A METHODOLOGY FOR GROUNDWATER MANAGEMENT IN DOLOMITIC TERRAINS WITH THE SCHOONSPRUIT COMPARTMENT AS PILOT AREA

by

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1 INTRODUCTION

"A new mindset and paradigm has been suggested for studies that may involve groundwater, the objectives being (1) getting optimal value from existing information, (2) reaching a high plateau of knowledge as a basis for further study and (3) providing an early perspective to be explained to involved stakeholders.

All capable hydrogeologists use past experiences, principles, generalisations and qualitative linguistic modelling to some degree and in some forms but rarely are these used in a systematic way to obtain the full synergistic value that will maximise public benefits and understanding. Application of systematic hydrogeological reasoning is referred to as prior conceptual model explanation (PCME) and represents an initial high grade, synergistic analyses of hydrogeological foreknowledge, derived largely from existing information. By using hydrogeological generalisations and inferences effectively in a composite way, existing information can be expanded readily.

The PCME approach does not go through a decision-tree approach or linear method, which may be directed to get a precise, or crisp, answer to a specific question. Rather, it leads to a cognitive network and an internal package of open-ended thoughts and statements that allow for suggestions for further study, provisional decisions, or definite decisions. If properly prepared and presented at an early stage, a large part of the total hydrogeological information needed for site studies at an average site is already available, partly in unrecognised or latent form. With this advanced background of foreknowledge, adequately developed and displayed, only a fraction of time and money normally used in site studies may be needed in most cases. Moreover, being fortified with balanced and unbiased analysis and concepts, this foreknowledge can serve as a useful perspective for judicious actions related to a variety of environmental issues." (LeGrand & Rosen, 2000)

The Methodology to Groundwater Management in Dolomitic Terrains is primarily based on this principle of PCME as described by LeGrand & Rosen. All relevant information should be assimilated and a good understanding formed of how the groundwater system works and what work is necessary to fulfil the requirements of the purpose and aim of the thesis. Currently in South Africa, funds cannot be used unwisely and in many instances a project leader will motivate for more funds to initiate more studies and still not have, at the end of a project, a practical and workable answer for the specific problem that should have been resolved.

This thesis intends using the least possible amount of funds to attain the greatest amount of information and understanding of the dolomitic terrains. The following gives an outline of what the proposed thesis entails:

1.1 Purpose

The use of basic geohydrological principles and previous studies as a source of information, to evaluate the current status of a dolomitic aquifer, and minimise further studies associated with the development of a groundwater management tool in a dolomitic area, thereby minimising costs associated with Catchment Management.

1.2 Aim

The development of a technical methodology and a first order technical groundwater management tool to manage groundwater geohydrologically, within a *Groundwater User*

Association, on a year to year basis, with the focus on volumes available in the aquifer for allocations.

1.3 Approach

The Schoonspruit Dolomitic Compartment is being used as an example on which to test these concepts. This area has had various studies done in previous years and a long time series of monitoring data available. This area will be used as an example of how the methodology was put together and as an example of how it could be applied in other dolomitic compartments. With the use of the information attained from this area, a methodology will be compiled, which will be easy to use and modify, to suit many other dolomitic areas.

The Schoonspruit Dolomitic Compartment is a dolomitic aquifer situated to the North and Northwest of the town Ventersdorp in the Northwest Province. The compartment has been named after the Schoonspruit Eye, which is dependent on the compartment for flow. The Schoonspruit Eye, in turn, is the sole reason why the Schoonspruit has a constant flow and provides a municipality and two surface water irrigation boards with surface water all year round.

Some controversy existed around 1994 due to the decrease of the Schoonspruit Eye's flow and blame was assigned solely to irrigation farmers on the compartment that were abstracting groundwater directly from the compartment. At the time all available data and information supported these claims and in 1995 the immediate groundwater catchment area of the Eye was proclaimed as a Subterranean Government Water Control Area. All existing groundwater abstractions at the time were proclaimed as legal and any expansion on groundwater abstraction had to be applied for at the Department of Water Affairs & Forestry. Although speculation exists as to the effectiveness of this proclamation in stopping irrigation expansion on the compartment, the flow of the Eye started increasimg in 1996.

With the proclamation of The National Water Act, Act 36 of 1998, a new responsibility towards groundwater and groundwater management as part of the hydrological cycle developed. The Minister of Water Affairs & Forestry was now the custodian of all water resources and Regional Offices were given the responsibility of managing these resources as acting Catchment Management Agencies. Groundwater was now seen as a resource that needed management and, although very little information existed in most cases, Regional Offices had to start taking decisions, based on sound scientific principles, as to allocable volumes from the groundwater resources.

This thesis's main focus will be on a methodology to establish allocable volumes for future allocations from dolomitic compartments. The principles of Catchment Management are therefore an integral part of the methodology. However, the aim is a practical methodology, which can be altered as new data and information comes to light, rather than an exhaustive methodology. It must be emphasised that the concept of *as much as possible information for the least amount of funds* will always be an integral part of the scope of work.

The following description of the different chapters gives a short outline of the thesis:

Chapter 2: DESCRIPTION

This chapter deals with the evaluation of all information and data available regarding the Schoonspruit Dolomitic Compartment prior to the start of this thesis (2001), including reports, water levels, chemistry, rainfall, flow (of the Schoonspruit Eye) and the proclamation information from 1995, as well as all information regarding dolomites in general. Work done prior to 2001 was mainly focused on resource assessment and not Catchment Management.

Chapter 3: GEOHYDROLOGICAL EVALUATION

This chapter deals with the work completed as part of this research, on the Schoonspruit Dolomitic Compartment since 2001, the purpose being mainly Catchment Management and establishing a technical groundwater management plan for the dolomitic compartment of Schoonspruit. It also includes technical assessments where information from *Chapter 2* is outdated, or otherwise shown to be erroneous.

Chapter 4: GROUNDWATER MANAGEMENT OF THE DOLOMITIC REGIME

In this chapter, *Chapters 2 & 3* will be incorporated into a technical methodology, extrapolated to other dolomitic areas, with the focus on what kind of information is essential and what kind of information is supplementary, but helpful, when managing groundwater in the dolomites. This chapter will also include an overview of the legal principles within which the dolomites are managed (explaining the concepts of Integrated Water Resource Management), institutional arrangements and the concepts of how the technical tool is developed, before actual data is included and made a practical and workable tool. *Chapter 4* should be used as a base for the groundwater management plans in other dolomitic compartments.

Chapter 5: GROUNDWATER MANAGEMENT OF THE SCHOONSPRUIT DOLOMITIC COMPARTMENT

This chapter will test the methodology, as described in *Chapter 4*, against the Schoonspruit Dolomitic Compartment and therefore summarise all the previous chapters' information without repeating work done. The technical tool, with data and formulas incorporated, as applied to this compartment, will be included. Therefore this chapter can be seen as the workable document, which should be used by the *Ventersdorp-Dolomite Water User Association (WUA),* for management of their groundwater resource. This WUA is the proposed institution to do the resource control of the Schoonspruit Dolomitic Compartment, as per draft constitution sent up to the Minister of Water Affairs & Forestry.

1.4 Deliverables

The deliverables of this thesis include (1) a workable methodology, which is easily modified, to use in other dolomitic terrains for groundwater management, and (2) a simplified technical tool, to use for allocation of abstraction volumes in the dolomitic compartment e.g. for licensing purposes or drought control.

2 DESCRIPTION OF THE SCHOONSPRUIT DOLOMITIC COMPARTMENT

A conceptual model of an area is the first stepping-stone of the geohydrological evaluation of an area. This chapter deals with previous reports, data and work done on the Schoonspruit Dolomitic Compartment and can therefore be seen as a synopsis report, of which some of the data might change as new information comes to light. As far back as 1971, Enslin stated that dolomitic water resources form one of the most important water resources in the Republic of South Africa. At the time the dolomitic water resources were seen as an endless supply of groundwater for human and animal consumption. The agricultural and mining sectors also realised the importance of the use of water yielded by these dolomitic compartments and several studies were initiated to evaluate the water bearing properties of the dolomites in South Africa. Two of the most relevant studies on the Schoonspruit Dolomitic Compartment were:

(1) The study by Polivka in 1987, where the water-bearing properties of the Schoonspruit Compartment were evaluated and the potential areas for groundwater development assessed and;

(2) The study by Kotze in 1994, where the geohydrological boundaries of the Schoonspruit Dolomitic Compartment and farms which fall within the catchment area of the Schoonspruit Eye were determined, for the proclamation of the Subterranean Government Water Control Area.

2.1 Geographical setting

The Schoonspruit Dolomitic Compartment is situated North and Northwest of Ventersdorp in the Northwest Province and is shown in Figure 1. The area is covered by the following 1:50000 topocadastral maps:

- 2526 CD (Lead Mine), DC (Grootpan).
- 2626 AB (Twee Buffels), AD (Coligny), BA (Zwartrand), BB (Swartplaas), BC (Makokskraal) and BD (Ventersdorp).
- 2627 AA (Mathopestadt) and AC (Rysmierbult).

The setting can be described in more detail as the compartment is categorised as Transvaal Highlands with elevation changes of more than 100 m over a 40-km distance. The topography slopes downward from the Northeast to the Southwest. The Pretoria Formation in the North forms the water divides, in the North of the compartment, between the Vaal and Limpopo rivers. The Schoonspruit compartment falls within the surface water drainage area C24, drained by the Schoonspruit, and circular depressions can be found in the area that shows elements of karstic evolution. Many farmers refer to an 'underground river' running along the Ventersdorp-Swartruggens road and the high yielding boreholes found alongside this road support this observation. However, this was never investigated, as no borehole logs were available. (Polivka, 1987)

The observation of an 'underground river' might be a zone of karstification where dissolution cavities have formed an extended area of higher yielding boreholes. Karstification is explained in more detail in section 2.4.2.2.

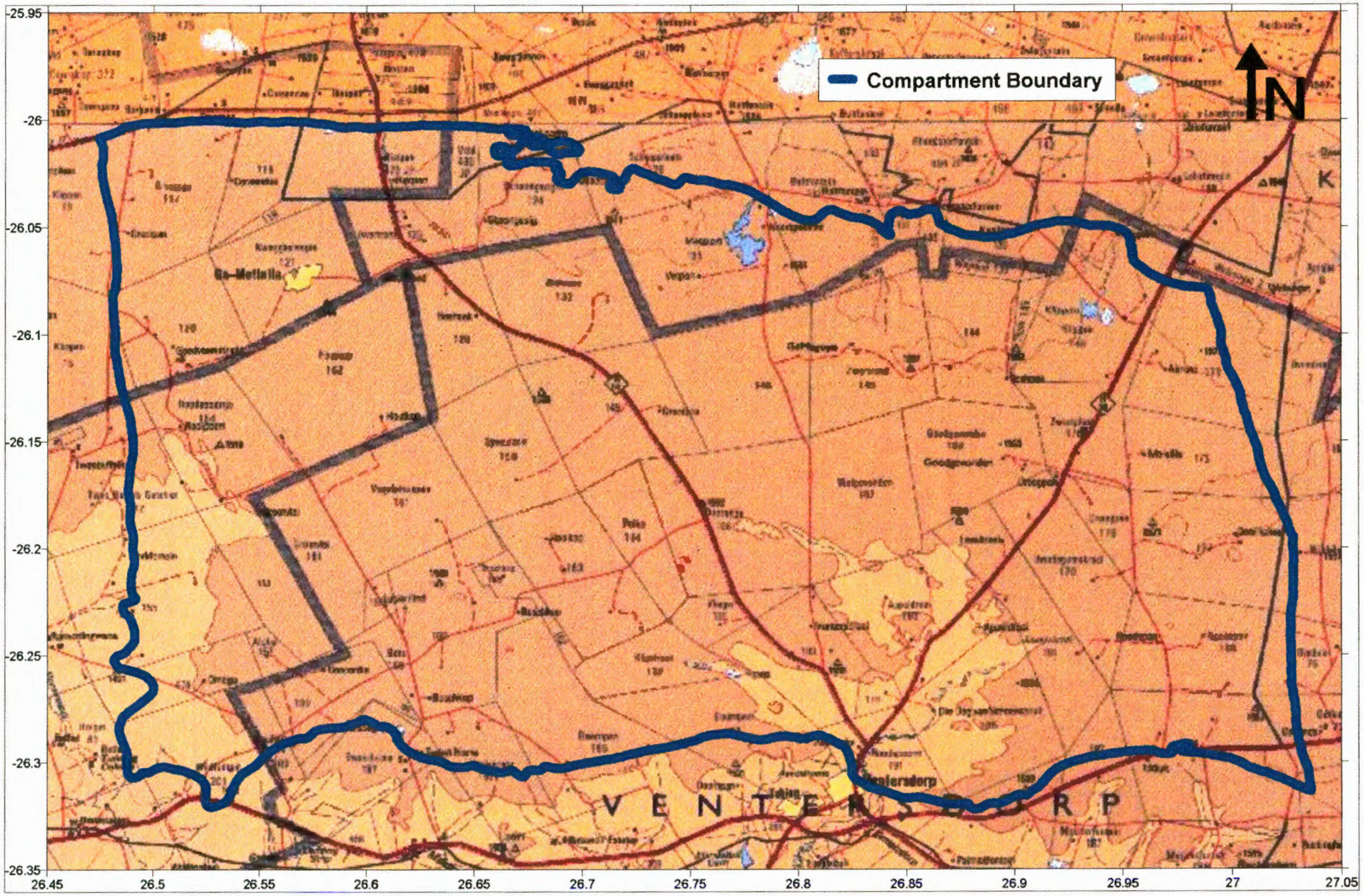


Figure 1: Topocadastral map of the Schoonspruit Dolomitic Compartment

2.2 Meteorology

The Ventersdorp area falls in the summer rainfall area and most of the rainfall occurs from November to February. The average rainfall for the area is in the vicinity of 606 mm and the average evaporation is in the vicinity of 1900 mm. Rainfall and evaporation values for the period 1980-1986 were calculated from data of the gauging station C2E16S. (Polivka, 1987)

2.3 Geology

The geology of the area can best be described by differentiating between the main geological systems. In general the geology is known as dolomites of the Malmani Subgroup that plunge regionally northward and are overlain by the Pretoria Group. Outcrops of the Witwatersrand Supergroup appear along the southern boundary of the dolomites. (Fleisher, 1981)

Aside from the common method of describing geology from geological maps, a geological log of a prospecting borehole on the farm Ystervarklaagte 135 IP was found drilled to a depth of 3688 m, which gave valuable information regarding the geology. The borehole was sited on Pretoria Formation, after which it penetrated the whole Malmani Formation (extending to a depth of 1657 m), the Ventersdorp Supergroup, the Group Dominion and it was stopped at a depth of 3688 m in Archaic gneiss and granite (Polivka, 1987). The rocks in all three compartments were deposited during the Vaalian Erratum (Transvaal Sequence) and the Randian Erratum (Ventersdorp Supergroup). (Kotze, 1994)

The geology of the area is shown in Figure 2 and is chronologically as follows:

2.3.1 The Ventersdorp Supergroup

The Ventersdorp Supergroup is characterised as andesite, porphyritic lava, pyroclasts and sediments. Mafic igneous rocks form the greatest part of this system and are present on the southern boundary of the dolomitic compartment. Pans are a common occurrence in this system and the topography is generally even, due to the good weathering characteristics of these rocks. (Kok, 1972)

The andesitic lava of this sequence unconformably overlies the quartzitic sequence of the Witwatersrand Supergroup, but the Wits do not outcrop in the study area and is fairly deep. (Polivka, 1987)

2.3.2 The Transvaal Sequence

The dolomite series of the Transvaal Sequence consists of dark grey dolomite ($CaMgCO_3$), chert, banded iron formation and shale (Enslin, 1971). The Sequence fills an east-west elongated basin and comprises a tectonic-sedimentary phase of clastic, volcanic and chemical sediments e.g. dolomites. Rocks of the Transvaal Sequence includes the Black Reef Formation to the south of the compartment, the Chuniespoort Group, which was part of a chemical sedimentation phase in distal environments, and the Pretoria Group, which comprises of the Rooihoogte Formation in the north of the compartment. The Malmani Subgroup represents the main dolomitic stage in the chemical sedimentation phase of the Chuniespoort Group. (Kotze, 1994)

ENLARGED LEGEND FIGURE 2

🟥	Springs
—	Sinkholes
—	Lineaments
-·-·-·-	Faults
—	Dykes.shp
—	Quartz Veins
—	Main Roads
—	Rivers
🟦	Dams
▨	Settlements
⬜	Schoonspruit boundary
⬜	Ventersdorp Eye SGWCA

GEOLOGY

🟩	ALLANRIDGE
🟨	BEVETS
🟦	BLACK REEF
🟧	BOSHOEK
🟩	BOTHAVILLE
▨	DASPOORT
🟨	DOMINION
🟫	DWAALHEUWEL
🟦	DWYKA
🟩	ECCLES
🟩	FRISCO
▨	GOEDGENOEG
🟫	GOVERNMENT
🟩	HEKPOORT
🟨	HOSPITAL HILL
🟫	KAMEELDOORNS
🟨	KLIPRIVIERSBERG
⬜	KOLOBENG NORITE
▨	LYTTELTON
▨	MAGALIESBERG
🟩	MAKWASSIE
🟩	MALMANI
🟧	MOKOLIAN
🟦	MONTE CHRISTO
▤	OAKTREE
🟨	ORANGE GROVE
🟨	QUATERNARY
🟧	RHENOSTERHOEK
🟧	RIETGAT
🟥	ROOIHOOGTE
🟧	SILVERTON
▥	STRUBENKOP
🟫	SWAZIAN
🟪	SYFERFONTEIN
▨	TIMEBALL HILL
🟨	Prov.shp

