartments are therefore hydrogeological isolated compartments and could represent groundwater resource units which could be managed and assessed individually.

A sufficient body of material already exists in the DWAF technical reports by Leskiewicz (1986), Kuhn (1989) and Hobbs (2004) to define the direction of groundwater movement in the north-western part of the study area. However, towards the Delmas area limited information exists regarding compartmentalisation and groundwater flow directions. The flow vectors was drawn tentatively based on the inverse distance weighting interpolated groundwater level data of June 2007 and from specialist reports. Groundwater flow is predominantly towards the northwest in the Bapsfontein, Elandsfontein and Witkoppies compartments and towards the east in the Delmas area. From the flow vectors and medium resolution digital elevation model in Figure 11.11 it appears that groundwater flow follows the surface topography. However, the correlation between the surface topography and the groundwater levels in the dolomitic compartment suggest otherwise with a correlation value of only 27.38% in the Delmas area (Figure 11.10). This would suggest karst conditions where cavities occur and gives an easy flow path for the groundwater.

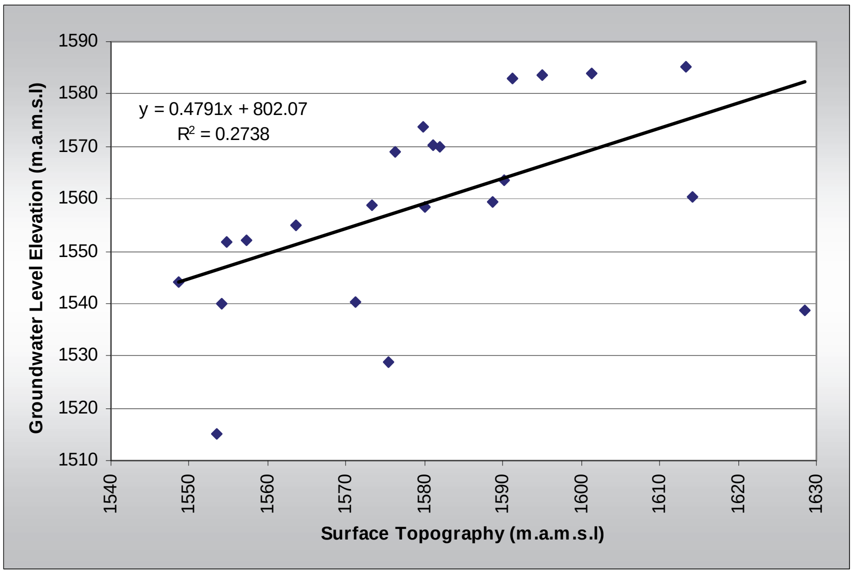


Figure 11.10. Correlation between surface topography and groundwater levels in the Delmas area.

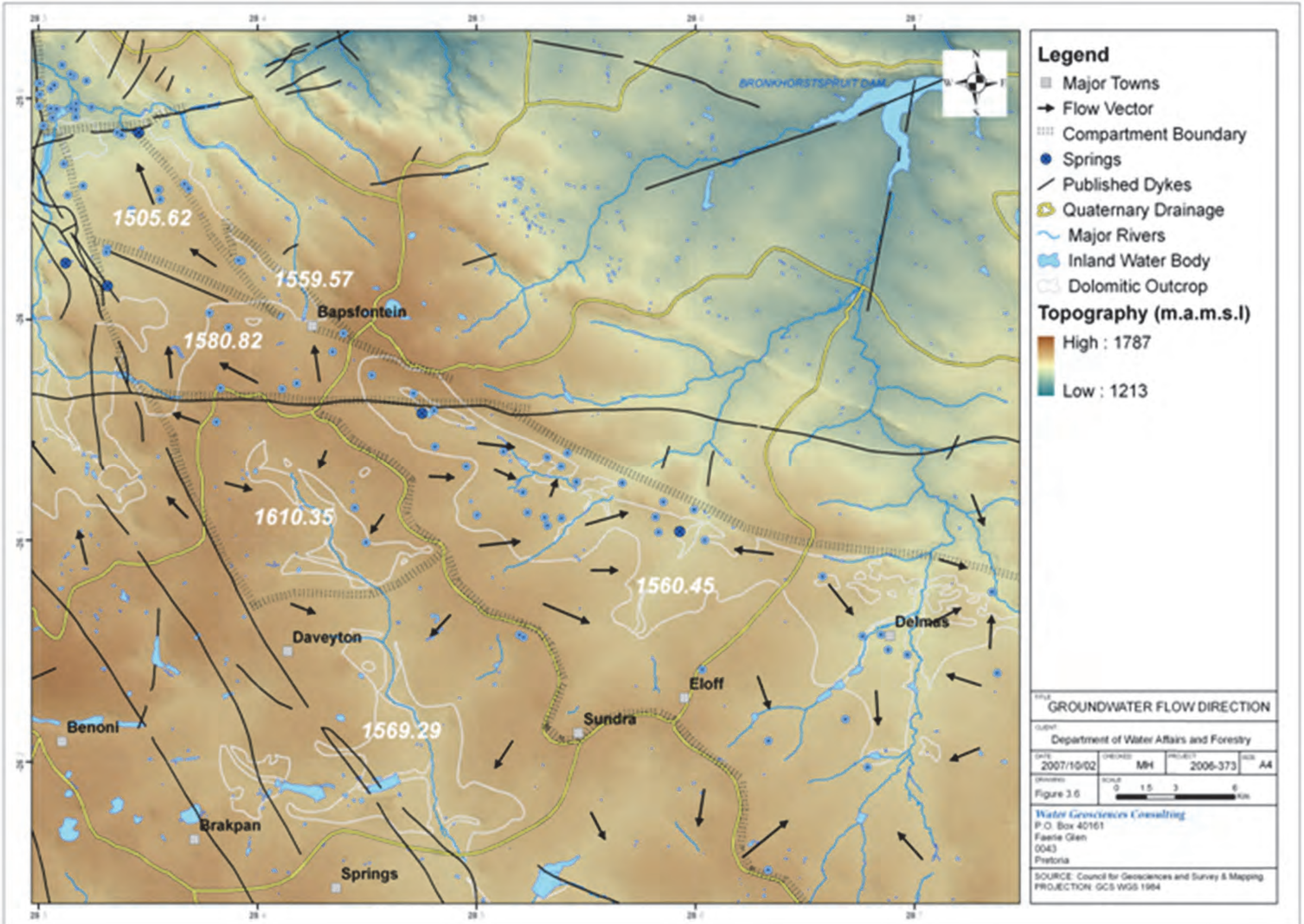


Figure 11.11. Groundwater drainage map (vectors drawn in tentatively) and representative mean groundwater elevation levels (m.a.m.s.l.).

11.4 Water Quality

The major concerns for water quality in the area are (Hobbs, 2004):

- Salinisation – concern for the increase in salts mainly as a result of anthropogenic causes such as discharge of industrial effluents, irrigation returns flows and urban run-off.
- Bacteriological contamination – concern for rising faecal contamination levels associated with increasing population densities and inadequate sanitation levels especially in regard to informal settlements.
- Organic chemicals and heavy metals – concern for the increasing contamination of the shallow Karoo aquifers underlying the Holfontein landfill site (2004).
    - Recent investigations at the Holfontein Waste disposal facility included the assessment of remedial measures, with the effectiveness of these remedial options evaluated using a geohydrological model. The results were submitted in report format, as well as presented to both DWAF on the 12th July 2006 and at the Impact Management Meeting on the 20th September 2006. A letter accepting the proposed remedial options was received from the Department of Water Affairs and Forestry on the 12th February 2007.
    - Quarterly monitoring of water levels and chemistry is undertaken in the leachate, leachate detection, sub-soil seepage, surface water, and groundwater (perched, weathered Karoo, fractured Karoo and dolomitic aquifers). The results of the 2006 / 2007 monitoring data were discussed in Jones & Wagener report number JW117/07/B200[4].

The location of the water quality monitoring points for the greater Delmas-Bapsfontein area, available at the time of the study, is illustrated in Figure 11.12. The following aspects related to the available groundwater chemical data include:

- Most groundwater quality monitoring locations are located around the towns of Delmas and Bapsfontein. The groundwater quality data generated by DWAF represents a once-off groundwater quality survey(s) rather than continuous monitoring programme.
- Groundwater quality data from monitoring locations around the towns of Delmas and Bapsfontein, managed by the respective local municipalities, were not available for this study.
- The DWAF monitors a few surface water localities in the greater Delmas-Bapsfontein area, however only a few stations have continuous data up to 2007.
- The limited groundwater and surface water quality monitoring localities in the Delmas-Bapsfontein area prevents a detailed description of the groundwater chemistry trends as well as the potential impacts of various land-use activities on the groundwater quality of the dolomitic aquifers.

[4] Personal Communication (2 October 2007) – John Glendinning (Jones and Wagener).

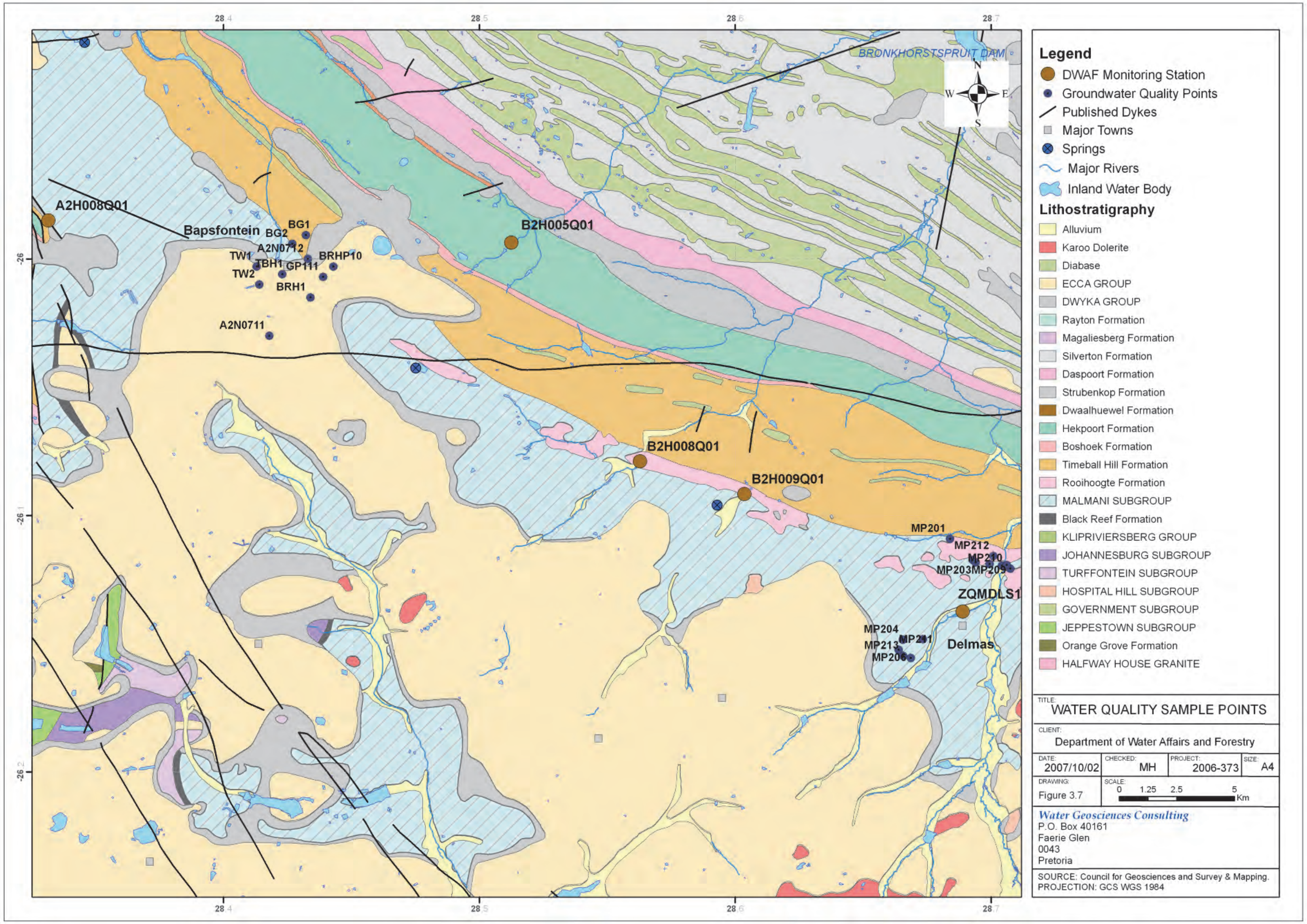


Figure 11.12. Surface water and groundwater quality sample locations.

11.4.1 Surface Water quality

The DWAF water quality database was sourced for long-term water quality monitoring data in the study area. Data was obtained for the following stations:

A2H090Q01 – Hennops River upstream of Rietvlei (1986 to 2004)

A2H008Q01 – Elandsfontein Eye at Elandsfontein downstream of Rietvlei stream (1980 to 1998).

B2H008Q01 – Rietvallei Farm at tributary of Koffiespruit (1985 to 2007).

B2H009Q01 – Olifantsfontein at Koffiespruit (1985 to 2002).

ZQMDLS1 – 2628BA00423 Delmas (1995 to 2001).

B2H005Q01 – Osspruit at Knoppiesfontein (1984 to 1998).

A detailed evaluation of the water quality of station A2H090Q01 (upstream of Rietvlei Dam) was conducted by Hobbs (2004). The study observed seasonal changes of electrical conductivity and TDS with associated patterns in the sodium and chloride concentrations. The author also noted that the surface water prior to March 2002 exhibits a Na-HCO_3 character in the winter and a Ca-HCO_3 in summer. Higher salinity values maintained since March 2002 led to the extent that the water more recently exhibits a varying Na-HCO_3 and Na-Cl composition throughout the year.

In karst regions, surface water becomes ground water when it sinks into the streambed or into sinking streams (swallow holes). On the other hand, karst groundwater becomes surface water when it emerges from springs. Therefore, the impact of surface water quality on the adjoining dolomitic groundwater regime is of importance. The mean chemical composition of the surface water monitored at station A2H008Q01 (1993), B2H009Q01 (2001) and B2H008Q01 (2006/2007) is illustrated in Figure 11.13.

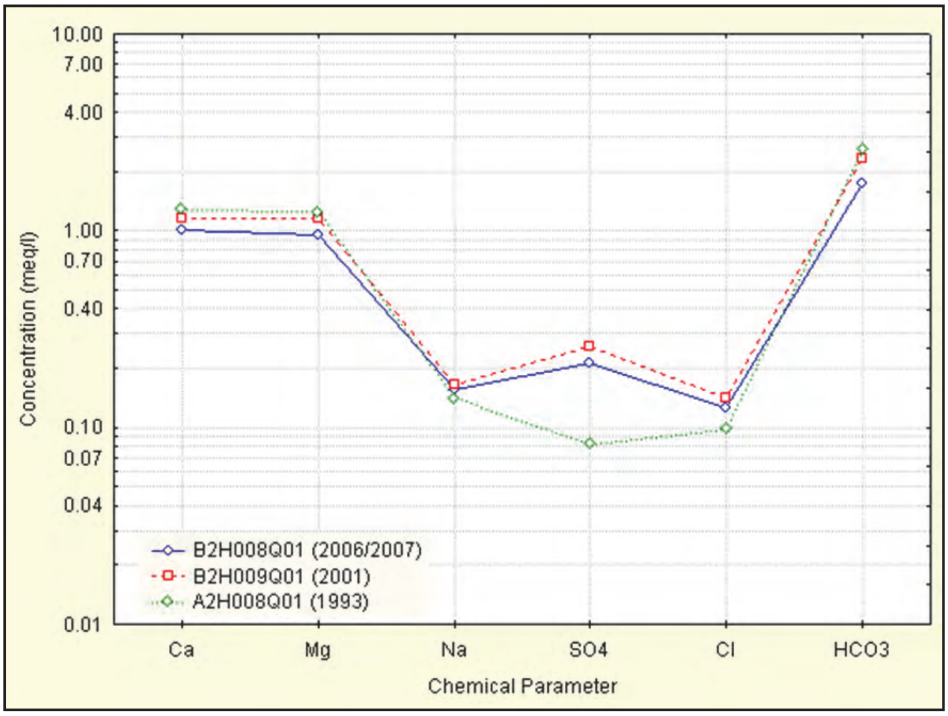


Figure 11.13. Characterisation of mean surface water chemistry for three monitoring stations.

A remarkable hydrochemical similarity exists between the three sampling stations. This indicates a holistically uniform and homogeneous hydrochemical "response" of the surface drainage systems in the study area. Further observations made on long-term monitoring data from station B2H008Q01 is based on the graphical evaluation of the water quality trend graphs presented in Appendix C. This reveals subtle differences in hydrochemical response patterns that are not evident in the holistic perspective presented above:

- Similar to A2H090Q01, a cyclical trend of electrical conductivity was observed. Salinity increases during dry winter months and decreases at the onset of the summer rainfall season (Appendix 11C-1.1). This trend is also observed in the sodium and chloride concentrations (Appendix 11C-1.2 and 11C-1.3).
- As can be expected from dolomitic regimes, the response of calcium and magnesium remains similar throughout the monitoring trend and seem to be in equal amounts (Appendix 11C-1.3).
- Bicarbonate concentration levels indicate a slight downward trend over time.

11.4.2 Groundwater quality

Groundwater generally exhibits differences in chemical composition that reflect either the lithological strata that host and support this resource or chemical signatures associated with anthropogenic pollution influences. Schoëller graphs are presented in Figure 11.14 and Figure 11.15 to graphically display hydrochemical information obtained from the NGDB.

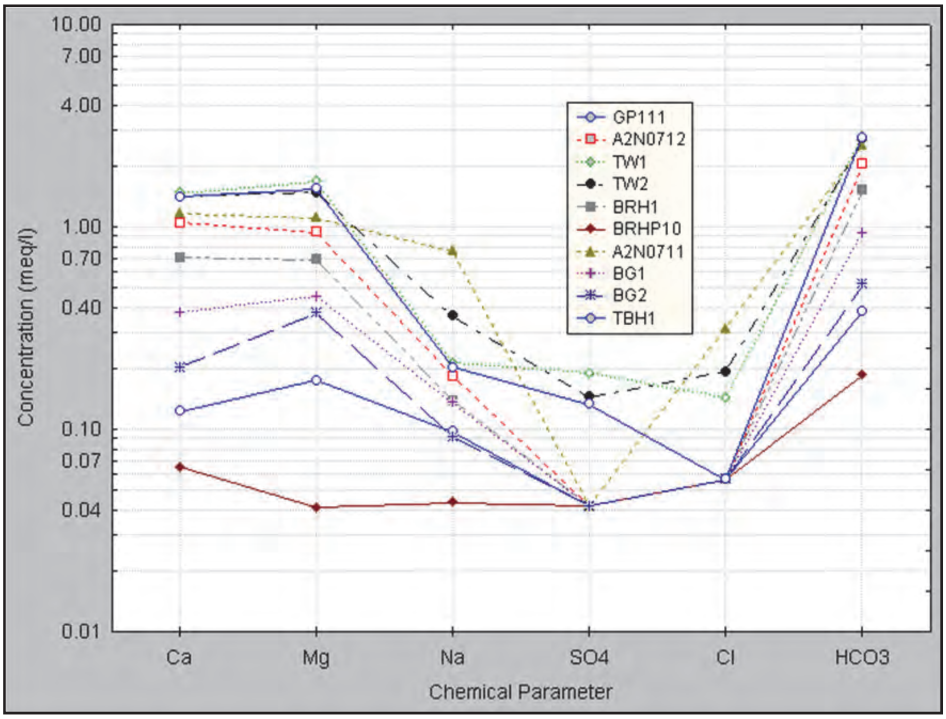


Figure 11.14. Characterisation of groundwater samples (2005) for the Bapsfontein town area.

The differences in groundwater chemical compositions at Bapsfontein are clearly evident emphasising the heterogeneity of the karst aquifer. The karst aquifer (dolomite) produces groundwater with a Ca-Mg-HCO_3 character with equal amounts of calcium and magnesium. Similar patterns are observed in the groundwater chemistry for the Delmas region (Figure 11.15). Calcium and magnesium represent the dominant cations and with bicarbonate representing the dominant anion. Chloride, sulphate and sodium concentrations remain low in both datasets.

From the Piper diagram (Figure 11.16) the water chemistry in both the Delmas and Bapsfontein can be classified as a Ca-Mg-HCO_3 water type. However, samples from the Delmas area show a distinct trend from a Ca-Mg to Na+K cation predominance and from a HCO_3 towards SO_4 or Cl anion predominance. Bapsfontein show similar trends from a cation perspective but to a lesser extent in the anion field where only one sample shifts from HCO_3 towards SO_4 or Cl. Samples with a Na+K signature might be attributed to the Karoo formation which consist of shale and sandstones which contain elements of Na and K. A slight anthropogenic impact may be observed in the Delmas area where a few samples show a Cl, SO_4 and Na signature. As more groundwater chemical data become available a more comprehensive geochemical description is required to accurately identify the impact of various land-uses on the dolomitic aquifers.

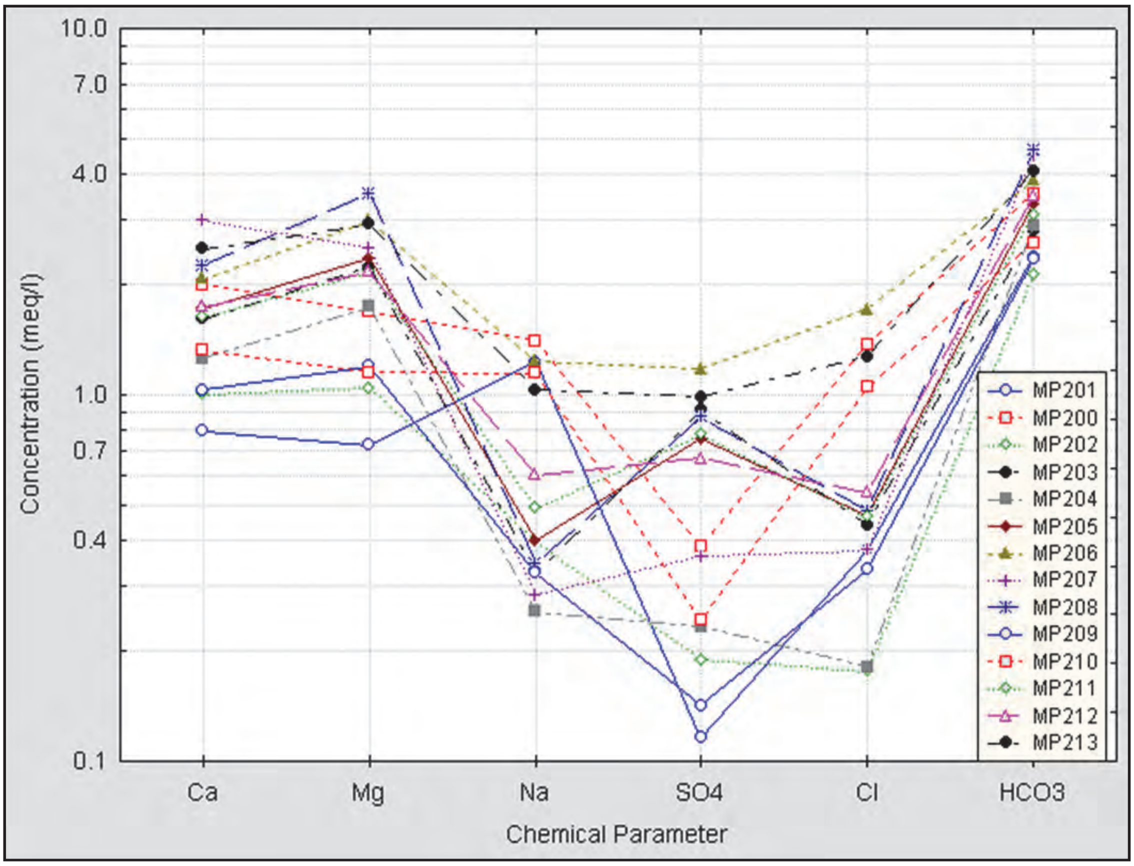


Figure 11.15. Characterisation of groundwater samples (2006/2007) for the Delmas town area.

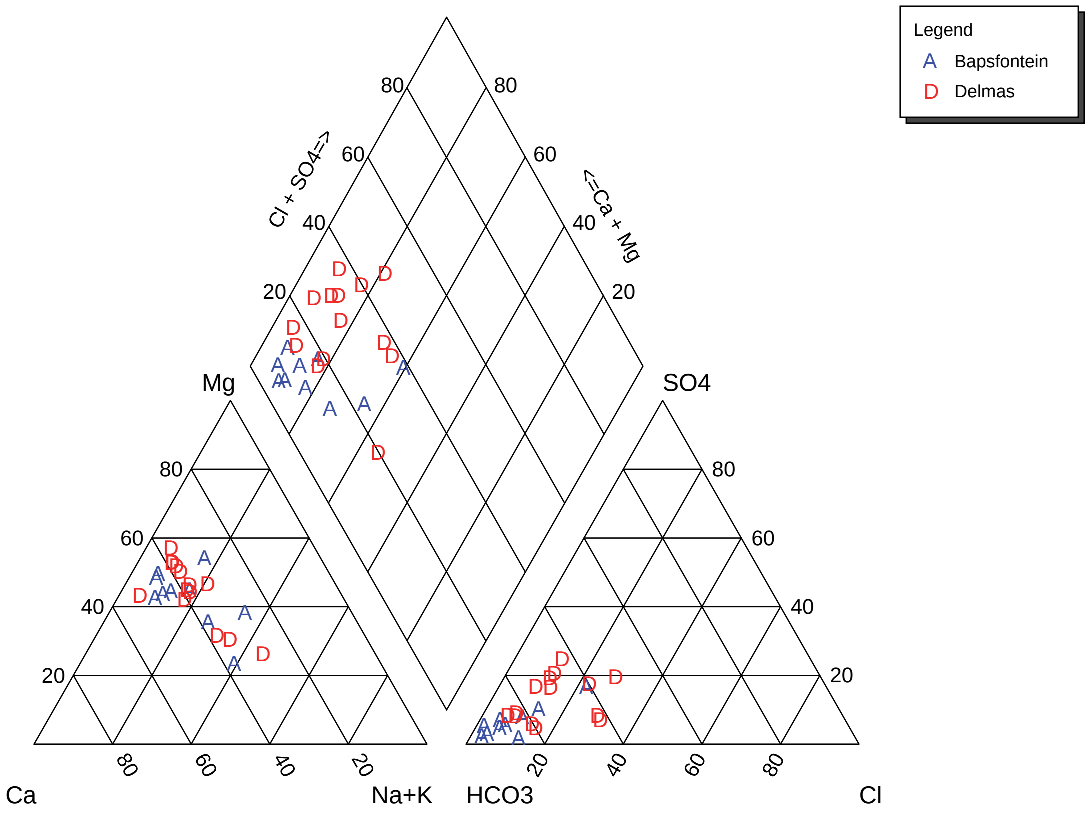


Figure 11.16. Piper plot of the Bapsfontein and Delmas groundwater samples.

11.5 Water Resources Evaluation

11.5.1 Groundwater Use

An evaluation of data sourced from the DWAF's Water Authorisation and Registration Management System (WARMS) yielded the summary of groundwater use information presented in Table 11.16. It is important to note that this data has not been verified by DWAF's regional offices; therefore evaluation of both the groundwater and surface water data should be done with this in mind.

Taken the accuracy of the data into consideration, the information nevertheless indicates a large number of registered groundwater users in the greater Delmas-Bapsfontein dolomitic area. The Bapsfontein and Elandsfontein compartments support a registered volume of approximately 3.66 Mm^3/a and 4.48 Mm^3/a respectively, which is a significant amount of water use relative to their respective catchment size. The Delmas area/compartment support a registered volume of 11.90 Mm^3/a over a fairly a large area. However, a notable omission from the WARMS dataset is the Delmas Municipalities groundwater use for domestic water supply. Delmas municipality has a water registration certificate, which accommodate for an annual abstraction volume of 3.03 Mm^3/a. Recent investigations by GCS (2005) suggested a revision of the abstraction volume, as the current groundwater use exceeds this amount by 30%.

Table 11.6. Summary of WARMS-based groundwater use information (2007).

Compartment/Area	Topo-cadastral Farm	No. of Users	Registered Volume (m^3/annum)	Water Use Sector
Witkoppies	Tweefontein 413 JR	6	1 912 726	Agriculture: irrigation
	Elandsfontein 412 JR	1	42 480	
		1	36 500	Agriculture: livestock
	Grootfontein 394 JR	1	4 860	Industry (urban)
	TOTAL:		**1 996 566**	
Elandsfontein	Bronkhorstfontein 20 IR	1	570 940	Agriculture: irrigation
	Elandsfontein 412 JR	6	2 795 180	
		2	185 312 (spring)	
	Rietfontein 21 IR	1	1 190	Agriculture: livestock
		2	483 500	Agriculture: irrigation
	Tweefontein 19 IR	1	315 360	Industry (non-urban)
		1	124 173	Agriculture: livestock
	TOTAL:		**4 475 655**	
Bapsfontein	Tweefontein 413 JR	12	3 664 225	Agriculture: irrigation
	TOTAL:		**3 664 225**	
Delmas	Droogefontein 242 IR	1	324 950	Agriculture: irrigation
	Elloff Agricultural Holdings	2	23 210	
	Geluk 234 IR	5	1 320 290	
	Goedgedacht 228 IR	3	1 191 950	
		1	1 000 000	Industry (urban)
	Goedklip 275 IR	1	1 105 550	Agriculture: irrigation
	Katboschfontein 22 IR	2	280 420	
	Leeuwpoort 205 IR	2	626 800	
	Middelbult 235 IR	13	2 382 150	
	Modderfontein 236 IR	1	51 300	
	Olifantsfontein 196 IR	7	998 038	Agriculture: irrigation
		1	1 825	Agriculture: livestock
		1	1 848	Industry (urban)
	Rietfontein 21 IR	8	1 154 060	Agriculture: livestock
		1	1 825	Industry (non-urban)
		1	73 000	Industry (urban)
	Rietvallei 195 IR	1	408 800	Agriculture: irrigation
	Rietkol 237 IR	3	559 070	
		1	14 600	
	Weilaagte 271 IR	1	90 200	
	Witklip 229 IR	2	328 100	
	Witklip 232 IR	2	1 494 659	
	Wolvenfontein 244 IR	1	320 000	
	TOTAL:		**11 897 654**	
Varkfontein	Zesfontein 27 IR	1	953	Industry (non-urban)
	TOTAL:		**953**	

The authorised groundwater abstraction volumes and localities are indicated in Figure 11.17.

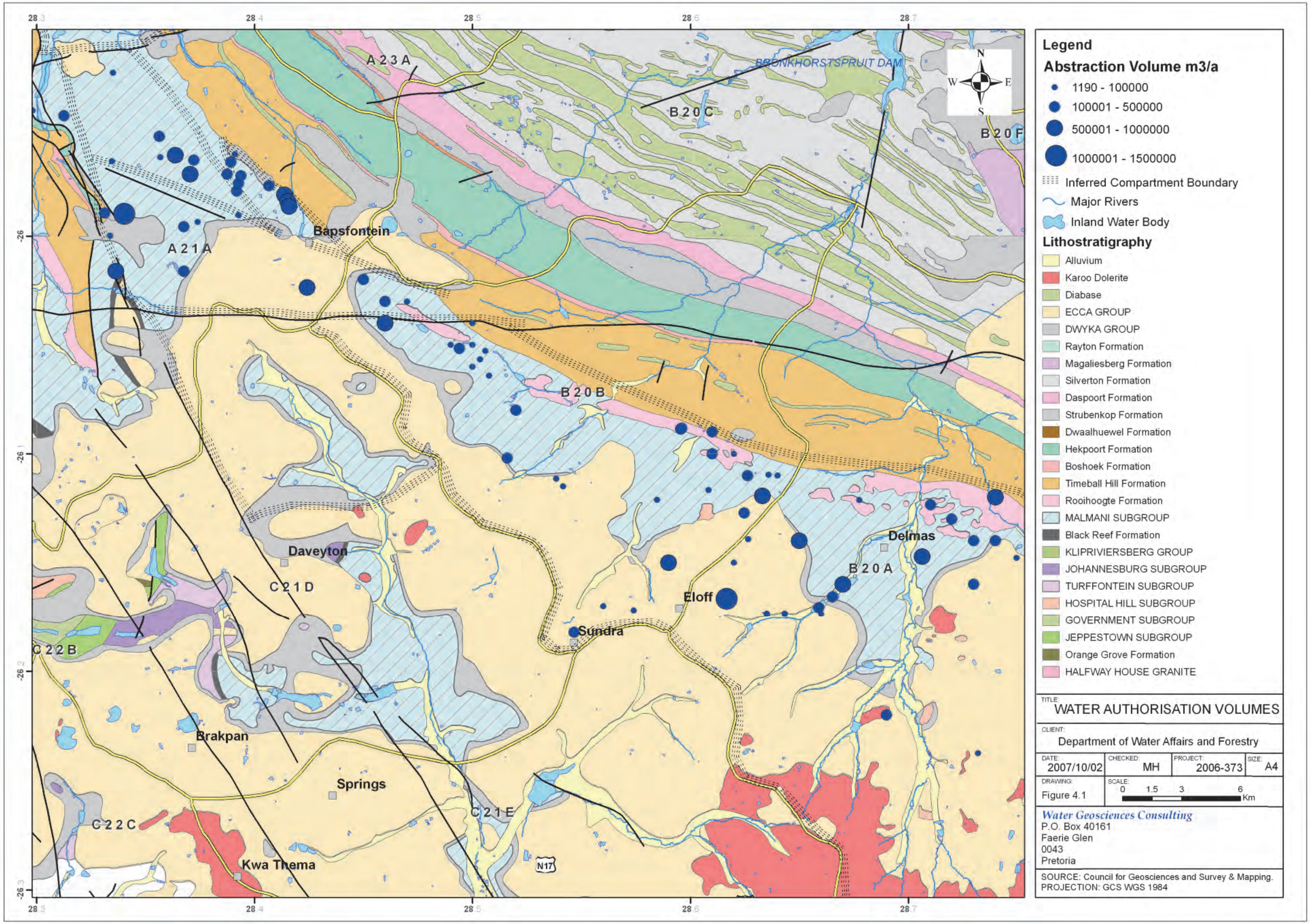


Figure 11.17. Location of annual groundwater authorisation abstraction volumes (Sourced from: WARMS).

11.5.2 Surface Water Use

An evaluation of data sourced from the DWAF's Water Authorisation and Registration Management System (WARMS) yielded the summary of surface water use information presented in Table 11.7.

Table 11.7. Summary of WARMS-based surface water use information (2007).

Compartment/Area	Topo-cadastral Farm	No. of Users	Registered Volume (m^3/annum)	Water Use Sector
Witkoppies	Witkoppies 393 JR	4	215 260	Agriculture: irrigation
	TOTAL:		**215 260**	
Delmas	Knoppiesfontein	1	85 460	
	Leeuwpoort 205 IR	1	266 200	
	Rietfontein 21 IR	5	810 500	
	Goedgedacht 228 IR	1	418 200	
	Weilaagte 271 IR	2	686 600	
	Weltevreden 227 IR	1	80 000	
	Witklip 232 IR	1	285 500	
	TOTAL:		**2 375 460**	

The information indicates that annual registered volume of surface water available for abstraction in the Delmas area/compartment amounts to 2.38 Mm^3/a. This amount is mostly for use in the agricultural (irrigation) sector. No other significant surface water usage is expected in the various other dolomitic compartments. Significant quantities of surface water from the Rietvlei Dam is utilised by the Tshwane Metropolitan Council's for municipal supply purposes. Hobbs (2004) made a detailed account of the various water use sectors in this area.

11.5.3 Water Balance Information

11.5.3.1 Groundwater Resource Units

In dolomitic environments it has been shown that with the presence of sub-vertical dyke's hydrogeological isolated compartments can be identified which exhibit different hydrostatic response patterns. The identification of groundwater resource units is imperative in Reserve determination assessments and accurate water use licensing. In this study a conceptual understanding of the Delmas-Bapsfontein area formed the basis for the identification of groundwater resource units. In the absence of a detailed account for the interaction between the overlying Karoo sediments and the dolomitic compartment in the Varkfontein and Delmas compartments, the identified major surface drainage will be regarded as the unit boundary. It is however noted that the Karoo sediments have different hydraulic properties which affects the movement and storage of groundwater in such aquifers. The proposed groundwater resource units as depicted in this study include:

- Witkoppies compartment (GRU 1)
- Elandsfontein compartment (GRU 2)
- Bapsfontein compartment (GRU 3)
- Varkfontein compartment (GRU 4)
- Delmas area (GRU 5)

11.5.4 Groundwater Balance

It is beyond the scope of this investigation to provide a detailed account of all the groundwater in flows, outflows and groundwater contributions to baseflow in the mentioned resource units. However to assess the status of the resource unit under investigation it remains critical to provide some basic water balance information (Table 11.8). This in return will assist in decision making regarding resource classification and setting of resource quality objectives which is imperative for Groundwater Resource Directed Measures (GRDM) assessments. A recharge value of 10% is used in the water balance and is based on the Bapsfontein Reserve determination conducted by Jasper Muller & Associates (2005). Compartment sizes and spring flow estimates are based on investigations by Vegter (1986) and Hobbs (2004).

Table 11.8. Water balance information for resource units identified.

Resource Unit	Area (km^2)	Recharge (10% of Annual Rainfall) (M Mm^3/annum)	Groundwater Abstraction (Mm^3/annum) Registered Volume	Spring Flow (Mm^3/annum)
GRU 1	45	3.08	2.0	3.22
GRU 2	60	4.32	4.48	1.26
GRU 3	9	0.65	3.66	-
GRU 4	40	2.89	0.95	-
GRU 5	200	12.59	11.90+ 3.03	1.45

Taking the absent water balance parameters into account it remains clear that most of the groundwater resource units of the Delmas-Bapsfontein area are stressed aquifers. Any future groundwater allocation will rely heavily on our ability to accurately predict the responses and status of the resource unit under investigation. In some situations (e.g. GRU 3) no further groundwater could be allocated and will require enforced restrictions of abstraction.

11.6 Conclusion & Recommendations

The dolomites of the greater Delmas-Bapsfontein area are extensively utilised for its superior water bearing characteristics. Unfortunately large scale aquifer exploitation and the associated rock characteristics of dolomites have lead to numerous sinkholes in the Bapsfontein compartment. The groundwater level fluctuations observed across the greater Delmas-Bapsfontein compartments are indicative of the over utilization of the aquifers. The lowering of the hydrostatic head in the dolomites is evident in the Witkoppies, Elandsfontein and Bapsfontein area, as well as, in the Delmas area. An outline of the outcome of the deliverables is as follows:

1) Evaluation of groundwater level fluctuations and trends in the dolomitic compartments and the interaction between the compartments.

   - This study revealed that significant groundwater level fluctuations, together with a decline in the mean groundwater levels particular after 1997, is evident in the Delmas dolomitic area. The range of fluctuations (maximum Δh) for the groundwater levels in the Delmas area varies between 4.14 to 46.45 m.b.g.l with a mean groundwater level decline (cumulative Δh) of 7.2 m since 1986.

   - A good outline of the regional extent (or hydraulic boundaries) for the Delmas-Bapsfontein dolomitic area defined from previous studies and aeromagnetic data now exist. However, the hydraulic connectivity between the dolomitic aquifers and the overlying Karoo sediments and Pretoria Group formations requires further investigation. A better understanding of the role of the bounding dykes on the groundwater flow and determining the extent of leakage through these almost impermeable barriers would be extremely valuable in future groundwater management decisions.

2) Identification of the impacts of various land-use activities on the groundwater quality.

   - Various land-use activities have been identified in the study area with potentially diverse impacts on the dolomitic aquifers. Impacts on the groundwater quality of the dolomitic aquifers may be associated with the irrigation return flows from large-scale agricultural practices, the potential for bacteriological contamination emanating from growing informal settlements, urban run-off and discharge of industrial effluents, the discharge of treated sewage effluent into surface water bodies from waste disposal sites and/or the potential contamination of aquifer systems underlying such waste disposal sites and mining activities.

   - The resultant impacts on the groundwater quality of the dolomitic aquifers are difficult to quantify at this stage due to a lack of continuous water quality monitoring data in the study area. This may be related to inefficient monitoring or data not forming part of the NGDB.

3) Assessment of the extent of groundwater use in the various dolomitic compartments.

   - The available information indicates that a large volume of registered groundwater use occur in the dolomitic areas. Groundwater authorised use in the Witkoppies, Elandsfontein and Bapsfontein compartment is 10.4 Mm^3/a. The Delmas area support a registered volume of 14.93 Mm^3/a.

   - With a groundwater recharge of 10% of mean annual rainfall, it is clear that abstraction in almost all compartments exceed this value. Enforcing restrictions on groundwater abstraction might be the only way forward for highly stressed aquifers.

Based on these outcomes the following recommendations are proposed:

a) To further elaborate on the groundwater level trends within the identified compartments, continuous, consistent and reliable monthly groundwater level measurements from identified monitoring stations should be conducted. More frequent monitoring is necessary in stressed groundwater resource units.

b) To identify possible structural discontinuities in the groundwater flow system and to assess the connectivity of the Karoo aquifers to the dolomite, more detailed investigations on specific resource units will be required. This will require identifying and surveying additional monitoring boreholes.

c) The current groundwater quality monitoring programme requires revision, if no systematic monitoring is in place a detailed hydrogeochemical study of the dolomitic aquifers in the Bapsfontein-Delmas area is necessary. This will address the impacts of the diverse land-use activities on the groundwater quality of the dolomitic aquifer system and will provide a detailed extent of monitoring necessary in future.

Appendix 11A

Groundwater level monitoring stations

Monitoring Station	Coordinates		Groundwater Level		Length of Record	
	Latitude	Longitude	Depth (m.b.g.s.)	Elevation (m.a.m.s.l.)		
Rietvlei Compartment						
A2N0119	28.30222	-25.91250	22.51	1482.74	1985/01/24 -	2007/07/16
A2N0121	28.30028	-25.90361	10.70	1480.27	1985/01/24 -	2007/07/16
A2N0122	28.30833	-25.90500	16.08	1492.73	1985/01/24 -	2005/05/23
A2N0123	28.30056	-25.89833	24.04	1499.05	1986/01/10 -	2006/06/15
A2N0124	28.30722	-25.89416	25.94	1475.74	1985/01/24 -	2007/07/16
A2N0125	28.31611	-25.89000	13.40	1483.71	1986/01/10 -	2007/07/16
A2N0129	28.31472	-25.88916	42.38	1484.05	1985/01/24 -	2005/05/23
A2N0131	28.32417	-25.90417	9.35	1483.85	1986/02/28 -	2007/04/10
A2N0132	28.30000	-25.89333	16.44	1488.94	1985/01/24 -	2006/11/29
A2N0136	28.30556	-25.89583	35.84	1475.03	1985/01/24 -	2007/04/10
A2N0138	28.31695	-25.90528	12.19	1482.65	1985/01/24 -	2007/04/10
A2N0139	28.31723	-25.90250	9.25	1480.71	1985/01/24 -	2007/07/16
A2N0141	28.30556	-25.90472	26.02	1483.50	1985/01/24 -	2007/07/16
A2N0142	28.30639	-25.90889	13.78	1485.45	1985/01/24 -	2007/04/10
A2N0143	28.31083	-25.88500	9.74	1481.57	1985/01/24 -	2006/10/25
A2N0145	28.31695	-25.90861	22.15	1479.06	1985/01/24 -	2007/07/16
A2N0146	28.32195	-25.89222	40.32	1483.89	1985/01/24 -	2007/07/16
A2N0717	28.30056	-25.89333	16.97	1489.20	1986/01/10 -	2007/07/16
A2N0729	28.31500	-25.90472	10.77	1482.13	1986/01/24 -	2007/04/10
Witkoppies Compartment						
A2N0702	28.36666	-25.93888	62.39	1517.61	1987/11/15 -	2007/06/05
A2N0703	28.36858	-25.94106	27.95	1542.05	1987/10/15 -	2007/06/05
A2N0704	28.35472	-25.94166	68.18	1511.82	1987/11/15 -	2007/06/05
A2N0705	28.35508	-25.94142	71.53	1500.79	1987/11/15 -	2007/06/05
A2N0706	28.35556	-25.94583	74.38	1505.62	1988/01/15 -	2007/06/05
A2N0707	28.34250	-25.95068	71.77	1505.68	1986/01/29 -	2007/06/05
A2N0708	28.32031	-25.93976	33.18	1511.57	1985/12/05 -	2007/06/05
A2N0709	28.31339	-25.94386	37.30	1505.53	1985/12/11 -	2007/06/05
A2N0713	28.31152	-25.92971	19.13	1505.14	1985/12/02 -	2007/05/08
A2N0714	28.33801	-25.91674	1.73	1499.76	1986/01/25 -	2007/06/07
A2N0777	28.33598	-25.91550	1.45	1500.20	2005/05/05 -	2007/06/05
Bapsfontein Compartment						
A2N0779	28.39289	-25.97360	79.20	1520.52	2005/05/05 -	2007/06/05
A2N0780	28.39141	-25.97335	41.60	1559.57	2005/05/05 -	2007/06/05
B2N0722	28.43927	-26.00643	80.13	1560.05	2005/05/05 -	2007/06/05
Elandsfontein Compartment						
A2N0710	28.41122	-26.03154	36.34	1600.45	1987/05/25 -	2007/05/09
A2N0711	28.41796	-26.02902	37.24	1597.70	1988/08/15 -	2007/05/09
A2N0712	28.43430	-26.01473	36.36	1589.88	1985/12/29 -	2004/03/03
A2N0715	28.33145	-25.96810	35.48	1532.79	1986/02/07 -	2007/06/05
A2N0781	28.37804	-25.99718	64.77	1552.21	2005/06/01 -	2007/06/05
A2N0782	28.38669	-26.00379	49.98	1578.71	2005/05/05 -	2007/06/05
A2N0784	28.33099	-25.96979	28.42	1538.91	2005/05/05 -	2005/09/01
B2N0021	28.45231	-26.02527	66.58	1570.69	1985/10/14 -	2007/03/19
B2N0022	28.47128	-26.03365	35.89	1585.53	1985/09/27 -	2004/08/03
B2N0717	28.38311	-26.03127	14.51	1633.21	1986/01/17-	2007/05/07
Varkfontein-Knoppiesfontein Area						
A2N0783	28.38116	-26.04644	20.73	1624.30	2005/05/05 -	2007/06/07
C2N0891	28.44442	-26.08538	9.65	1603.70	1987/08/17 -	2007/06/07
C2N0893	28.44957	-26.10093	5.12	1610.35	1987/08/22 -	2007/06/07
Bapsfontein-Delmas Area						
B2N0001	28.67642	-26.14332	5.43	1551.95	1968/01/03 -	2007/03/19

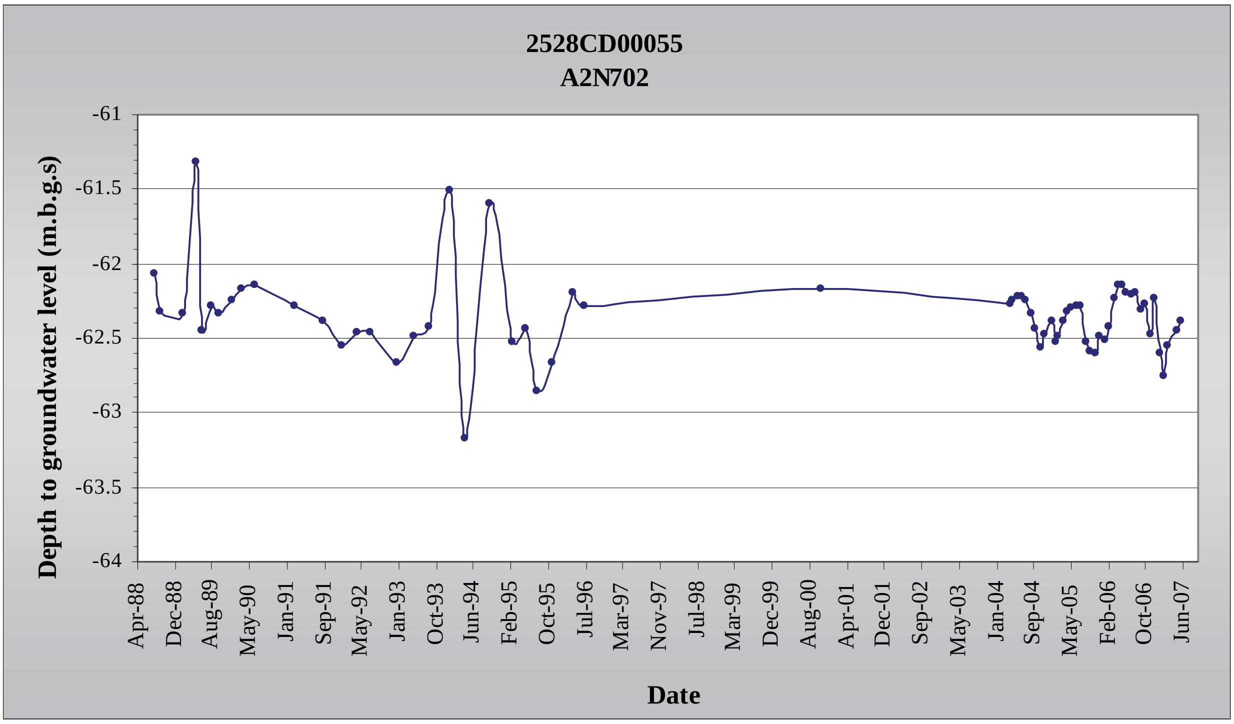
Monitoring Station	Coordinates		Groundwater Level		Length of Record	
	Latitude	Longitude	Depth (m.b.g.s.)	Elevation (m.a.m.s.l.)		
B2N0003	28.68481	-26.14256	3.03	1551.78	1977/03/07 -	2007/03/19
B2N0028	28.51239	-26.05975	24.58	1561.65	1987/05/08 -	2005/11/10
B2N0031	28.53232	-26.06239	29.39	1559.26	1987/05/19 -	2007/06/08
B2N0032	28.53876	-26.06662	21.57	1558.38	1987/03/19 -	2007/06/08
B2N0034	28.54568	-26.07364	14.31	1558.89	1987/03/26 -	2007/06/08
B2N0036	28.53881	-26.09000	15.51	1565.69	1987/03/31 -	2005/01/20
B2N0037	28.53881	-26.09000	11.05	1570.15	1987/05/14 -	2007/06/08
B2N0038	28.53112	-26.08973	11.41	1583.52	1987/04/14 -	2007/06/08
B2N0039	28.52128	-26.07829	26.54	1563.53	1987/05/04 -	2007/06/08
B2N0041	28.50026	-26.08869	13.68	1593.84	1987/05/26 -	2007/06/08
B2N0043	28.52336	-26.08745	17.29	1583.99	1985/10/05 -	2007/06/08
B2N0044	28.59946	-26.08611	14.01	1540.11	1985/04/15 -	2007/06/12
B2N0049	28.58325	-26.09637	30.91	1540.36	1985/10/23 -	2007/06/08
B2N0050	28.58178	-26.08954	5.92	1573.90	1985/06/18 -	2007/06/08
B2N0053	28.60320	-26.15839	53.72	1560.45	1986/01/18 -	2007/06/12
B2N0056	28.73560	-26.12329	38.61	1514.96	1985/08/20 -	2007/06/12
B2N0057	28.63321	-26.24881	89.75	1538.75	1985/11/06 -	2007/06/12
B2N0058	28.60435	-26.09994	11.11	1547.02	1985/07/10 -	2006/05/16
B2N0059	28.58534	-26.08271	26.31	1545.41	1985/05/28 -	2006/05/11
B2N0060	28.56662	-26.07413	4.46	1544.09	1985/11/04 -	2007/06/12
B2N0061	28.54162	-26.06048	7.14	1569.08	1985/10/08 -	2007/05/10
B2N0063	28.53250	-26.09343	8.14	1583.06	1987/05/10 -	2007/06/08
B2N0066	28.49547	-26.06658	28.32	1585.09	1987/05/12 -	2007/06/07
B2N0068	28.48111	-26.05750	17.75	1662.25	1987/06/20 -	2007/06/07
B2N0069	28.69689	-26.15174	4.00	1550.71	1985/10/29 -	2004/09/10
B2N0071	28.73802	-26.16005	11.90	1569.99	1985/11/23 -	2007/06/12
B2N0073	28.67873	-26.20245	46.56	1528.75	1985/11/20 -	2007/06/12
B2N0076	28.48070	-26.04131	19.11	1582.50	1985/10/20 -	2005/08/04
B2N0081	28.63333	-26.19055	75.84	1524.16	1985/12/15 -	2007/06/12
B2N0506	28.68802	-26.14942	8.73	1554.85	1985/08/01 -	2007/03/19
B2N0719	28.66855	-26.18080	20.10	1572.48	2005/07/28 -	2006/12/11
B2N0721	28.65819	-26.11637	22.66	1569.64	2005/07/28 -	2006/12/11
East Rand Basin						
C2N1113	28.51962	-26.14270	49.71	1570.53	2005/07/07 -	2007/06/08
C2N1114	28.52155	-26.14379	53.91	1568.04	2005/05/10 -	2007/06/08

Appendix 11B

Groundwater rest level trends

11B-1 : Witkoppies Compartment

Station : A2N702



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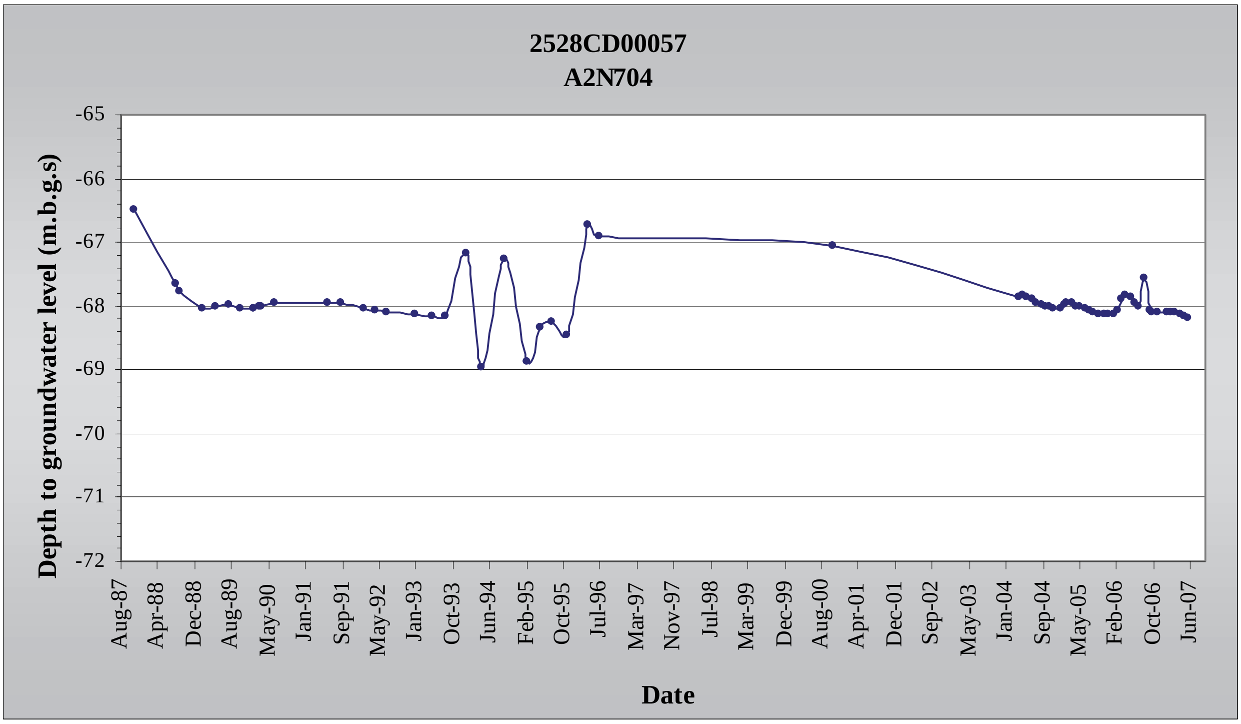
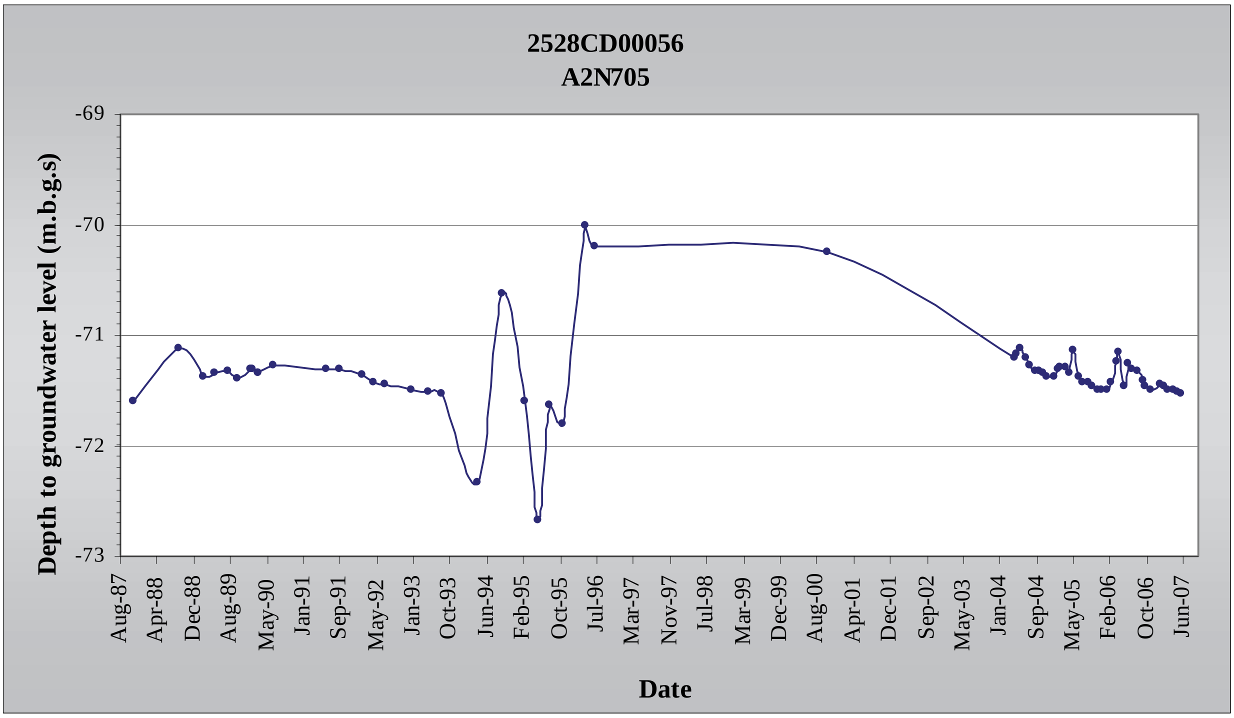
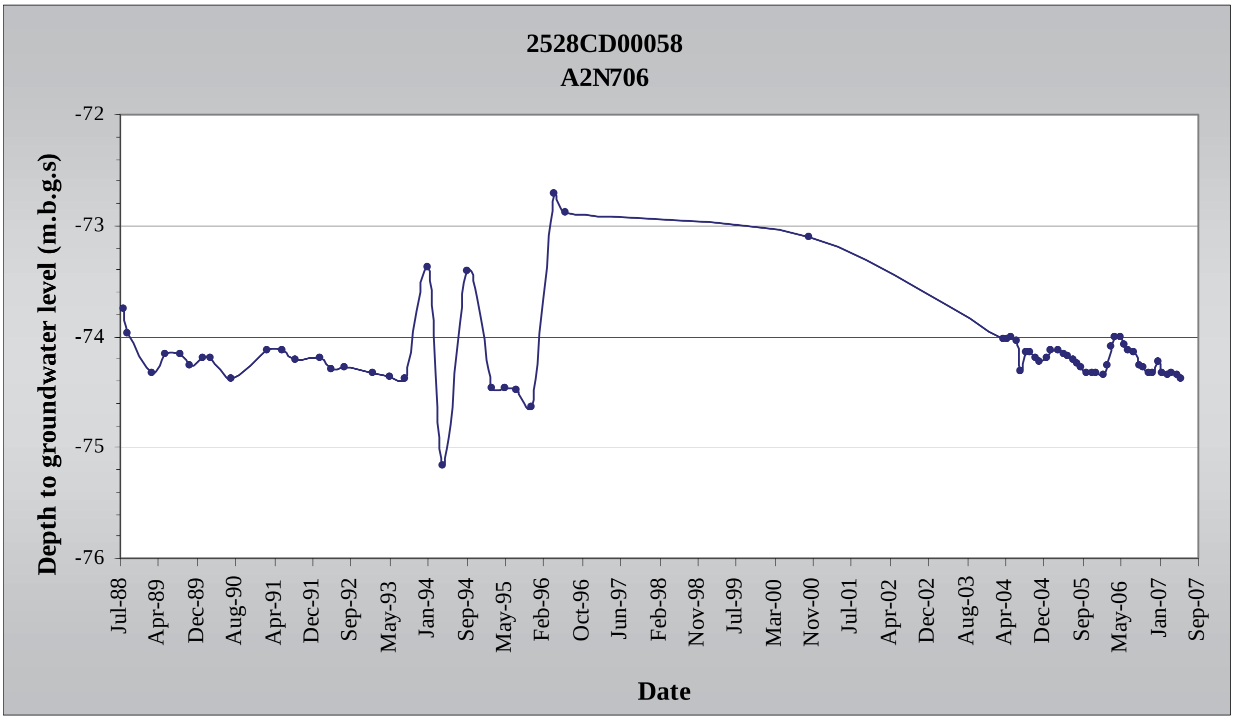