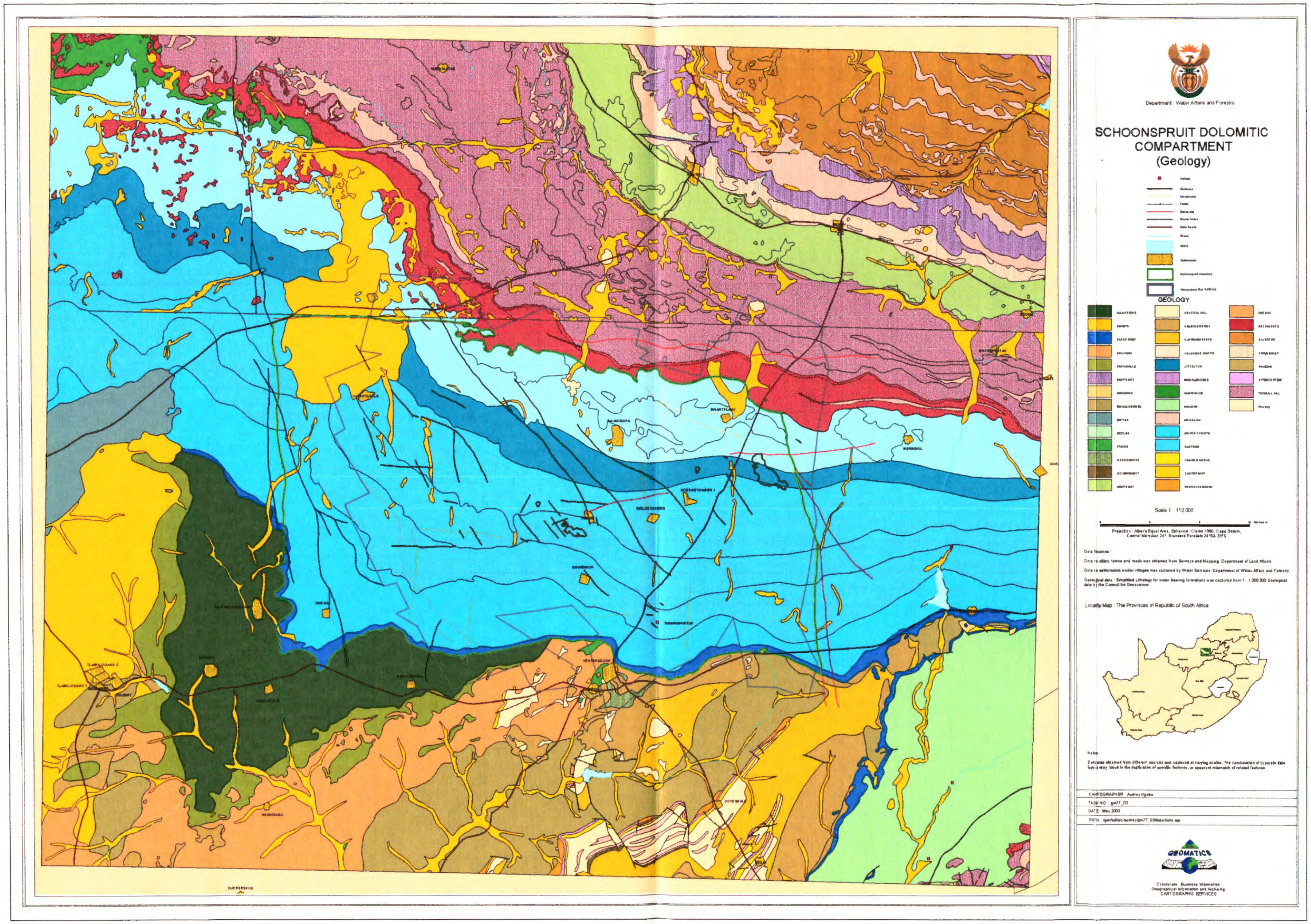


Figure 2: Detailed geology of the Schoonspruit Dolomitic Compartment (Geomatics, DWAF)

2.3.2.1 The Black Reef Formation

The Black Reef Formation can be characterised as quartzite, conglomerate, tillite and andesite, consisting mostly of massive quartzite and occurs only as small outcrops at the bottom of the dolomite series (Kok, 1972). The Formation ranges from 6 to 26 m and rests unconformably on the Ventersdorp lava. This rock consists mainly of shale and quartzitic bands, with the dip in the quartzite between 5° and 10° northwards. (Polivka, 1987)

2.3.2.2 The Malmani Subgroup

The Malmani Subgroup is described as dolomite, banded iron formation, chert and shale. This series consists mostly of layered strata of calcium magnesium carbonates ($CaMgCO_3$), some layers massive and some with chert bands. Secondary limestone also occurs in the dolomites and is widely mined for the manufacturing of cement. Dolomites in this area are generally easily weathered and form undulating landscapes. (Kok, 1972)

The Subgroup is further described as representing the dolomitic sequence and is largely concealed by overburden throughout the study area and therefore difficult to trace (Polivka, 1987). The majority of outcrops and aquifers in the area are associated with the Malmani Subgroup (Kotze, 1994).

Four different formations were distinguished on the basis of chert content, the presence/absence of algae structures and the type of algae structures found in the dolomite. This subgroup therefore comprises of the Oaktree, Monte Christo, Lyttleton and Eccles Formations. (Polivka, 1987 & Kotze, 1994)

1. The Oaktree Formation rests conformably on the Black Reef Formation, with a total thickness of up to 280 m. The dolomitic formation is finely grained and chert-poor, and interbedded shale layers are common throughout the formation.
2. The Monte Christo Formation is up to 660 m thick and consists of chert-rich, medium to coarsely grained, and light coloured dolomites. In the formation one can also distinguish between two layers; oolithic chert and banded chert layers.
3. The Lyttleton Formation is up to 210 m thick and is generally chert-poor, fine to medium grained, dark coloured and have a grey elephant skin appearance on weathered surfaces.
4. The Eccles Formation is up to 400 m thick and is a chert-rich formation, lightly coloured, and stromatolites in the dolomite, up to 10 m in height can be observed.

The Monte Christo formation is the predominant and most chert-rich formation of the dolomitic formations. (Polivka, 1987 & Kotze, 1994)

2.3.2.3 The Pretoria Group

The Pretoria Group is characterised as comprising of quartzite, shale, hornfels, limestone, andesite, tuff, conglomerate, lava, jaspilite, banded iron formation, chert and tillite. The group forms the upper part of the Transvaal Sequence and consists mainly of quartzite and shale, which has been intruded by andesite and diabase dykes and sills. The group contains ore of which iron, asbestos, fluorite, manganese, kaolin, andalusite and diamonds are the most common. The quartzite is resistant to weathering and forms the prominent ridges to the north of the West Rand dolomites. (Kok, 1972)

This Group unconformably overlies the Malmani Subgroup and outcrops at the northern boundary of the dolomitic compartment. The base of the group is formed by the Rooihoogte Formation, which contains chert breccias, quartzitic sandstone and shale layers. The dip in this formation ranges between 4° and 15° northwards. (Polivka, 1987)

2.3.3 Structural Geology

Visible diabase outcrops were identified on the farm Almoro 107 IP, for a distance of 640 m. The East-West dyke intersects the farms Almoro 107 IP, Avondzon 88 IP and Morgenzon 42 IP, and was delineated with the help of magnetic geophysical surveys. A wide North-South dyke (91 m) is found on the farm Almoro, crossing the East-West dyke and splitting into 4 dykes, with each arm found on the following farms; (1) Morgenzon to Klipgat, (2) Illmasdale, (3) Wildebeestlaagte to Ryedale and (4) Illmasdale to Wildebeestlaagte to Wolvefontein. (Erasmus, 1967)

The thick cover and deep weathering of the dykes is the reason why no outcrops are found on the surface topography. Lineaments were traced from aerial photographs and later confirmed in the field, by means of magnetic geophysical surveys, and steps in the groundwater level. Two basic trends in dykes appear in the study area, namely North-Northwest to South-Southeast and West-Southwest to East-Northeast. Structures were digitised from the map that Polivka compiled and is illustrated in Figure 2. (Polivka, 1987)

The NNW-SSE trending fault intruded by a dyke separates the Groot Marico Compartment in the North from the Schoonspruit Compartment. The Mooi River Compartment lies to the East of the Schoonspruit Compartment (Kotze, 1994). The massive dolomite also appears to be brittle and intensive tectonic processes have produced extensive joint and fault systems. These structures initiate karstification of the dolomite, both horizontally and vertically. (Polivka, 1987)

2.3.4 Borehole Logs

Geological logs of over 100 boreholes exist on the NGDB (National Groundwater Database) in and close to the compartment. Valuable information was obtained through these logs and it was decided to include the 9 borehole logs, available on the database, of the monitoring boreholes described in section 2.7, as well as borehole logs that confirm structures and boundaries as described in sections 2.3.3 & 2.4.3. Positions of the boreholes are shown in Figure 3 and the borehole logs have been added in APPENDIX A, with an example of a log in Figure 4. The order of the borehole logs in APPENDIX A is the same order in which the borehole logs are discussed below.

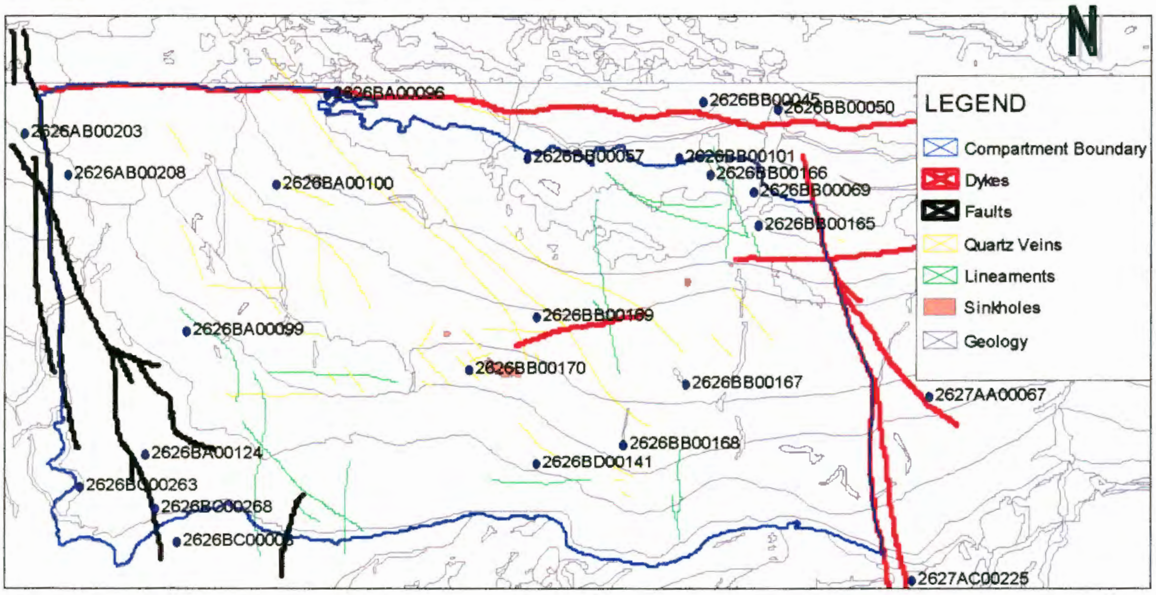


Figure 3: Positions of the boreholes with geological logs as described

Monitoring borehole logs:

- 2626BA099: Chert to a depth of 40m followed by fractured dolomite.

- 2626BA100: Clay up to a depth of 9m followed by hard dolomite. Fractured dolomite is found at 34-36m.
- 2626BB165: Chert up to a depth of 33m followed by pegmatite.
- 2626BB166: Shale up to a depth of 50m followed by fractured dolomite.
- 2626BB167: Chert up to a depth of 25m followed by dolomite to a depth of 64m, shale up to 69m and stopping again with dolomite.
- 2626BB168: Chert up to a depth of 27.5m.
- 2626BB169: Chert up to a depth of 21m followed by weathered and, thereafter, fractured dolomite.
- 2626BB170: Chert up to a depth of 16m followed by dolomite.
- 2626BD141: Dolomite to a depth of 50m followed by a meter of shale, stopping again in dolomite.

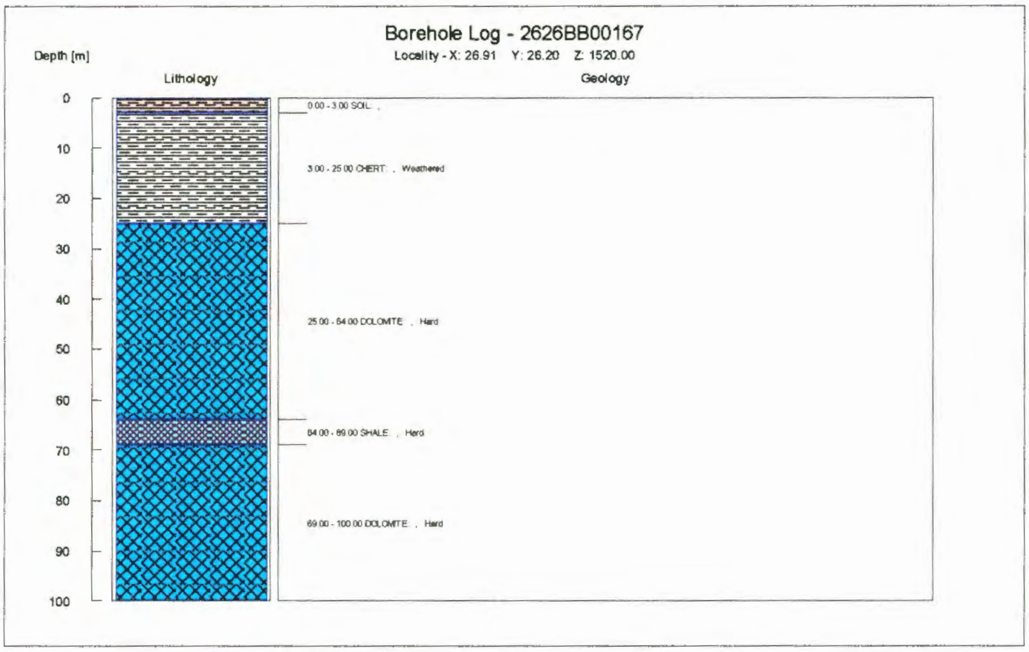


Figure 4: Example of a geological borehole log

Boundary borehole logs:

- 2626BA096 & 2626BB045: Confirming the Northern boundary (EW dyke), between the Schoonspruit and Grootpan compartments.
- 2626BB050, 057, 069 & 101: Confirming the contact and depth of contact between the dolomitic compartment and the Rooihoogte Formation in the North.
- 2627AA067 & AC225: Confirming two arms of the Eastern boundary (NS dyke), between the Schoonspruit and Mooiriver compartments.
- 2626BA124 & BC263: Confirming the Black Reef Formation to the South of the compartment.
- 2626AB203, 208, BC008 & 268: Confirming the Western boundary (NS fault system, intruded by diabase) of the Schoonspruit compartment, borehole BC008 showing the fault system continuing into the Ventersdorp lavas.

Borehole logs are a valuable set of data and these have once more confirmed the geology and structures associated with the dolomitic compartment.

2.4 Geohydrology

The physical and geohydrological characteristics of formations in an area will determine the groundwater occurrence and availability, and is determined by the following factors (Vegter, 2001):

- Storage and transmissive properties of the geological formation.
- Volume and frequency of recharge.
- Rate of groundwater movement to discharge points/areas.
- Rate of groundwater discharge as springs and effluent seepage in streams.
- Loss through evapotranspiration, leakage and/or abstraction.

Recharge also depends on (Vegter, 2001):

- Rainfall – the volume, intensity, frequency and temporal distribution.
- Availability of surface water.
- Land surface configuration
- Soil and vegetation cover.
- Subsurface moisture retention and evapotranspiration.

Groundwater systems are driven by recharge, but this does not necessarily mean that it determines the sustainable groundwater supply (Vegter, 2001).

This report further explains that in hard-rock formations exploitable groundwater is found in weathered and fractured rock that lies below the surface and is generally less than 50 m deep. The rate of groundwater movement is also determined by the hydraulic gradient (head), which depends mostly on surface topography. The thickness and hydraulic properties of the weathered and fractured layers depend on the following factors (Vegter, 2001):

- Mineral composition and texture of rocks.
- Degree of tectonic deformation and fracturing.
- Degree of non-tectonic fracturing – sheet jointing and thermal shrinkage.
- Amount of dissolved oxygen and carbon dioxide in the percolating water.
- Climate (rainfall and temperature, past and present).
- Age of the land surface.
- The relief.

Groundwater flow rates control the rate of chemical weathering by the extent to which hydrogen ions and dissolved oxygen is supplied. The flow rate in turn depends on the availability of recharge, the permeability of the weathered material and hydraulic gradient between recharge and discharge areas. The hydraulic conductivity is a function of the chemical weathering and therefore linked to the historical groundwater flow through the system. A complex interaction exists between the occurrence and chemical character of groundwater and the weathering processes responsible for the water-bearing character of weathered hard rock formations. (Vegter, 2001)

In the dolomitic region this is important as introduction of atmospheric CO_2 together with rainfall, forms a weak acid and dissolves the dolomitic rock. Higher rainfall and higher infiltration rates leads to more dissolution of the dolomite and the hydraulic properties of the rock is enhanced. This is the major governing factor in the formation of karst features and will be explained in detail in section 2.4.2.2.

Groundwater regions consist mainly of secondary water-bearing formations, on the basis of both lithostratigraphy and physiography. The groundwater region no. 10 (the Karst Belt) composed of Vaalian Strata is defined as: Consisting of sedimentary rock types, the principal water bearing rocks are the Chuniespoort dolomite and chert, subordinate Black Reef quartzite, conglomerate and shale. (Vegter, 2001)

As can be seen, the geohydrology of an area is very dependent on the geology of the area, for the geological properties will determine the water bearing properties of any given layer or strata. Therefore the geohydrology of the Ventersdorp Supergroup and the Transvaal Sequence will be dealt with separately and is illustrated in Figure 5.

2.4.1 The Ventersdorp Supergroup

The overall geohydrology of the Ventersdorp Supergroup can be described as a system with good groundwater storage capacity and boreholes' yields vary from 0.14 to 278 l/s, with higher yields occurring in areas where water is being abstracted out of weathering basins in the igneous rocks (Kok, 1972). The Ventersdorp lava is only water bearing in its upper-most weathered zone and secondary developed fractures (Polivka, 1987).

2.4.2 The Transvaal Sequence

2.4.2.1 The Black Reef Formation

The Black Reef Formation is only water bearing in its upper-most weathered zone and secondary developed fractures (Polivka, 1987).

2.4.2.2 The Malmani Subgroup

The Schoonspruit Compartment study area covered an area of about 1900 km^2 and the most representative morphological feature in the area is that of sinkholes and depression valleys, with gentle slopes, spread out all over the compartment due to karstification (Polivka, 1987).

Karst comprises of distinctive landforms and hydrology because of a combination of high solubility of rocks and well-developed secondary porosity, illustrated in Figure 6. The main features can be divided into erosional and depositional zones. The erosional zone being the zone of net removal of karst rock and the depositional zone the zone where new karst is being formed. The landforms that form karst, above and below ground, develop as a result of solution along preferential pathways and can be viewed as an open system integrating hydrological and geochemical processes. (Ford & Williams, 1989)

The dolomites are well known for the formation of caves and canals (both are Karst features) and this occurs when rainwater with carbon dioxide (CO_2) in solution forms a weak acid that dissolves the carbonate rocks (Kok, 1972). Carbonate rocks contain more than 50% carbonate minerals by weight and two common end members of the series exist, limestone (calcite or aragonite) and dolostone (dolomite). The solubility of these minerals in pure water is very low and only increases to a point where solution can take place due to the hydration of atmospheric CO_2, which is fairly abundant in most carbonate terrains. Carbonic acid is produced in turn and solution further enhanced. The dissolution of CO_2 in water and its reaction with dolomite, can be written as follows (Ford & Williams, 1989):

Equation 1

$$\mathrm{Ca\,Mg\,(CO_3)_{2\,(s)} + 2CO_2 + 2H_2O \leftrightarrow Ca^{2+} + Mg^{2+} + 4HCO_3}$$

ENLARGED LEGEND FIGURE 5

■	Springs
—	Sinkholes
—	Quartz Veins
—	Lineaments
- - -	Faults
—	Dykes.shp
—	Main Roads
—	Rivers
🟦	Dams
🟨	Settlements
☐	Lithology boundaries
🟩	Schoonspruit boundary
☐	Ventersdorp Eye GWCA

PRINCIPAL GROUNDWATER OCCURRENCE

Aquifer Types :

	🟨	Vp
Fractured :	🟩	b3
	🟩	b4
	🟩	b5
Karst :	🟩	c2
	🟩	c3
	🟩	c5
Intergranular and fractured	🟨	d2
	🟧	d3
	🟧	d4
	🟧	d5

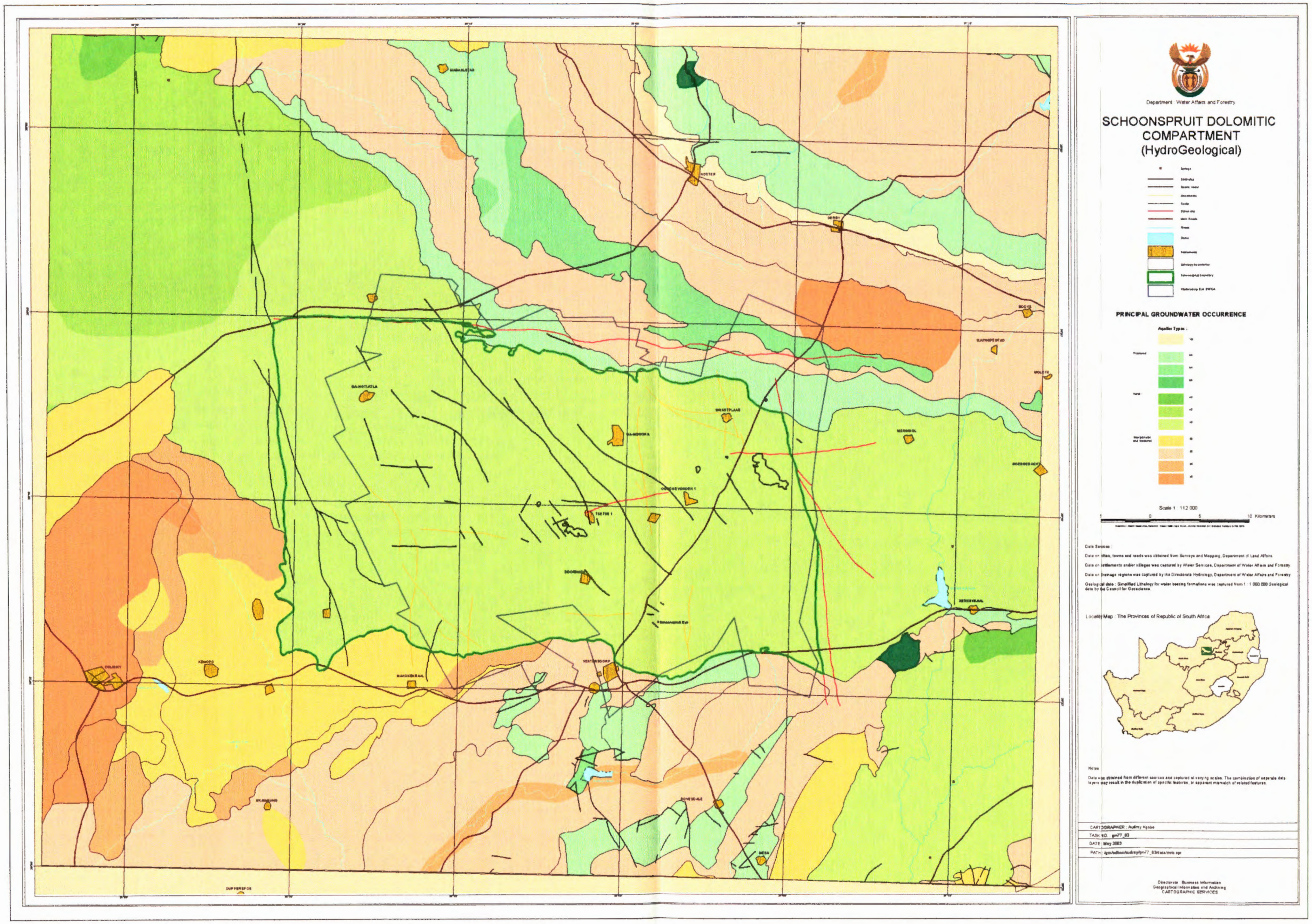


Figure 5: General Geohydrology of the Schoonspruit Dolomitic Compartment (Geomatics, DWAF)

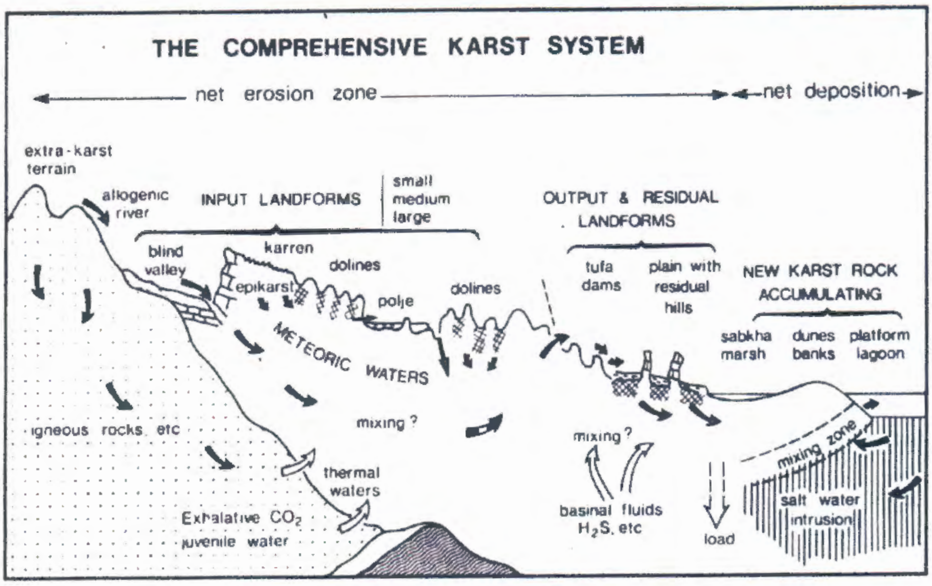


Figure 6: A composite diagram illustrating the major phenomena encountered in active karst terrains. (Ford & Williams, 1989)

The dissolution process can be further described as follows: The dolomite is soluble in a weak acid and, over geological time, this has caused dissolution of the rock along zones where groundwater movement is present. Therefore this dissolution would have been more pronounced along fault zones, contact zones and intrusions. Polivka, 1987, explains that a correlation exists between the development of sinkholes and depressions with structural features. The surface structures give way to preferential water flow, therefore enhancing dissolution of the dolomite. Surface drainage also occurs through underground canals or conduits via sinkholes or networks of joints and cracks. High yielding boreholes are commonly associated in the area with 'underground rivers', which might be explained by karstification, but such claims must be confirmed. These flow conduits also seem to be controlled by the direction of the quartz veins, which in turn extends towards the Schoonspruit Eye. (Enslin, 1971)

Karstification is the major process in the weathering of carbonate-rocks, and dissolution mainly occurs at the phreatic level, where meteoric water passes through more rapidly and ion exchange can take place. Contact zones in the host rock (dolomite) forms differential pathways for rapid infiltration of meteoric water, e.g. intrusive dykes or chert sheets. It is because of these characteristic that dolomites develop a higher permeability. (Fleisher, 1981)

The high borehole yields are a good groundwater system for the provisioning of water and groundwater occurrence in the dolomite is described as compartments, which are hydraulically linked and compartmentalised through geological features such as fault zones, geological layers and intrusive dykes and sills (Enslin, 1971). The sizes of the different compartments vary greatly and groundwater storage is dependent on the Karst features (Kok, 1972). Where natural recharge of the dolomitic aquifer is less than groundwater losses, through evaporation, abstraction, etc., groundwater will leave the system at the lowest topographical point and an eye or fountain may develop (Kok, 1972 & Enslin, 1971). Historically these eyes or fountains have been used as surface water resources since before the 20th century. Recharge of the aquifer system is generally described as a percentage of rainfall, but only a certain amount of this recharge can be abstracted out of the groundwater system due to certain factors that has to be taken into account. Enslin, 1971, however, stated that in the dolomitic environment it is possible to abstract the total amount of recharge due to the specific geological properties. This groundwater resource is therefore very valuable for water provisioning, irrigation, industrial and mining purposes. Boundaries of the dolomitic compartments rarely coincide with surface water catchment boundaries and surface water runoff from dolomitic terrains only occurs during very high rainfall events. The contributions from these compartments to the surface water bodies in their immediate vicinities can only be attributed to fountains and eye flows from the topographical lows. (Enslin, 1971)

The dolomitic aquifer of the Schoonspruit dolomitic compartment consists of four different formations (Polivka, 1987). Of these the chert-rich formations, Monte Christo and Eccles, are better aquifers compared to the chert-poor formations, Oaktree and Lyttleton, and boreholes drilled on fault intersections also gave high yields (>10l/s) (Kotze, 1994). The strata dip northward and are overlain by the Pretoria Group. Average borehole yields differ for the different formations and were tabled as follows by Polivka, 1987:

Table 1: Average borehole yields (Polivka, 1987)

Formation	Ave Yield (l/s)	No of Boreholes
Eccles	**11**	**150**
Lyttleton	**3**	**40**
Monte Christo	**12**	**500**
Oaktree	**6**	**160**

Locally more favourable yields are associated with structures such as faults or dykes. In the Northeast side of the compartment the dolomite appears to be massive since some boreholes in this area were drilled up to 100 m without intersecting any groundwater. The groundwater level in the area indicates that most of the drainage is towards the Schoonspruit Eye. (Polivka, 1987)

The distribution of boreholes showed that the dolomitic formations that are chert-rich, associated with quartz veins and where dykes and/or other structures are present, are the most productive aquifers i.e. the Eccles and Monte Christo Formations. Surface deposits in the area do not influence infiltration from precipitation to a large degree, but alluvial clays do cause local confinement of the dolomite and can cause certain boreholes to overflow after heavy rains. The importance of dykes in the study area is that they act as partial water barriers because of their low permeability, and quartz veins influence the natural groundwater flow since they have caused a degree of compartmentalisation within the dolomite. The groundwater conditions can be classified as unconfined to semi-unconfined in some places and a North-South groundwater divide exists between Nooitgedacht and the Commonage of Ventersdorp. (Polivka, 1987)

The Schoonspruit dolomitic compartment is classified, by Vegter, 2001, as early Cretaceous African surface as principal cyclic land surface and having a good probability of a successful borehole yielding more than 2l/s.

2.4.2.3 The Pretoria Group

Limited information is available regarding the borehole yields in this series, but it is mentioned that it varies from 0.14 to 16.67 l/s of which the higher yields are intercepted in the shale (Kok, 1972).

2.4.3 Boundaries

The physical boundaries of the Schoonspruit Dolomitic Compartment was defined as the following (Polivka, 1987):

- The northern boundary formed by the contact with the Rooihoogte Formation (Pretoria Group) and an E-W dyke (nearly impermeable with water level step of 25 m) running along the Koster - Lichtenburg road,
- The eastern boundary formed by the NNW-SSE dyke approximately on 27° longitude (almost impermeable with water level step between 15 and 20 m),
- The western boundary formed by the North-South running fault system following approximately 26°30' longitude in the West (water level step of 10 m), and
- The southern boundary formed by the contact with the Black Reef Formation.

During the study, the farms in the area were surveyed and over 1200 boreholes identified. The water level steps across the dykes and fault system indicated the compartmentalisation of the dolomitic aquifer, with impermeable dyke and fault systems (Polivka, 1987).

The proposed area delineated by Polivka as the Schoonspruit Dolomitic Compartment, as derived from Enclosure 1 of the report of 1987, included 91 farms as listed in APPENDIX B and shown in Figure 2 & Figure 5.

2.4.4 Groundwater Levels

Groundwater level contours were used to delineate the compartments. Fleisher, 1981, pointed out that westerly striking dykes do not actually function as groundwater barriers. It was found that in demarcated compartments the water level forms a continuous plane with very flat gradients, which is seldom steeper than 1:250 (i.e. a 1m drop over a distance of 250m). Cones of depression develop in areas where groundwater is abstracted as well as upstream of dolomitic eyes or springs. It was stated that if continuity exists in the water levels over a supposed barrier according to the applicable groundwater hydraulic equations, then the structure does not form a barrier. Therefore, outflow and inflow of groundwater within the dolomitic compartment can be distinguished via water level contours relating to the point of discharge. If the water level contours are bent upstream then outflow seepage takes place, if it is bent downstream inflow seepage takes place. (Enslin & Kriel, 1960)

2.4.5 Groundwater Chemistry

65 groundwater samples were taken during May 1978 and it was found that the concentration of sulphate was very low and instances where it did occur, it was probably due to external influences. Concentrations of nitrate were considerably higher than was expected, and exceeded values from other dolomitic compartments. The reason for this is probably contamination from livestock wastes or fertiliser application. It was also mentioned that the most commonly applied fertiliser at the time was 3:2:1 and the application rate recommended was 300kg/ha/crop. (Fleisher, 1981)

The groundwater in the compartment was classified as typically hard to very hard and moderately alkaline, with a total dissolved solid content ranging from 200 to 748 mg/l. The dolomitic water is predominantly calcium-magnesium-carbonate with a Mg/Ca ratio ranging between 1.2 and 1.8, although one would expect a ratio of 1 in dolomitic areas and if not, one would definitely not expect Mg to be at a greater concentration than Ca. The groundwater is of good quality and of fairly recent origin, therefore recently recharged and typical of a dolomitic groundwater. (Polivka, 1987)

2.4.6 Aquifer Parameters

The average transmissivity of the dolomites was calculated as 3000 m^2/d. The specific yield of a dolomitic compartment was calculated as ranging between 4.34% and 9.07%. The recharge of a dolomitic compartment was calculated as 10.57% of annual rainfall, with the best reliable data set at the time. (Enslin & Kriel, 1960)

Polivka, 1987, estimated aquifer parameters as:

- Transmissivity, through the use of groundwater contour maps, estimated as 31 149 m^2/d.
- Baseflow towards the river beyond the gauging station, estimated at 0.182 Mm^3/d.
- Transmissivity of 12 m^2/d was used over the outflow boundaries.
- Recharge of the dolomitic aquifer from rainfall was calculated as 59.7 Mm^3/a.
- The volume of groundwater stored in the dolomitic compartment was calculated as approximately 1 440 Mm^3, assuming an average water level of 23 m below surface, a specific yield of 3 % and 30 m of leached and fractured dolomite below the present water level.

Rainfall recharge studies conducted on similar geohydrological compartments indicated recharge values of 8.9.to 10 % of average rainfall (Kotze, 1994).

Recharge for the Schoonspruit Dolomitic Compartment was calculated, on average, as 9 % of average rainfall and amounted to 57 Mm^3/a for the dolomitic aquifer (Kotze, Dziembowski & Botha, 1994).

2.4.7 Dolomitic Springs

The yield of the dolomitic spring, Schoonspruit Eye, of which the catchment area only recharges from part of the dolomitic compartment, was calculated in 1972 as 7180 M Gallons/a or 32.63 Mm^3/a (Kok, 1972).

Since 1966 reliable flow of the Schoonspruit Eye was measured and recorded at the C2M hydrology measuring station and gauged at station C2M40. The first of the springs feeding the eye originates at the contact of the Monte Christo oolithic chert and banded chert layers. The compartment recharges six springs in the area of which the Schoonspruit Eye is the most prominent and originates from an approximate area of 5 km^2. The total measured spring flow for 1986, of 55.4 Mm^3/a, included flows from five of the six springs (Schoonspruit Eye - 52.78 Mm^3/a). The municipality of Ventersdorp and two large irrigation boards were utilising the Schoonspruit Eye flow respectively, for drinking water and irrigation of 2400 ha out of the surface water body. The decrease in flows from 1980 to 1986 could have been due to different factors, including decrease in rainfall, therefore decrease in recharge to the groundwater system, and increase in irrigation abstraction from groundwater in the compartment. (Polivka, 1987)

2.4.7.1 Spring Flow Simulation

With the help of flow simulation, it was calculated that the dolomite needs at least an annual rainfall above 313 mm to be recharged, and even then only 30 % of the rainfall in excess of this value contributes to the annual recharge. The effective recharge area to the eye was estimated at 760 km^2, and it was determined that the eastern portion of the study area represented a large groundwater potential, where the yield could be further exploited. Reconstruction of the flow also showed that 50 % of the flow is determined by the previous year's flow contribution, and this is an indication that aquifer storage is relatively high. (Polivka, 1987)

Bredenkamp & Swartz, 1987, simulated the flow of the dolomitic spring with the help of estimated annual recharge by means of Equation 2:

Equation 2

$$RE\ (I) = A.\ (RF\ (I) - B)$$

RE (I) – annual recharge

RF (I) – annual rainfall

A – lumped catchment parameter = 0.3

B – threshold rainfall = 313mm

A & B implies that mostly 30% of rainfall above 313mm contributes to annual recharge in dolomitic areas. The simulation is shown in Figure 7.

For the Schoonspruit Eye A had to be adjusted and another factor C incorporated into the equation, forming Equation 3.