11B-1 : Witkoppies Compartment

Station : A2N705

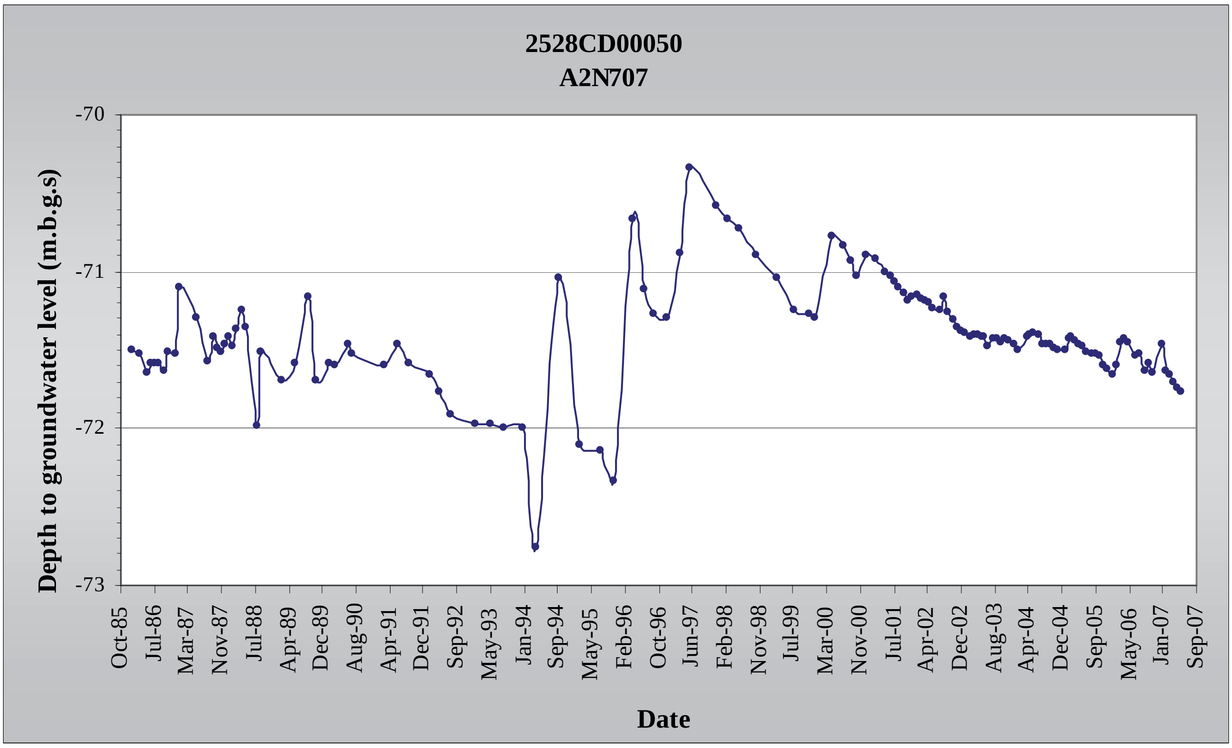


Station : A2N706

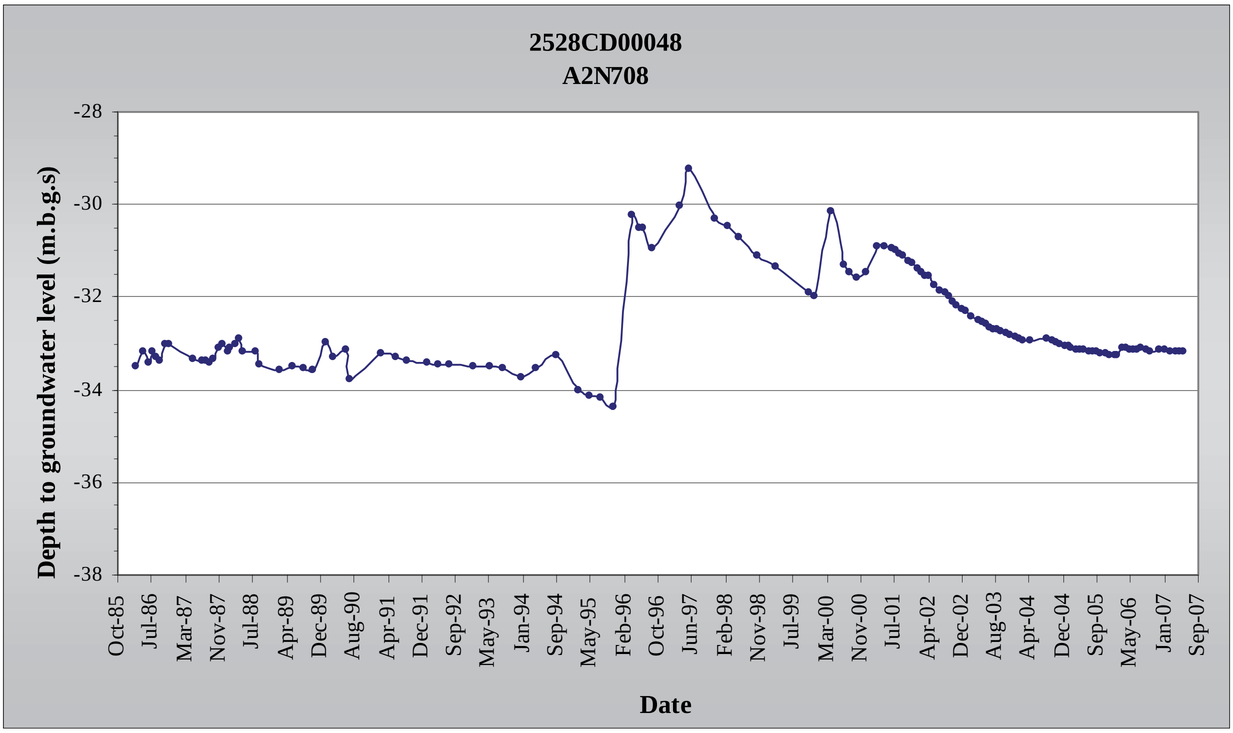


11B-1 : Witkoppies Compartment

Station : A2N707

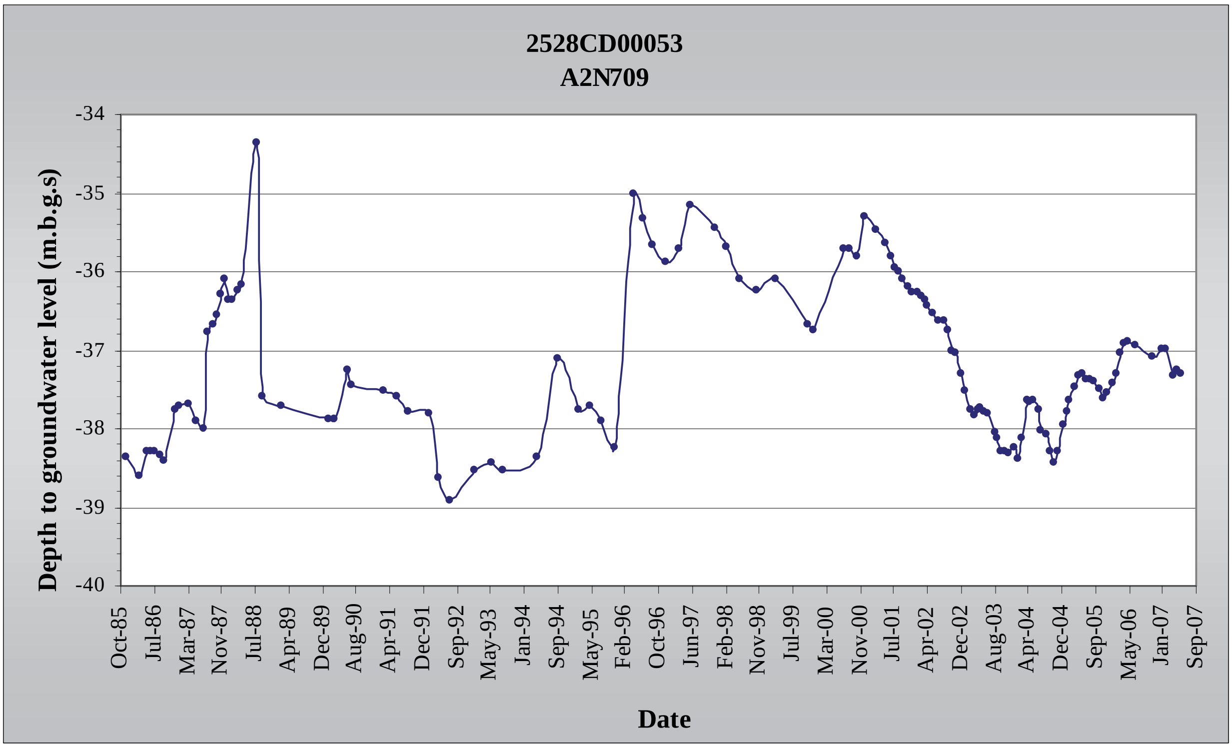


Station : A2N708

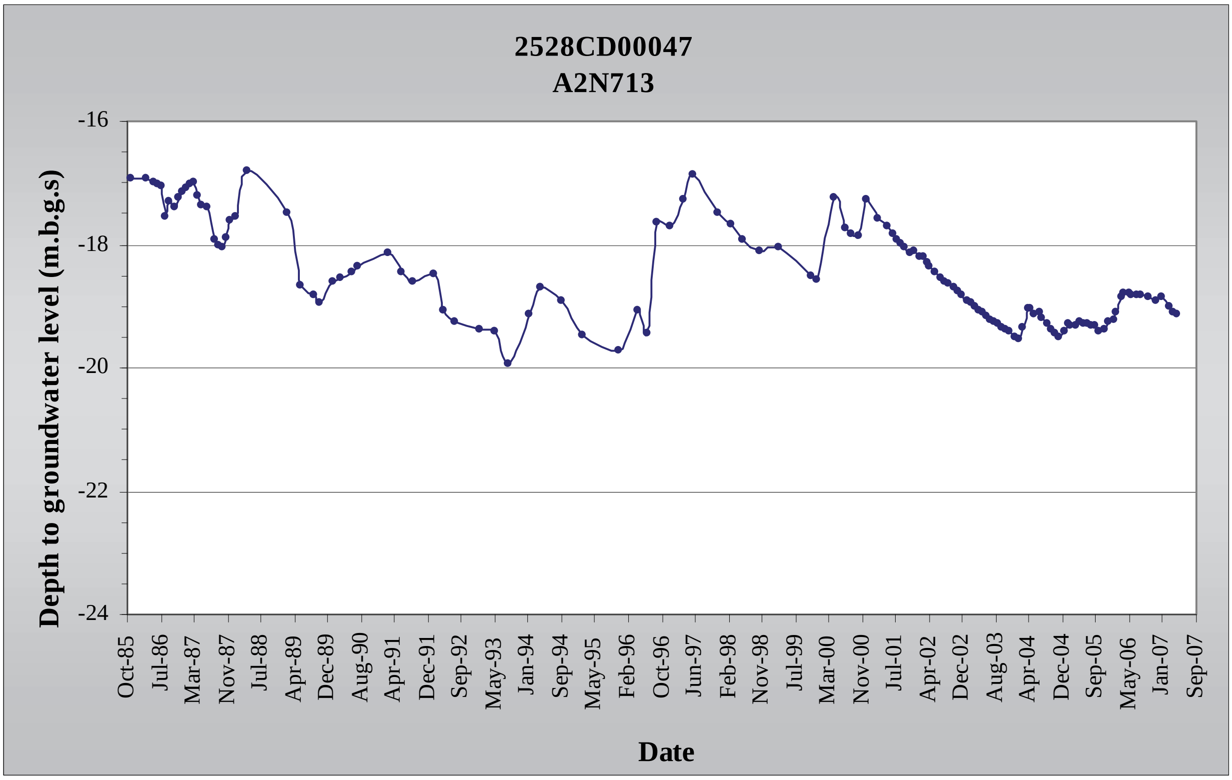


11B-1 : Witkoppies Compartment

Station : A2N709

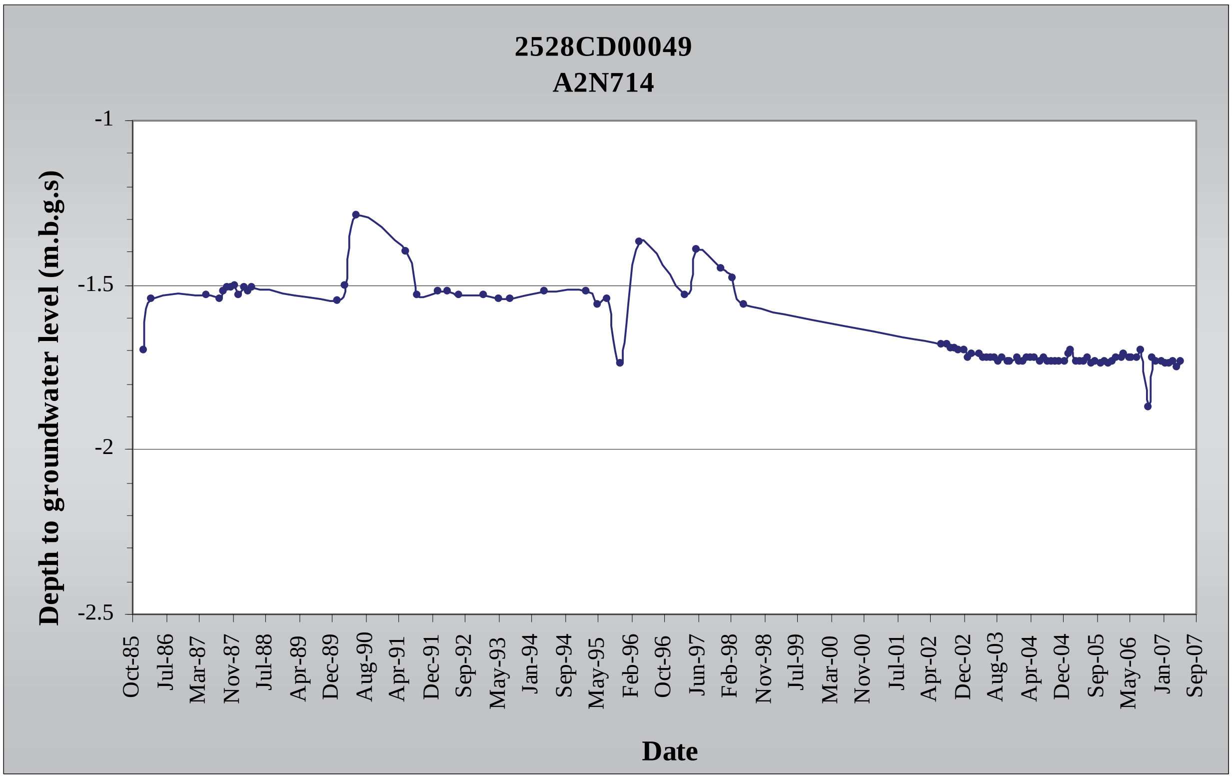


Station : A2N713

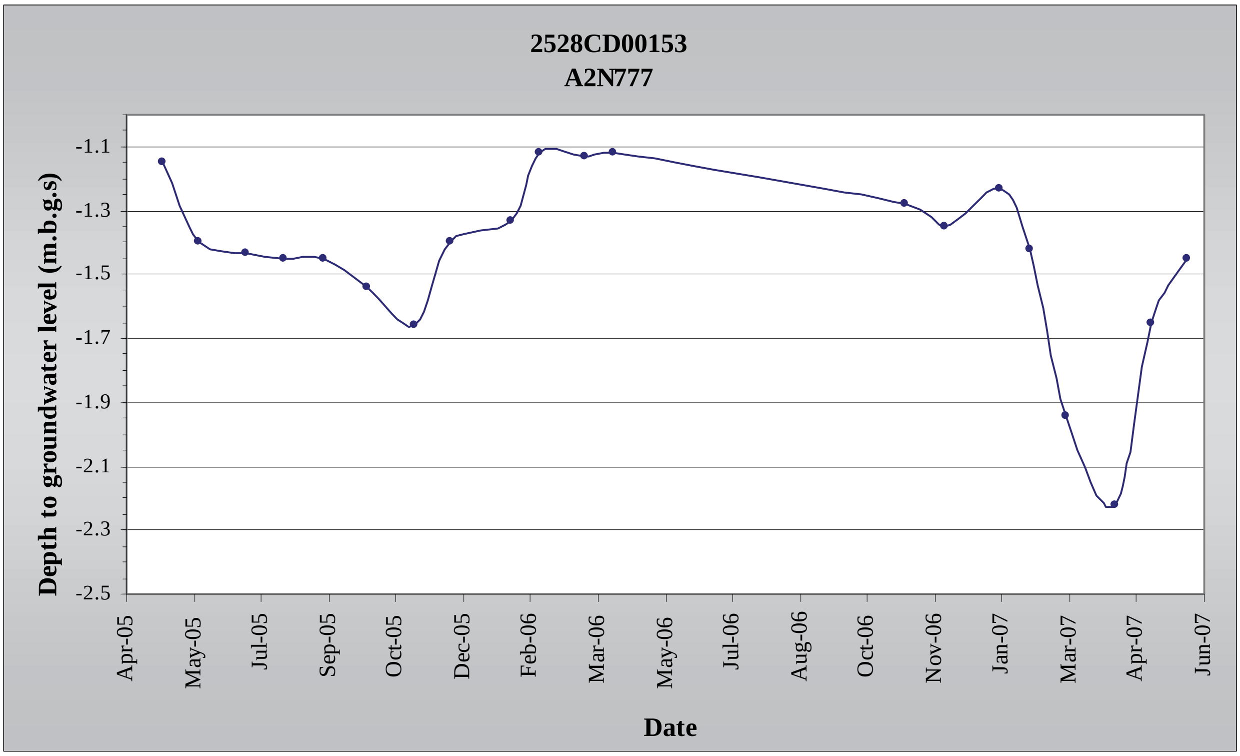


11B-1 : Witkoppies Compartment

Station : A2N714

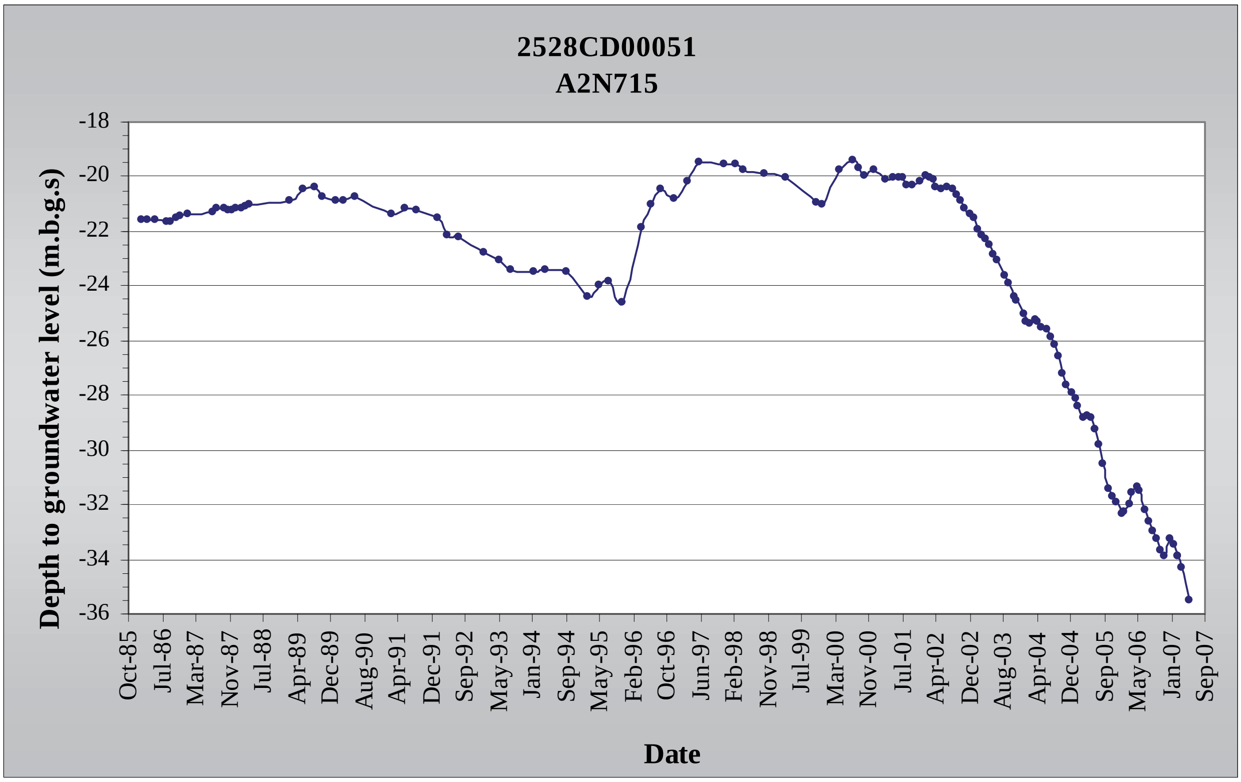


Station : A2N777

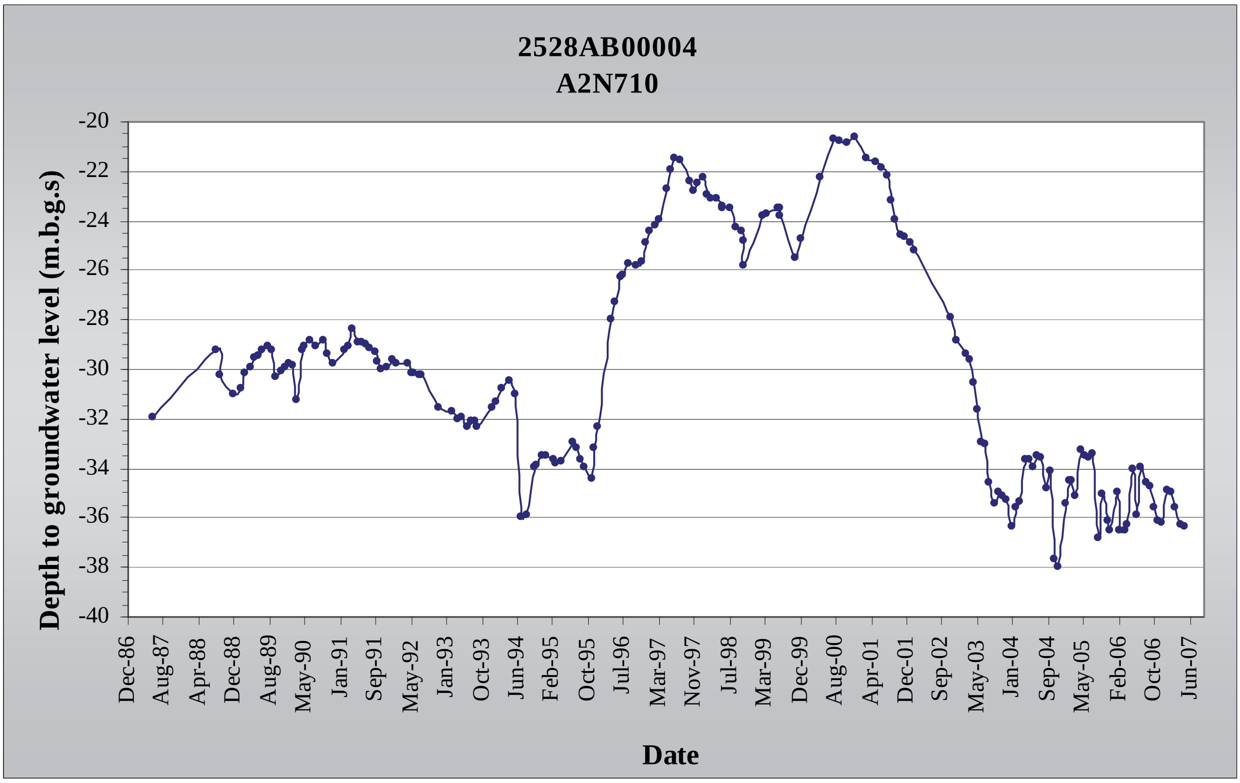


Appendix B-2 : Elandsfontein Compartment

Station : A2N715

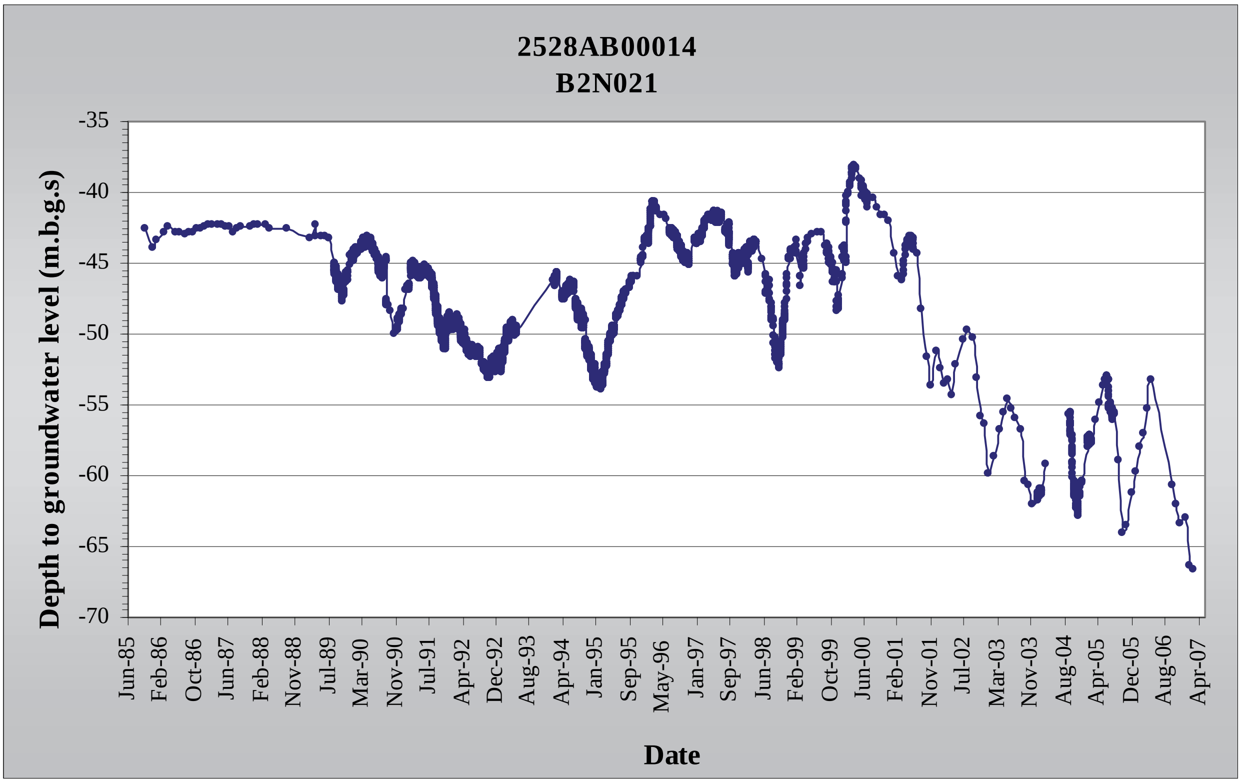


Station : A2N710

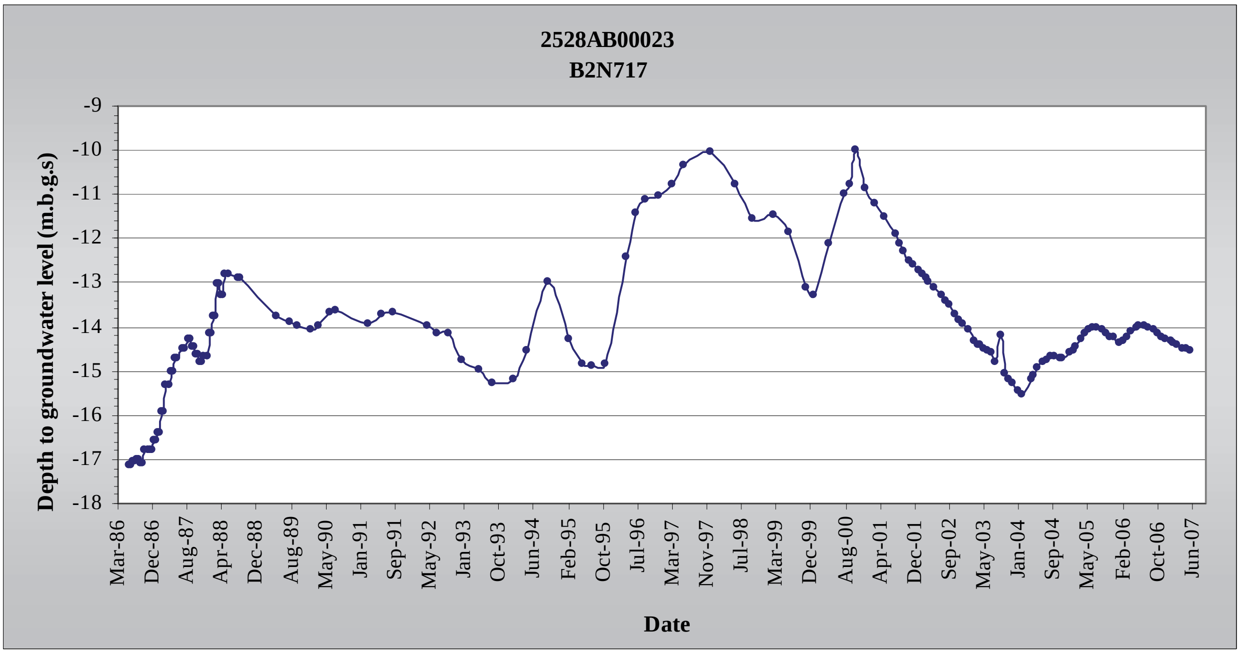


11B-2 : Elandsfontein Compartment

Station : B2N021

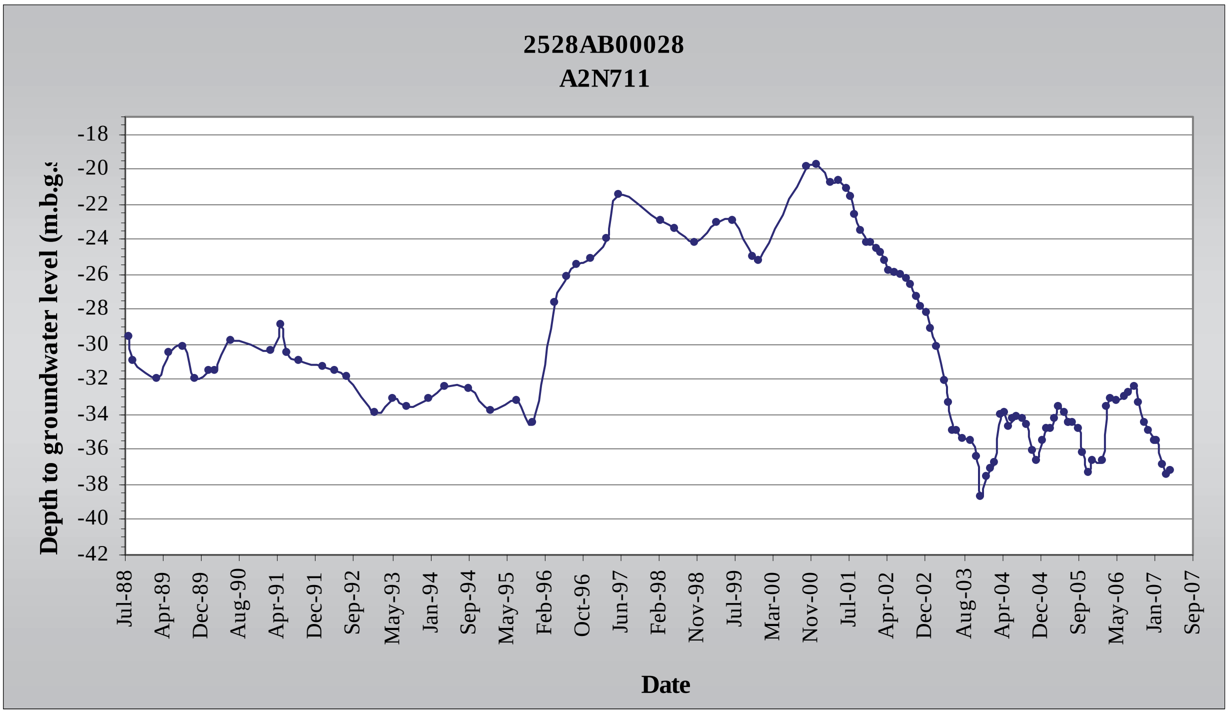


Station : B2N717



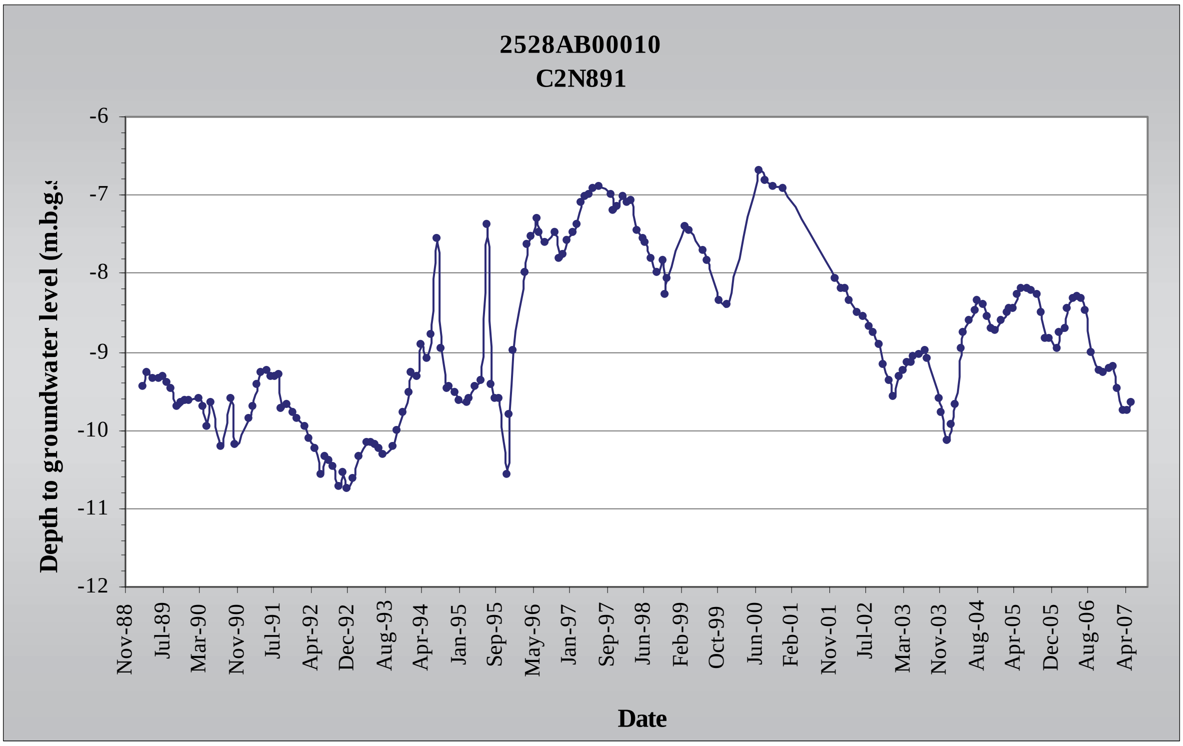
11B-2 : Elandsfontein Compartment

Station : A2N711



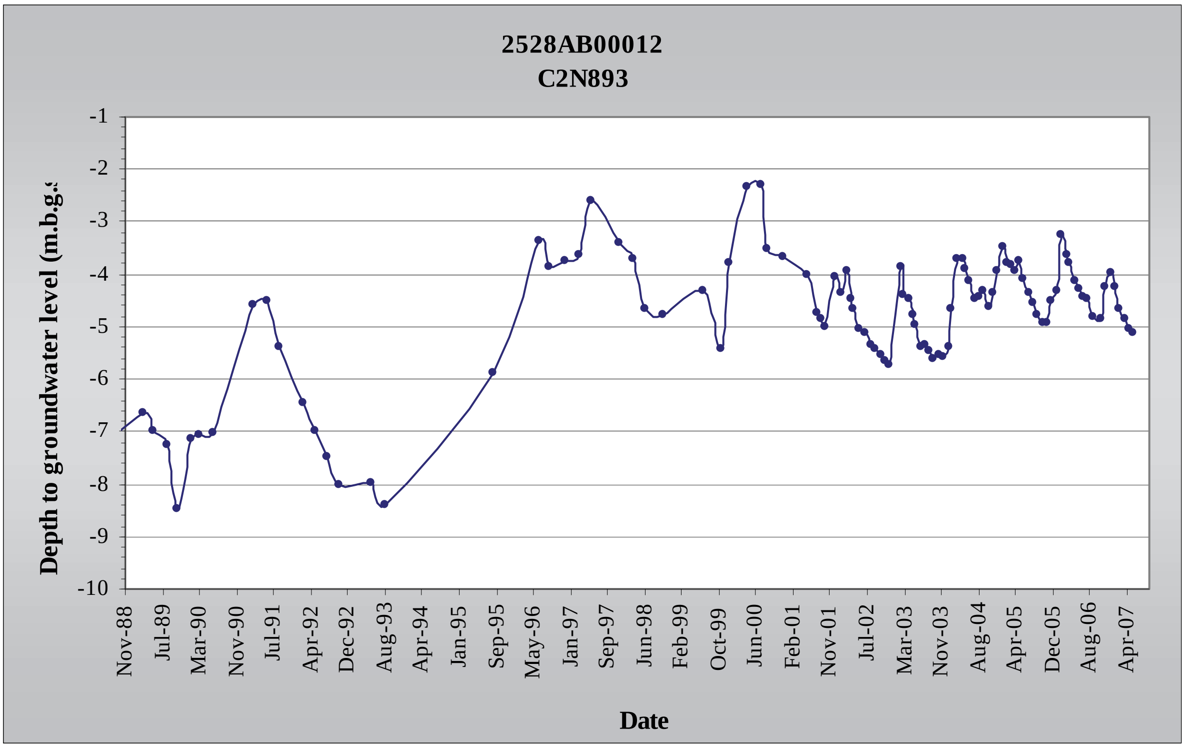
Appendix 11B-3 : Varkfontein-Knoppiesfontein Area

Station : C2N891



11B-3 : Varkfontein-Knoppiesfontein Area

Station : C2N893



Appendix 11B-4 : Delmas-Bapsfontein Area

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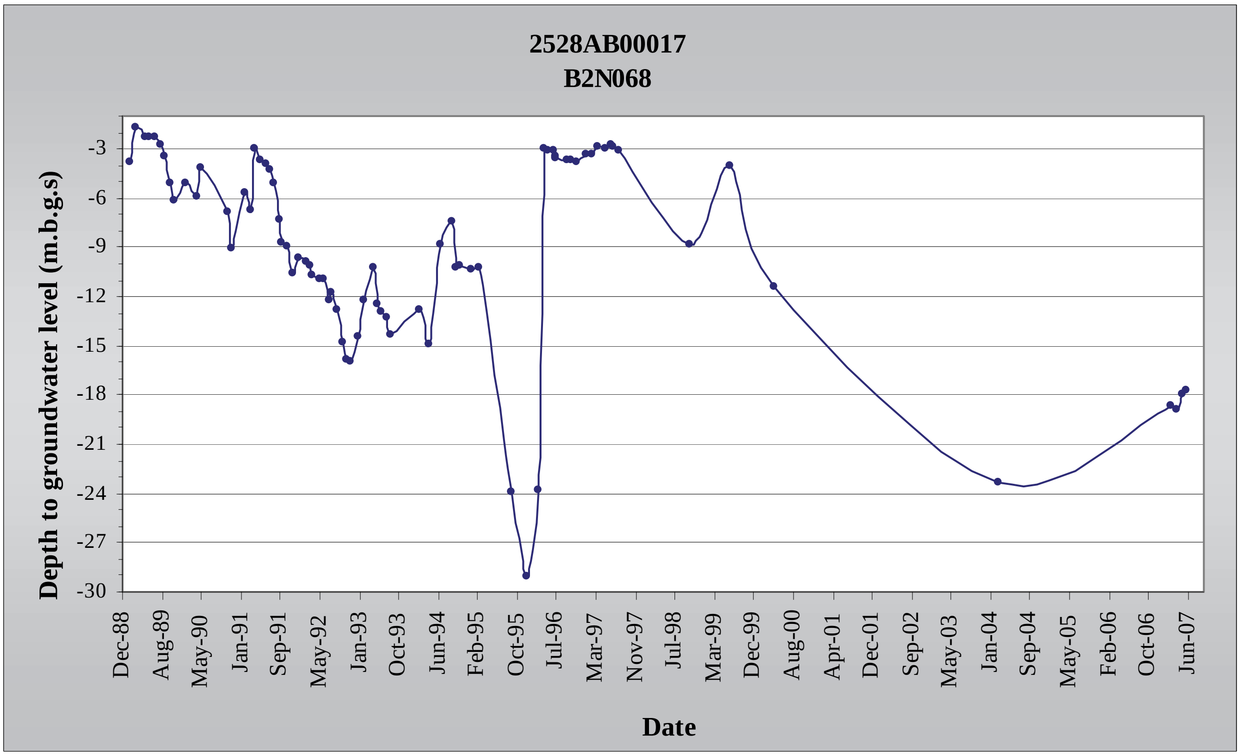

11B-4 : Delmas-Bapsfontein Area

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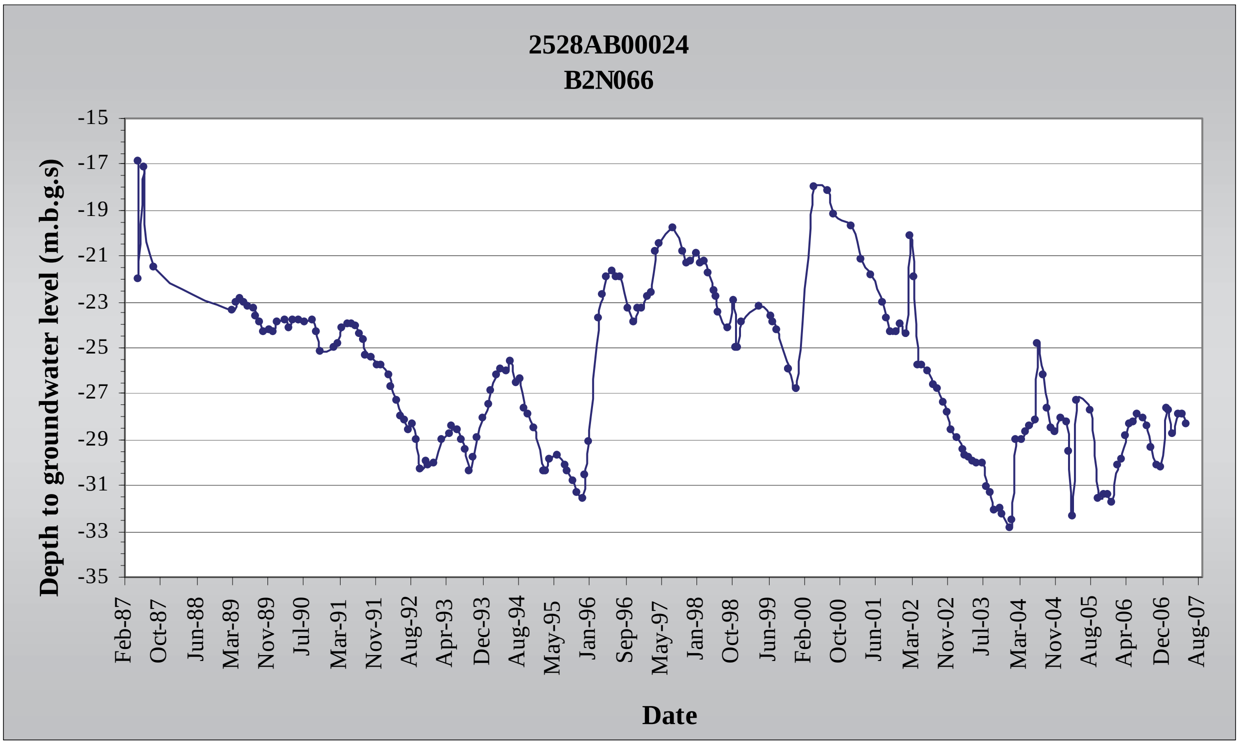