Equation 3

$$RE\ (I) = A.\mathbf{RF}\ \{1 - C.\mathbf{RF}/RF\ (I)\}$$

RF – average rainfall

C.**RF** – B (threshold rainfall)

The values for A & C were calculated as A (0.66) and C (0.8), via trial and error, and is shown in Figure 8 (Bredenkamp & Swartz, 1987)

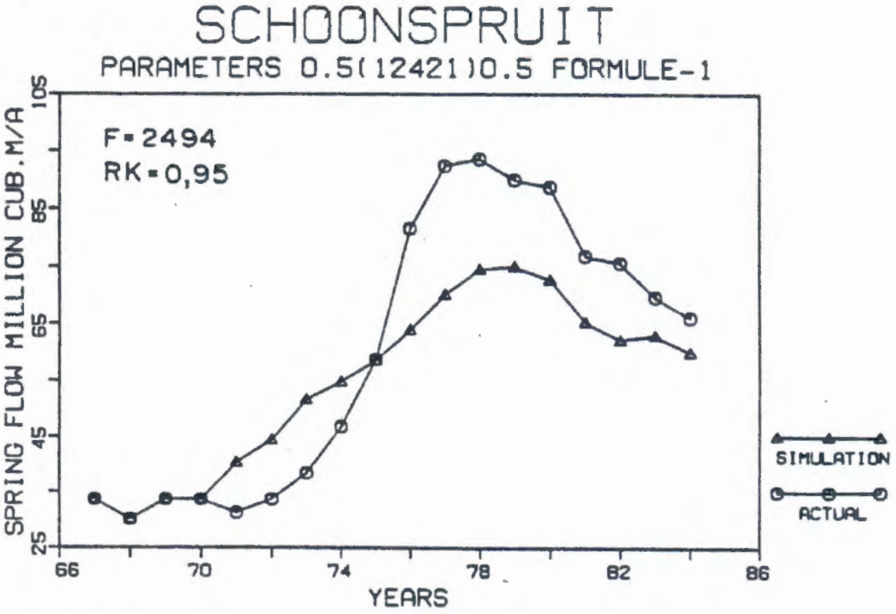


Figure 7: Comparison between measured and simulated flows to estimate recharge, using equation 2. (Bredenkamp & Swartz, 1987)

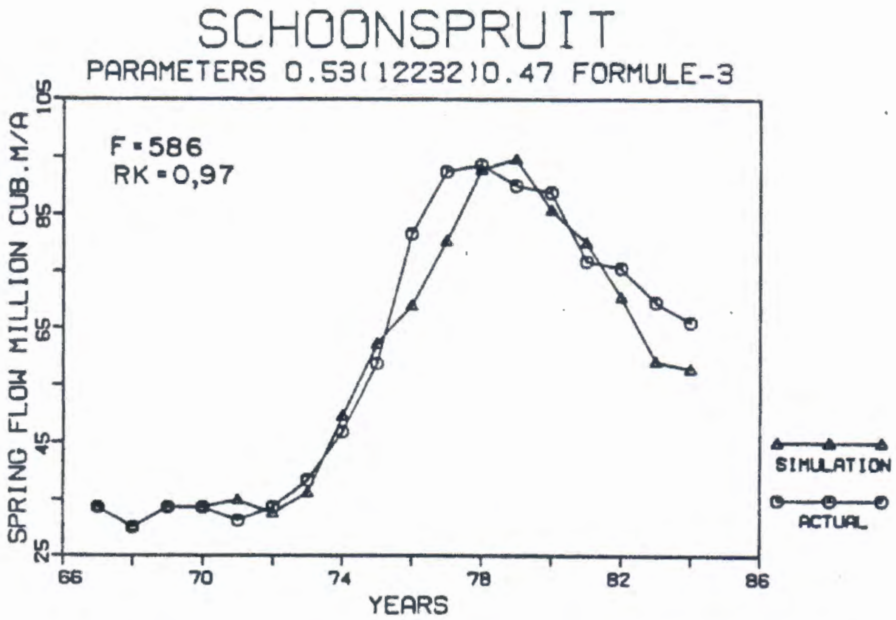


Figure 8: Improved correspondence between measured and simulated flows to estimate recharge, using equation 3. (Bredenkamp & Swartz, 1987)

Bredenkamp & Swartz, 1987, further said that average spring flow is sustained by average recharge over an effective area and was simulated with Equation 4:

Equation 4

$$QR = RE.AREA$$

QR – average spring flow

RE – average recharge

AREA – effective recharge area

The preceding year's flow had to be incorporated for better simulation of the springs. Use of rainfall from different rainfall stations also improved the degree of simulation. This dependency of spring flow on the previous year's flow is an indication of the significant transient storage of groundwater. An improvement in the simulations was obtained by incorporating recharge for the present year (I) and the four preceding years. The relative proportion of recharge for the Schoonspruit Eye was 30% for year one, 20% for year 2 to 4 and 10% for the year 5. (Bredenkamp & Swartz, 1987)

The recharge determinations of the spring flow discussed in this section will be evaluated and discussed in detail in section 3.4.7.2.

The catchment area of the Schoonspruit Eye, based on the groundwater level contour map, was delineated with 52 farms included in the catchment area. The farms are listed in APPENDIX B. (Kotze, 1994)

It was determined in 1994 that the flow in the Schoonspruit Eye had decreased dramatically over time from a maximum of 8.5 Mm^3/month in 1979 to a minimum of 1.9 Mm^3/month in 1994. Average annual flow rates varied between 5.64 Mm^3/month (1971 – 1986) to 2.9 Mm^3/month (1987 – 1993) to 1.96 Mm^3/month (April 1994). The position of the weir had changed from the 200m upstream 'Bovenste Stuwal' before 1968, to gauging station C2F064 in 1969, because of the large amount of water that had escaped over the 'Bovenste Stuwal'. In 1994 flow was measured at two gauging stations C2H064-A01 (weir) and C2H109-A01 (channel) and the flow of the spring was calculated as the sum of these two stations. It was determined that the yield of the eye had gradually decreased since 1979 to 1987, but it could have been attributed to a decrease in rainfall. The flow rate further decreased from 1987 to 1994 even though the average rainfall (Rf) had stayed approximately the same. The recharge in dolomitic areas was taken as an average of between 8.9% and 10%. (Kotze, Dziembowski & Botha, 1994)

Rainfall in arid areas typically has large spatial differences in precipitation. Three rainfall stations were chosen to calculate average rainfall for the area namely 473/025, 473/559 and 474/198. Average rainfall for the period 1963 – 1994 was calculated as 52.67 mm/month. (Kotze, Dziembowski & Botha, 1994)

The total area covered by reeds at the Schoonspruit Eye wetland area was 271 ha in 1994, compared to 236 ha in 1975. The area covered by reeds has therefore expanded by 35 ha. Water losses due to evapotranspiration were therefore 5.783 Mm^3/a (1994) compared to 5.036 Mm^3/a (1975). This increased loss in volume of water through evapotranspiration was only 0.747 Mm^3/a and could not lead to the drastic decrease in flow of the Schoonspruit Eye. (Kotze, Dziembowski & Botha, 1994)

Kotze, Dziembowski & Botha, 1994, also simulated groundwater level variations by means of the Cumulative Rainfall Departure (CRD) with Equation 5:

Equation 5

$$CRD_I = Rf_I - ARf + CRD_{I-1}$$

i – monthly time increment

Rf – rainfall

ARf – average rainfall

As spring flow is dependent on groundwater levels, this method was used for the simulation of the spring flow. Aquifer characteristic changes during wet and dry cycles and the equation was adopted to include the short and long term 'memory' of the aquifer system. The short term 'memory' being the delayed effect of recharge ($n = 9$ months) and the long term 'memory' being the natural losses of the aquifer system depended on the current status of the aquifer ($m = 96$ months). The difference in actual spring flow and simulated spring flow simulated with this method was evident and shown in Figure 9.

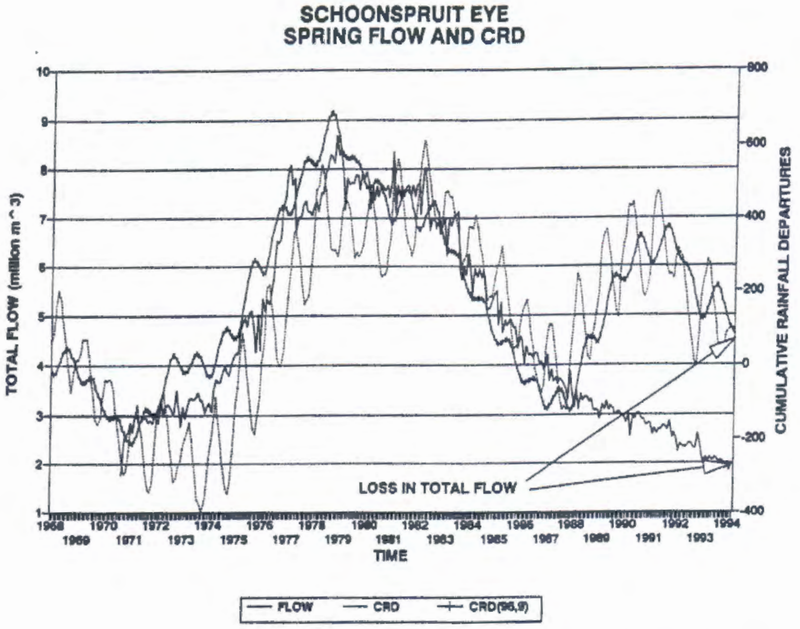


Figure 9: Comparison between the Cumulative Rainfall Departures from the mean and the flow of the Schoonspruit Eye. (Kotze, Dziembowski & Botha, 1994)

Spring flow according to the simulation should have increased, contrary to the actual decrease since 1987. (Kotze, Dziembowski & Botha, 1994)

2.4.8 Groundwater Balance

The groundwater potential analysis showed that most of the recharge was being used for irrigation and that the area of water use for irrigation should be limited, in view of apparent over abstraction at the time. The groundwater level showed rapid recovery after heavy and sustained rainfall. (Polivka, 1987)

Polivka, 1987, further defined the influence of the geohydrological boundaries on the groundwater balance:

- Inflow of groundwater occurs through the eastern and northern boundaries.
- Groundwater supplies the river beyond the gauging station, estimated at 0.182 Mm^3/d.
- Groundwater outflow occurs through the southern boundary, the western and south-western boundary (estimated at 6.33 Mm^3/a).
- Estimated abstraction out of the compartment at the time was calculated as 34.8 Mm^3/a (31.8 Mm^3/a from irrigation). It was assumed that irrigation practices did not allow for infiltration of irrigated water back into the groundwater system.
- Recharge of the dolomitic aquifer from rainfall as 59.7 Mm^3/a.
- Losses from spring flows amounted to approximately 26.2 Mm^3/a, of which the municipality was using on average 6.81 Mm^3/a.
- Groundwater stored in the dolomitic compartment, at the time, was calculated as approximately 1 440 Mm^3.

These estimated volumes indicated that adequate groundwater reserves were available at the time to cope with the demand at the time. (Polivka, 1987)

With the help of groundwater level contour maps, Kotze, 1994, found that:

- Inflow occurs at the north-western corner of the compartment where water probably enters the compartment via the fault system. This indicated that the westerly striking dykes do not function as an impermeable boundary between the compartments.
- The water level contours indicated the presence of a North-South trending watershed in the west. This prevents groundwater from the west recharging the Schoonspruit Eye.
- Some groundwater outflow existed in the south-western corner of the Schoonspruit compartment recharging the Ventersdorp lava.
- The steeper groundwater gradients to the East were an indication of an impermeable boundary with groundwater overflow to the Mooi River Compartment.
- The statement was put forward, that a possible perched water table exists in the Pretoria Group in the north-east corner of the compartment. Geological logs and geophysical borehole logging would have provided clarity on the matter. (Kotze, 1994)

2.4.9 Summary

The Schoonspruit Dolomitic Compartment is a complex system, with various aspects playing a role in the groundwater flow regime. The geohydrological boundaries have been defined, groundwater levels are relatively flat, water quality are generally very good and flow at the spring has decreased as a result of various factors. This shows that the catchment area of the Schoonspruit Eye needs some form of protection for sustainable flows, but a part of the dolomitic compartment does not fall within this area and can be utilised when done sustainably. Factors such as karst features, variations in rainfall, ability to handle contamination and hydraulic gradients towards outflow points all contribute to the yield and sustainability of use from the whole dolomitic compartment.

It is apparent that the Schoonspruit Dolomitic Compartment has been impacted on with regard to groundwater use, but that rainfall also plays a major role in the recharge mechanism of the geohydrological environment and therefore a management tool for groundwater balances, as well as a mechanism to predict future use, is of the utmost importance in the dolomitic environment.

2.5 Water Users

This section gives an overview of the water use situation as it was at the specified times, in order to compare it with the present water use situation. This is crucial for understanding how the system reacted on external influences at the time, versus how it is reacting at present.

2.5.1 Agriculture

Cultivated lands had replaced most of the natural grassland in 1987 and the main crops were maize, sunflower, wheat, vegetables and Lucerne. The only natural grass veldt seemed to be on outcropping hard rocks due to the restriction of development of arable land. (Polivka, 1987)

Irrigation requirements and uses indicated that groundwater use in the compartment exceeded that of the crop requirements and unnecessary groundwater losses occurred, with excess irrigation calculated up to 84%. The average yield of a windmill was calculated as 700 m^3/a for a windmill with a wheel diameter of 3 m and a pipe size of 51 mm. The agricultural potential of the area showed the following: land available for farming (137 000 ha), land not available for farming (4 000 ha), arable land (35 000 ha) and pasture land (35 000 ha). Some 4000 ha (2% of the area) were irrigated during the 1986/87 agricultural season and the live stock units showed considerable overgrazing, up to 70%, of the area (42000 cattle and 12000 sheep). (Polivka, 1987)

In 1994 results from various reports were compared and it could be seen that irrigation requirements per ha ranged between 9102 and 9125 m^3/a. An excellent relationship was found between the theoretical water requirements per ha and the electrical power (Kwh) readings converted to $3.34m^3/Kwh$. This value corresponded to the similar value of 3 – 4 m^3/Kwh according to engineering standards. The water used for irrigation in 1986 was assumed to be 21.5 Mm^3/a for the whole dolomitic compartment of Schoonspruit. (Kotze, Dziembowski & Botha, 1994)

2.5.2 Mining

Residual red soils, rich in iron and manganese oxides and hydroxides, are common in the area and a typical weathering product of the underlying dolomite. Alluvial diamonds and manganese nodules were mined throughout and are remnants of N-S paleo-river valleys. Brecciated quartz veins occur with a NE-SW direction and mostly appear not to have any prevalence for water occurrence, although some exceptions exist. (Polivka, 1987)

2.5.3 Domestic

The water used for household and stock watering in 1994 was quantified as 2 Mm^3/a for the whole Schoonspruit dolomitic compartment. (Kotze, Dziembowski & Botha, 1994)

2.5.4 Downstream

The downstream users of the Schoonspruit were considered as the wetland area, Ventersdorp municipality, the Schoonspruit Governmental Water Scheme (SGWS) and the Klerksdorp Irrigation Board (KIB). The total annual release needed for the four users were calculated in 1994 as 36.6 Mm^3/a, taking losses due to evaporation, friction, etc. into account. At the time the average flow out of the eye amounted to 34.48 Mm^3/a, and therefore the flow at that stage was insufficient to supply the downstream users. (Kotze, Dziembowski & Botha, 1994)

2.6 Ventersdorp Eye SGWCA

The most likely explanation that could be given for the decrease in the flow of the Schoonspruit Eye was that of over abstraction from the dolomitic aquifer, and it was necessary to control irrigation activities out of the Schoonspruit Dolomitic Compartment. (Kotze, Dziembowski & Botha, 1994)

The Minister of Water Affairs and Forestry, according to section 28 of the Water Act, 1956 (Act No. 54 of 1956), proclaimed the catchment area of the Schoonspruit Eye, as the Ventersdorp Eye Subterranean Government Water Control Area, as proclamation no. 777 of 2nd June 1995 in the Government Gazette (Schoeman & Partners, 1996).

Section 31 of the Water Act, 1956, stipulates that after such a proclamation it was necessary to do a census of such an area to quantify the properties, users, uses and volumes in the control area. This census was done from June 1995 to April 1996. Aerial photographs were used to delineate property boundaries, visits to farms were the method of gathering detailed information and compilation maps were produced to give a summary of the information gathered during the census. Files for each property were opened where information gathered for the properties were stored. (Schoeman & Partners, 1996)

A survey was conducted by Schoeman and Partners in 1996 and yielded the following information for the Ventersdorp groundwater control area:

Schoeman & Partners, 1996, have included 9 additional farms with the original 52 selected by Kotze (1994) as the catchment area of the Schoonspruit Eye and excluded one farm from the original 52 selected by Kotze (1994). A list of the farms are given in APPENDIX B and shown in Figure 5.

The number of topocadastral farms included in the proclamation totalled 60, and information gathered by Schoeman & Partners, 1996, included the following:

- Average yearly rainfall (604 mm) and rainfall records for the station Dwarsfontein 511120 were used for the calculation.
- Average yearly A-pan evaporation (2134 mm)
- Amount of farms visited (59)
- Amount of properties visited (470)
- Total amount of boreholes (1412), of which 721 were active and 691 were inactive.
- Total irrigation area at the time (2722.5 ha), percentage of crops irrigated in summer (49.3%), in winter (22.1%), throughout the year (28.6%), and the main crop types were maize, wheat, grazing and vegetables. The irrigation requirement added up to 8225 m^3/ha, if irrigation was practised correctly, and therefore, the total volume of groundwater needed for irrigation at this time was 22.39 Mm^3/a. This volume of water would fulfil the irrigation requirements for at least 80% of the time.
- The volume of groundwater needed for other uses was 1.78 Mm^3/a. This did not include water related to mining activities.
- The total abstraction of water out of groundwater was therefore estimated at 24.17 Mm^3/a.
- Arable land in the control area added up to 52000 ha.
- Landowners and four communities (Ga-Motlatla, Ga-Mogopa, Goedgevonden and Tsêtsê) were dependent on the groundwater for daily needs.

2.7 Monitoring

The Department of Water Affairs & Forestry's Hydrometry Section in the Gauteng Province does water level monitoring on a monthly base. Table 2 gives a list of the boreholes that are currently being monitored, in and around the compartment, which will be used as part of the evaluation in *Chapter* 3.

Table 2: List of water level monitoring boreholes

SITE ID	G-NO	Hydrological Gauging Station	Reporting Institution
2526DC00029	**39316**	**C2N1039**	**WA-G**
2626AB00002	**39317**	**C2N1022**	**WA-G**
2626AB00051	**39318**	**C2N1035**	**WA-G**
2626AB00052	**39569**	**C2N1036**	**WA-G**
2626AB00053	**39571**	**C2N1034**	**WA-G**
2626AB00054	**39570**	**C2N1037**	**WA-G**
2626BA00099	**39319**	**C2N1023**	**WA-G**
2626BA00100	**39315**	**C2N1024**	**WA-G**
2626BB00165	**39307**	**C2N1025**	**WA-G**
2626BB00166	**39308**	**C2N1026**	**WA-G**
2626BB00167	**39309**	**C2N1027**	**WA-G**
2626BB00168	**39310**	**C2N1028**	**WA-G**
2626BB00169	**39312**	**C2N1029**	**WA-G**
2626BB00170	**39314**	**C2N1030**	**WA-G**
2626BD00141	**39311**	**C2N1033**	**WA-G**

*WA-G – The Directorate Geohydrology of the Department of Water Affairs & Forestry

Groundwater level data from these boreholes have been evaluated and discussed in detail in section 3.4.4, section 3.4.6.2 & section 3.6.1. The monitoring boreholes are shown in relation to the compartment in Figure 10.

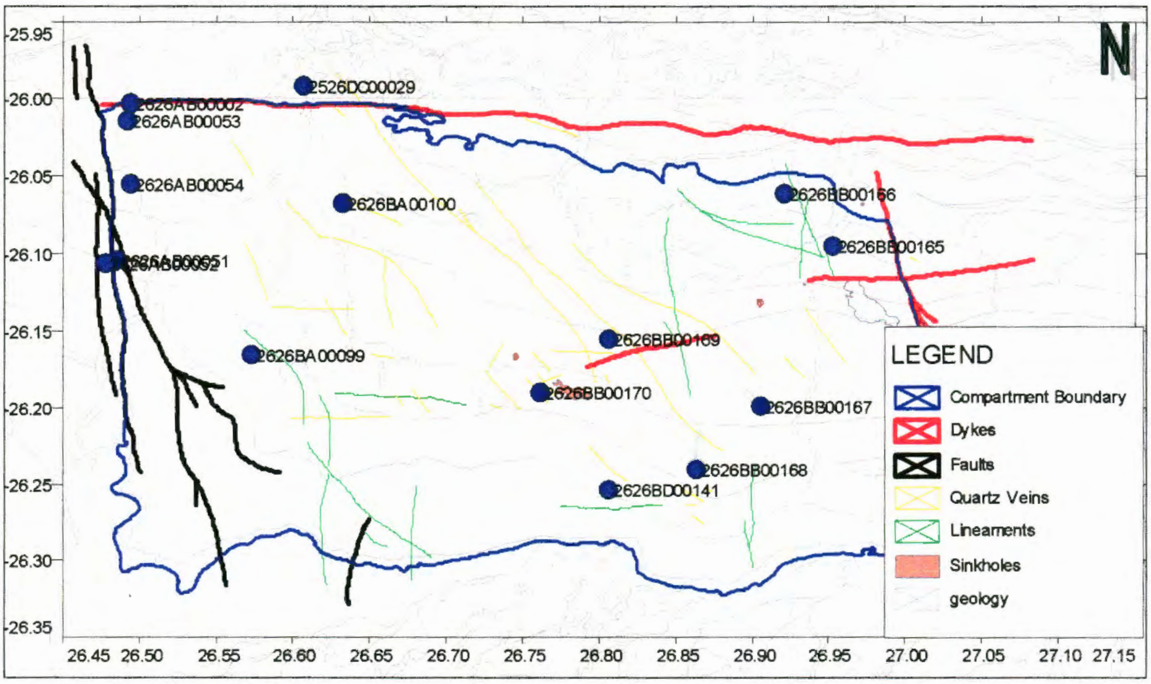


Figure 10: Water level monitoring boreholes in and around the Schoonspruit Dolomitic Compartment

2.8 Conclusions regarding the Description

The available reports on the Schoonspruit Dolomitic Compartment provided very valuable information regarding geology, geohydrology and water uses. This information is critical in the development of the conceptual model of the groundwater system and cannot be duplicated without enormous expenses. This chapter has already shown the need and necessity of a thorough investigation into available information before commencing with any groundwater study.

The available information, that will be used in *Chapter 3* as part of the geohydrological evaluation of the aquifer, can be summarised in the following two tables, with a short description of information pertaining to each.

Table 3: Aquifer characteristics

Information	**1960 - 1972 / 75**	**1986 / 87**	**1994 / 95**
Average Rainfall (mm/a)		606	604
Average Evaporation (mm/a)		1900	2134
Transmissivity Dolomites (m^2/d)	2982.85	31 149	
Transmissivity Boundaries (m^2/d)		11.5	
Specific Yield, Sy (%)	4.34 – 9.07		
Recharge, Re (%)	10.57	10	8.9 – 10 Ave = 9
Wetland Area (ha)	236		271

The general aquifer characteristics are summarised as follows:

- The Ventersdorp Supergroup is only water bearing in its upper most weathered zones and where secondary structures occur. In general borehole yields and transmissivity are low.
- The Black Reef Formation is only water bearing in its upper-most weathered zones and where secondary structures occur. Groundwater abstracted from this formation is probably also linked to the dolomitic compartment. Little storage of groundwater is expected in this formation.
- The Malmani Subgroup can be up to 1550 m thick, and the chert-rich Monte Christo and Eccles Formation form the better yielding aquifers in the Subgroup.

- The Pretoria Group has low yielding boreholes on average, except where shale is intercepted or boreholes are drilled through to the dolomites.
- The study area can be found within the following geographical co-ordinates:

Latitudes:	25°45'00" – 26°30'00"
Longitudes:	26°15'00" – 27°15'00"

- The boundaries of the Schoonspruit Compartment can be defined as:

  North – The Pretoria Group and Blaauwbank Dyke

  East – The NNW-SSE dyke following approximately 27° longitude

  South – The contact between the Black Reef Formation and Ventersdorp Supergroup

  West – The N-S fault system following approximately 26°30'00" longitude
- The study area covers an area of approximately 1900 km^2, while the compartment covers an area of approximately 1585 km^2 (derived from the digitised boundary).
- The catchment area of the Schoonspruit Eye covers an area of approximately 760 km^2.
- Four separate communities on the compartment are dependent on groundwater namely Ga-Motlatla, Ga-Mogopa, Goedgevonden and Tsêtsê.
- Groundwater in the study area occurs mainly in the dolomitic rocks, and high yielding boreholes are present in the vicinity of structures or where karstification has developed.
- Karstification is important with regard to the formation of sinkholes, depression valleys, caves and canals. This character gives the dolomites its high yielding properties and dissolution is more pronounced along fault zones, contact zones and intrusions.
- Two main trends of dykes exist, NNW-SSE and WSW-ENE.
- The importance of dykes is twofold; (1) they form preferential pathways and (2) they can act as flow boundaries.
- 30% of rainfall in excess of 313 mm/a contributes to recharge.
- A great amount of recharge can be abstracted sustainably in the dolomites.
- The short-term delay in recharge is 9 months before it contributes to spring flow.
- The long-term delay due to natural losses is 96 months (8 years).
- Equation 4 can be used to determine the recharge to the Eye.
- A simulation of the flow of the Eye can be done using equations 3 & 5.
- The contribution of the dolomites to surface water bodies from runoff is very little. Topography is generally flat and infiltration fast.
- The contribution to surface water bodies is mainly through springs and eyes.
- The transmissivity of dolomites is much higher than surrounding rocks and this gives rise to the forming of springs and eyes on contact zones.
- Groundwater level contours that bend upstream are an indication of outflow seepage and groundwater levels that bend downstream an indication of inflow seepage.
- Groundwater quality in general is good and indicates recently recharged groundwater.

Table 4: Water balance information

Information	1960 - 1972 / 75	1986 / 87	1994 / 95
Groundwater Irrigation Requirement (Mm^3/a)		21.5 31.8	22.39
Groundwater Domestic Requirement (Mm^3/a)		3	2 1.78
Eye Flow (Mm^3/a)	32.63	55.4	34.48
Evapotranspiration Losses (Mm^3/a)	5.036		5.783
Inflow Boundaries (Mm^3/a)			
Outflow Boundaries (Mm^3/a)		0.633	
Downstream Surface Water Requirement (Mm^3/a)			36.6

- Inflow of groundwater occurs through the eastern and northern boundaries.
- Outflow occurs through the southern (0.245 Mm^3/a), western and south-western (0.391 Mm^3/a) boundaries (Polivka, 1987).
- Groundwater supplies the river beyond the gauging station, estimated at 0.182 Mm^3/d.
- Losses from spring flows amounted to approximately 26.2 Mm^3/a of which the municipality was using on average 6.81 Mm^3/a.
- Mining has not been taken into account with regard to the water balance or the proclamation.
- The volume of groundwater stored in the dolomitic compartment, in 1987, was calculated as approximately 1 440 Mm^3 assuming an average water level of 23 m below surface and 30 m aquifer below the present water level.

3 GEOHYDROLOGICAL EVALUATION

A geohydrological evaluation involves development and refinement of the conceptual model, of the groundwater system under investigation, and is an on-going process. The purpose of the investigation determines the conceptual model's degree of sophistication. (Vegter, 2001)

The geohydrological evaluation of the Schoonspruit Dolomitic Compartment will focus on information and analyses of data necessary to determine the aquifer characteristics and define the water balance of the aquifer, therefore refining the conceptual model and understanding the dynamics of the groundwater system better. For this purpose an accurate assessment of the status quo and detailed analysis of accurate data is required. Three studies initiated by the Department of Water Affairs and Forestry proved to be of essential value for this evaluation:

(1) The hydrocensus by Rudolph in 2001, where groundwater information, including accurate water levels and groundwater samples of the Schoonspruit Dolomitic Compartment were gathered and;

(2) The field survey of geographical co-ordinates by Smith in 2002, where co-ordinates of boreholes identified by the hydrocensus of the compartment were determined with 10 cm accuracy in the X, Y and Z axes and;

(3) The groundwater situation analyses done by Darcy Consultants in 2002, where a detailed overview of the area was given with regard to available information and data, all groundwater quality and quantity issues, current groundwater users and usage, emerging quality and quantity issues and future groundwater management recommendations were made.

The geohydrological evaluation, however, will not include verifying previous groundwater related work done on the compartment and, wherever applicable, this will be noted. Verifying existing knowledge will defy the purpose of minimising costs associated with the thesis, except where erroneous data or interpretation is presented.

3.1 Previous Delineation of Compartment

The delineation of the compartment by Polivka, 1987, was done on the basis of sound scientific investigations and Kotze, 1994, verified this with groundwater level contour interpretations. This delineation was accepted as a true reflection of the situation in the catchment and no further work was deemed necessary in this regard. Figure 5 shows the geohydrological boundaries in relation to the area.

3.2 Meteorology

The climate in the area is typical South African 'Highveld', with temperatures averaging at 30°C in summer and 18°C in winter (Darcy Consultants, 2002). Figure 11 was obtained from the Department of Environmental Affairs and Tourism's website and gives an indication of the mean annual precipitation (MAP) for the area. MAP for the Schoonspruit compartment ranges between 480 – 620 mm/a.

Schoeman & Partners, 2003, defined the homogeneous climate zones over the compartment as part of the satellite interpretation study done for the verification process, Section 35 of the National Water Act, Act 36 of 1998 (NWA, 1998). A homogeneous climate zone is an enclosed area similar in precipitation (both quantity and monthly distribution) and evaporation characteristics. The homogeneous climate zones for the Schoonspruit compartment are shown in Figure 12. Climate Zone 1 is defined as Koster with a MAP of 608.1mm/a and Climate Zone 2 is defined as Kwaggasnek with a MAP of 478.6mm/a.

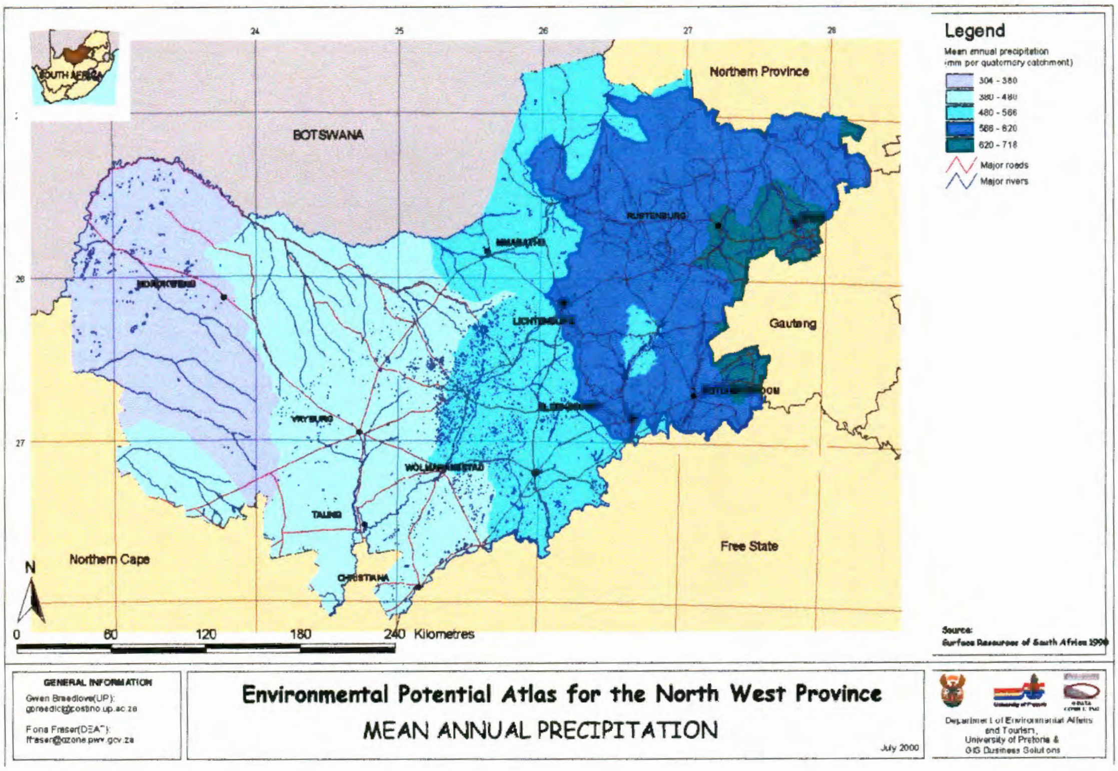


Figure 11: MAP of the Northwest Province (DEAT)

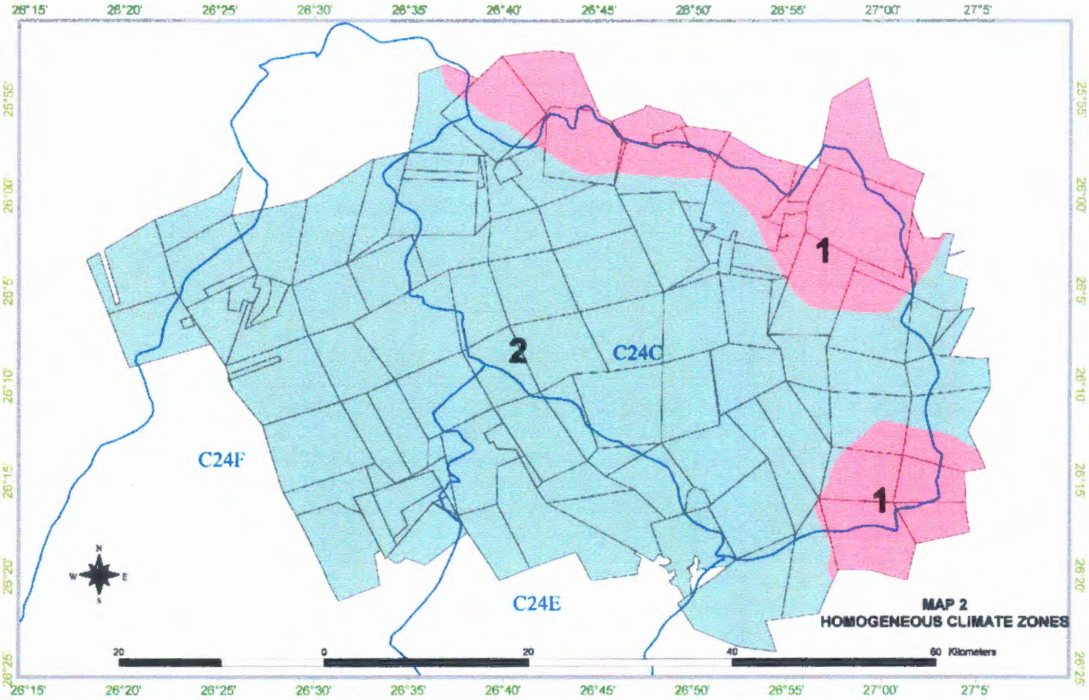


Figure 12: Homogeneous climate zones for the Schoonspruit Dolomitic Compartment (Schoeman & Partners, 2003)

For an accurate evaluation of rainfall, rainfall data was obtained from the South African Weather Buro and positions are shown in Figure 13. The different stations' data is graphed in

Figure 14 and trend lines were fitted, of which the Ventersdorp, Klerkskraal POL and Lichtenburg MNN showed similar trends. The Ventersdorp Rainfall station has the best spatial relation with regard to the dolomitic compartment and therefore this station was selected for evaluation. However, rainfall data series for this station is not complete and longer time series was deemed necessary. The Ventersdorp rainfall station needed patching of the rainfall data.