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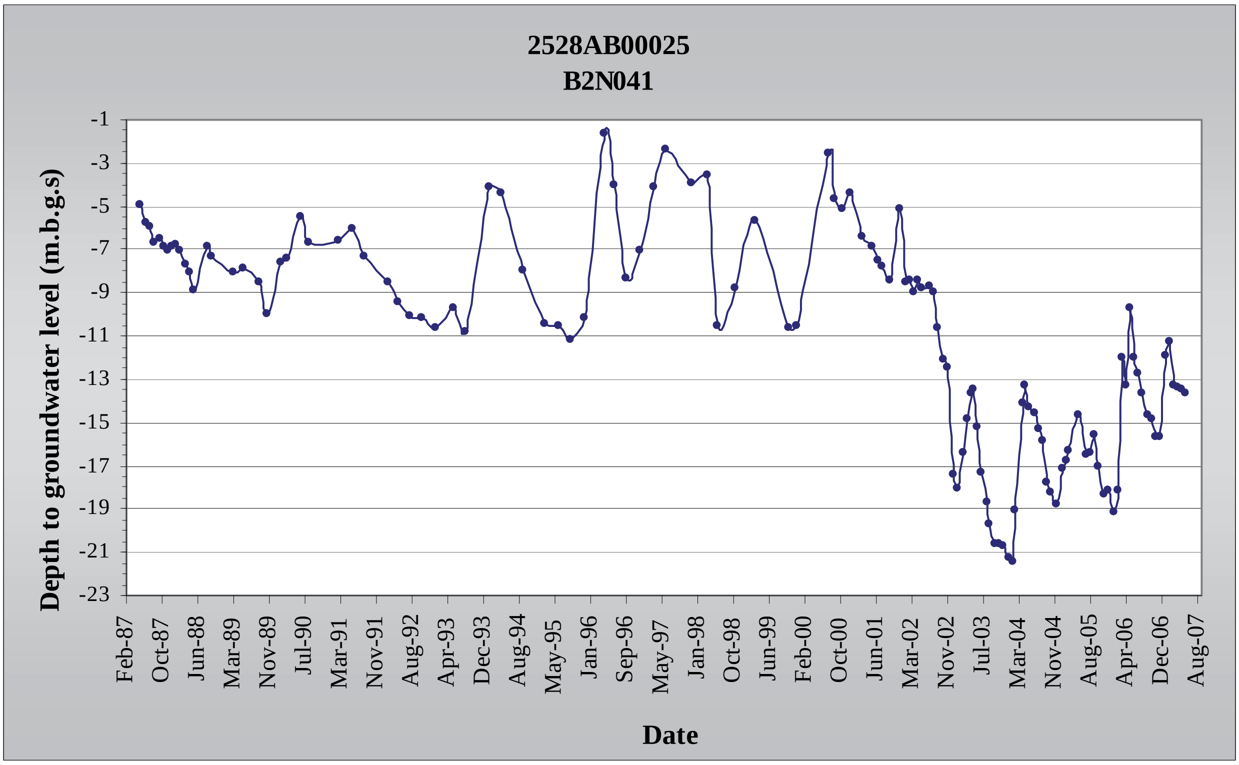

11B-4 : Delmas-Bapsfontein Area

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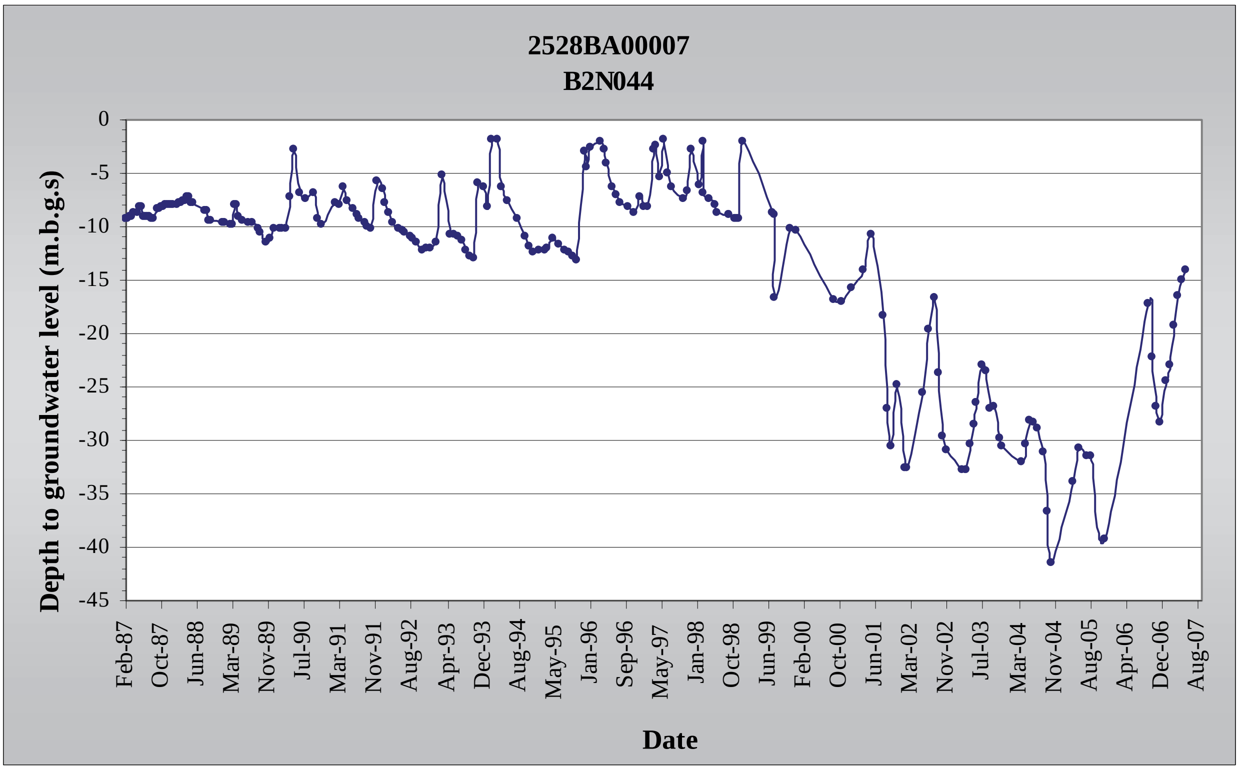

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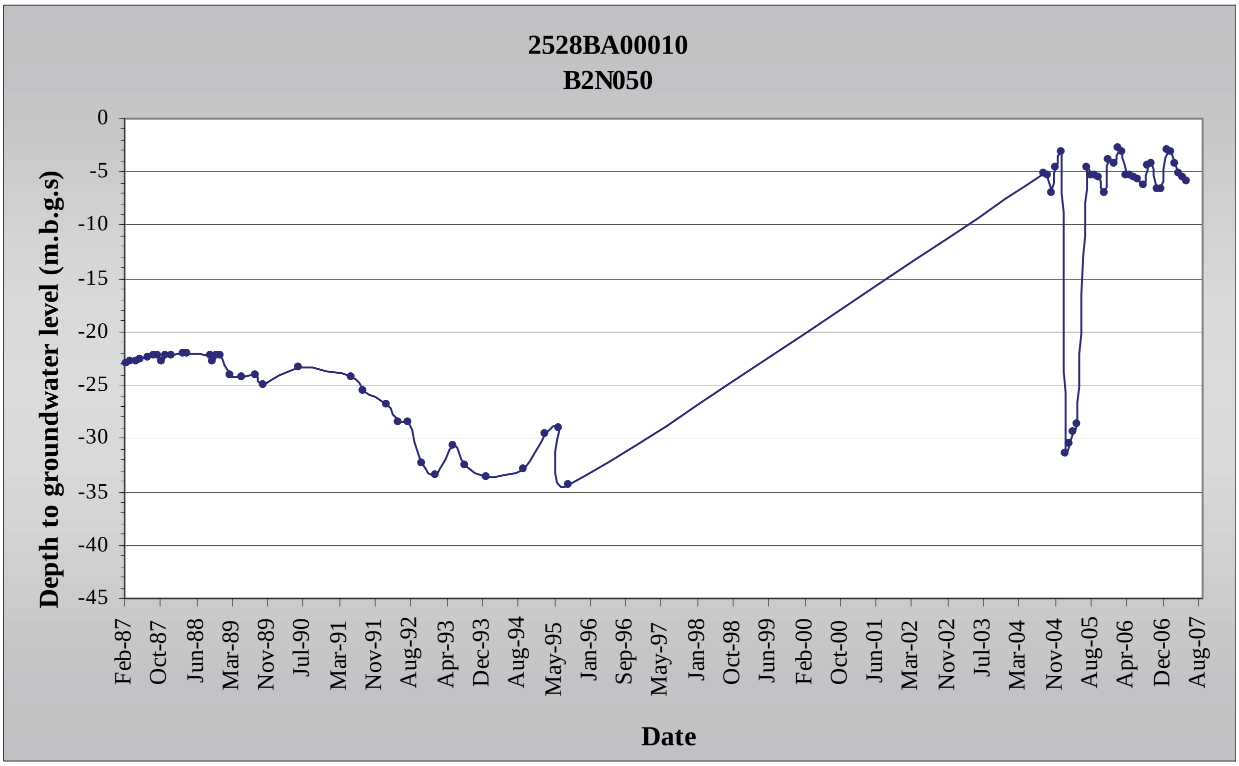

11B-4 : Delmas-Bapsfontein Area

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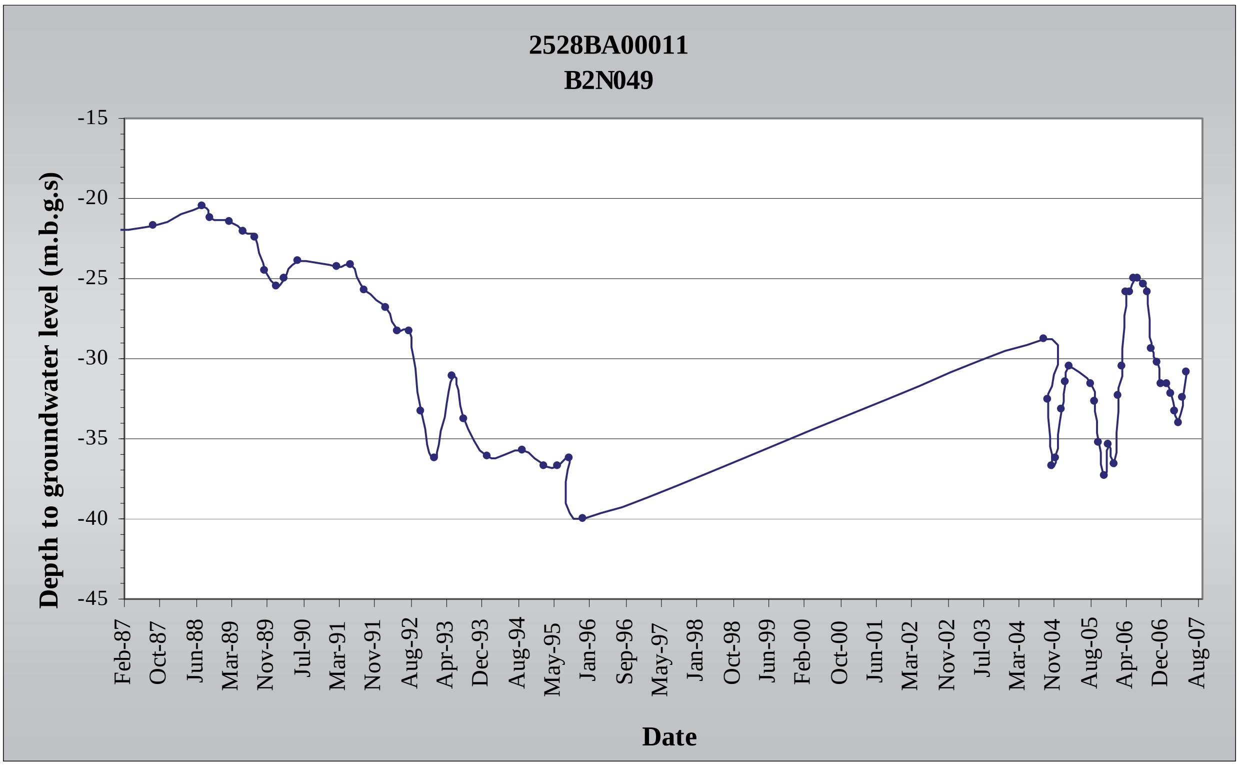

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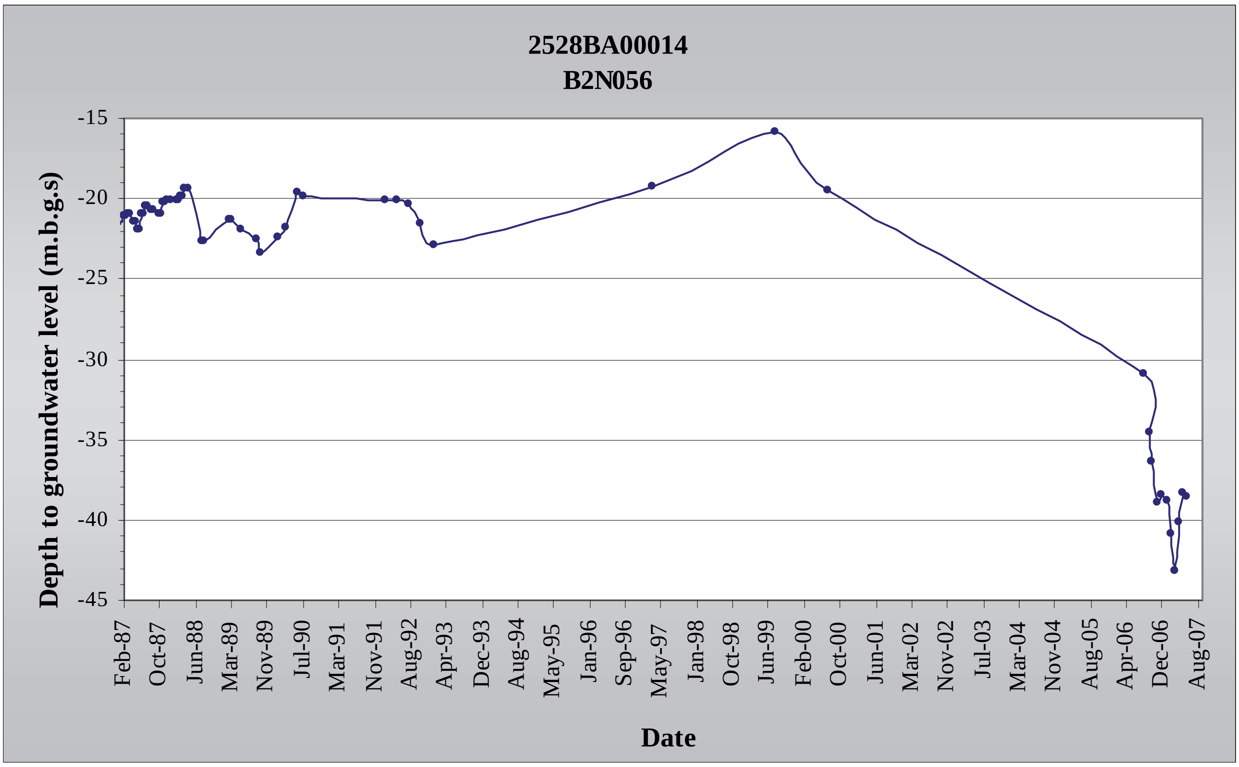

11B-4 : Delmas-Bapsfontein Area

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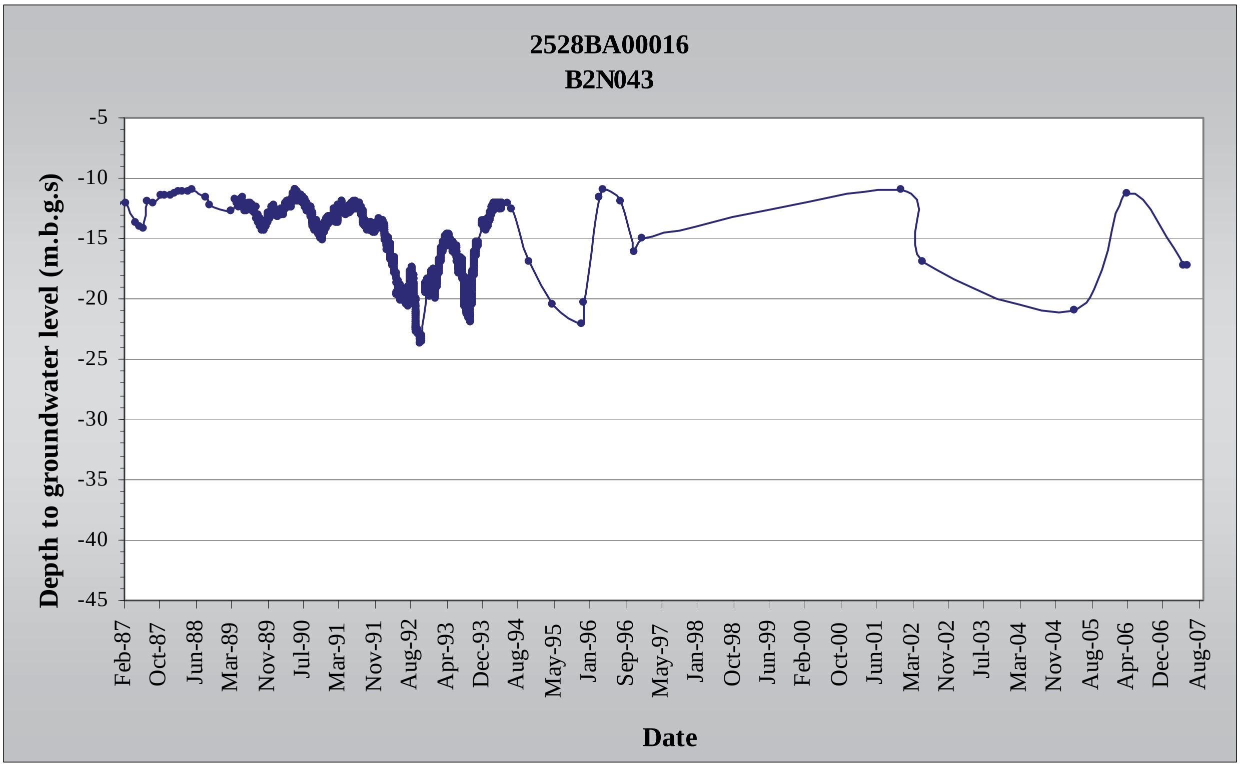

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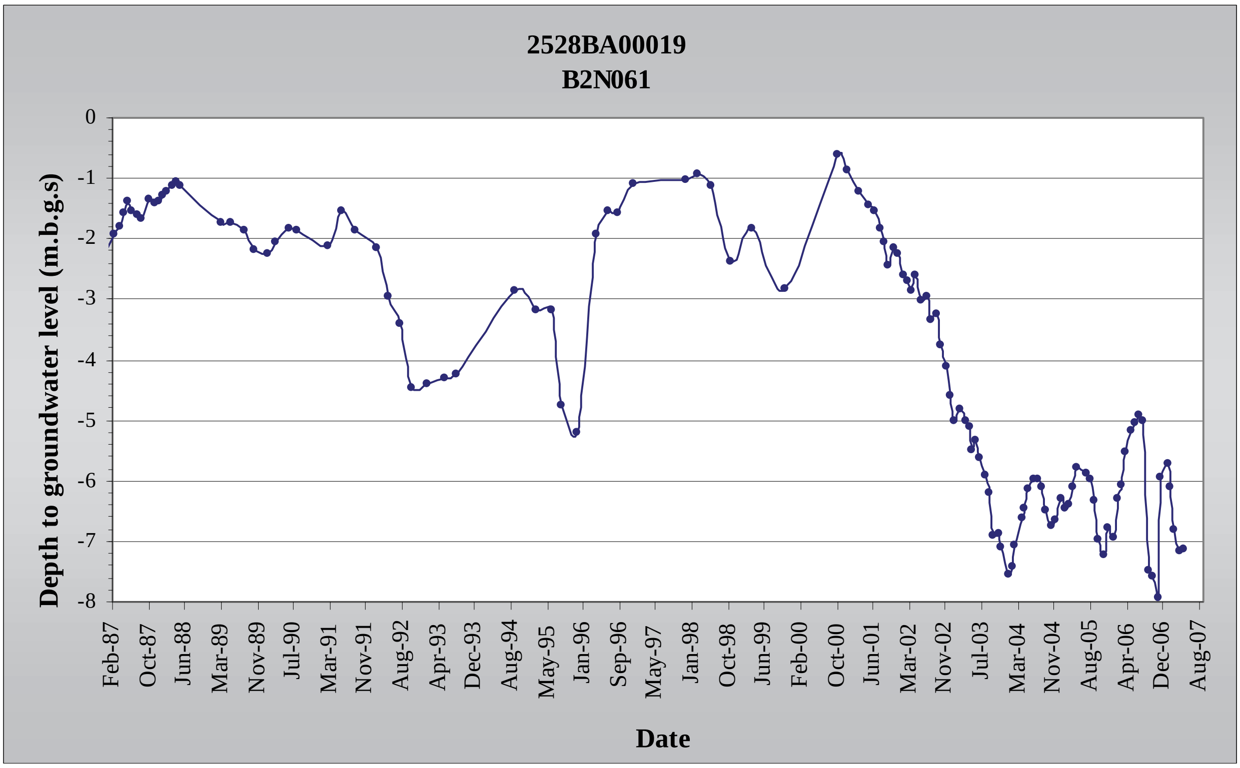

11B-4 : Delmas-Bapsfontein Area

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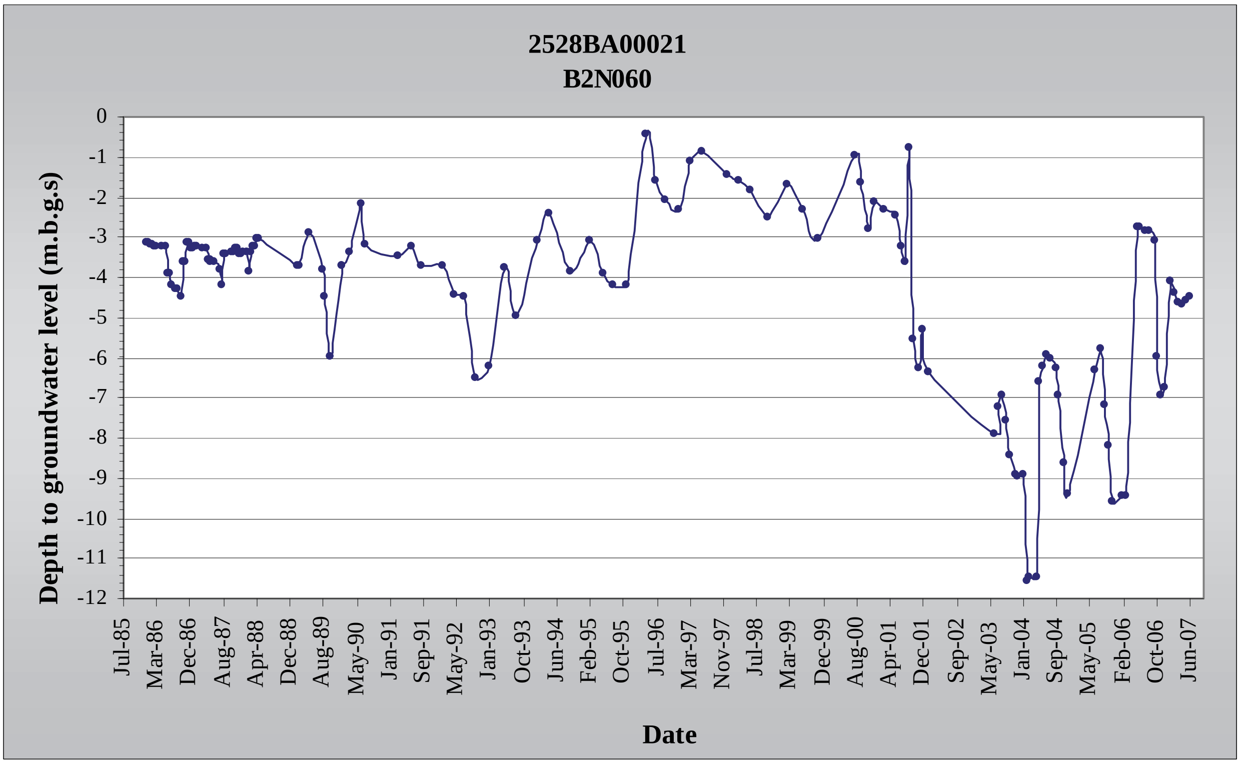

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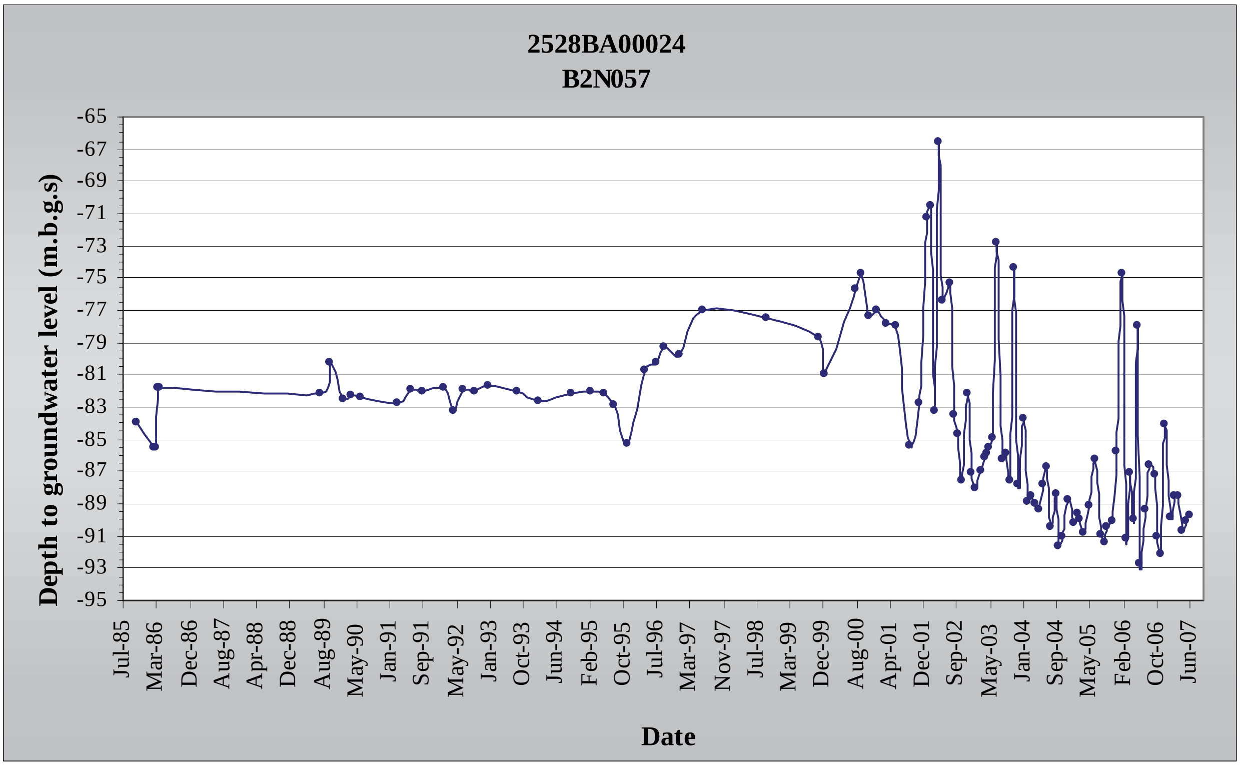

11B-4 : Delmas-Bapsfontein Area

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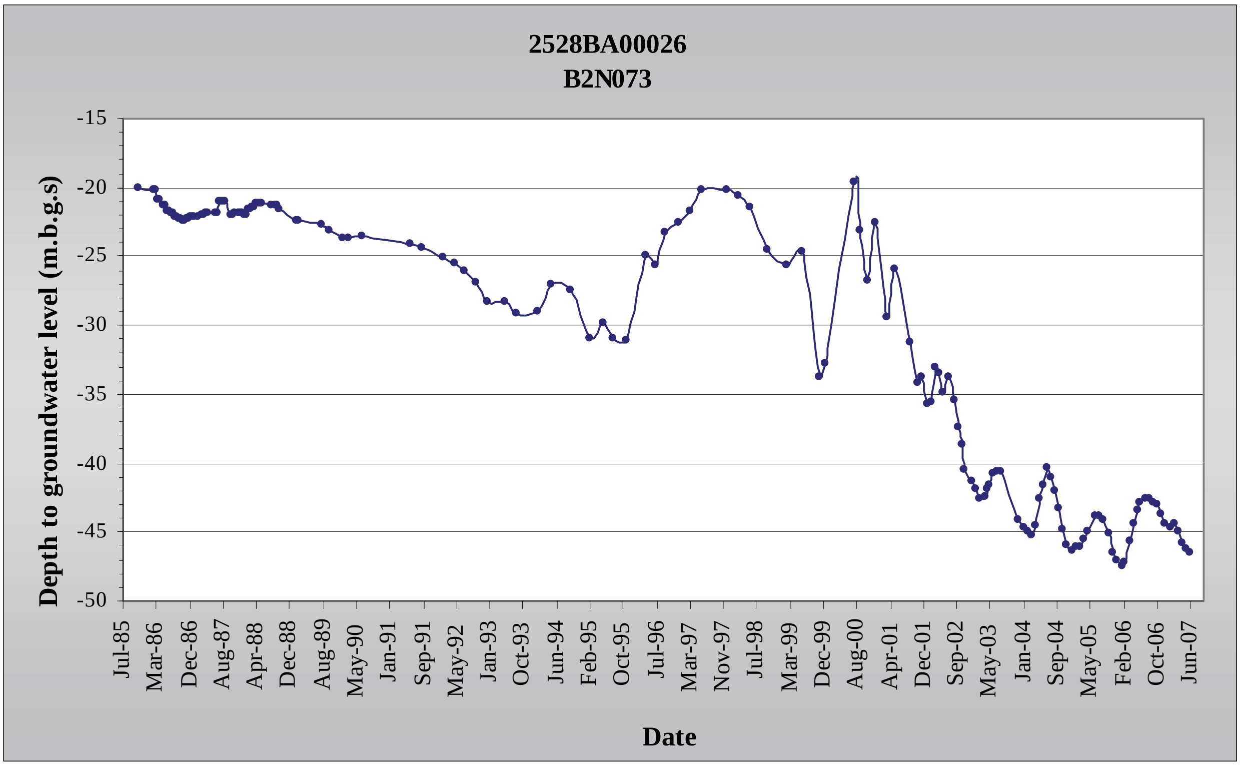

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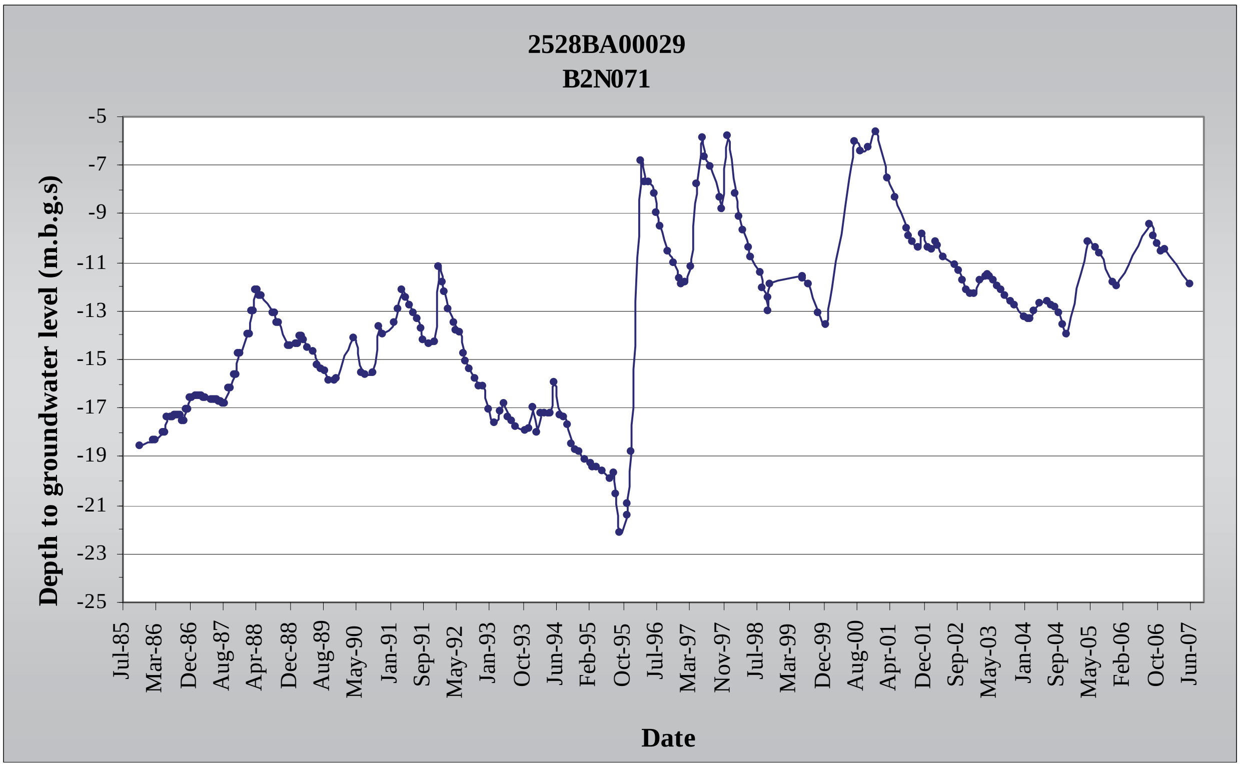

11B-4 : Delmas-Bapsfontein Area

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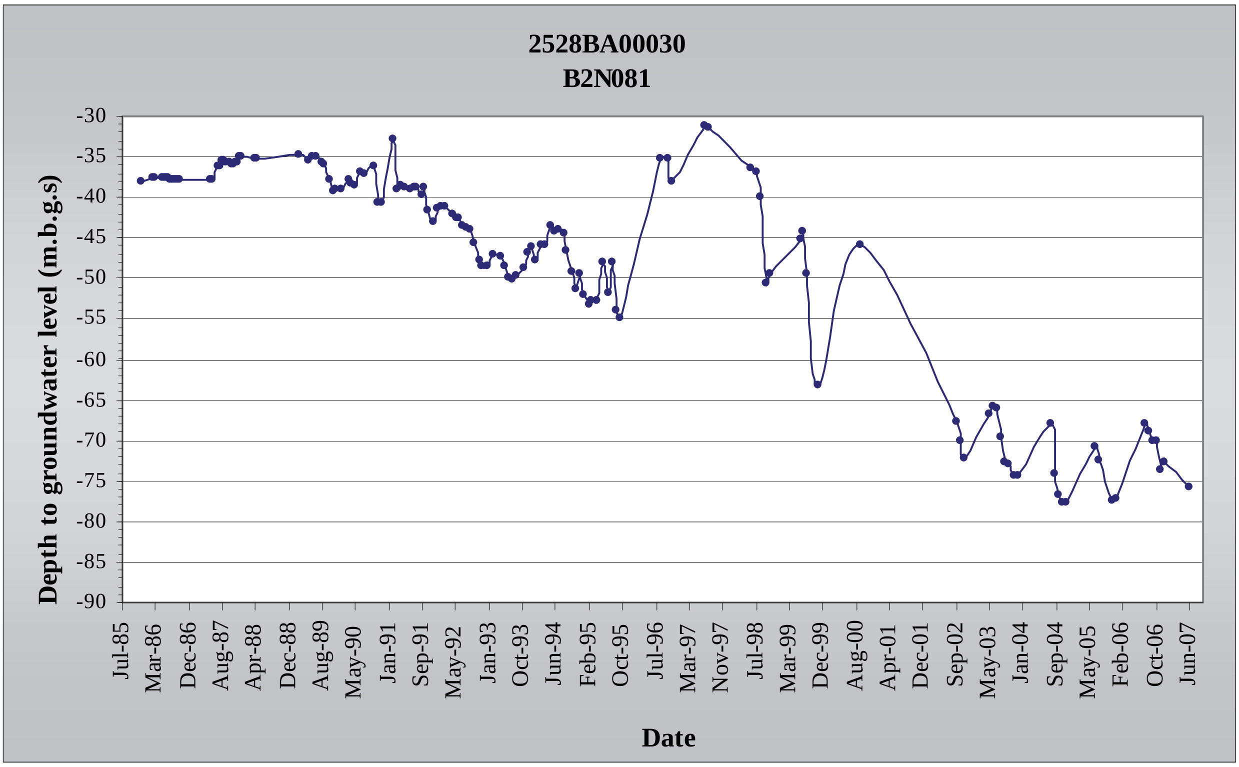

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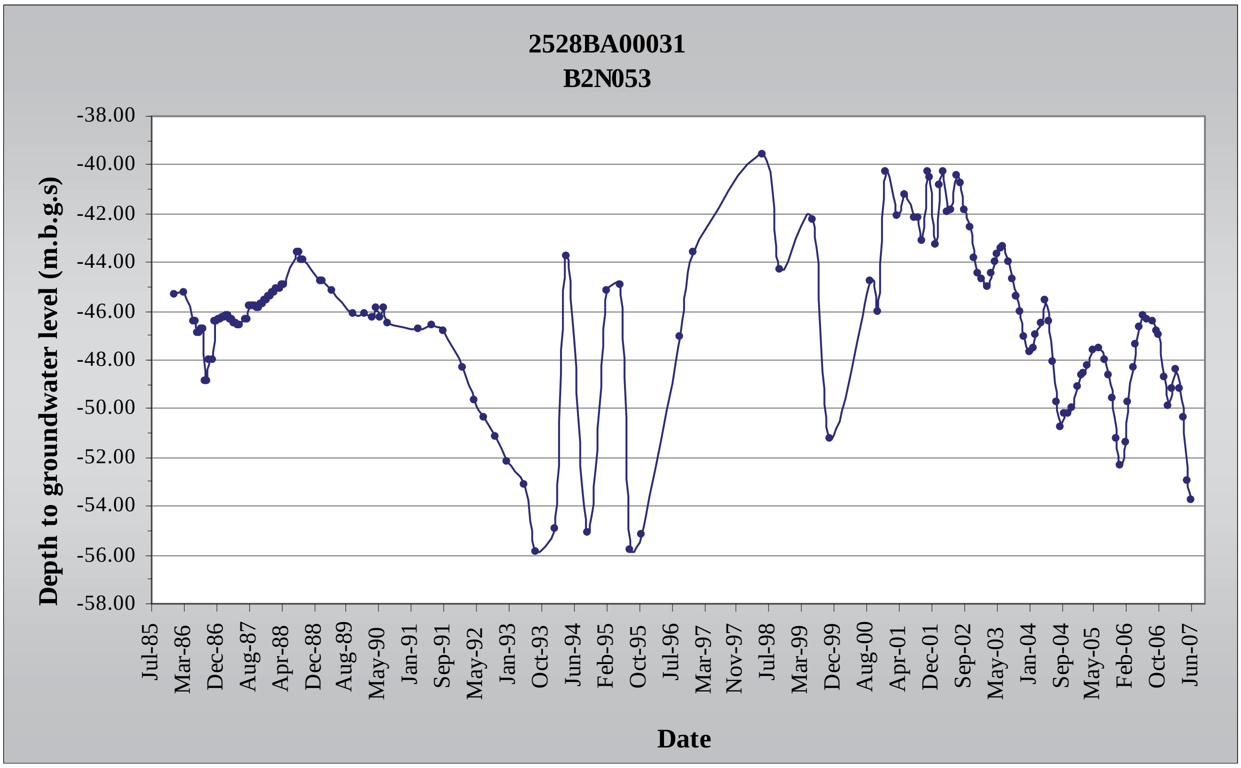

11B-4 : Delmas-Bapsfontein Area

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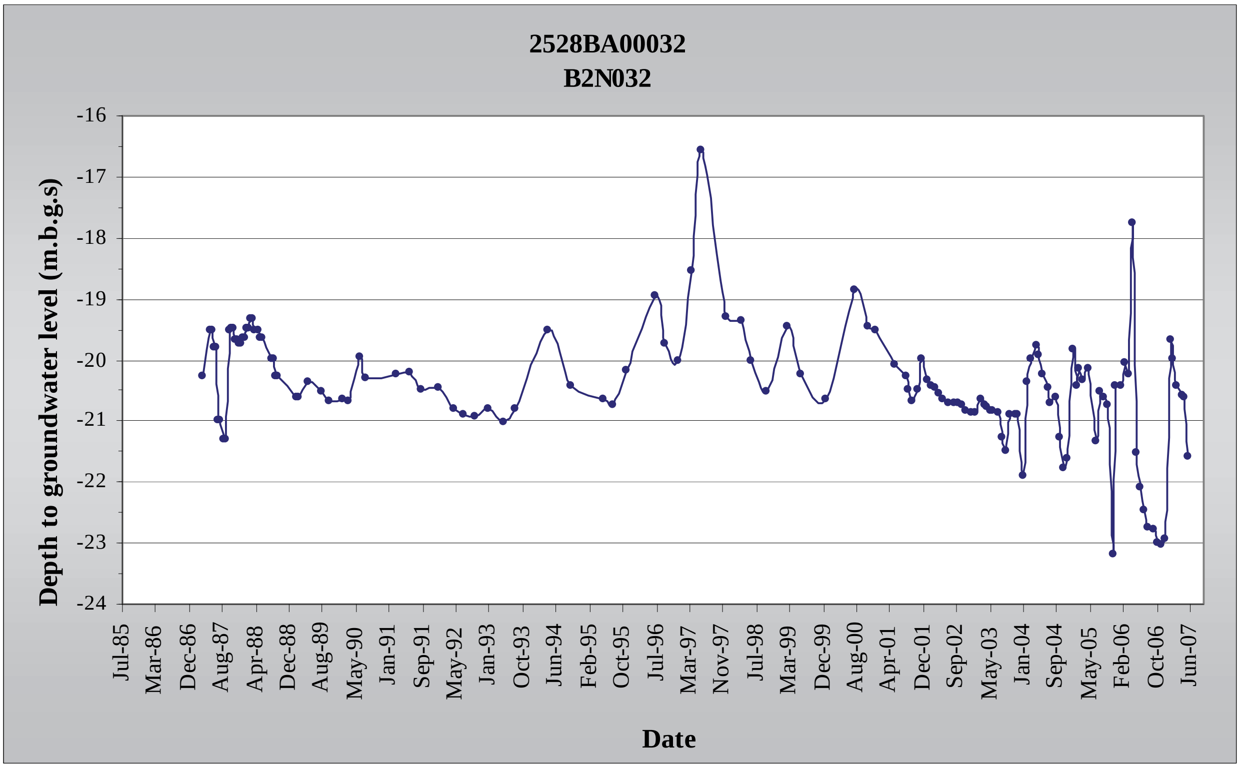

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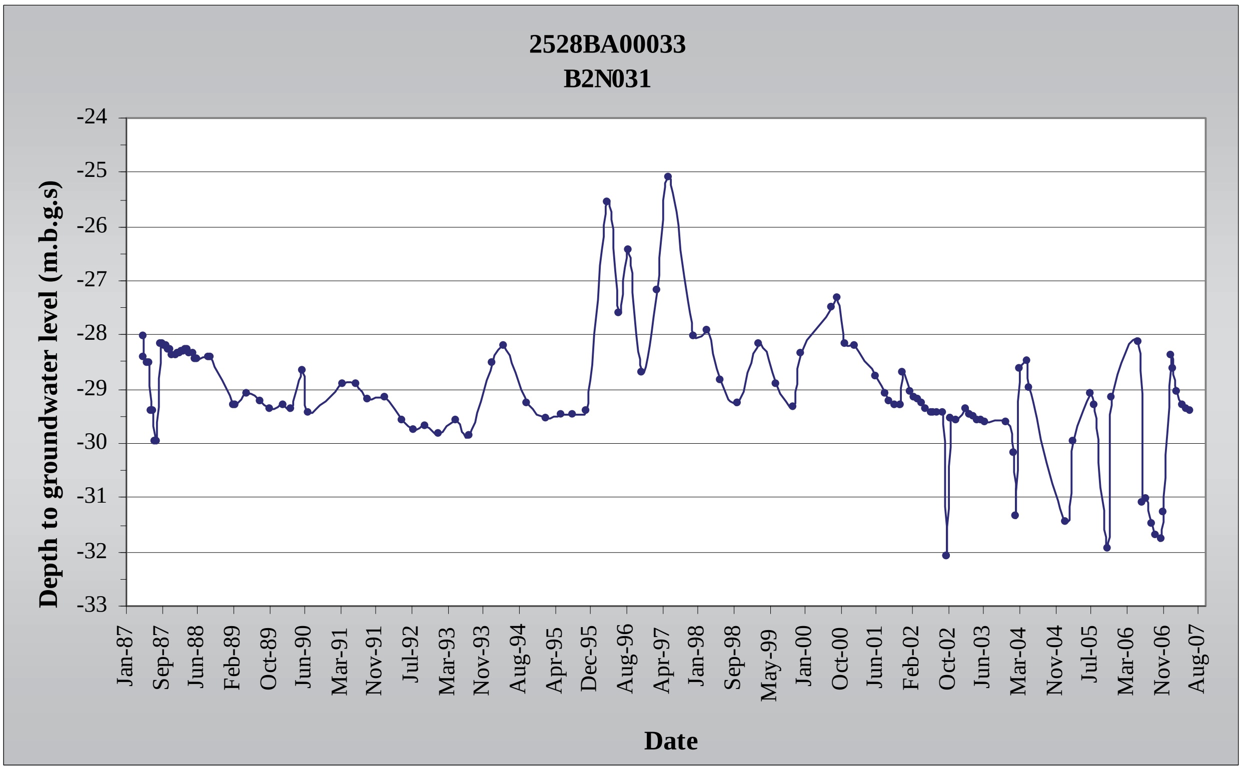

11B-4 : Delmas-Bapsfontein Area

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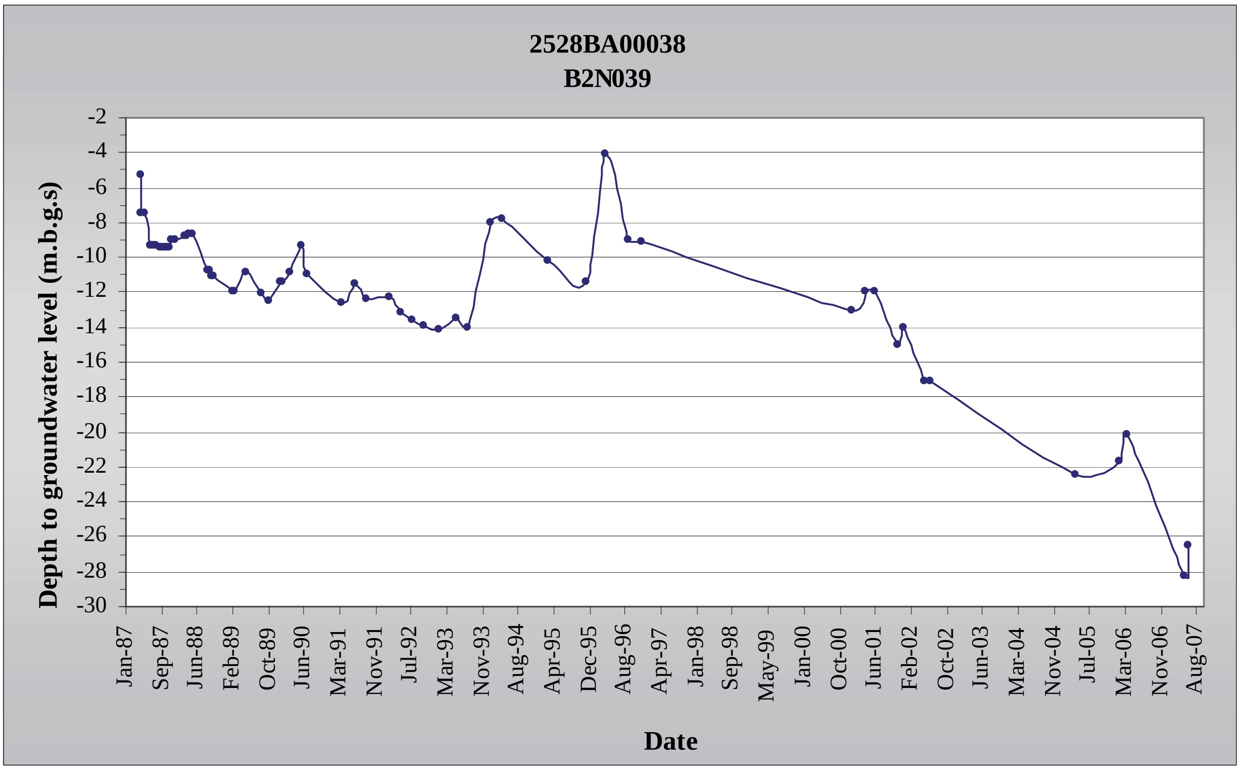

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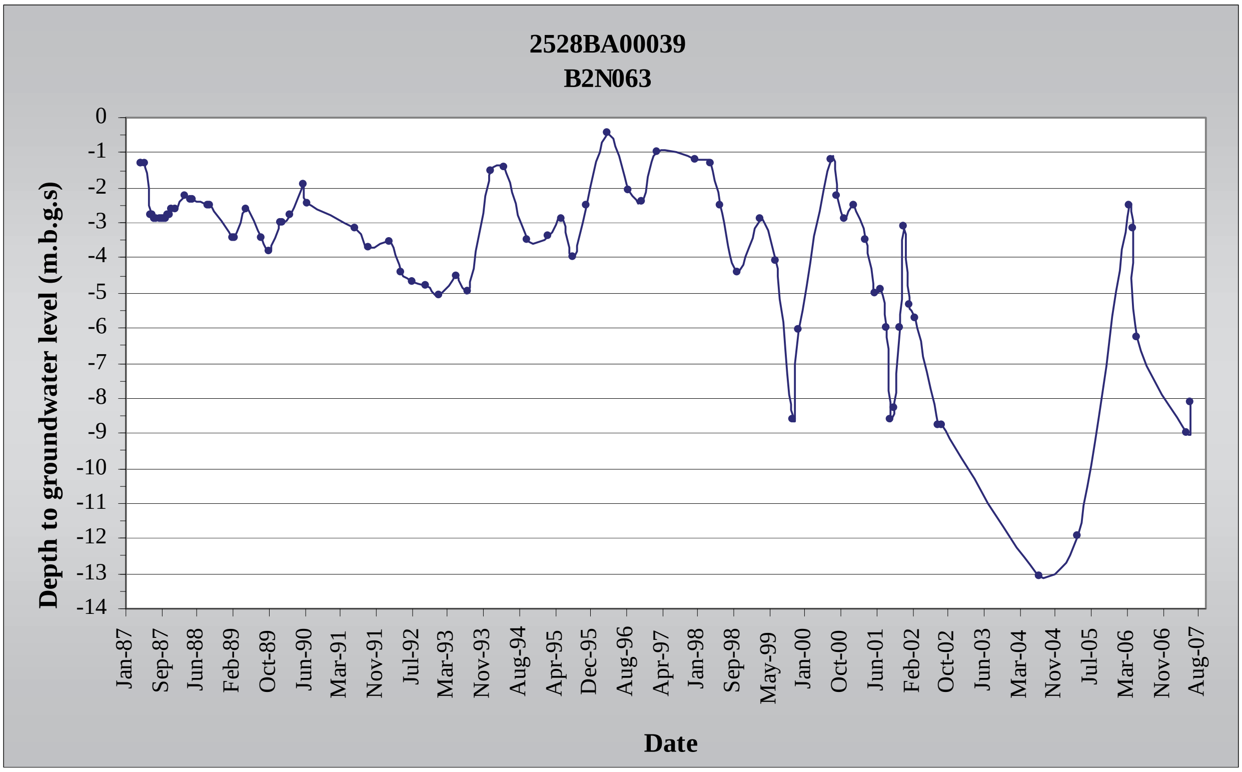

11B-4 : Delmas-Bapsfontein Area

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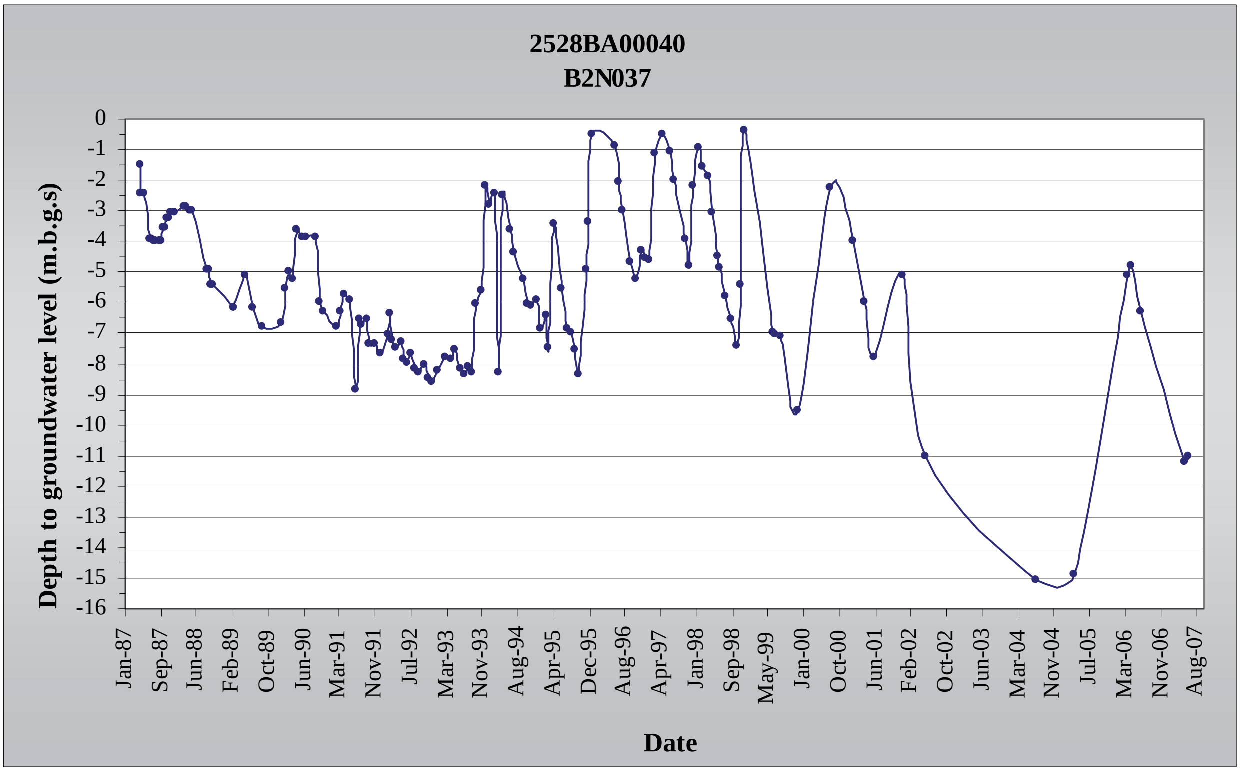

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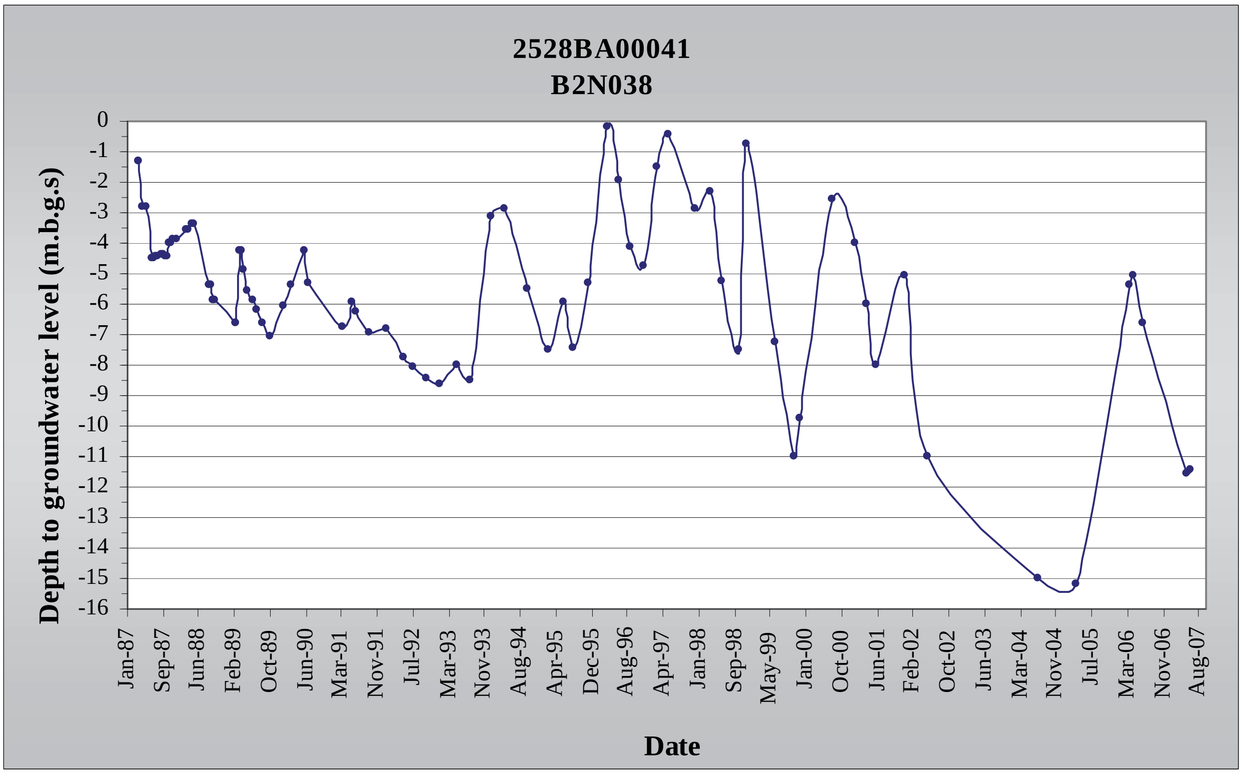

11B-4 : Delmas-Bapsfontein Area

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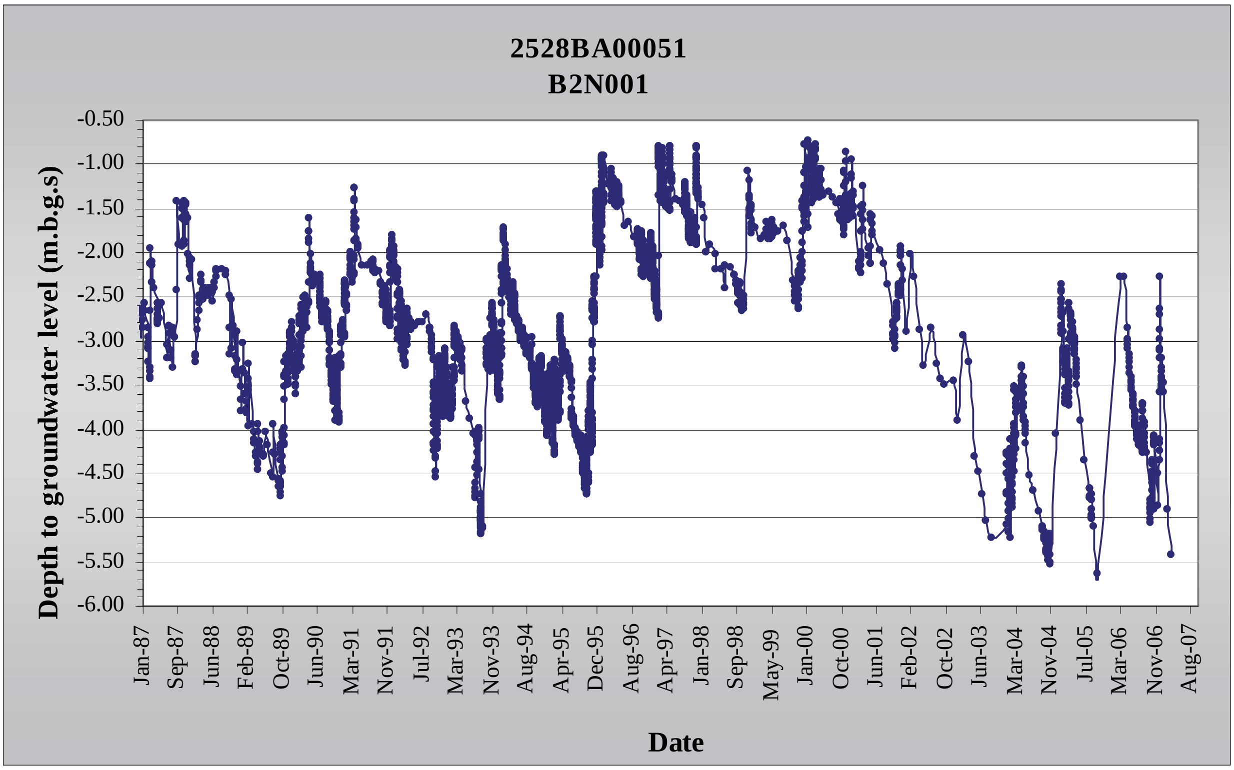
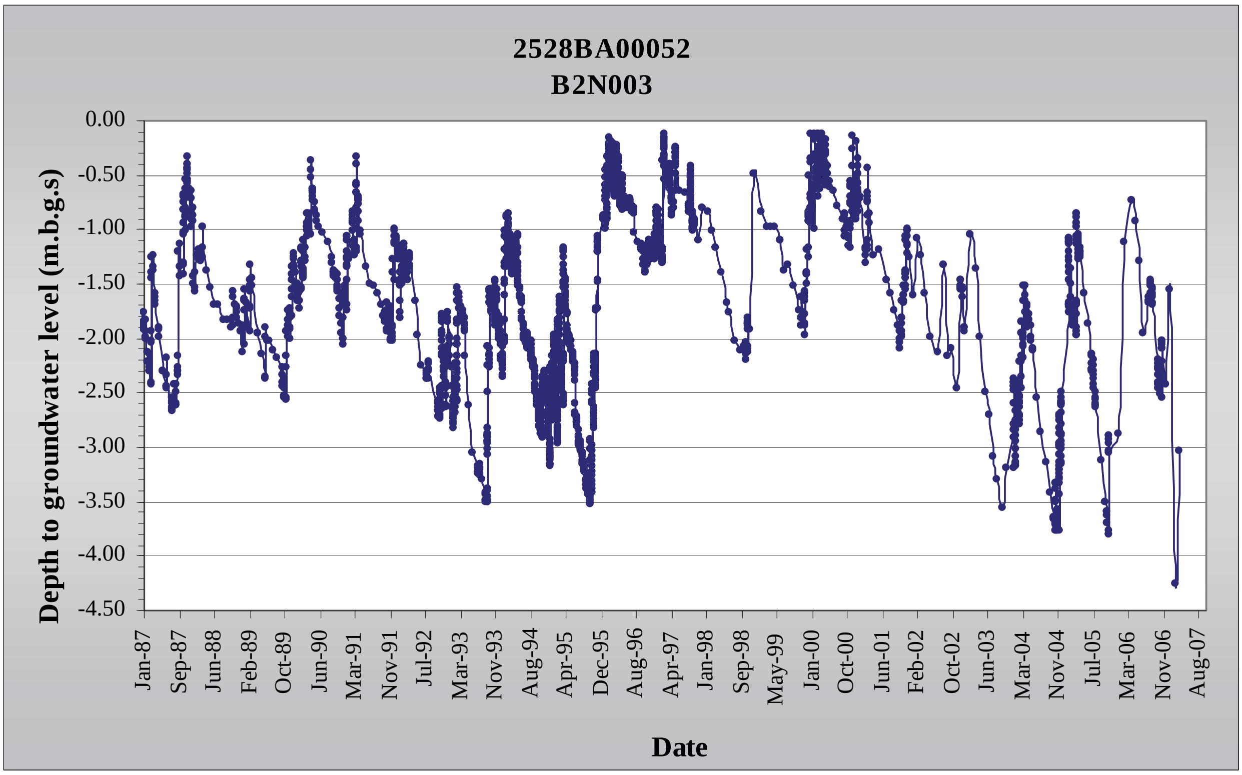
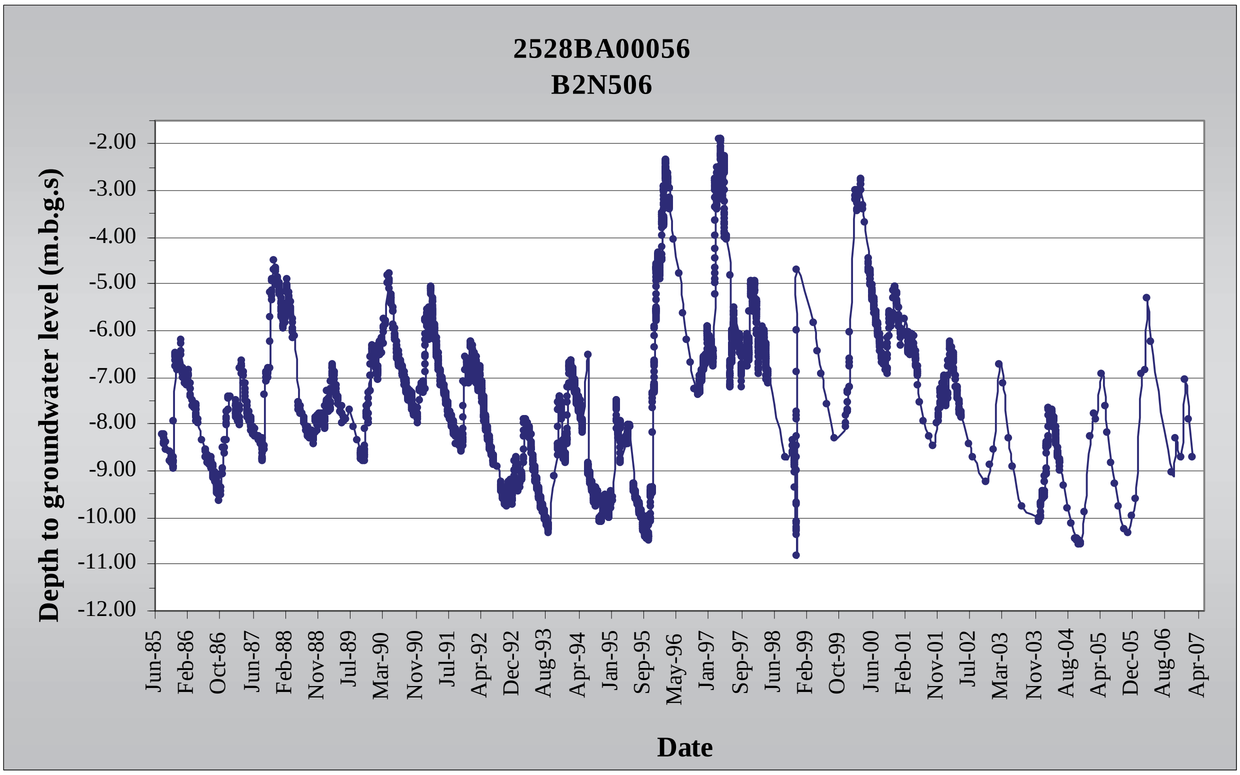