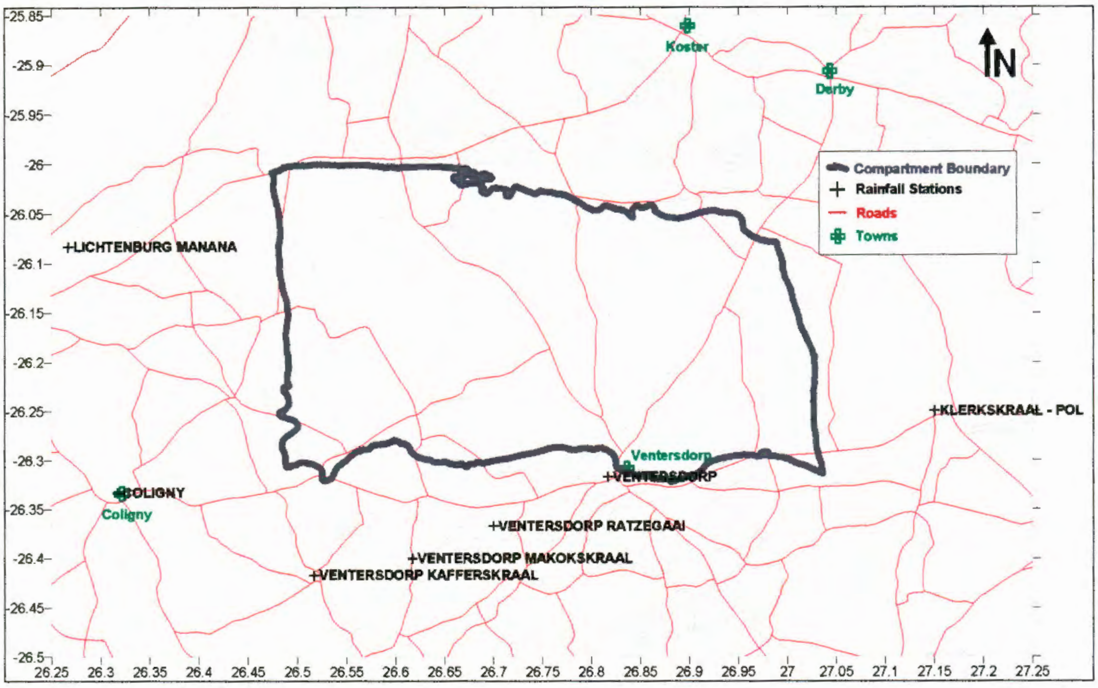


Figure 13: Positions of rainfall stations evaluated

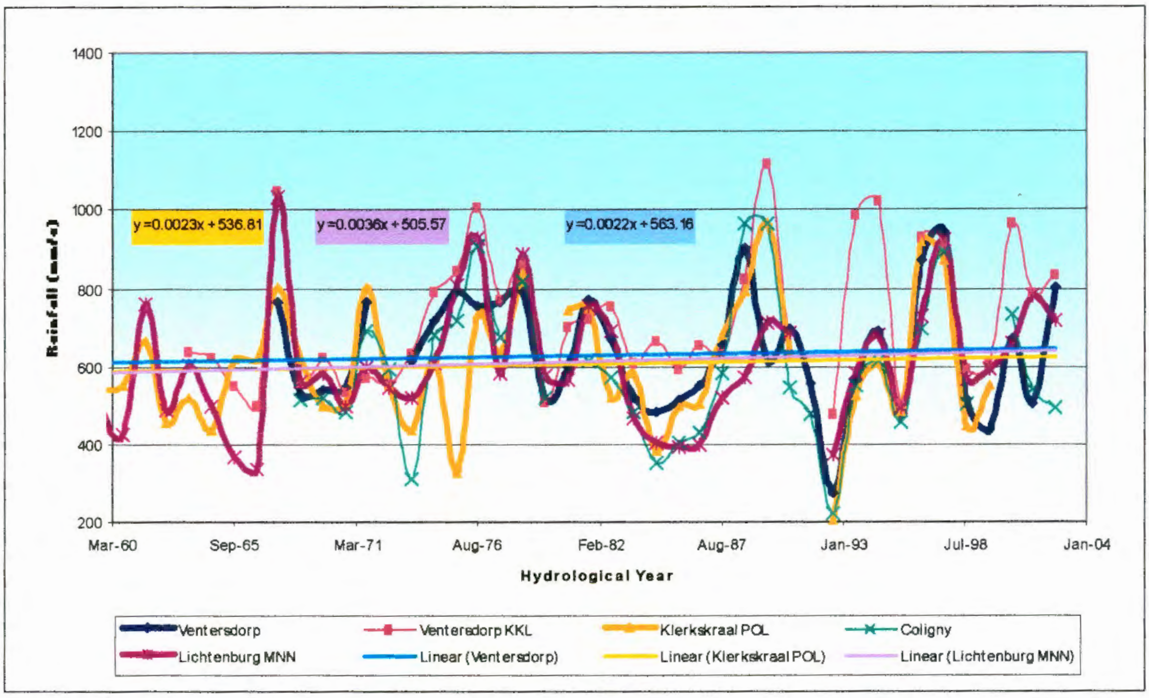


Figure 14: Annual Rainfall for the Hydrological Years, with Trend Lines of Rainfall Stations in close proximity to the Schoonspruit Dolomitic Compartment

From Figure 14 the correlation between the three stations appeared good, but it was still necessary to test it statistically. Graphs were drawn of annual and monthly correlations of

Ventersdorp & Lichtenburg MNN and of Ventersdorp and Klerkskraal POL. The graphs are shown in Figure 15 to Figure 18.

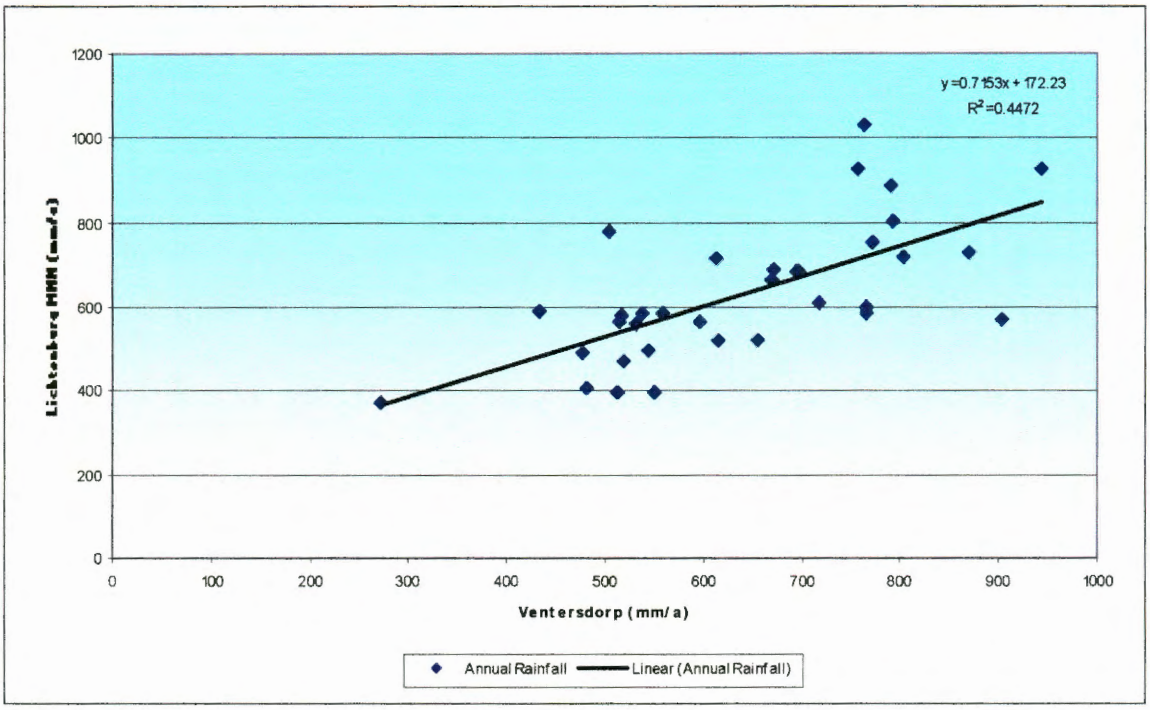


Figure 15: Annual Correlation between Rainfall Stations Ventersdorp & Lichtenburg MNN

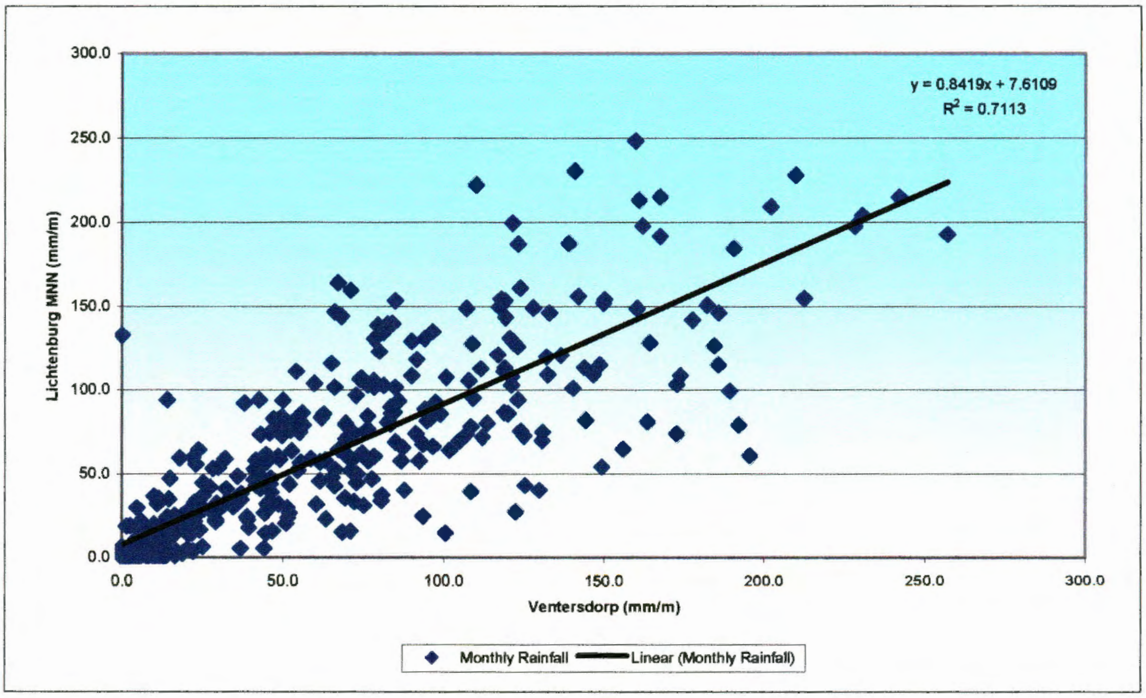


Figure 16: Monthly Correlation between Rainfall Stations Ventersdorp & Lichtenburg MNN

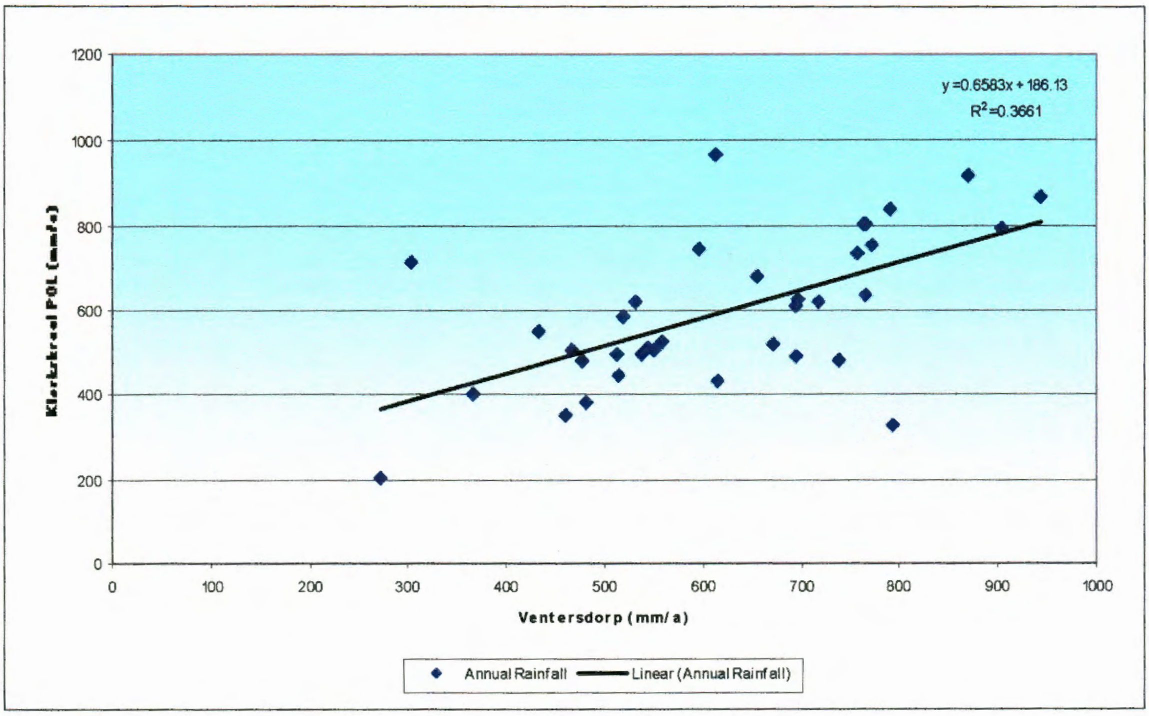


Figure 17: Annual Correlation between Rainfall Stations Ventersdorp & Klerkskraal POL

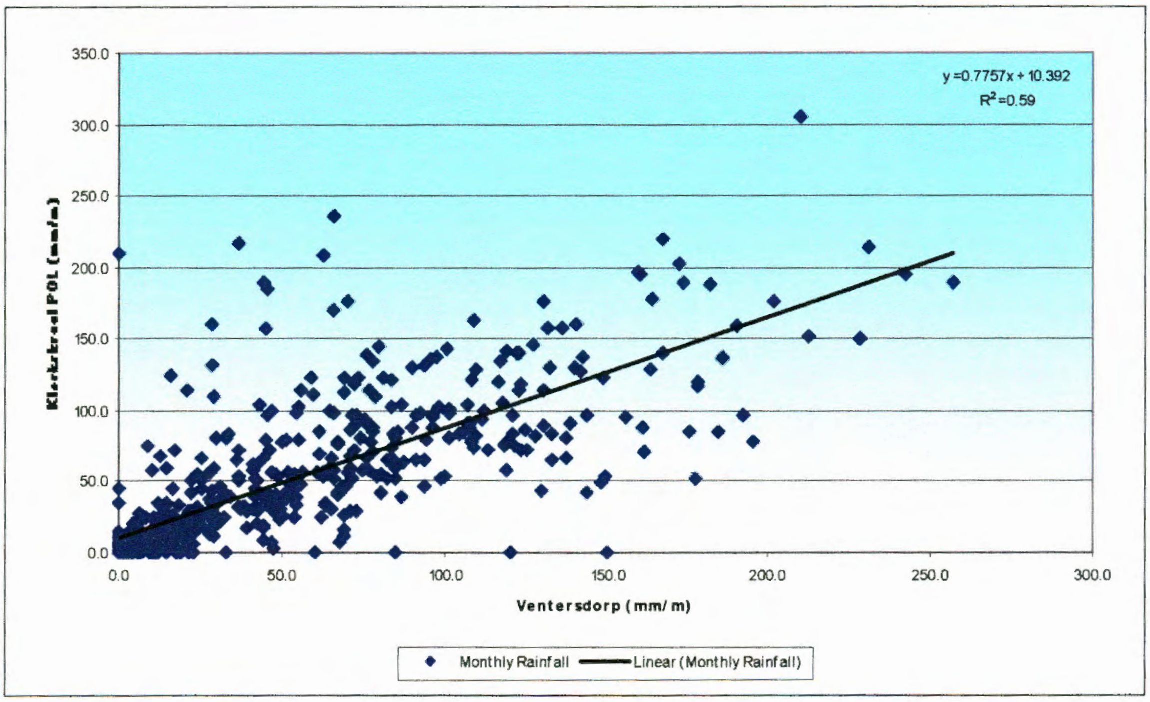


Figure 18: Monthly Correlation between Rainfall Stations Ventersdorp & Klerkskraal POL

The correlation coefficients of Ventersdorp & Lichtenburg MNN for both the annual and monthly correlations were better than the correlation coefficients of Ventersdorp & Klerkskraal POL, although not good enough for statistical use. The reason being that outliers, typically months of low rainfall in the one and high rainfall in the other, would have too much influence in the correlation coefficient.

A cumulative monthly rainfall graph for Ventersdorp & Lichtenburg MNN was created to determine if the cumulative effect of rainfall over time shows a better correlation. The results are shown in Figure 19.

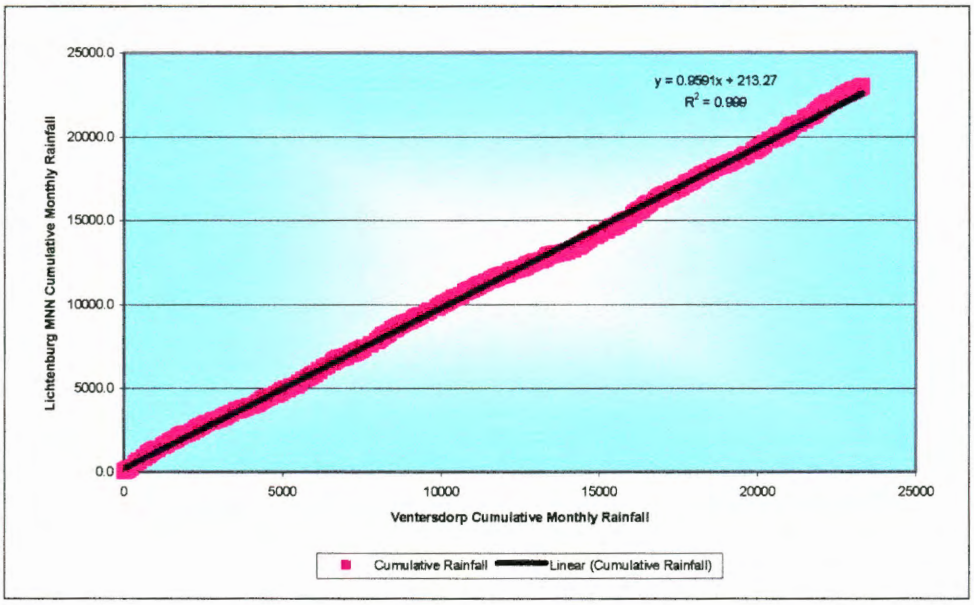


Figure 19: Correlation between the cumulative monthly rainfalls for Ventersdorp & Lichtenburg MNN

As can be seen there is a 99.9% correlation between the cumulative monthly rainfall values and the data of the Lichtenburg MNN rainfall station, which can be used for an extended time series of data that is missing in the Ventersdorp rainfall station time series. For smaller numbers of months where data needs to be patched, the cumulative monthly rainfall should be compared for the two stations, in order to attain a relevant representative value.