Station : B2N003



11B-4 : Delmas-Bapsfontein Area

Station : B2N506



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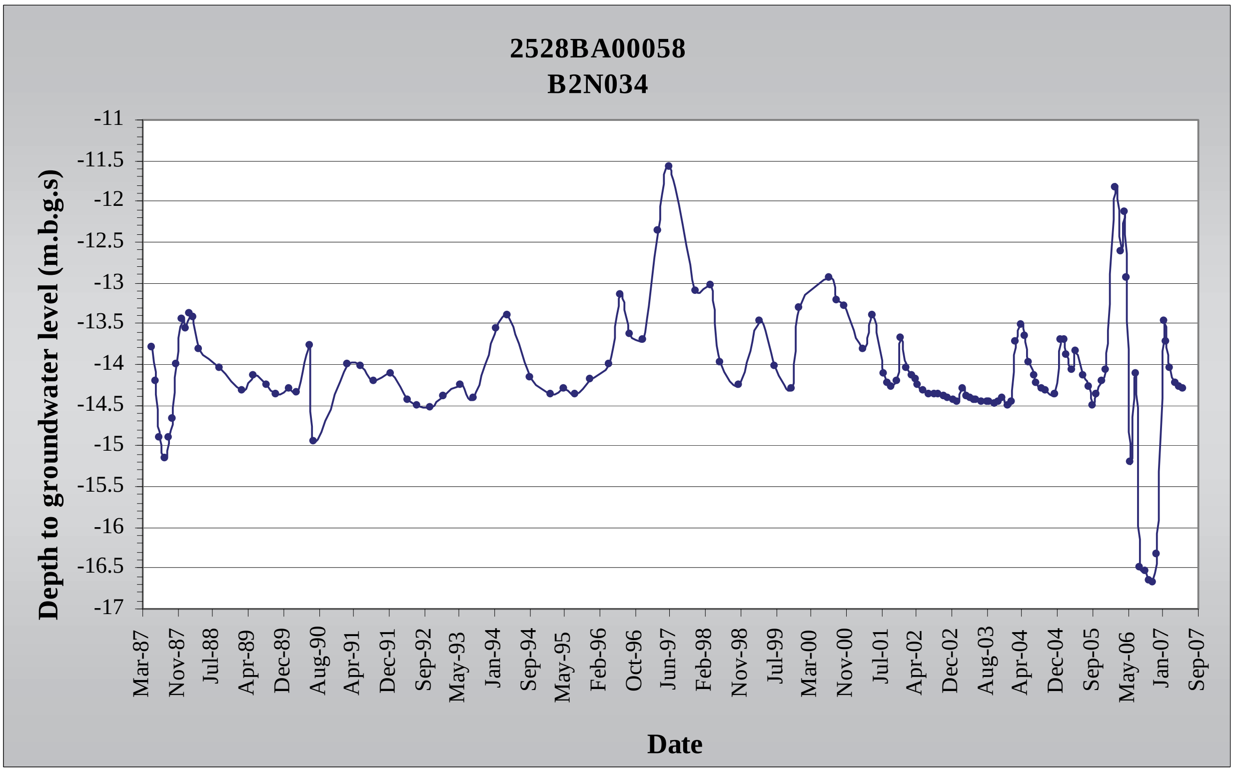
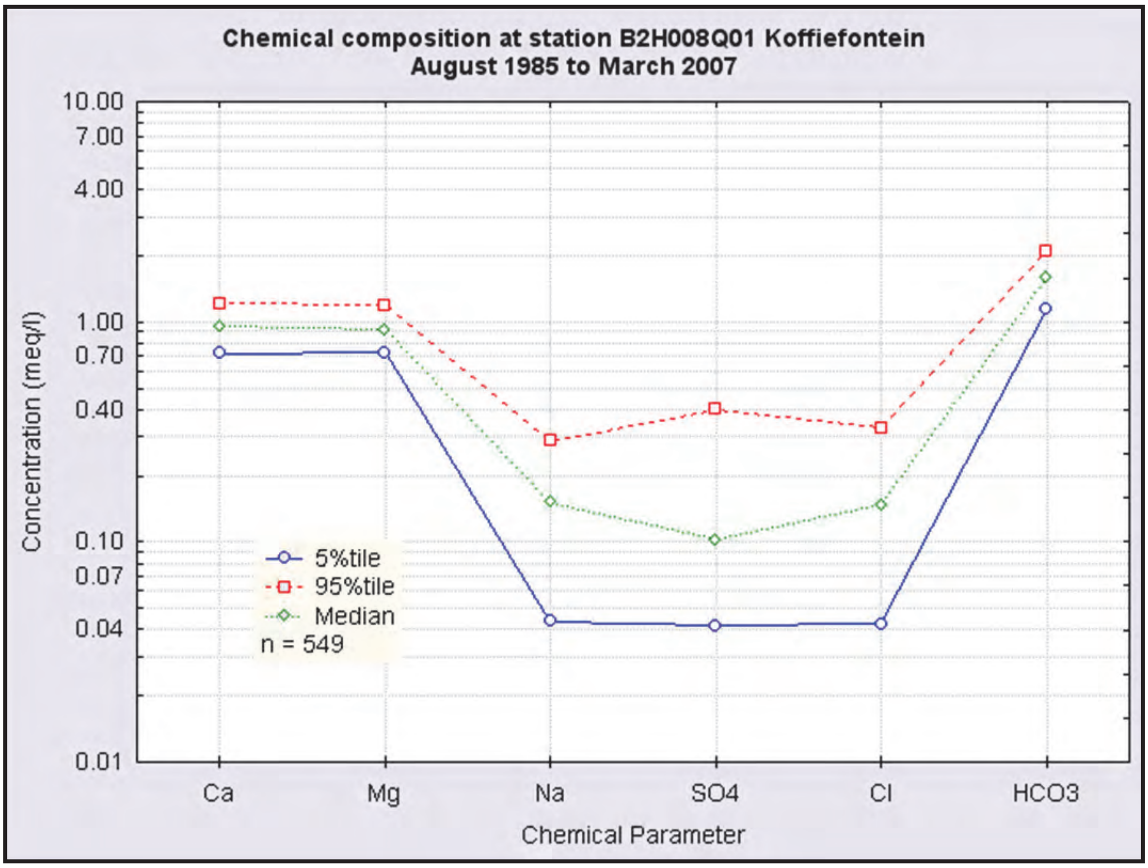


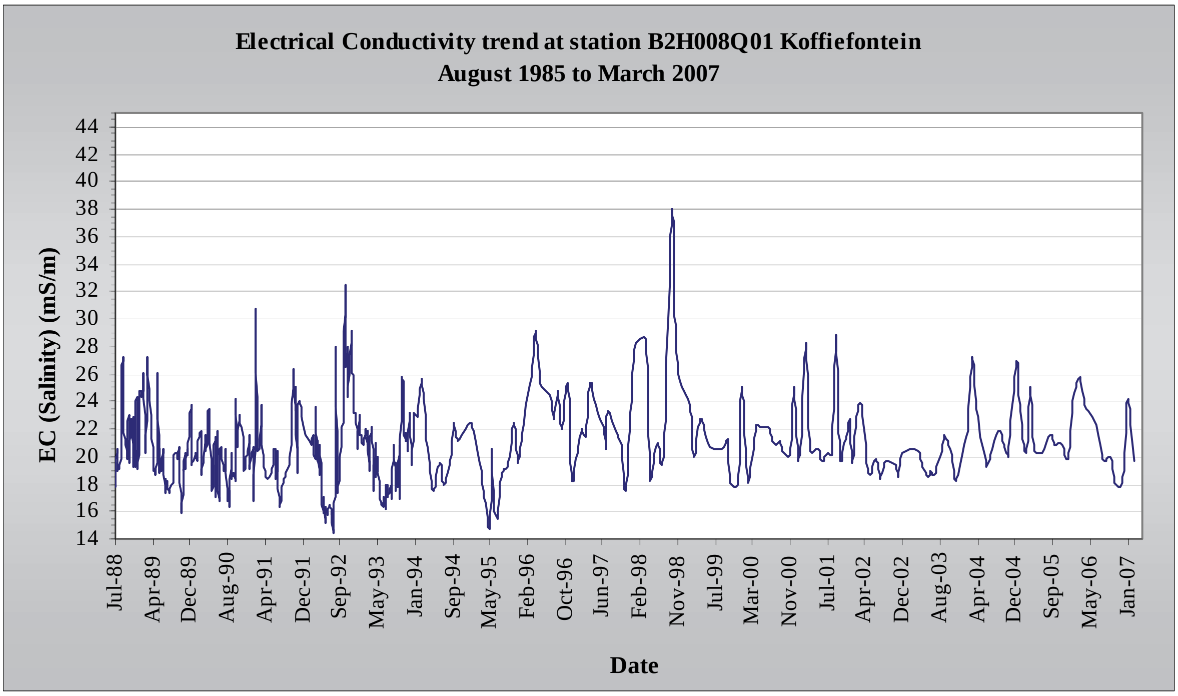
Appendix 11C

Surface water chemical composition and trends

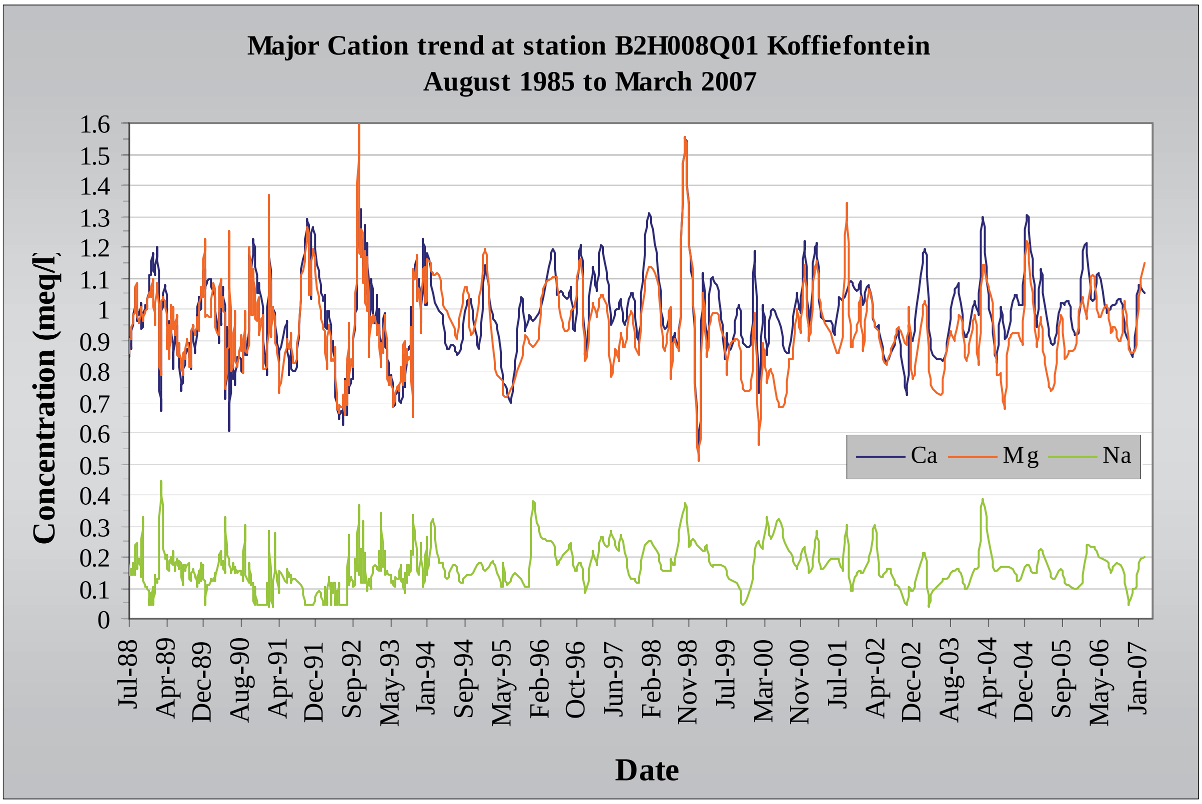
11C-1.1 : Chemical Composition



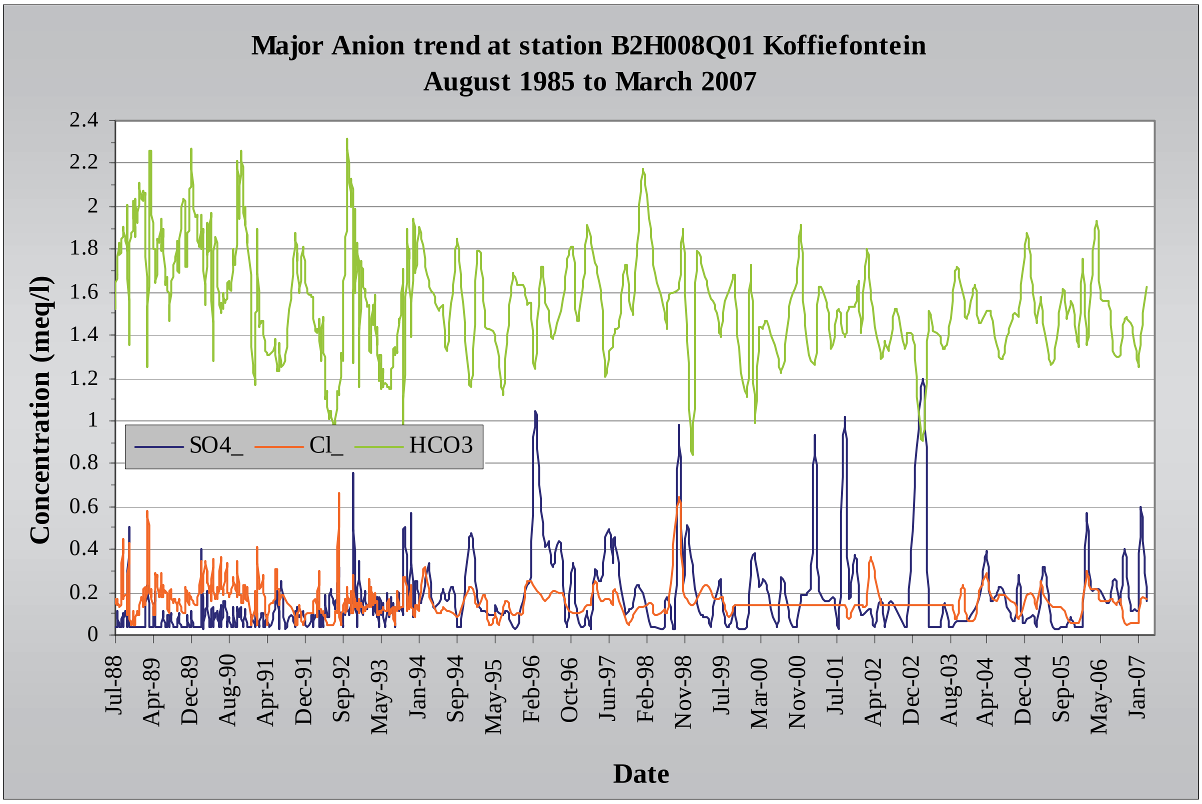
11C-1.2 : Electrical Conductivity



11C-1.3 : Major Cation Trend



11C-1.4 : Major Anion Trend



12 STATISTICAL ANALYSIS OF BOREHOLE INFORMATION

12.1 Introduction

The Terms of Reference for this appointment require that statistical analyses of available borehole information have to be conducted. The methodology used by Vegter for some of the other Groundwater Regions and described in earlier reports to the WRC (for example Vegter 2000a; 2000b, 2003) was again used. The procedure proposed by Vegter (2000) to analyse the borehole and groundwater information is designed to use information recorded in the National Groundwater Database (NGDB). Two methodologies were developed: one that is generally applicable to information from all regions, and one that was adapted for analyzing groundwater occurrences associated with dyke intrusions in Karoo geological environments. For Groundwater Region 10 the "General Scheme", as defined by Vegter (2000) was used to analyse the available information recorded in the NGDB. The NGDB recorded information for boreholes within Region 10 was extracted and analysed. A number of the graphs already prepared are included in this report and show the results of the statistical analyses for the different components listed below graphically:

- the borehole depth distribution across the Region 10;
- the water level depth distribution;
- the distribution of depth at which water strikes occurred below ground surface;
- the borehole yield distribution across Region 10; and
- the water level/borehole yield distribution.

12.2 Borehole depth distribution

A total of 3 643 boreholes are recorded in the NGDB within the boundaries of Groundwater Region 10. For only 1 777 of the 3 643 entries information on the depth drilled is recorded in the database. The depth distribution across the entire region 10 is displayed in Figure 12.1. This graph shows that approximately 80% of all recorded boreholes are shallower than 100 m. Boreholes deeper than 200 m are rare and the 56 recorded cases and it is believed that most of these were drilled during the exploration for deep groundwater as a possible emergency water supply option during the severe drought of the early 1980s. The deepest water borehole depth on record is 450 m.

12.3 Water level depth distribution

The water level depth distribution across Groundwater Region 10 for the number of boreholes where water levels have been recorded is shown in Figure 12.2. The total number of recorded water levels in the NGDB are only 839 out of the 1777 boreholes for which depths are recorded or the 3 643 total number of boreholes on record. This graph indicates that almost 75% of recorded water levels are within the upper 40 m below ground level, where after a steady decline in water level depth sets in up to the approximate depth of 100 m. Occasionally water levels of deeper than 100 m have been recorded in the past. In the procedure developed by Vegter (2000), he also determines the frequency distribution of water levels within a certain depth range in terms of the total number of boreholes on record that have penetrated the different depth ranges. The benefit of this calculation is not clear and he also provides no explanation why this calculation and graphical display is recommended.

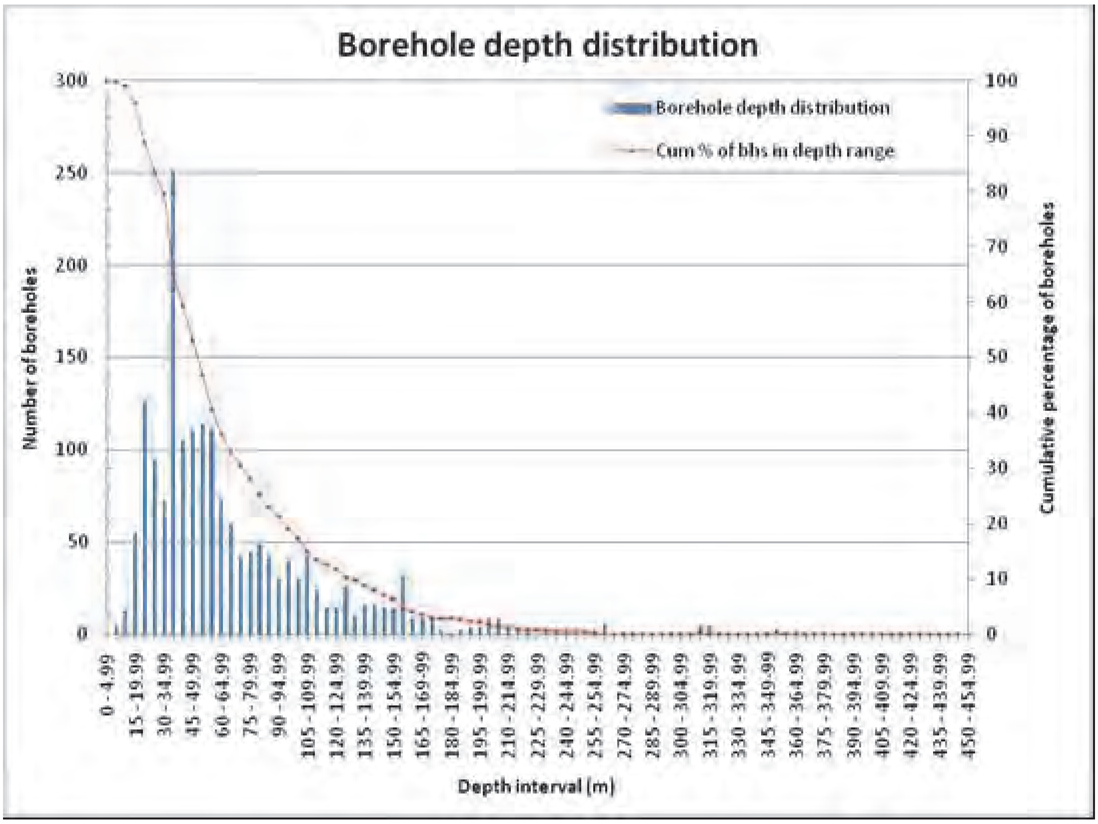


Figure 12.1: Borehole depth distribution across the entire Groundwater Region 10.

12.4 Water strike statistics

The total number of boreholes in which water strikes were recorded is 790, while the number of water strikes recorded in those boreholes total 1014. In some boreholes up to four water strikes at different depths have been noted. Two graphs are shown: (i) water strike frequency below ground surface (Figure 12.3), and (ii) water strike frequency below static water level (Figure 12.4). Figure 12.3 indicates that the maximum strike frequency occurs in the upper 50 m but that despite the number of boreholes decreasing with increasing depth, the strike frequency in terms of the number of deep boreholes and with depths up to 200 m below surface. Figure 12.4, showing the water strike frequency below static water level for 953 water strikes, shows an initial declining frequency to reach a plateau around a frequency of about 0.25 and up to a depth of about 50 m and then another plateau at a frequency of about 0.1 to a depth of 75 m.

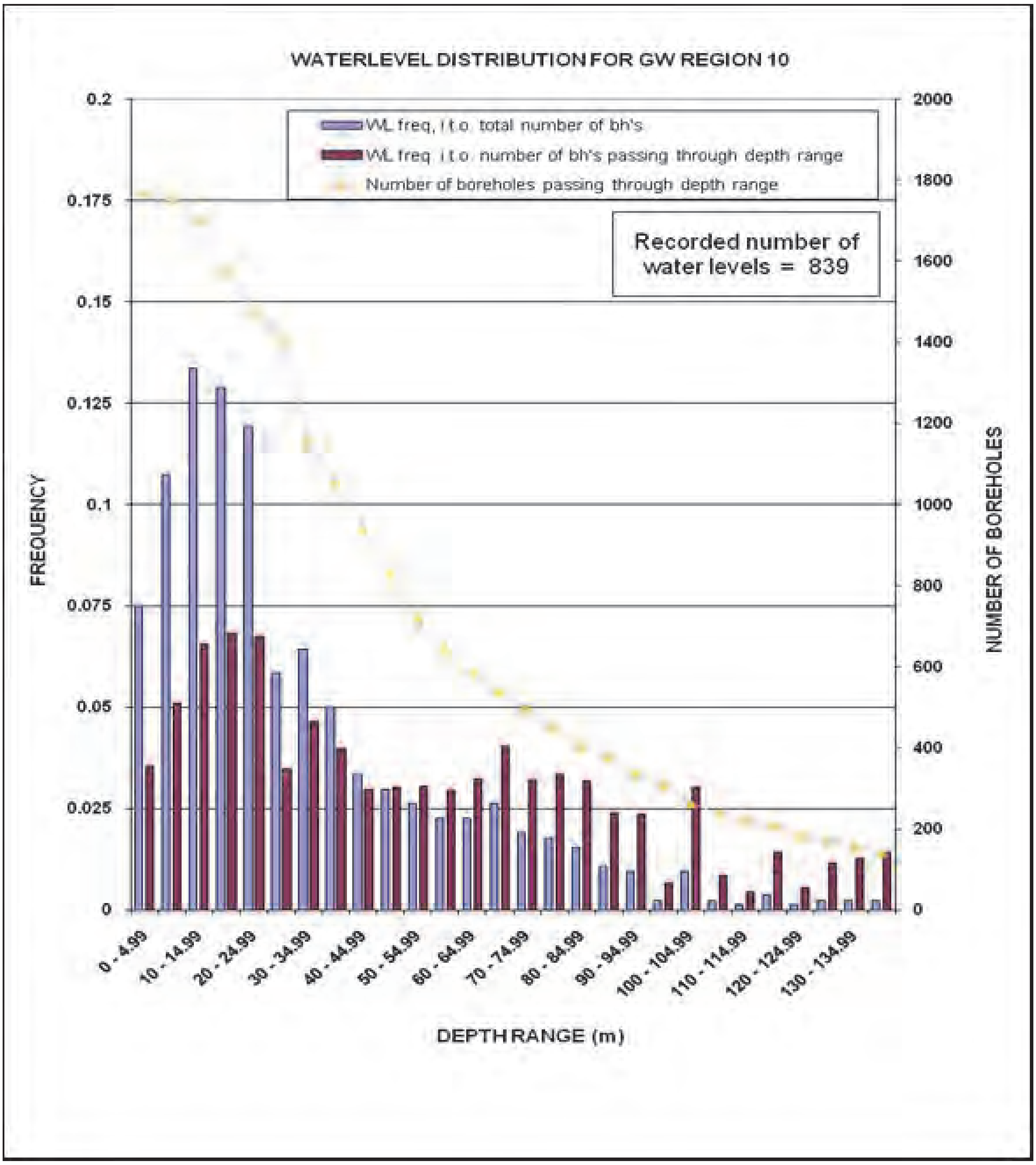


Figure 12.2: Water level depth distribution for Groundwater Region 10.

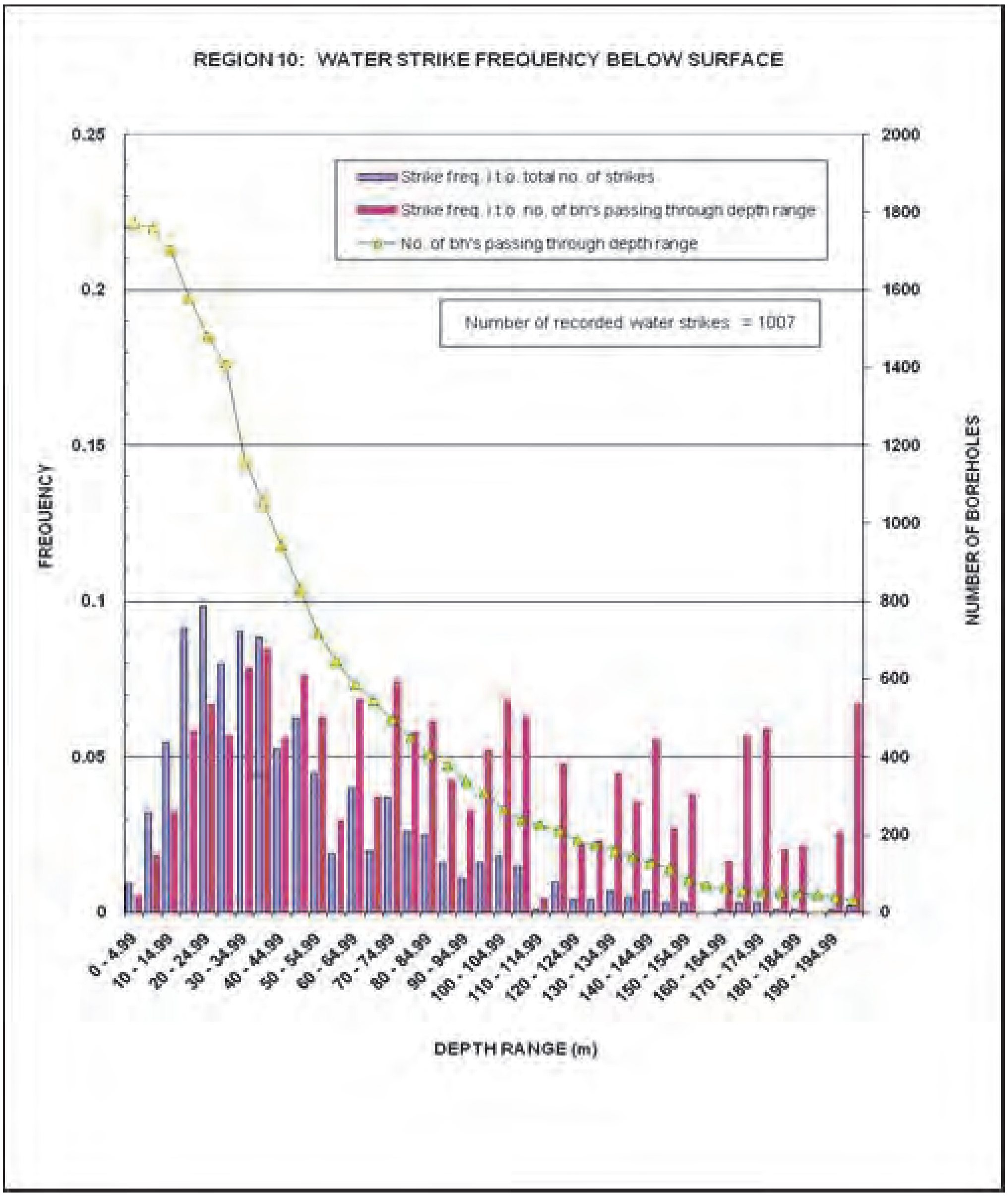


Figure 12.3: Water strike statistics below ground surface for Groundwater Region 10.

Strike frequency reaches a minimum between 60 m and 75 m and as the depth increases to 115 m the frequency increases again to a level of around 0.4. No realistic explanation for this phenomenon is available yet, but should be investigated.

12.5 Borehole yield

The water strike – yield relationship for all boreholes in Region 10 where water strikes and associated yield is recorded, is displayed in Figure 12.5. This graph indicates the median yield of the sum of yields reported within a specific depth range. The graph shows that up to a depth of around 60 m the median yield is around 1 l/s, where after more fluctuation in the median yield with two isolated, but much higher median yields of 20 l/s and 10 l/s occur at the depth ranges of 115 m to 120 m and 155 m to 160 m respectively. The ~1 l/s yield obtained from boreholes extends to a depth of around 100 m.

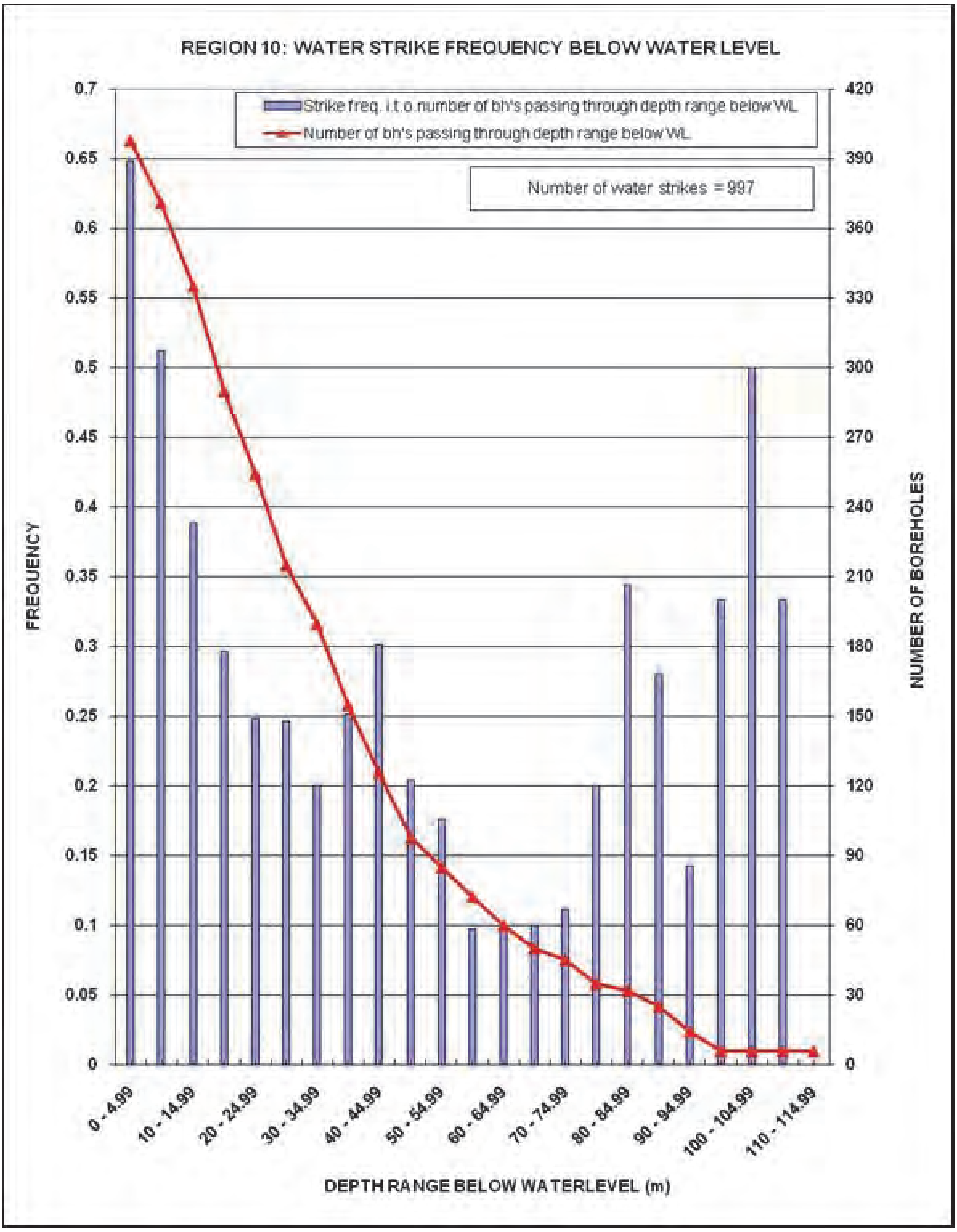


Figure 12.4: Water strike statistics below water level for Groundwater Region 10.

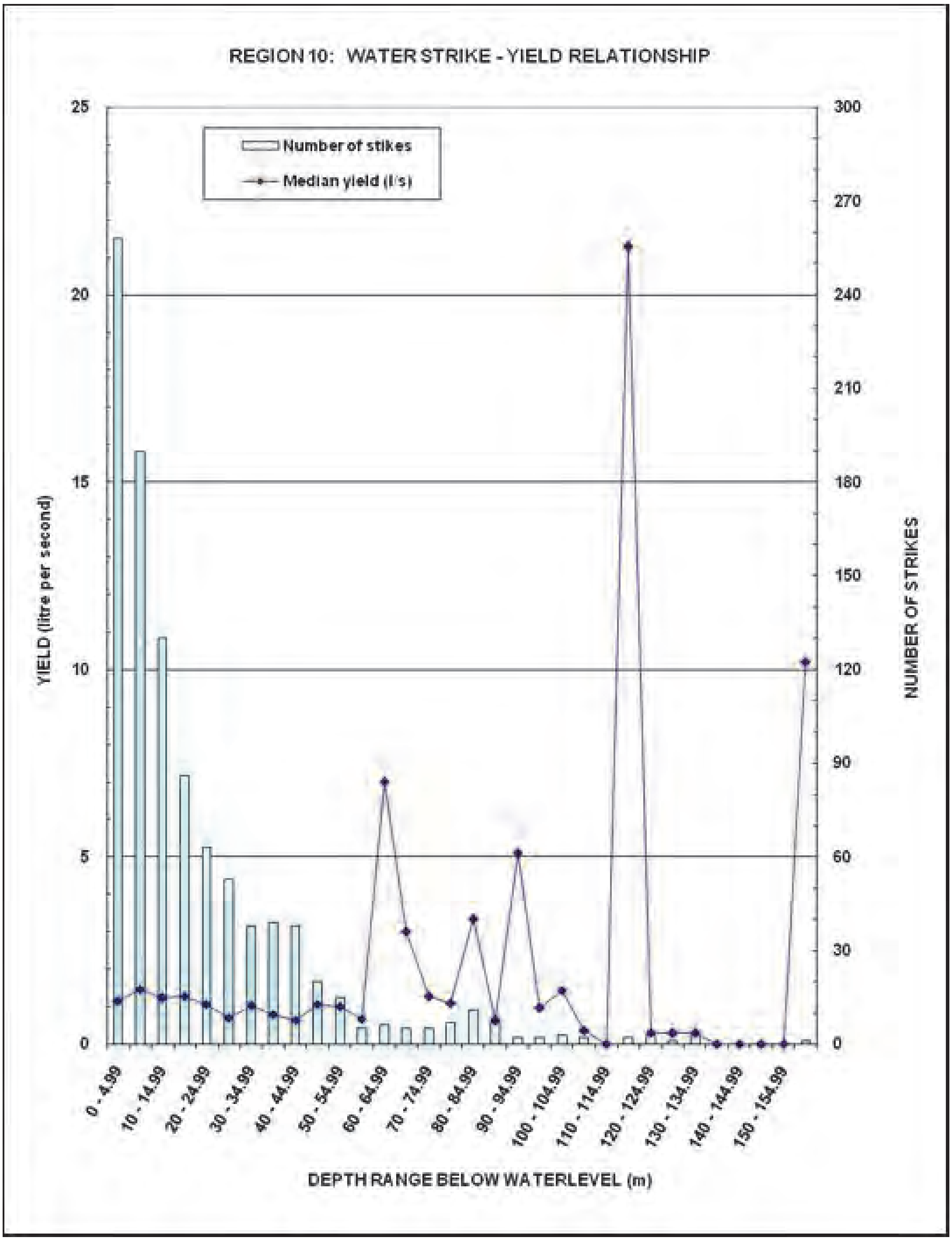


Figure 12.5: Borehole yield statistics for Groundwater Region 10.

12.6 Proposed additional statistical analyses

It is proposed that an additional statistical analysis of water strike and borehole yield information is done on available NGA data by comparing these two variables with the geological formation the borehole intersected. As this may not always be possible due to poor geological description of the formations penetrated, it is proposed that at least a correlation be done using surface (outcrop) geological information. This would be a test for the field observations that higher borehole yield are generally obtained when drilling into the chert rich formations, i.e. the Eccles and Monte Christo formations. Some interpolation of the geological formation boundaries will be required as the geological mapping has not been done to the same detail across the entire Groundwater Region 10.

13 GEOPHYSICAL INVESTIGATIONS AND BOREHOLE TESTING TECHNIQUES

Geophysical techniques have been extensively used in the past to select potential drilling targets. The dewatering of dolomitic compartments on the Far West Rand during the late 1950s and 1970s, to create safer underground mining conditions by decreasing the risk of underground flooding, resulted in many intensive studies related to ground stability using geophysical, geological and geohydrological techniques. The results from these studies led to an improved understanding of the dolomitic aquifers and were put to good use in the identification of drilling targets for both production and recharge boreholes on the West Rand. The large scale dewatering in the Far West Rand led to the formation of many large sinkholes which again sparked off geophysical research programmes to experiment with and improve geophysical methods to detect areas prone to sinkhole development. Electrical, electromagnetic, gravity, magnetic and seismic techniques were all tested to establish which could delineate potential problem areas best. In the end the gravity and magnetic methods were found to provide the best results. As a result large gravity surveys were commissioned especially across compartments being dewatered and areas overlying gold mining areas. The magnetic method was used to determine the positions of the dykes forming the compartment boundaries.

Kleywegt (1988) argued that the advantage of using geophysical data was not only to select sites for groundwater abstraction, but also to locate and define the extent of the aquifer and to assess the possible effect of lowering of the water table on the prevailing ground stability. By combining the geophysical determined geometry of the aquifer, partly calibrated with borehole information, with test pumping information, it should be possible to determine the storage capacity of the aquifer. Kleywegt (1988) proposed the following procedure comprising of four steps to determine the storage capacity of a dolomitic aquifer:

- Extensive gravity surveys with a suggested line and station spacing of 100 m and 50 m respectively to locate and delineate the aquifer.
- Process gravity data to derive residual gravity maps. Wiegmans (1988), based on experience from delineating dolomitic aquifers using residual gravity data, used as guideline an average value of 4 m of low density material per 0.1 mGal residual gravity value to determine the outer edge of dolomitic aquifers.
- Interpretation of the gravity data by using numerical modeling techniques to prepare two-dimensional cross-sectional models. Reliable interpretations can only be achieved if the density contrasts are well known. The volume of the aquifer can then be determined from these cross-sectional models. With the advances in numerical and computational techniques three-dimensional modeling can be done easily today thereby considerably reducing the time to derive at the volume of the aquifer.
- The volume of water stored in the aquifer can be calculated using the volume determined in the previous step and the estimated porosity of the aquifer material. He cites estimates of porosity derived from density contrasts which vary between 550 kg/m^3 to 750 kg/m^3, of 19% and 31% respectively.

The experience gained with different geophysical techniques in the Far West Rand during the early to mid-1980s came to good use when the water resources in the northern part of the country were under pressure as a result of a severe drought. The groundwater potential of the dolomite formations between Delmas and Pretoria, south of Johannesburg and at Tarlton was considered for urban water supply and became the target of focused geohydrological investigations with the aim of using the groundwater resources of the dolomites should emergency situations develop. The experience gained with different geophysical methods during the earlier investigations of the dolomitic areas of the West Rand was beneficial during the planning stages of this emergency water supply scheme. Regional gravity surveys covering several hundreds of square kilometers in the three areas mentioned above were commissioned by the then Department of Water Affairs in association with the Geological Survey. The results of these surveys were used to construct residual gravity contour maps which then formed the basis for not only selecting sites for drilling deep exploration and production boreholes, sometimes to depths in excess of 200 m, but also for deriving the storage capacity of aquifers.

Two distinct anomaly patterns are often revealed by these residual gravity maps: (i) broad gravity low anomalies, and (ii) linear gravity low areas. According to Wiegmans (1988) broad gravity low areas could represent:

- Dissolution in areas associated with broad fracture zones in chert-rich formations with the presence of water saturated overburden, cavities and dissolute fractures at depth;
- Palaeo-valleys, infilled with Karoo sediments and often associated with chert-rich formations at depth;
- Chert-rich formations with relative high surface elevations where most of the overburden and cavities can be above the static groundwater level.

Linear gravity lows could be the result of:

- Zones of faulting and fracturing along which extensive dissolution has occurred;
- Weathering of dykes and dissolution of dolomite along contact zones with dykes and sills.

Broad and linear residual gravity low anomalies coinciding with groundwater gradients of less than 1:1 000 are often indicative of the presence of high permeability dolomitic aquifers. Where overburden or highly weathered material below groundwater level causes broad residual gravity low anomalies, this represents aquifers with a high storage potential.

Experience in the selection of drilling targets based on residual gravity anomalies has shown that the depth to groundwater level has to be considered. In cases of shallow water levels (say <30 m below surface) the success rate of drilling high yielding boreholes is higher when the drilling site is selected and the foot of the gravity low feature rather than at the centre. It is argued that the gravity low represents highly dissolute dolomitic material that could adversely affect drilling conditions, increase drilling and construction costs and may even lead to the abandoning of a borehole. In contrast, the centre of the gravity low can be the target when deep groundwater levels are present.

For selecting drilling targets to establish production boreholes based on gravity data the following recommendations in decreasing order of priority have been proposed by Wiegmans (1988):

- Deep and broad residual gravity low areas where no Karoo cover is present;
- Linear residual gravity low anomalies that correlate with lineaments identified on aerial photos and mapped faults;
- Linear residual gravity low anomalies with strike direction parallel to that of dykes and usually at a distance of between 200 m and 1000 m from dyke;
- Broad and deep residual gravity low anomalies in the presence of Karoo sediments and where Karoo is underlain by chert-rich formations;
- Broad residual gravity lows where chert-rich formations are at relative high surface elevation and cavities and overburden material are probably above the water table.

A success rate of 75% and 52% was achieved in the Middle and Lower Klip River Valley, Bapsfontein-Delmas and Tarlton areas when drilling sites were selected on gravity low anomalies in chert-rich and chert-poor formation respectively. A borehole with a yield of 25 l/s or more was considered as a successful borehole.

14 HYDROCHEMISTRY AND WATER QUALITY

Chemical analyses of water samples collected from boreholes and springs within Groundwater Region 10 available on the Department of Water Affairs database were used to construct two Piper diagrams (Figures 14.1 and 14.2).

In Figure 14.1 the analyses were grouped according to the Electrical Conductivity value in three classes based on the SANS 241:2006 (Edition 6.1):

- (i) Class I: EC <150 mS/m
- (ii) Class II: EC in the range of 150-370 mS/m
- (iii) EC > 370 mS/m.

More than 95% of the analyses on record are within the Class I EC category and only a few isolated cases are on record where the EC in excess of 370 mS/m. This agrees with the conclusions reached by Barnard (2000).

Note: Towards the end of 2011 the SANS 241:2006 (Edition 6.1) standard was superseded by SANS 241-1:2011 (Edition 1.1) and SANS 241-2:2011 (Edition 1.1). In the new standard the Class I and II categories are replaced by only one standard limit. In the case of EC this is set at <150 mS/m.

In the Piper diagram shown in Figure 14.2, the analyses are plotted according to the Quaternary catchment in which the borehole is located. In this case prominent groupings can be seen, for example, A10A and D41A around Mafeking and Zeerust as one group, and those catchments around Steenkoppies and Tarlton (A21D and C23F).

Barnard (2000) analysed the results of 223 chemical analyses. His results are reflected in Table 14.1 below.

Table 14.1: Variation in chemical composition of water samples from the Chuniespoort Group (after Barnard, 2000)

Element/ Parameter	**Statistics drawn from a population of 223 analyses**				
	Min. value	**Mean value**	**Max. value**	**Standard deviation**	**Coef. of variation (%)**
pH	5.8	7.6	9.5	0.4	5
EC (mS/m)	4.4	62.9	397	56	89
TDS (mg/l)	43.1	443.6	3402	403	91
Ca (mg/l)	1.0	52.7	436	54	102
Magnesium (mg/l)	1.0	35.4	223	31	88
Sodium (mg/l)	1.0	24.1	299	39	162
Potassium (mg/l)	0.1	2.3	39	4.2	183
Chloride (mg/l)	1.0	37.7	900	83	220
Sulphate (mg/l)	1.0	70.5	2172	233	330
Tot. Alk (mg/l)	8.0	177.3	664	94	53
Nitrate (mg/l as N)	0.1	5.6	122	12.1	216
Fluoride (mg/l as F)	0.1	0.3	2.8	0.4	133
SAR	0.03	0.5	2.9	0.5	100

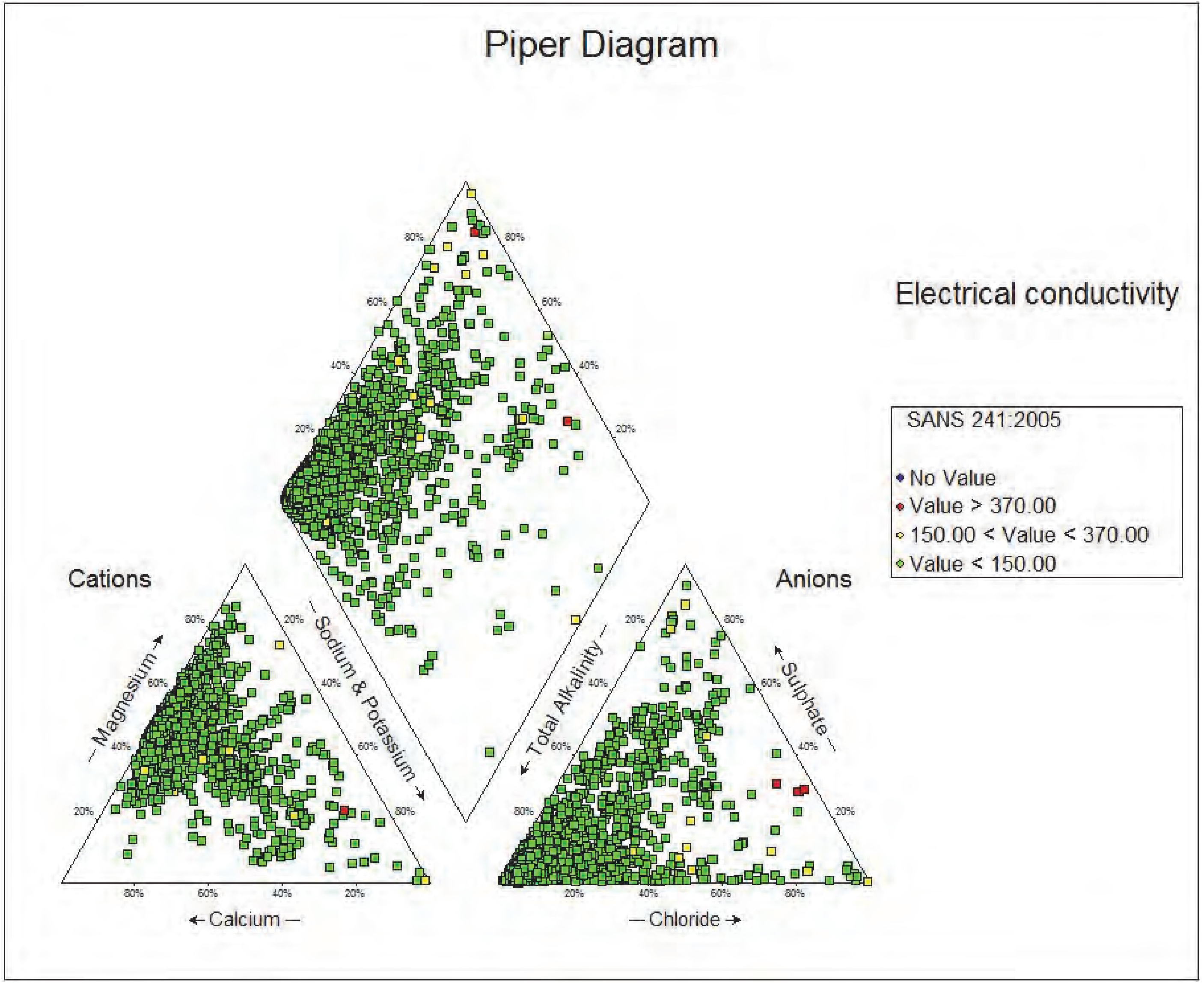


Figure 14.1: Piper diagram based on Electrical Conductivity groupings

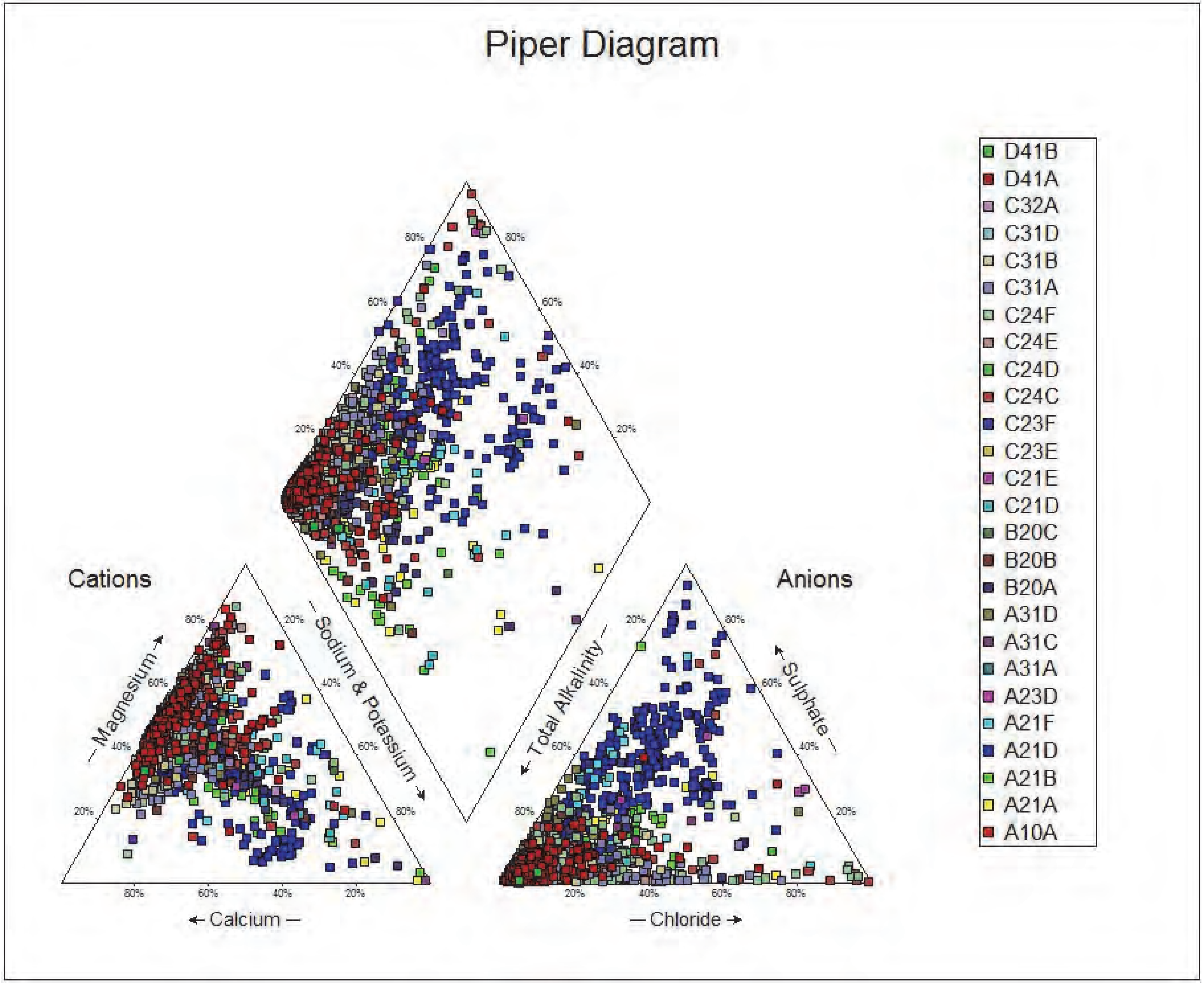


Figure 14.2: Piper diagram of water quality according the Quaternary catchments.

15 GROUNDWATER USE

Information from the Department of Water Affairs WARMS database was obtained for all the Quaternary catchments within Groundwater Region 10. At the end of 2011 there were 1024 registered water users identified as having an “Active” status. The total registered water use amounts to 225.7 Mm^3/a. The registered water use is allocated to the categories of:

- Irrigation: Aquaculture
- Irrigation
- Livestock watering
- Industrial use
- Urban use
- Mining related use
- Recreational use
- Schedule 1; and
- Water Supply Services

The total registered water use for each of the GMAs was calculated and the GMA was allocated to one of the 10 water use ranges, the lowest being no groundwater use (no GMA fits into that category) to the highest range being 24 to 37 Mm^3/a. The allocation to each of these categories for each of the 24 Groundwater Management Areas (GMAs) is schematically illustrated in Figure 15.1.

The lowest water allocations occur in the GMAs around the Johannesburg Dome and are within the range of 0.01 to 1.0 Mm^3/a. These are:

A21G; A21H; A21A-B; A21B-K; A21A-S and A23D

In the rest of the GMAs the water use allocated is >3 Mm^3/a.

In only one GMA (Dinokana) the water use is almost totally allocated to water supply services. In the majority of cases irrigation and agriculture is the dominant water use. The only area where a substantial amount of water is allocated to mining, is in GMA A31A to the southwest of Zeerust. Schedule 1 water use dominates the allocating in GMA A21A-R near the Rietvlei dam south of Pretoria. The only areas where substantial groundwater volumes are allocated to Urban use, id in the Centurion and Bapsfontein areas. To the west of Pretoria and around Springs in the East Rand, some groundwater is allocated to industrial use.

However, it should be mentioned that the WARMS database of the Department of Water Affairs does not provide an accurate reflection of actual groundwater use within Groundwater Region 10 as not all groundwater user are registered on the database. The groundwater use distribution as shown in Figure 15.1 is therefore not true reflection of the groundwater use within Groundwater Region 10 and should only be used as an approximate indication of groundwater use across the Region 10.

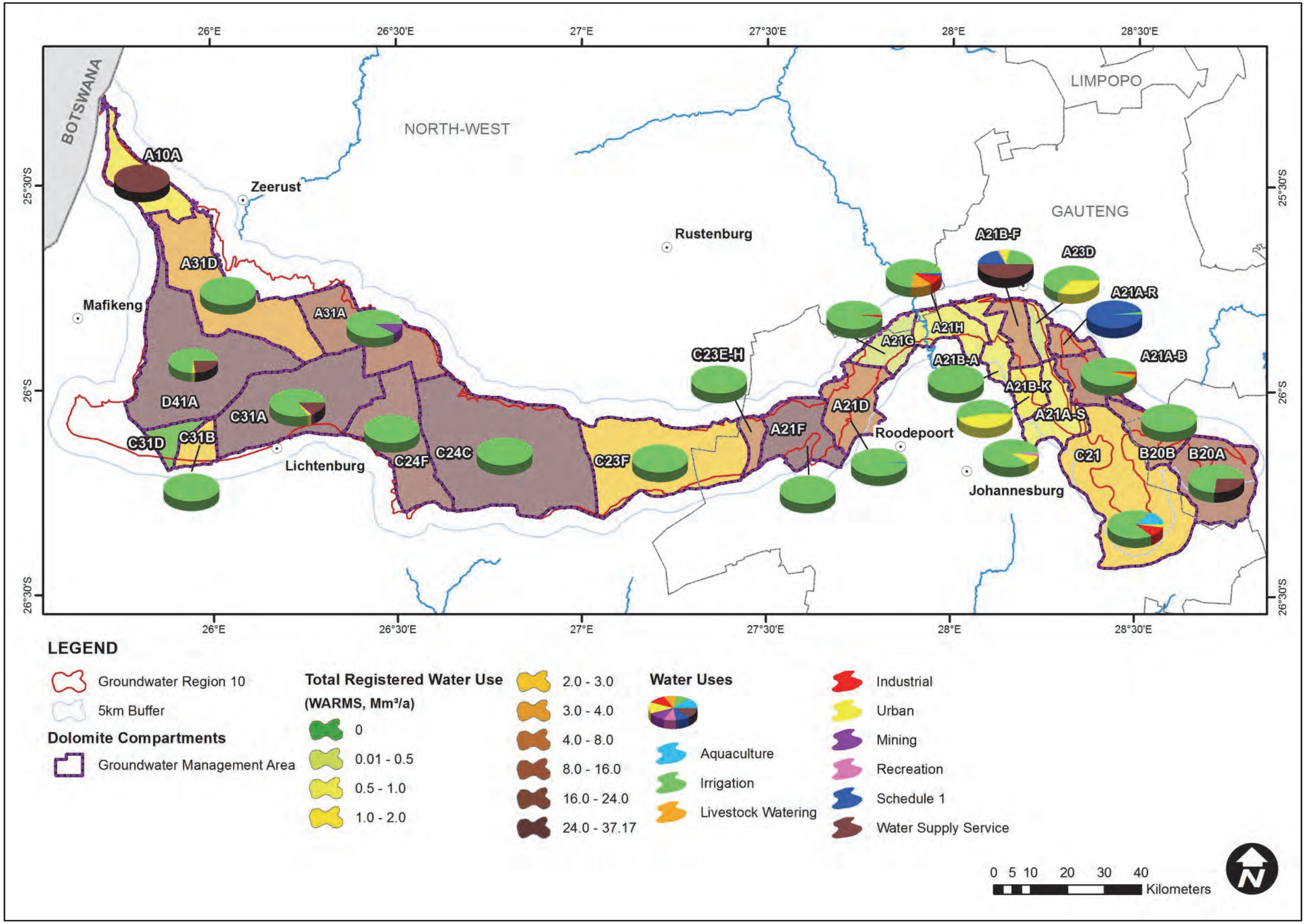


Figure 15.1: Total water used per quaternary catchments as registered with DWA WARMS

16 GEOTECHNICAL INVESTIGATIONS, DOLOMITE STABILITY AND ROLE OF / RELATION TO GROUNDWATER

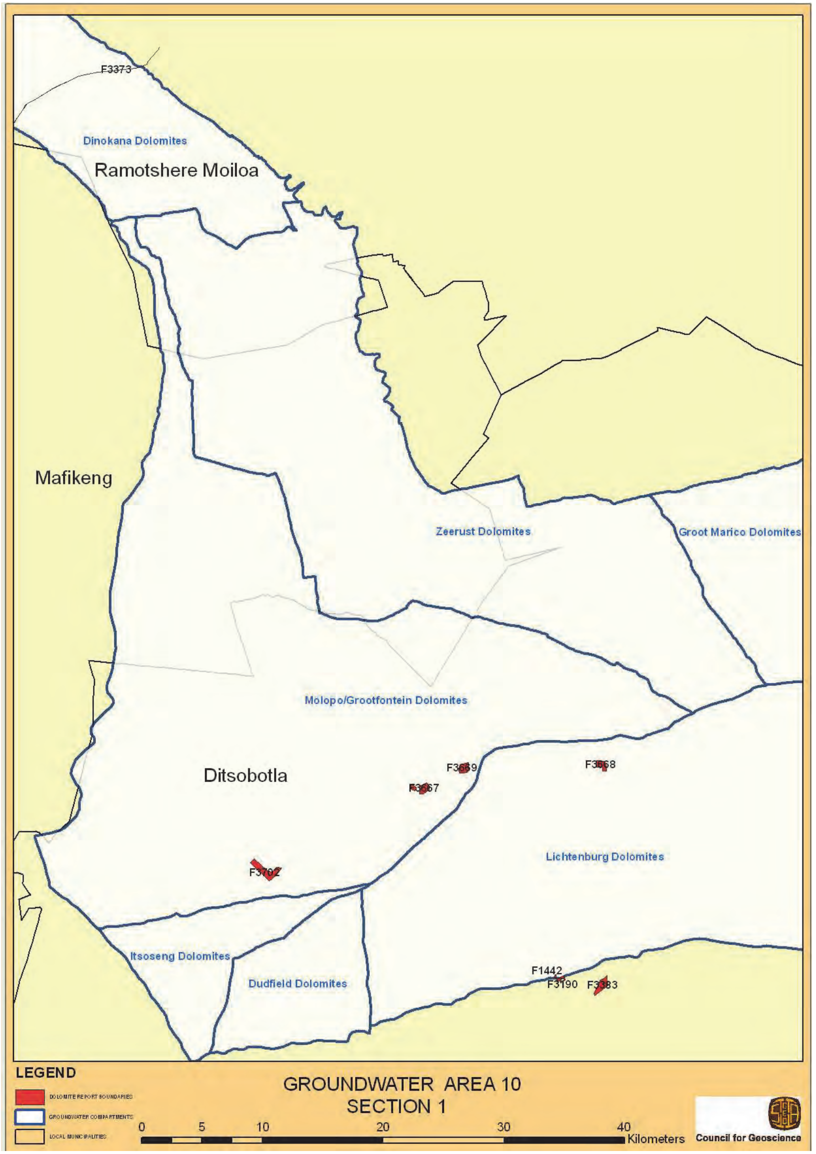
16.1 Geotechnical information

A considerable amount of time was spent to scrutinize a selection of geotechnical dolomite stability reports done mainly to assess stability and foundation conditions for proposed new infrastructure developments (mainly housing developments) which have been submitted over many years to the Council for Geoscience as part of a geotechnical approval process for all new developments on land underlain by dolomite. The CGS maintains a database of boreholes drilled during geotechnical investigations. This database currently contains information on some 17 000 boreholes within Groundwater Region 10 drilled for geotechnical stability investigations of dolomitic land and which are referred to in reports on investigations submitted to the CGS.

As can be expected the majority of reports describe investigations in highly build-up areas such as southern Tshwane, northwestern Ekurhuleni and Springs. Less information is available for surrounding areas such as the Bapsfontein/Delmas areas and very sparse information for the western area towards Lichtenburg. The southern Tshwane and north-western Ekurhuleni area (and especially the area previously known as the Lyttleton Agricultural Holdings) has been investigated in great detail and a large number of investigations only cover an area of 2 ha and sometimes even smaller. Many of the original stands are now being developed for housing and office complexes and detailed geotechnical investigations are required before approval for development can be granted. For these investigations it is not uncommon to have a borehole density of 10 or more boreholes per hectare.

Because of budgetary and time constraints it is clear that not all the dolomite borehole information contained in the CGS Geotechnical Borehole Database can be analysed for the current project and therefore only a selection of reports were reviewed. The reports selected cover the whole area from the Botswana border to Delmas and Springs. A total of 97 reports, mainly covering the period 1990 to 2009, were reviewed. The areas for which reports were selected for review are shown in Figures 16.1 to 16.3. The reason for selecting later reports is that investigations became more regulated and boreholes were drilled deeper (up to 60 m depth) in later reports. Special attention was given to the geological descriptions of new boreholes drilled during each investigation and which included references to static water levels, water strike depths and borehole yield. Depth to dolomite bedrock was also noted where possible as dewatering in poor dolomite residuum (weathered dolomite) indicates a high dolomite stability risk. The results regarding groundwater levels were disappointing as very little new geohydrological information has been documented in these reports. Notes on each report reviewed are summarized in the attached table (Table 16.1). The geohydrological information available in the selected reports, were arbitrarily grouped into three categories: A – Contains acceptable level geohydrological information (often geohydrological studies); B – Contains geohydrological information which can be consulted in further studies; and C – Contains poor geohydrological information. Only 7 of the 97 reports reviewed, were given an A rating, while most reports obtained a B rating (see Table 16.1).

Because of the limited information obtained through these reviews, further reviews of additional geotechnical reports are not envisaged. A positive outcome is however that a flaw in the reporting of groundwater data in the reports has been identified and is likely that the method of groundwater reporting will be improved and formalized documents on dolomite stability investigations such as the new SANS 1936 1-4 documents which will regulates development on dolomite in new guidelines and SANS 1936 documents.



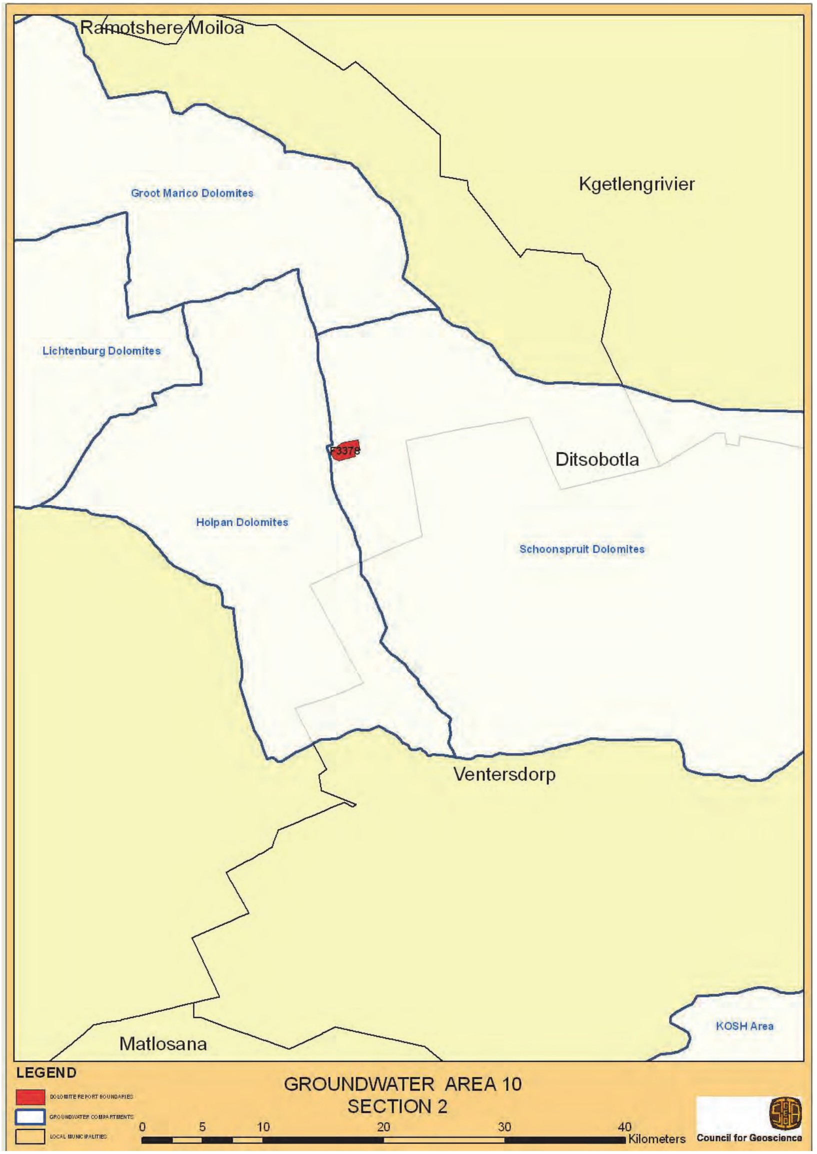


Figure 16.1: Geotechnical reports (shown in red) selected for review in the most western parts of Groundwater Region 10.

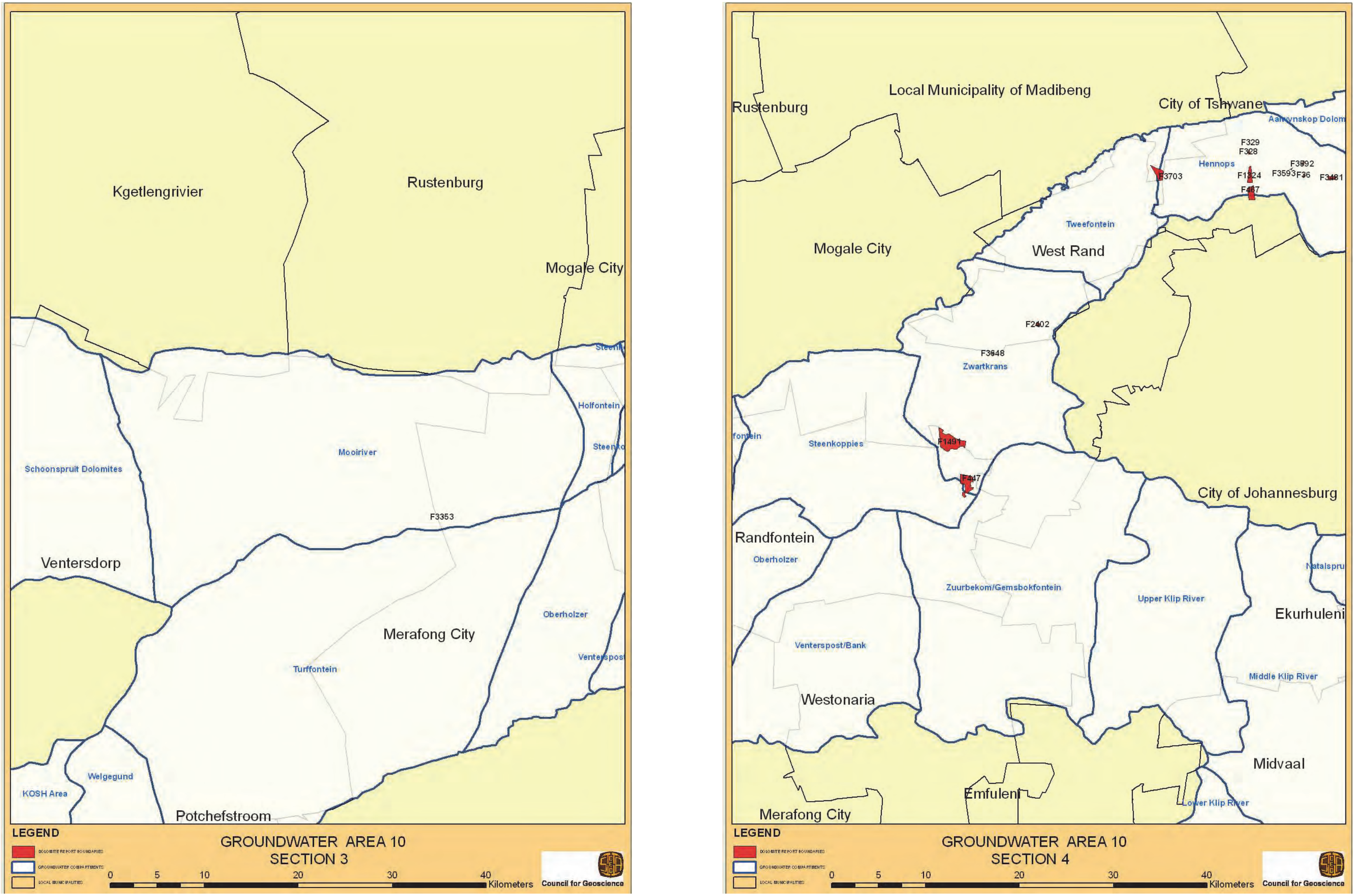


Figure 16.2: Geotechnical reports (shown in red) selected for review in the Central and West Rand areas of Groundwater Region 10.