Figure 20 shows the correlation between the monthly cumulative patched rainfall data for the rainfall station Ventersdorp (Ventersdorp PD) and the monthly cumulative rainfall data for the rainfall station Lichtenburg MNN. The correlation between the two stations is 99.9%

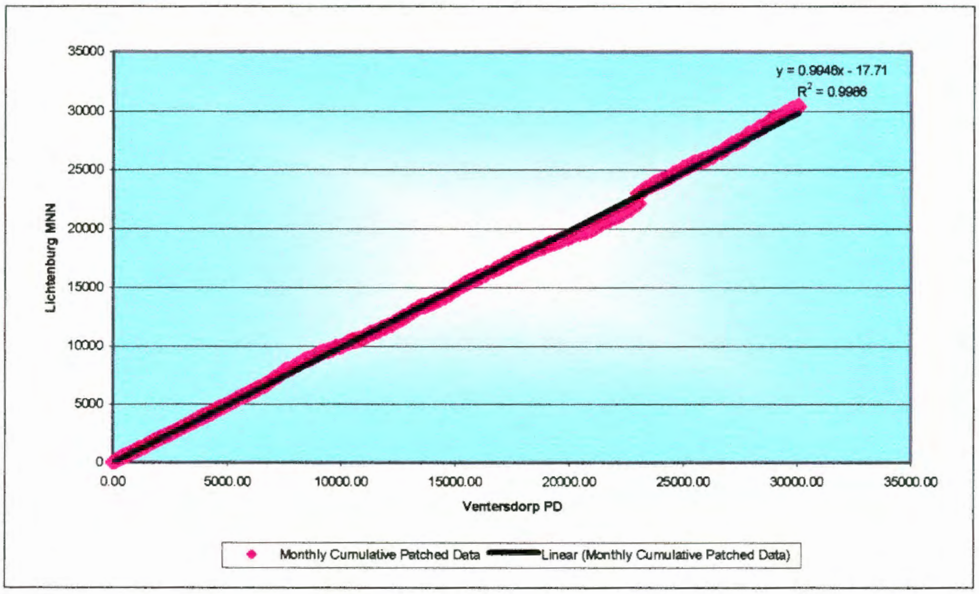


Figure 20: Correlation between the monthly cumulative rainfalls of Ventersdorp PD & Lichtenburg MNN

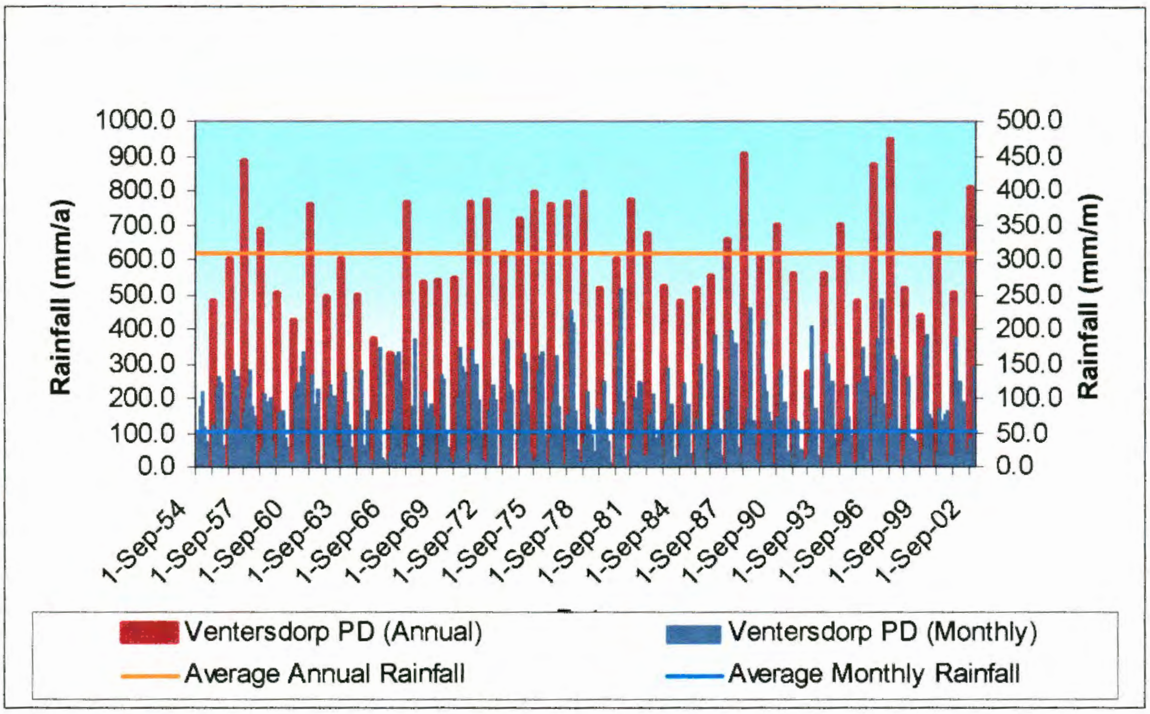


Figure 21: Ventersdorp PD Annual and Monthly Rainfall

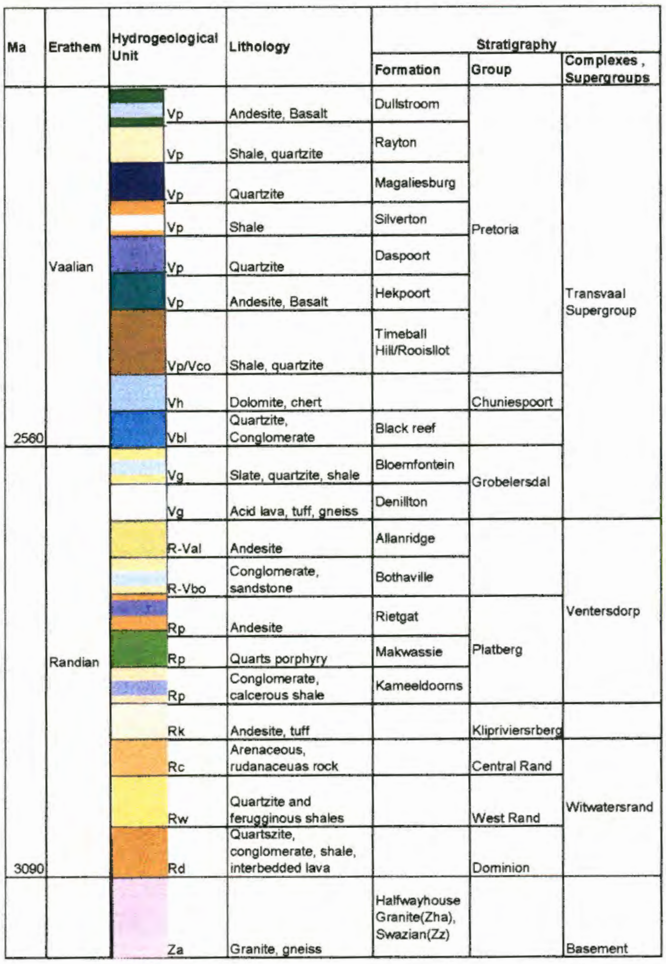
Figure 21 shows the annual and monthly rainfall of the patched rainfall, Ventersdorp PD, as well as the average annual and monthly rainfall. Rainfall data for the dolomitic compartment is now available from 1954 and flows of the Schoonspruit Eye are available from 1965. Therefore, this rainfall series should be sufficient for flow interpretations.

The average monthly rainfall amounted to 51.7 mm/m and the average annual rainfall to 620.2 mm/a.

If a longer time series of rainfall is necessary, the same exercise could be performed for the relationship between Ventersdorp PD and Klerkskraal POL rainfall stations.

3.3 Geology

The geology of the area was described in detail in section 2.3. Figure 22 shows the extent of the geology in relation to the area. A lithostratigraphic legend for the geology in the Ventersdorp area is as follows:



Ma	Erathem	Hydrogeological Unit	Lithology	Stratigraphy		
				Formation	Group	Complexes , Supergroups
	Vaalian	Vp	Andesite, Basalt	Dullstroom	Pretoria	Transvaal Supergroup
		Vp	Shale, quartzite	Rayton		
		Vp	Quartzite	Magaliesburg		
		Vp	Shale	Silverton		
		Vp	Quartzite	Daspoort		
		Vp	Andesite, Basalt	Hekpoort		
		Vp/Vco	Shale, quartzite	Timeball Hill/Rooisllot		
		Vh	Dolomite, chert		Chuniespoort	
2560		Vbl	Quartzite, Conglomerate	Black reef		
	Randian	Vg	Slate, quartzite, shale	Bloemfontein	Grobelersdal	
		Vg	Acid lava, tuff, gneiss	Denillton		
		R-Val	Andesite	Allanridge		Ventersdorp
		R-Vbo	Conglomerate, sandstone	Bothaville		
		Rp	Andesite	Rietgat	Platberg	
		Rp	Quarts porphyry	Makwassie		
		Rp	Conglomerate, calcerous shale	Kameeldoorns		
		Rk	Andesite, tuff		Klipriviersrberg	
		Rc	Arenaceous, rudanaceuas rock		Central Rand	Witwatersrand
		Rw	Quartzite and ferugginous shales		West Rand	
3090		Rd	Quartszite, conglomerate, shale, interbedded lava		Dominion	
		Za	Granite, gneiss	Halfwayhouse Granite(Zha), Swazian(Zz)		Basement

Figure 22: Lithostratigraphic legend for the geology in the Ventersdorp area (Darcy Consultants, 2002)

3.4 Geohydrology

The objectives of the Ventersdorp Hydrocensus study was to gather information on groundwater users, uses, characteristics, to determine boundaries, groundwater leakage over boundaries, the influence of pans on groundwater quality and the influence of local geology, groundwater flow and recharge. Information on property owners, property names and numbers, boreholes, abstractions, surface water features, geological features, position and size of possible springs, wetlands and groundwater pans had to be gathered, as well as groundwater samples for the DWAF collected, for further evaluation by the DWAF. (Rudolph, 2001)

An area of approximately 2400 km^2 was covered with 562 boreholes located, of which 106 groundwater levels and 102 groundwater samples could be taken. Surface water samples were taken at 4 pans and 4 springs. Co-ordinates were taken with hand held GPS equipment and measured in Cape Datum. Co-ordinate accuracy was quoted as below 10 m and elevations interpolated from maps also approximately 10 m accurate. (Rudolph, 2001)

The Section Survey of the DWAF of the Potchefstroom Office surveyed the 562 boreholes identified in the Ventersdorp Hydrocensus to an accuracy of less than 10 cm on the X, Y and Z co-ordinates (Smith, 2002). Surveyed co-ordinates were incorporated into the database at the DWAF Geohydrology section at the Bloemfontein Office for use in data evaluation.

According to farm owners a hydrocensus was also conducted around 1999 in the area. It is unclear whom the organisation was that did the census and whether it would be possible to get a hold of any data. It was noted that this could contribute significantly to the success of a groundwater management plan for the area. (Rudolph, 2001)

Several minor aquifers have developed throughout this area in association with strata of the Pretoria Group, Ventersdorp Supergroup and Karoo Sequence, which lie stratigraphically above the dolomite. However, since these aquifers have generally developed in association with structural features or zones of preferential weathering, they are therefore limited in terms of their yield characteristics and spatial extent. (Darcy Consultants, 2002)

Figure 5 shows the general geohydrology for the Schoonspruit dolomitic compartment. From the situation analyses by Darcy Consultants, 2002, the following information was added to the geohydrological regime:

3.4.1 The Ventersdorp Supergroup

The Ventersdorp lava acts as a host for the development of aquifers. However, the Ventersdorp lava is also developed below the dolomite rocks at depth and in these environments, act as an impermeable aquiclude. (Darcy Consultants, 2002)

Good yields in the rocks are often associated with structural features. The permanent groundwater table is associated with the upper fractured and jointed region of the weathered portion of the andesitic rocks. Good yielding boreholes are often aligned along linear features such as major joints or dyke intrusions. The depth to the permanent water table varies between 5-12 m below surface. In places a temporary, perched water table may develop within the residual andesite soils, often in association with a ferricrete horizon. Groundwater associated with the Ventersdorp lava is considered to be of regional importance. (Barnard, 2000)

3.4.2 The Transvaal Sequence

3.4.2.1 The Black Reef Formation

No new information was obtained on this formation. It has been said in general, that for the area where the Black Reef Formation is in contact with the Schoonspruit compartment, the groundwater abstracted from this formation is nothing less than dolomitic groundwater from the Schoonspruit compartment. Therefore any abstractions form this formation has to be viewed in the same light as abstractions from the dolomitic compartment.

3.4.2.2 The Malmani Subgroup

The most significant aquifer in the region is the Malmani dolomite, which forms part of the Chuniespoort Group of the Transvaal Sequence, and as a resource this is the most important groundwater related body in the area. Although the dolomite has a relatively low primary permeability, the development of karstic features, due to the preferential solution along discontinuities such as joints, faults and bedding planes, has served to develop the secondary permeability of the rock mass, particularly in chert-rich units such as the Monte Christo and the Eccles Formations. (Barnard, 2000)

The chert-rich formations - **Eccles** and **Monte Christo** of the **Malmani Subgroup** - have proven to be the best aquifers. Boreholes that are drilled on the intersection of dykes include:

Doornkop and Blaaubank dyke intersection on the farm Duikerfontein (Groot Marico Compartment); as well as Blaaubank and Lichtenburg dyke intersections on the farm Klippan. Further, fault intersections give high yields (>10 l/s): Grootpan, where two faults intersect in a sinkhole; and Sterkfontein, where there is a joint intersection. (Barnard, 2000)

3.4.2.3 The Pretoria Group

Extractable groundwater held within the Pretoria Group shale is usually associated with water-bearing fractures within the rocks, or the fractured contacts adjacent to intrusive dykes or sills. In general, the groundwater potential of these rocks is moderate to low, although significant yields have been reported where boreholes are sited within topographically low-lying flood plains or alluvial valleys. In these settings, exploitation of the shallow (2-5 m deep) perched water table, alluvial aquifer usually takes place. However, increased recharge from the perched water aquifer to the underlying fractured rock or contact aquifer will allow for greater yields from deep boreholes in the area. (Darcy Consultants, 2002)

3.4.3 Aquifer Classification

An aquifer classification system provides a framework and objective basis for identifying and setting appropriate levels of groundwater resource protection (Darcy Consultants, 2002).

The aquifer classification system used to classify the dolomitic aquifer is the proposed National Aquifer Classification System of Parsons, 1995. This system has a certain amount of flexibility and can be linked to secondary classifications such as a vulnerability or usage classification. Parsons, 1995, suggests that aquifer classification form a very useful planning tool that can be used to guide the management of groundwater issues. He also suggests that some level of flexibility should be incorporated when using such a classification system.

Five major classes present the South African Aquifer System Management Classification and is mostly based on the ability of the aquifer to yield water: (Parsons, 1995)

Sole Source Aquifer System

Major Aquifer System

Minor Aquifer System

Non- Aquifer System

Special Aquifer System

A second variable classification is needed for sound decision making, as the ability of an aquifer to yield water to a particular user is not adequate. In this case it was decided to use the vulnerability of the aquifer to contamination as a second parameter. A weighting and rating approach was then used to decide on the appropriate level of groundwater protection, Table 5. (Parsons, 1995)

Colvin, 2000 states that groundwater which is particularly vulnerable to contamination tends to occur in aquifers with the following characteristics:

- A shallow depth to the water table (e.g. < 5 m).
- Where pathways for rapid migration to the water table exist, such as cracks in the soil, fractures in the rock, or sinkholes.
- The soil and unsaturated zone are highly permeable and relatively inert with low levels of organic matter and clays.
- There is a relatively high rate of recharge by rain or irrigation water.

Table 5: Ratings for the aquifer quality management classification system (Parsons, 1995)

AQUIFER SYSTEM MANAGEMENT CLASSIFICATION		AQUIFER VULNERABILITY CLASSIFICATION	
Class	Points	Class	Points
Sole Source Aquifer System	**6**	**High**	**3**
Major Aquifer System	**4**	**Medium**	**2**
Minor Aquifer System	**2**	**Low**	**1**
Non-aquifer System	**0**		
Special Aquifer System	**0-6**		

After taking into consideration all information, rating the aquifer system management and the aquifer vulnerability, the points are multiplied to obtain a GQM (Groundwater Quality Management) index, Table 6. (Parsons, 1995)

Table 6: Appropriate level of groundwater protection required (Parsons, 1995)

GQM INDEX	LEVEL OF PROTECTION
<1	**Limited protection**
1-3	**Low Level protection**
3-6	**Medium level protection**
6-10	**High level protection**
>10	**Strictly non-degradation**

The Schoonspruit dolomite aquifer is regarded as a special aquifer, rating as a 6 in terms of importance as an aquifer, where the groundwater is considered important enough to qualify as a sole source or special aquifer. A sole source aquifer is defined as " An aquifer which is used to supply 50% or more of domestic water for a given area, and for which there is no reasonable alternative should the aquifer be impacted upon or depleted." (Darcy Consultants, 2002)

The vulnerability of this aquifer is regarded as medium and therefore rates as a 2 (Darcy Consultants, 2002).

The GQM index for this aquifer is calculated at 12 (6x2 = 12). The appropriate level of protection for the aquifer is thus strictly non-degradation in terms of quality and quantity. (Darcy Consultants, 2002)

Based on the considerations the aquifer vulnerability in the Ventersdorp area can be summarised by Table 7 below:

Table 7: Aquifer Classification Table (Darcy Consultants, 2002)

Geological Unit	Code	Aquifer System	Vulnerability	Classification
FRACTURED AQUIFERS				
Black Reef	**Vbl**	**2**	**1**	**2**
KARST AQUIFERS				
Chuniespoort group	**Vh**	**6**	**2**	**12**
INTERGRANULAR & FRACTURED AQUIFERS				
Pretoria Group	**Vp**	**2**	**1**	**2**

The values in this table are naturally subjective, but based on the aquifer descriptions given previously. The importance of each aquifer should provide guidance on the protection to be assigned to each area. (Darcy Consultants, 2002)

3.4.4 Groundwater Levels

The hydrocensus done by Rudolph, 2001, reported the following general information for general groundwater levels in the compartment.

Table 8: Hydrocensus borehole information (Rudolph, 2001)

	Borehole Depth (m)	Water Level (mbgl)	Yield (l/s)
Average	**52**	**20.5**	**14.7**
Min	**10**	**1.4**	**0.2**
Max	**196**	**73.2**	**56.3**
No of Values Obtained	**94**	**106**	**78**

From the groundwater level data interpretation by Rudolph, 2001, it was clear that boundaries and the influence of small dyke structures could not be determined due to inaccurate borehole elevations. Definite trends could, however, be seen and interpretations made regarding the groundwater level contours:

- A large groundwater gradient could be seen in the north-east from the quartzite towards the dolomite. This gradient was most pronounced on the farm Kerkgrond, where groundwater level differences of 60 m over 100 m were measured.
- Outflow occurs in the south over the Black Reef and corresponds to surface water drainage.
- Groundwater level elevations suggest that the fault zone in the west is mostly an outflow boundary and the step in groundwater levels is approximately 10 – 15 m away from the Schoonspruit compartment.
- A groundwater mound exists in the east in the vicinity of 27°, but it was unclear if this is due to a dyke structure. The continuity of this groundwater divide is also unknown due to a lack of information in that vicinity.

A more detailed analysis showed that 15 of the current monitoring boreholes have a direct relation with the dolomitic compartment or the boundary effects of adjacent compartments. The positions of these boreholes are shown in Figure 10 with their relation to geology and mapped structures. These monitoring boreholes have water level data from 1990.