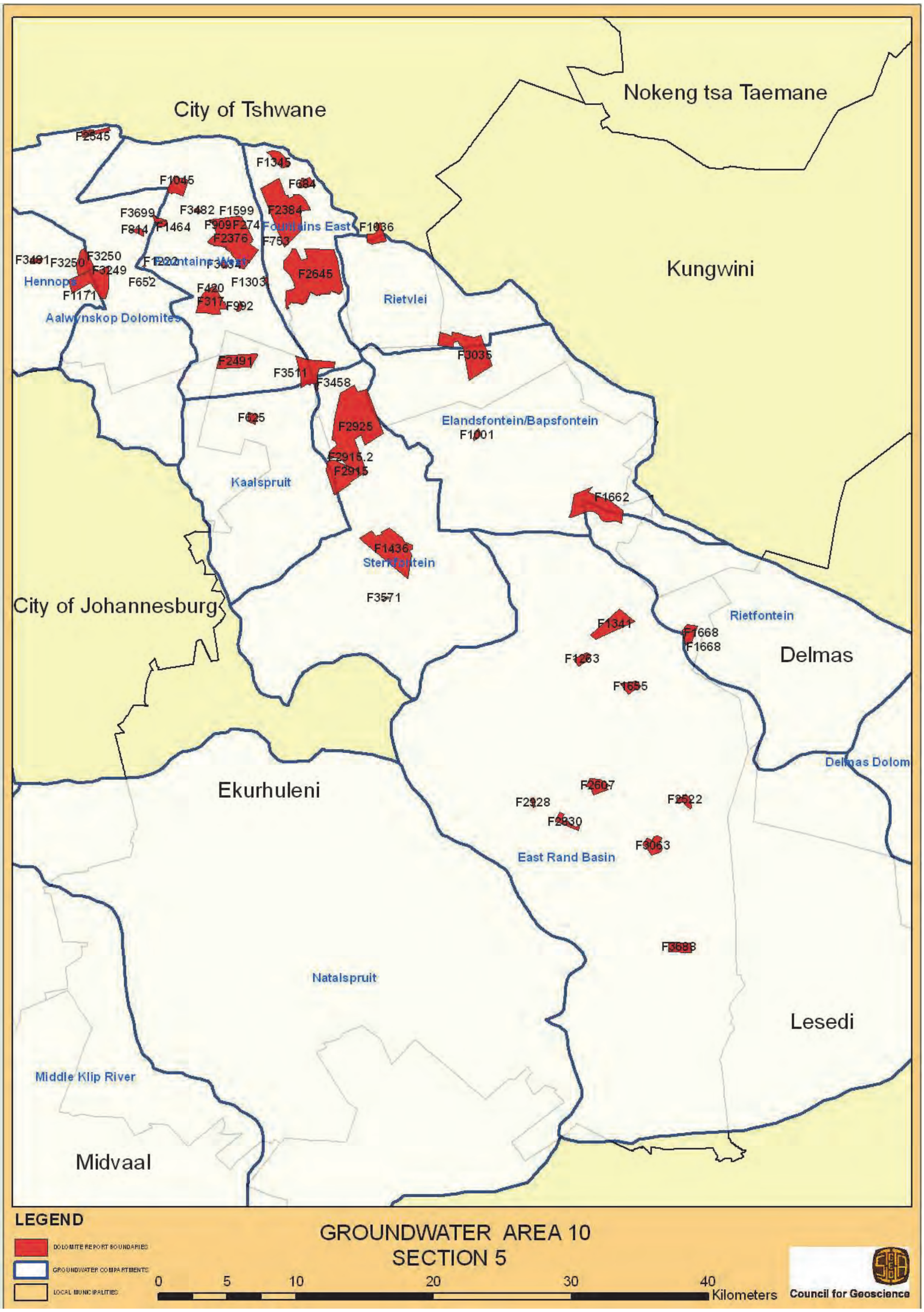


Figure 16:3: Geotechnical reports (shown in red) selected for review in the Tshwane/Delmas/East Rand Basin parts of Groundwater Region 10.

Table 16.1: Summary of geohydrological information sourced from geotechnical reports submitted to the CGS

FOLDER NO.	REPORT DATE	LOCATION	CONSULTANT	NR. OF BH'S	DWAF INFO	INFO - OTHER SOURCES	WL DEPTH BELOW SURFACE ON SITE	WL ELEV. mamsl	LEVEL OF GW INFO	DEPTH RANGE TO DOLOMITE BEDROCK	PRESENCE OF OTHER ROCK TYPES	DEPTH RANGE OF OTHER ROCK TYPES	DEPTH RANGE OF BH'S	REMARKS	COMPARTMENT/ AREA
F3373	02/1990	Road B40/17 Dinokana to Mogosane	RMS				16,5		C	shallow				Windmills in area.	Dinokana
F3669	11/2008	Bakerville Rural Area, North West Province	Holland-Muter & Assoc.	89			>40		B	2-29			10-40	No water strikes.	Molopo compartment
F3702	04/2009	Sheila	Mbongendhlu Geo-environmental Engineers	41			25-40		B	15-59			25-64	Site is within Polfontein Compartment (Nel, 2000). Compartment is important aquifer. Bredenkamp (1992) predicted drop in levels due to demand. Water strikes at 34-50 m.	Molopo compartment
F3667	12/2009	Grasfontein Rural Areas, NW Province	Holland-Muter & Assoc.	111			>45		B	1->40			10-40		Molopo compartment
F1442	06/2005	Ptn 66, Elandsfontein 34-IP, Lichtenburg	Jan Cronje			"very deep"				1-4			10	Water levels (if any) very deep according to experienced contractor.	Lichtenburg
F3668	12/2009	Welverdiend Rural Areas, NW Province	Holland-Muter & Assoc.	59			>50		B	1-60			10-60		Lichtenburg
F3383	04/1973	Ptn Lichtenburg Town and Townlands 27-IP	E H Mathews	6			>69			64-65 (weath)	Dwyka	Sh 2,5-64	37-69	Lime and weathered Dwyka shale overlying dolomite.	Aslaagte
F3190	04/2006	Retiefspark X3, Lichtenburg	Jan Cronje	15			>31			11-24			17-31	Water levels (if any) very deep according to experienced contractor.	Aslaagte
F3378	12/2009	Ga-Motlatla rural areas, NW Province	Holland-Muter & Assoc.	38			>50		C	4-38			10-45	No water strikes.	Schoonspruit
F3353	06/1997	P28-1 Krugersdorp/Ventersdorp road	Council for Geoscience	7		40	>16			9-12			16-17	Investigation of sinkhole 14 km west of R500 Carltonville turn-off (situated on Boskop-Turffontein compartment)	Mooirivier
F2402	09/2007	Ptn 26, Kromdraai 520-JQ, Mogale City	Africa Exposed	12			7-27	1415	B	6-30			12-36	Water level average of depths encountered.	Zwartkrans
F3648	01/2009	Hold.16, Oaktree AH's Mogale	Dolmatec				>15		B	5,3-9,1			11-15		Zwartkrans
F1491	06/1983	Fariaville	Partridge De Villiers & Assoc				>30		C				30	Seepage water levels at 2,4 -15,5 m encountered.	Zwartkrans
F447	04/2007	Erven 134 and 137, Robin Park X2, Randfontein	Africa Exposed	18			2,6-43,5	1695 (Ave)		35-38			30-51	Dolomite on eastern part of site, only 2 holes stopped in dolomite, others mainly in quartzite.	Zwartkrans
F2491	08/2005	Ptns 48, 49 and Rem Ptn 1 Olifantsfontein 410-JR	JP Venter/ Dolomite Technology	203	1445-1455		5,9 - 23,3		B		Sye			Water levels probably perched.	Kaalspruit
F3703	06/2009	Mountain View Estate	Louis Kruger Geotechnics	14				1328,3-1375,3	B	1330,3-1369	Syenite	Sye 0 -44	11-44	Syenite dykes seem to divide the site into different compartments.	Cross boundary Hennopsrivier/Tweefontein
F1324	07/2008	Rem Ptn 62 Hennopsrivier 489-JQ	Dolmatec	2			33		C	23,5-37,3?	Syenite	Sye 0-10	23,5-37,3	Water strike at 33 m.	Hennopsrivier
F329	06/2005	Ptn 71, Ptn of Ptn 70 Hennopsrivier 489-JQ	Dolomite Technology	3			>15		B	1-10	Syenite	Sye 1-14	13-15		Hennopsrivier
F328	08/2005	Ptn 177, Ptn of Ptn 70, Hennopsrivier 489-JQ	Dolomite Technology				>13		B	2-7,3			10-13		Hennopsrivier
F467	02/2007	Ptn 6 and 106 Doornrandje 386-JR	Africon	28			10,3 - 27,4		B	1-23	Intrusive Black Reef	Intr 1-29; BR 1-40	10-40	Groundwater strikes only in 2 holes.	Hennopsrivier
F2591	02/2009	Gerhardsville AH No2. Ptn 1	AMB	3		>60			B		Sye	Sye 2-18	12-18		Hennopsrivier
F1171	03/2004	Holdg 23, Monavoni, Tshwane	Dolomite Technology	1			24	1449	B	4	Syenite	Sye 17,8-26	26		Hennopsrivier
F3593	10/2008	Gerhardsville AH 45, Centurion	Geoburo	2	1330		>26		B	15-22,5	Syenite	Sye 6-26	21-26		Hennopsrivier

Table 16.1 (cont**.): ** Summary of geohydrological information sourced from geotechnical reports submitted to the CGS (cont.)

FOLDER NO.	REPORT DATE	LOCATION	CONSULTANT	NR. OF BH'S	DWAF INFO	INFO - OTHER SOURCES	WL DEPTH BELOW SURFACE ON SITE	WL ELEV. mamsl	LEVEL OF GW INFO	DEPTH RANGE TO DOLOMITE BEDROCK	PRESENCE OF OTHER ROCK TYPES	DEPTH RANGE OF OTHER ROCK TYPES	DEPTH RANGE OF BH'S	REMARKS	CCOMPARTMENT/ AREA
F3592	10/2008	Gerhardsville AH 7, Centurion	Geoburo	2			19	1372	B	31->22	Syenite	Sye 0,5-22	22-31	Water table probably perched because of syenite intrusion.	Hennopsrivier
F3481	07/2008	Ptn 238, Knopjeslaagte 385-JR, Centurion	Geo Buro		1385		15		B						Hennopsrivier
F36	08/2008	Hold.84, Gerhardsville, Centurion	Dolmatec	2		25			B	7	Syenite	Sye 10-16	9-16		Hennopsrivier
F3249	03/2006	Monavoni Area	VGI Consult	94		1420 (20-30)	17-21		B	1-32	Intrusive and Black Reef	Intr. 0-31, BR 18-30	7-39	Only 3 holes showed water. Geocon report G/R/01/07/09 dated July 2001 on farm Brakfontein 390-JR.	Hennopsrivier
F3250	09/2009	Greater Monavoni Area 2	VGI Consult			1420 (20-30)	9-19,8		B	1-23	Intrusive	Intr. 0-25	10-25	Only 2 holes intercepted water.	Hennopsrivier
F3250	09/2009	Monavoni X50 and 51 on Ptn of Ptn 5 Mooiplaats 355-JR	RMS	63	1435 to 1410		8-30	1445, 1435, 1424 and 1418	B	1-41	Syenite	Sye 1 - 19	10-47	Seems to be 4 compartments. DWAF report no 3502 by P Hobbs do not suggest compartments.	Hennopsrivier
F2545	01/2003	Atteridgeville X14	Geostrata	9			34-38(IS)		C	15-50	Transvaal Mudrock	Mudrock 1-50	20-57	Water intersections at 34 and 38 m probably perched water tables on shale dolomite contact.	Aalwynskop
F2545-1	07/2008	Atteridgeville X39	RMS	5			>53		C	23-39	Transvaal Mudrock	Mudrock 4-30	29-53		Aalwynskop
F2545-2	07/2008	Atteridgeville X41	RMS	5			>57		C	49	Transvaal Mudrock	Mudrock 1-49	20-57	Water intersection in 1 BH at 34 and 38 m - probably perched water at shale/slate contact	Aalwynskop
F2545-3	07/2008	Atteridgeville X42	RMS	4			>57		C	38-49	Transvaal Mudrock	Mudrock 1-49	20-57	Water intersections at 34 and 38 m - probably perched water tables at the shale/slate contact.	Aalwynskop
F652	06/2002	Ptn 64, Zwartkop 383-JR	Paul Roux				>25		C		Syenite		22-25		Aalwynskop
F814	04/1996	Eldoraigne X31	BKS				5,5-18,6	1374-1382	A					Geohydrological study by BKS. Water levels in surrounding areas also provided.	Aalwynskop
F274	07/2007	Rem Holdg 172, Lyttelton AH's	Holland-Muter & Assoc.	14	>95		>54		B		Sye	Sye 1-41	31-54	Refer to GH 3502.	Pta Fountains West
F1045	06/1999	Valhalla Townhsip Area 1	BKS	12		40-60	>50		B	0,1 - >50	Syenite		10-50	Syenite encountered in one hole.	Pta Fountains West
F3482	07/2008	Ptn 508 and Rem Ptn 395, Zwartkop 356-JR	Geo Buro		around 1345				C					In Fountains West Compartment.	Pta Fountains West
F3034	01/2006	Erven 48, 49 and 58, Verwoerdburgstad	Schwartz Tromp & Assoc.	27			>42		B	6->42	Syenite	Sye 2-33	10-42	No water encountered on Tshwane Convention Centre (Also report by Holland-Muter & Assoc. 07/2006).	Pta Fountains West
F1599	01+05/200	Holdg 236, Lyttelton AH's	Holland-Muter & Assoc.	8			>63		C	18-55	Syenite	Sye 1 - 41	24-63		Pta Fountains West
F1600	01/2004	Holdg 238, Lyttelton AH's	Holland-Muter & Assoc.	10	>60		>60		C	8-59	Syenite	Sye 1-54	15-60		Pta Fountains West
F1603	05+06/200	Holdg 274, Lyttelton AH's	Holland-Muter & Assoc.	52			>42		C	0-38	Syenite	Sye 2-15	5-42		Pta Fountains West
F1464	11/2002	Eldoraigne X53 (Ptn 279 Zwartkop 356-JR)	Johann van der Merwe	40				1376-1386	B	2-63	Syenite	Sye 0-45	6-69		Pta Fountains West
F1464	08/2003	Eldoraigne X53 (Ptn 279 Zwartkop 356-JR)	Hobbs Consulting				17	1382	A			45		Geohydrological report by P J Hobbs	Pta Fountains West
F814	04/1996	Ptn 173 of Ptn 1 Zwartkop 356-JR	Louis Kruger Geotechnics				5-15		B	2-21	Syenite	Sye 19-45	17-45		Pta Fountains West
F909	11/2001	Holdg 9, Lyttelton AH'S	Johann van der Merwe	9		35-80	>46		B	1->40			10-46		Pta Fountains West
F3285	09/2006	Ptn 1 Erf 2179, Lyttelton Manor X3	Dolomite Technology	2		around 60	>19			13			19		Pta Fountains West

Table 16.1 (cont.): Summary of geohydrological information sourced from geotechnical reports submitted to the CGS (cont.)

FOLDER NO.	REPORT DATE	LOCATION	CONSULTANT	NR. OF BH'S	DWAF INFO	INFO - OTHER SOURCES	WL DEPTH BELOW SURFACE ON SITE	WL ELEV. mamsl	LEVEL OF GW INFO	DEPTH RANGE TO DOLOMITE BEDROCK	PRESENCE OF OTHER ROCK TYPES	DEPTH RANGE OF OTHER ROCK TYPES	DEPTH RANGE OF BH'S	REMARKS	CCOMPARTMENT/ AREA
F1222	07/2006	Holdg 19, Raslouw AH's, Centurion	Holland-Muter & Assoc.	13	>37				B	1-5	Syenite	Sye 2-13	7-21	Water level information from Report GH3502 borehole 17. No water strikes.	Pta Fountains West
F2376	03/1976	Lyttelton AH's	Dr B H Relly	88			11,8 - 41	1385,9-1414	B	0-45	Diabase (Syenite?)			Most water strikes in area near the river. Water levels measured in only 10 boreholes (out of 88)	Pta Fountains West
F1547	08+09/200	Holdg 61, Lyttelton AH's	Holland-Muter & Assoc.	66			>40		C	2-33	Syenite	Sye 2-25	5-40		Pta Fountains West
F420	06/2005	Highveld X58 (Part of Ptn 60, Brakfontein 390-JR)	Dolomite Technology	95			5-7		B	1-6				Geohydrology of Portion 60 in Geocon July 2001 report.	Pta Fountains West
F992	02/2001	Highveld X23	Louis Kruger Geotechnics	42			23		B	9-30	Syenite	Sye 1-30	11-31	Water only in one hole.	Pta Fountains West
F2645	02/1996	Rem Ptn 5 and 131, Doornkloof 391-JR	Jan Cronje	around 50	>80				B					Only 1 of 50 BH's showed a shallow perched water table.	Pta Fountains East
F760	06/2002	Lyttelton Manor X11: Erf 2285	AMB	3			>18		C	2-12			10-18	Shallow holes - no groundwater.	Pta Fountains East
F753	06/2002	Lyttelton Manor X11: Erf 2284	AMB	2			>10		B	1-2			10	No water strikes.	Pta Fountains East
F1303	10/2000	Irene X's 4 and 5	Johann van der Merwe				2,9-14		C		Syenite			Syenite present in profiles but no more details.	Pta Fountains East also West
F2384	09/1999	Waterkloof Airforce Base	VGI Consult		1375				B	1->60	Karoo syenite		60	Base situated on East Fountain Catchment Area. Refer to DWAF reports GH3502 and GHP 6740.	Pta Fountains East
F684	04/2002 + 08/2003	Rem Waterkloof 428-JR and erven 485, 479, 1449 and 1443, Monumentpark	Louis Kruger Geotechnics	23				1453-1484	B	3-21	Mudrock	Mr 0-13	19-25	Site on dolomite/Timeball Hill contact. More groundwater on eastern side (possibly because of dyke).	Pta Fountains East
F1345	11/2004	Sterrewag X2 and 3	SRK (Report by Hobbs Consulting)					1375	A					Situated in East Fountain compartment just east of Pretoria dyke and dolomite/ Timeball Hill contact. Geohydrological report by Hobbs Consulting for SRK. Mudrocks overlie dolomite on the site.	Pta Fountains East
F1036	05/1987	Ptn Rem Ptn 52 Garsfontein 374-JR	RMS				>25			11-21,5			25?	Yielding BH's in shale at 80 to 100 m depths - not in dolomite area.	Rietvlei
F3035	09/2007	Ptn 20 Grootfontein 394-JR	Intraconsult	81			1484 Rietvlei A, 1484 Rietvlei B, 1496 Rietvlei C, 1500Grootfontein, 1504 Erasmus, 1524 Unnamed			4->60	Karoo Intrusive	Karoo 0-60, Intr. 1-47		Dolomite stability study in which groundwater levels are considered very important.	Rietvlei/Elandsfontein-Babsfontein
F1001	09/1996	Ptn 88 Elandsfontein 412-JR	Johann van der Merwe	4		>50 m	>30		B	9-23	Sye	Sye 2-30	15-30	Also Holland-Muter 4/2005 report. Perched water table at 20 m. No yielding BH's in dolomite.	Elandsfontein/Babsfontein
F1662	11/2005	Bronkhorstfontein 22-IR	Louis Kruger Geotechnics	8		15-75	1,3-29,8			25-72			29-78	Reference to geohydrological study by Jasper Muller Associates (2005) on the Babsfontein and surrounding compartments.	Elandsfontein/Babsfontein
F1668	09/2005	Etwatwa X36	ANT Geoconsultants	19			3-14	1611-1624	A		Karoo (thick)			Hobbs Consulting study of Etwatwa X9 and 10 mentioned. Water levels from 1989, 2003 and 2005 listed. Also report by PG Hansmeyer.	Rietfontein
F1668	02/1989	Etwatwa X16	SRK	7			6-12	1614-1619	B		Karoo + Diabase			Karoo and diabase overlie dolomite.	Rietfontein
F3458	09/2008	Erf 1491, Eldoraigne, Tshwane	Dolmatec	1		45			C		Syenite	Sye 3-43	43		Sterkfontein also Kaalspruit

Table 16.1 (cont.): Summary of geohydrological information sourced from geotechnical reports submitted to the CGS (cont.)

FOLDER NO.	REPORT DATE	LOCATION	CONSULTANT	NR. OF BH'S	DWAF INFO	INFO - OTHER SOURCES	WL DEPTH BELOW SURFACE ON SITE	WL ELEV. mamsl	LEVEL OF GW INFO	DEPTH RANGE TO DOLOMITE BEDROCK	PRESENCE OF OTHER ROCK TYPES	DEPTH RANGE OF OTHER ROCK TYPES	DEPTH RANGE OF BH'S	REMARKS	CCOMPARTMENT/ AREA
F2915		Ptn 8 Hartbeesfontein 17-IR Area 2 Phase 2	Dolomite Technology	92			24			2-36	Syenite	Sye 0 - 35	8-42?	Extensive syenite present in localized areas. Only 1 BH (out of 92) struck water.	Sterkfontein Upper
F3571	11/1994	Holdgs 88 and 97, Bredell AH's, Benoni	Johann van der Merwe	3			13,2-19,5		B	20	Dwyka tillite, Black Reef Quartzite	Tillite 12-15, Qtze 5-30	26-30	Dolomite between Dwyka and Black Reef Quartzite. Wad and dolomite only encountered in two holes.	Sterkfontein Upper
F2915.2	02/2008	Rem Ptn 3 Hartbeesfontein 17-JR Area 2 Phase 2 (Junction 21 Development)	Dolomite Technology	97										Water tables in only 4 holes, 3 with syenite. Levels irregular, probably perched WT's. Situated in East Sterkfontein Compartment.	Sterkfontein Upper
F2915	09/2006	Rem Port. 3 Hartbeesfontein 17-JR Area 2 phase 3		49(2007)			>31						31	Information from SP Kok (personal communication)	Sterkfontein Upper
F1550	09/2007	Ptn 1 Holdg 89, Bredell AH's	Holland-Muter & Assoc.	3			>45		C	2-22	Shale	Sh 2-24	30-45		Sterkfontein Upper
F3511	06/2009	Ptns Olifantsfontein 402, + 410JR and Sterkfontein 401, JR	RMS	169				1451-1490	B	2-47	Syenite (limited)	Sye 4-37	10-52	Water rest levels recorded in 28% BH's but some backfilled without measurement. Discussion of probability of dewatering of compartments in report. Refer to DWAF report GH3502 (P Hobbs and Doornkloof West and Doornkloof East compartment)	Fountains East, west, Kaalspruit & Sterkfontein
F2925	?	Ptn of Sterkfontein 401-JR Areas 3-7	Soilkraft			25-45			B		Rooihoogte Timeball Hill and intrusive rocks			In Sterkfontein east compartment with boundaries Pretoria dyke , Pinedene dyke and Tweefontein dyke. Water encountered in 22 out of 356 boreholes. Also refer to Hobbs report on Catchments on A21A and A21B.	Sterkfontein East
F625	11/2008	Clayville X52	VGI		1480-1500		2-21	1480-1500		1472-1500 1-35	Syenite	Sye 9-34 1478-1495	7-41	DWAF reports GH3501 and GH3502. Site in Sterkfontein Water Compartment.	Kaalspruit
F2607	09/2008	Ptn 258, Geduld 123-IR, Springs	Africa Exposed	24			11-47	1582	B	26-49	Dolerite	Dole 20-50	26-60	Water level average of depths encountered.	East Rand Basin
F2522	06/1998	"The Arc" and Portions of Welgedacht, Springs	Intraconsult	8			4-14		B	9-23	Karoo intrusive	Karoo 2-18; Intr. 1-27		Groundwater level hydraulically connected to Blesbokspruit	East Rand Basin
F3688	05/2009	Zincor New Residue Disposal Facility	Knight Piesold	7			19,3-22,2			10-51	Dwyka and Ecca rocks	Dwyka and Ecca prob 10-51	55-60	Report is mainly EIA geohydrological study. Reference made to study by Scott (1995).	East Rand Basin
F3699	05/2009	Eldoraigne X73, Rem Ptn 279, Zwartkop 356-JR	Golder Associates	29			1,6-13,4	1381,3-1392	A	7,3-27,3	Syenite	Sye 2-33	15-47	Geohydrological report. Other geohydrological data available in report.	Erasmia Rietspruit
F1263	10/2004	Mayfield X8	Martin van der Walt	4			4,5-20,5	1583,3 - 1603	B		Dolerite and Karoo rocks			Geological map indicate Dwyka Formation south and dolomite north. Dolomite only encountered in one hole at depth of 46 m.	East Rand Basin
?	02/2006	Serengeti (Witfontein 16 -IR)	Dolomite Technology	44			4-46,1		B	5,1->60			11-60	Syenite and mudrock (Karoo) often encountered. Water strikes in large percentage (61%) of holes.	

Table 16.1 (cont.): Summary of geohydrological information sourced from geotechnical reports submitted to the CGS (cont.)

FOLDER NO.	REPORT DATE	LOCATION	CONSULTANT	NR. OF BH'S	DWAF INFO	INFO - OTHER SOURCES	WL DEPTH BELOW SURFACE ON SITE	WL ELEV. mamsl	LEVEL OF GW INFO	DEPTH RANGE TO DOLOMITE BEDROCK	PRESENCE OF OTHER ROCK TYPES	DEPTH RANGE OF OTHER ROCK TYPES	DEPTH RANGE OF BH'S	REMARKS	CCOMPARTMENT /AREA
F317	03/1996	Ptn 60 Brakfontein 390-JR	BKS	23		1439 (10 m below surface)	0,7-13,9		B					Owner at time stated that water levels are at 16-22 m below surface with good yields.	
F317	07/2001	Ptn 60 Brakfontein 390-JR	Geocon	22				1482-1450	A					Geohydrological report by Geocon. Two aquifers present: bedrock and perched.	
F3063	03/2010	Strubenvale X2, Springs	RMS	8			2-30	1583-1555	B	29-56	Dolerite, Shale & Coal	Dol, 1-60, Sh+C 8-53	27-81		East Rand Basin
F2830	07/2008	Krugersrus X3, Springs	Africa Exposed	25			9-43 (27)	1573	B	10-54	Dolerite, Black Reef Quartzite, Karoo		15-60	Area overlain by Karoo sediments especially on southern and eastern portions of site.	East Rand Basin
F1655	10/2006	Chris Hani X2	RMS					1585-1588	B	10-46	Karoo	Karoo 6-60	16-52	Area overlain by varying thicknesses of Karoo rocks.	East Rand Basin
F1341	12/1997	Mogoba Village Ptn of Knoppiesfontein 23-IR	RMS		1586, 1606		1-12	1593-1604	A		Karoo Dolerite			Groundwater in all boreholes drilled. Eastern edge is covered by Karoo rocks.	East Rand Basin
F1341	12/1997	Ptn 5 Knoppiesfontein 23-IR	RMS	14			10		B	23-89	Karoo dolerite	Karoo 2-75, Dolerite 24-100	27-92	Water flows out of a DWA borehole (37674) near the site. Three phases of drilling discussed separately in report.	East Rand Basin
F2928	09/1986	Cons Modderfontein Mine, Staff Housing	Weber De Beer Assoc.				29		B	12->30				Further mining will probably lower water table. Part of the area is already dewatered.	East Rand Basin

LEGEND:						
				Dol	:	Dolomite
Ptn	:	Portion		Dole	:	Dolerite
Rem	:	Remainder		Qtze	:	Quatzite
Holdgs	:	Holdings		Sye	:	Syenite
IS	:	Intersections		Sh	:	Shale
Ave	:	Average		Mr	:	Mudrock
NW Provi	:	North West Province		BR	:	Black Reef
RMS	:	Relly Milner & Shedden		WT	:	Water table
AH's	:	Agricultural Holdings		Intr	:	Intrusive

16.2 The role of groundwater in dolomite stability and dolomite stability investigations

16.2.1 Background

Dolomite stability investigations for townships started in the early 1970s following some disastrous collapses (the formation of large sinkholes) in the far West Rand Area. Geotechnical reports on areas to be developed were submitted to the Geological Survey of South Africa (now the Council for Geoscience) for review and comments. Depending on the outcome of the review of the report, the township development was either approved or declined. At that stage no formal guidelines as to the type and detail of investigations required for development on dolomitic land were available.

At various times the investigation procedures became more formal or better defined as more guideline documents were published, e.g.

- Geological Survey of SA (1990). Characterization and appropriate development of sites on dolomite. Perspectives of the Unit for applied studies on dolomite, SA Geological Survey. A special report by D B Buttrick – Report No. 1990-0054.
- National Homebuilders Registration Council 1999. Home Building Manual Part 1 + 2 (Revision No.1: February 1999).
- Council for Geoscience (CGS)/SA Institute of Engineering and Environmental Geologists (SAIEG) (2003). Guidelines for engineering geological characterization and development of dolomitic land. Published by CGS.
- Council for Geoscience (2004). Approach to residential development on dolomite October 2004.
- Council for Geoscience (2007). Consultants Guide: Approach to sites on dolomite land. November 2007

All these documents provided more formal guidelines as to how dolomitic land should be investigated and which types of development are suitable for the different inherent hazard classes identified during the investigations.

16.3 Brief description of investigation methods and inherent hazard zoning

The investigative methods generally used include:

- Field inspections and mapping when numerous outcrops are present;
- Geophysical surveys. A gravity survey is generally done but other methods, such as magnetic or electromagnetic surveys are also often employed to map intrusive dykes or sills.
- Percussion drilling. Locations for percussion drilling are selected on geophysical anomalies and to provide good cover of the area.

The drilling density has increased markedly since the publications of the CGS documents in 2004 and 2007. At present a drilling density of 3 holes per hectare is a good average in the different inherent hazard classes.

Up to about 2004 boreholes were drilled down to 30 m or 6 m into solid dolomite. At present the guideline is to drill to 60 m if no dolomite bedrock is encountered. In such areas it is recommended to drill a number of holes deeper to determine the depth of the dolomite bedrock below surface.

Using all the available results but especially the percussion drilling results the area is divided into different inherent hazard class zones (previously inherent risk classes). Depending on the type of overburden material and the depth to dolomite bedrock a borehole (or a group of boreholes) is assigned a hazard class. The main principle is that there is a higher hazard in an area with poor (erodable) overburden on deeper dolomite bedrock for the formation of larger sinkholes. Poor material on more shallow dolomite will indicate a high hazard for a small or medium sized sinkhole. A thick protective non-dolomitic layer may change the hazard rating to low while a cover or good overburden material on dolomite will indicate medium hazard conditions.

The inherent hazard classes are shown in Table 16.2 below (adapted from CGS/SAIEG, 2003 – Revised modified hazard (risk) classification (after Buttrick et al, 2001).

Table 16.2: Hazard classes used during the assessment of dolomitic terrain for development

Inherent hazard class	Small sinkhole	Medium sinkhole	Large sinkhole	Very large sinkhole	Risk of subsidence formation
Sinkhole diameter	<2 m	2-5 m	5-15 m	>15 m	
Class 1	Low	Low	Low	Low	Low # NDS or DS
Class 2	Medium	Low	Low	Low	Medium # NDS
Class 3	Medium	Medium	Low	Low	Medium # NDS
Class 4	Medium	Medium	Medium	Low	Medium # NDS
Class 5	High	Medium	Low	Low	High # NDS
Class 6	High	High	Medium	Low	High # NDS
Class 7	High	High	High	Medium	High # NDS
Class 8	High	High	High	High	Low-High #NDS or DS

16.4 Influence of groundwater

As is evident from Table 16.1 the groundwater level in dolomite is a very important factor in dolomitic stability. The depth to the static groundwater level is important mainly due to the following two most important factors:

- It determines the level of erosion during a leakage e.g. the hazard of any instability in an area with a high water table will be a medium to low if the material above the water table has a low mobilization potential. The material below the water table can be highly erodable but if there is a very low probability that the regional water level will drop, it does not affect the hazard class. If there is a high probability the hazard rating changes from low to high as the deeper poor materials below the present water level will then be exposed to erosion.

- Dewatering of an area with low density dolomite residuum can results in subsidences at ground level because of the consolidation of the low density materials.

Water levels in dolomite and the likelihood of dewatering (and rewatering) are therefore very important during the drilling and the evaluation of dolomite stability conditions.

16.5 Present studies of groundwater information in dolomite stability reports

As mentioned and explained above the measurement of groundwater levels in boreholes and a study of regional groundwater levels should be very important in any dolomite stability report. Unfortunately this was found not to be the case during a study of a large selection of geotechnical reports within Groundwater Region 10. Groundwater level depths were mostly measured in each borehole but very few profiles or tables provided borehole collar elevations. Only information that allowed evaluation and a discussion of the effects of drawdown in a specific borehole or number of boreholes were therefore given and not information to allow comparison of water levels and the changes in levels over larger areas and in different groundwater compartments.

16.6 Future studies of groundwater monitoring

Fortunately, the study of groundwater information in dolomite stability reports coincided with the revision of the draft SANS 1936 series of documents on Development of Dolomite Land. A number of requirements could therefore be added to the documents which should form part of a dolomite stability report. The following is presently included in SANS 1936-2: 2011 under section 4.2.5 and 4.2.6.1. SANS 1936 is still in draft format and not yet officially approved.

"4.2.5 Gathering of geohydrological data

4.2.5.1 Geohydrological data should be obtained from a relevant authority or reputable source in the industry. Wherever practically feasible, the following data should be obtained and recorded:

a) the presence of groundwater compartments in the region and the name of the compartments;
b) the National Quaternary catchment number in which the site is located;
c) original groundwater level (OWL) in metres above mean sea level;
d) coordinates, collar elevation, groundwater level, pumping equipment installed in the borehole and water use for all existing boreholes on or in close proximity to the property being investigated;
e) the presence of any large scale groundwater abstraction or de-watering activities in the vicinity of the property being investigated, e.g. center pivot irrigation, large scale groundwater abstraction for mining, municipal, domestic or irrigation use, etc. as these could impact on or influence groundwater levels;
f) any planned future water abstraction activities in the area;

g) the presence of any regular groundwater-related monitoring activities (e.g. water levels, pumping records) and the custodian of such data;

h) location and yield of springs on or in close proximity to the property being investigated and the likely reason for their existence; and

i) location of pans, state of pans, variation in water level and the likely reason for the existence of the pans;

4.2.5.2 Where groundwater is encountered in a new borehole, the following shall be recorded:

a) borehole coordinates stating how these were determined (survey, handheld GPS, interpolated from maps or plans, etc.)

b) borehole collar elevation (metres above mean sea level) and a note on how the elevation was determined, e.g. survey, handheld GPS reading or interpolated from contour plan).

c) depth drilled (metres below collar elevation);

d) depths at which groundwater strikes were encountered and an estimate of yields at each water strike e.g. weak; medium or strong;

NOTE: On completion of drilling, a total blow yield may be estimated and recorded.

e) static groundwater level measured at least 24 h after completion of drilling as a depth below collar; and

f) date of each observation

NOTE: if the borehole is found to be dry, it should be reported as "borehole dry". If the borehole has (partially) collapsed during this period, it should also be recorded and to what depth.

4.2.6 Report

4.2.6.1 the investigator shall document and report all findings and determinations in a written report that:

a) provides a description of the site and defines its extent and boundaries;

b) describes the investigation carried out and presents the results thereof in detail;

c) establishes the geotechnical model for the site;

d) establish the nature, fluctuations and compartmentalization of groundwater, and original groundwater levels from geohydrological data;

e) assesses the effect of changes to the groundwater level;

f) determines the inherent hazard class of the site or of the various portions thereof;

g) determines the dolomite area designation and appropriateness of proposed land usage in accordance with the requirements of SANS 1936-1;

h) provides the information needed for identification of the precautionary measures required in accordance with SANS 1936:3, and the risk management strategies required in accordance with SANS 1936:4; and

i) identifies any outstanding information to be determined or confirmatory investigation to be undertaken during the design-level investigation, particularly in respect of verifying or refining the inherent hazard class of the site or parts thereof.

4.2.6.2 Drawings shall be to a suitable scale, legible and easily reviewed. All drawings shall be fully annotated and show a coordinate grid. The coordinate system used (e.g. Cape, WGS84, local etc.) shall be stated on the drawing.

NOTE: The preferred coordinate system for new projects is the WGS84 coordinate system.

4.2.6.3 Borehole coordinates and collar elevations shall be shown on the borehole logs and shall be listed in the drawings."

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