3.4.4.1 Water Level Trends

Figure 23 shows the monitoring boreholes grouped into 4, as described further in this section.

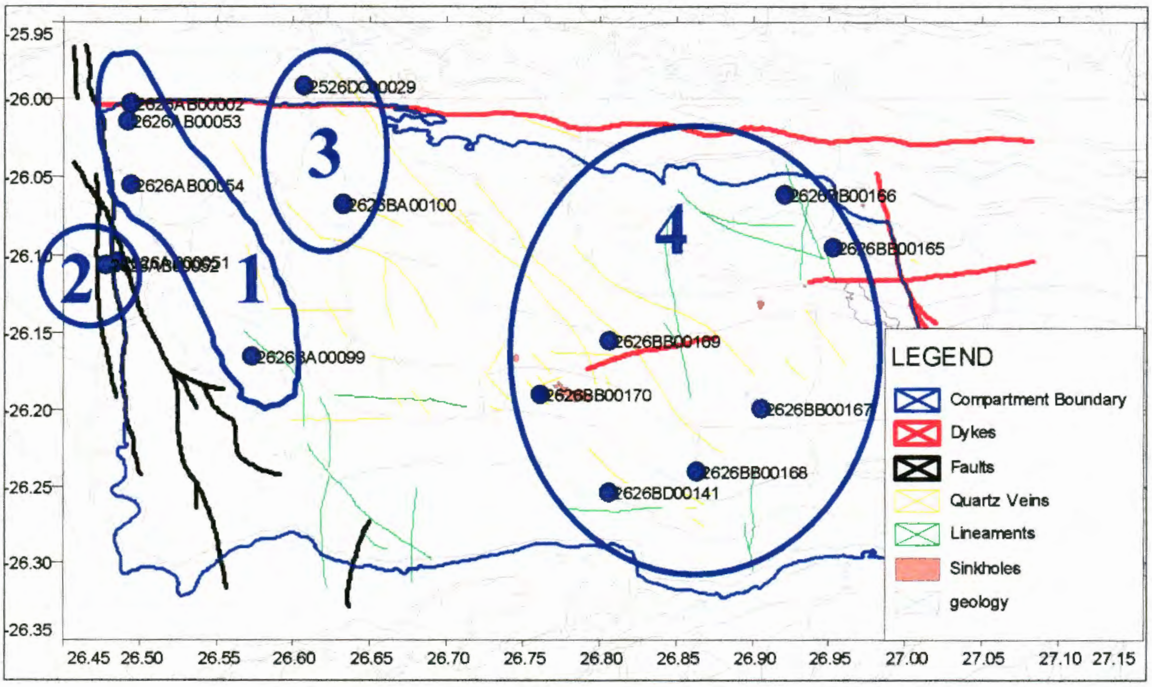


Figure 23: Monitoring boreholes with groupings as described in 3.4.4.1

Figure 24 shows the water level elevation data time series, from the monitoring boreholes. This monitoring was initiated after the irrigation began and one will not be able to see the influence on the groundwater levels, should there be any. Variations in water levels over time can be seen, but at the moment the groundwater levels are rising and on average at the same level as in 1990.

Closer inspection of the water level elevations of the monitoring boreholes and their spatial relations does show rather interesting phenomena:

- Group 1: Boreholes 2626AB002, 053, 054 and 2626BA099 have water level elevations in the same 5m ranges, although 2626BA099 is removed from the other three and in a different formation of the Malmani Subgroup. 2626AB002 showed a 4m difference from 2626AB053 in the past.
- Group 2: Boreholes 2626AB051 and 052 have a 10m difference between the water level elevations, although they are in close proximity to one another. This is presumably because of the boundary effects of the fault zone in the west between the Schoonspruit and the Grootpan compartments.
- Group 3: Boreholes 2526DC029 and 2626BA100 have water level elevations in the same range, but water level elevations in the past showed a 4m difference.
- Group 4: 2626BB166, 167, 168, 169, 170 and 2626BD141 are in the same 8m ranges, with 2626BB166, 167 & 2626BD141 and 2626BB168, 169 & 170 in the same 2m ranges.
- 2626BB165 is elevated 20-25m above the boreholes in the group 4, which might be due to the effect of local dykes and therefore an indication of structural effects. This water level elevation difference is not attributed to surface elevations, as the borehole is elevated 20m below 2626BB166. Large variations within the time graph of

2626BB165 are visible and can be attributed to nearby pumping influences. It is unlikely that these large variations are due to natural water level fluctuations, especially when taking into consideration the borehole's fluctuation trend before 1995 and the fluctuations of the other boreholes' monitoring data.

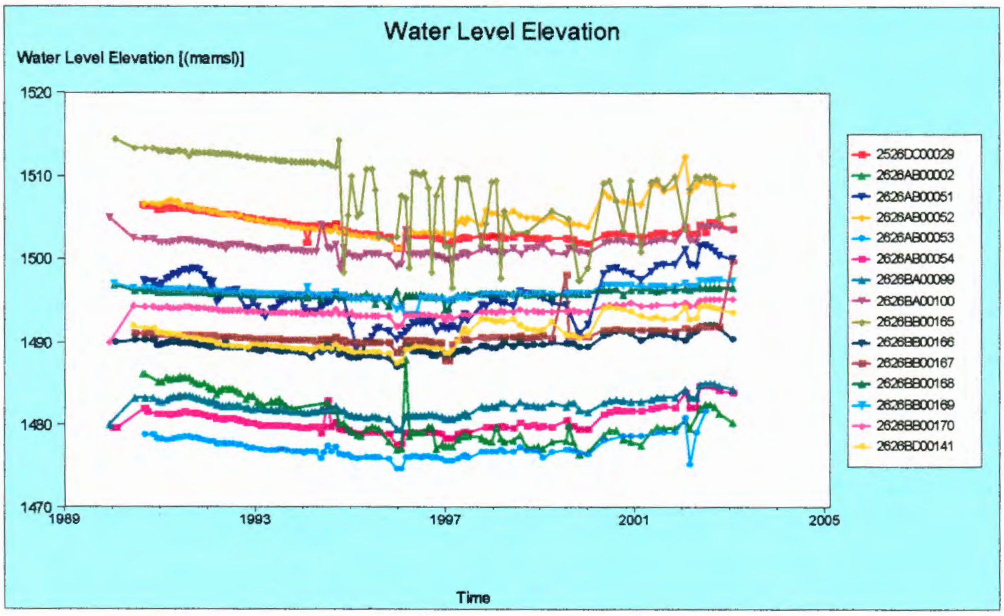


Figure 24: Water level elevation graphs of monitoring boreholes

Comparing these phenomena with the boreholes' water level depths, Figure 25, gives the following:

- Borehole 2626AB002's water level depth is on average 15-20mbgl (meters below ground level), 2626AB053 & 054 40mbgl and 2626BA099 28mbgl.
- 2626AB051's water level depth is on average 20-25mbgl and 2626AB052 10-12mbgl, indicating once more the difference in water levels between the two boreholes.
- 2526DC029's water level depth is on average 13-18mbgl and 2626BA100 18mbgl, showing once more differences in the past but water levels overlapping at present.
- The water level depth of 2626BB166's is on average 70mbgl, 2626BB167 30mbgl, 2626BB168 3-4mbgl, 2626BB169 20-22mbgl, 2626BB170 25mbgl and 2626BD141 18-20mbgl. The depth of 2626BB166 attributed to the borehole's elevation being 40 – 60 m above the rest of the boreholes.
- 2626BB165's water level depth is on average 30mbgl, coinciding only with 2626BB167 in its immediate vicinity.

This tendency of the water level depths of the monitoring boreholes, not to mimic the trends found with the water level elevations, might indicate that groundwater levels in the compartment is not governed by surface topography. To test this, it is necessary to draw a graph of water level elevations in the compartment, at a specific time, against surface topography elevations. Since the 2001 hydrocensus' boreholes where surveyed, this data will be used.

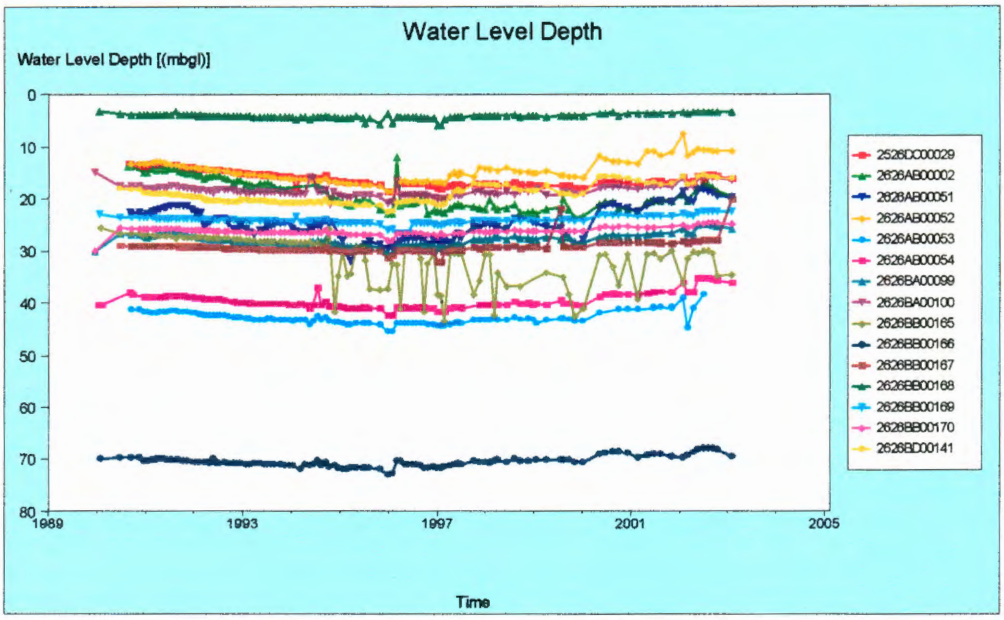


Figure 25: Water level depth graphs of monitoring boreholes (Darcy Consultants, 2002)

3.4.4.2 Spatial Distribution

The spatial distribution of groundwater levels in an area determines the groundwater level contours of the surface of the water table. This is used to visualise the variations in groundwater level elevations, determine flow directions and define aquifer boundaries. The correlation between the surface topography and the groundwater levels in the dolomitic compartment is 51.8%, therefore Figure 26 indicates that the surface topography does not govern the water level elevations in the dolomitic compartment, most probably because of the chert-rich layers of dolomite being more resistant to weathering and the water level table in the dolomite flattening out because of the hydraulic properties of the rock.

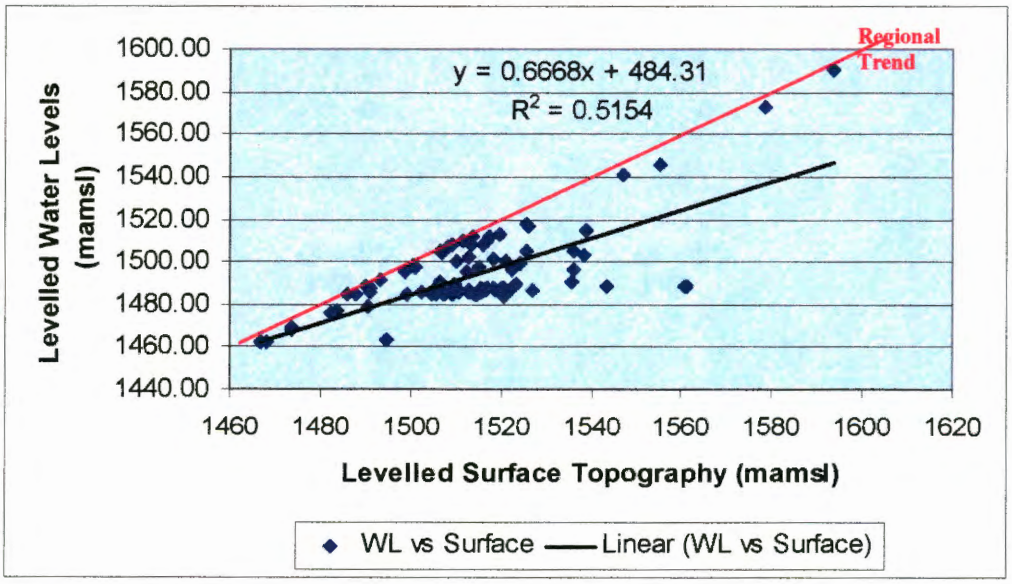


Figure 26: Correlation between surface topography and groundwater levels

However, a regional trend is observed in the data, which could possibly be used in a regional evaluation of water levels between different compartments. Bayesian interpolation of the water level elevations in the Schoonspruit compartment is not applicable and Kriging will be used to interpolate water level elevations, for use in spatial groundwater level contour maps and to determine flow directions in the compartment.

Figure 27 shows the groundwater level elevations of the Schoonspruit dolomitic compartment.

The groundwater level elevations contour map show the following:

- The large groundwater gradient in the northeast is confirmed, due to the occurrence of the Pretoria Group with its large surface elevations. This is defined as an inflow boundary.
- The EW striking dyke in the north does not cause significant differences in groundwater level elevations.
- The fault system in the west has significant groundwater elevation differences.
- Groundwater flow in the south over the Black Reef is confirmed, although a very shallow gradient is observed.
- The NS striking dyke in the east has a definite influence on the groundwater contours.
- Structures within the compartment do not influence the groundwater levels significantly. Some influence can be seen in the area of the EW striking dyke in the middle of the compartment, but even this does not have a significant influence.
- Groundwater water levels may have been impacted on by groundwater abstraction at site-specific places.
- Groundwater level contours at the Schoonspruit Eye are flat. If groundwater levels in the vicinity of the Eye are lowered, it will have a significant impact on flow directions and therefore the yield of the Eye.

The groundwater level elevations vector map, Figure 28, show the following:

- The large groundwater gradient in the northeast is defined as an inflow boundary.
- The EW striking dyke in the north does not seem to be a no-flow boundary, although general flow directions shows that it might be an inflow boundary.
- The fault system in the west is an inflow boundary due to the huge groundwater elevation differences.
- Groundwater flow in the south over the Black Reef is confirmed, although a very shallow gradient is observed.
- The influence of the NS striking dyke in the east can clearly be seen and is defined as an inflow boundary.
- Except for the EW striking dyke in the middle of the compartment, no structures within the compartment govern groundwater flow directions.
- The groundwater gradient at the Schoonspruit Eye is very flat and any abstraction will influences the flow direction of the groundwater. This can be seen throughout the compartment, as the slightest change in elevation has an enormous effect on the groundwater flow vectors.
- The delineation of the Schoonspruit Eye catchment area can easily be seen as a result of the flow vectors and is shown on the topocadastral map in Figure 29.

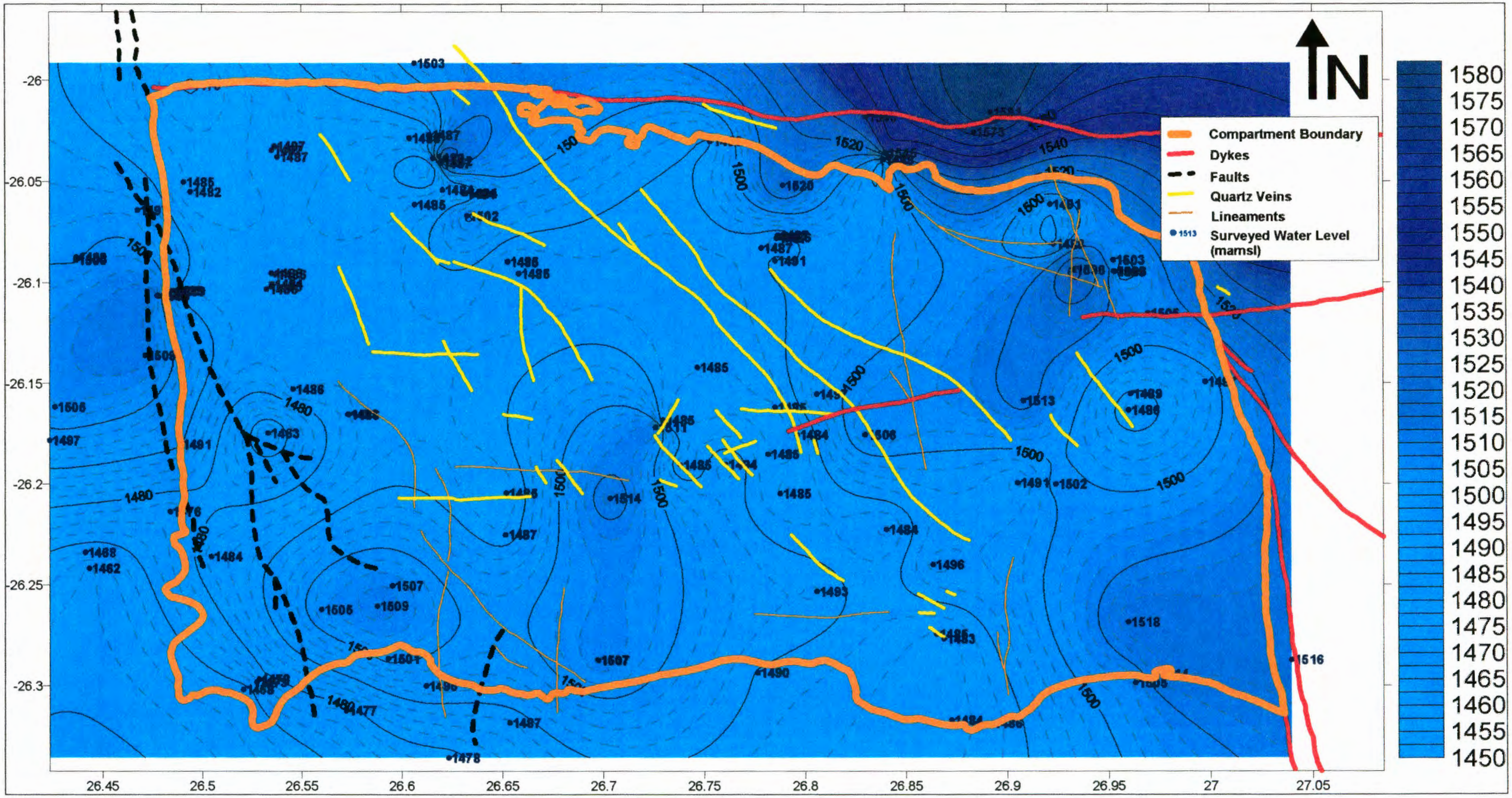


Figure 27: Water level elevation (mamsl) contours of boreholes throughout the Schoonspruit Dolomitic Compartment for the year 2001

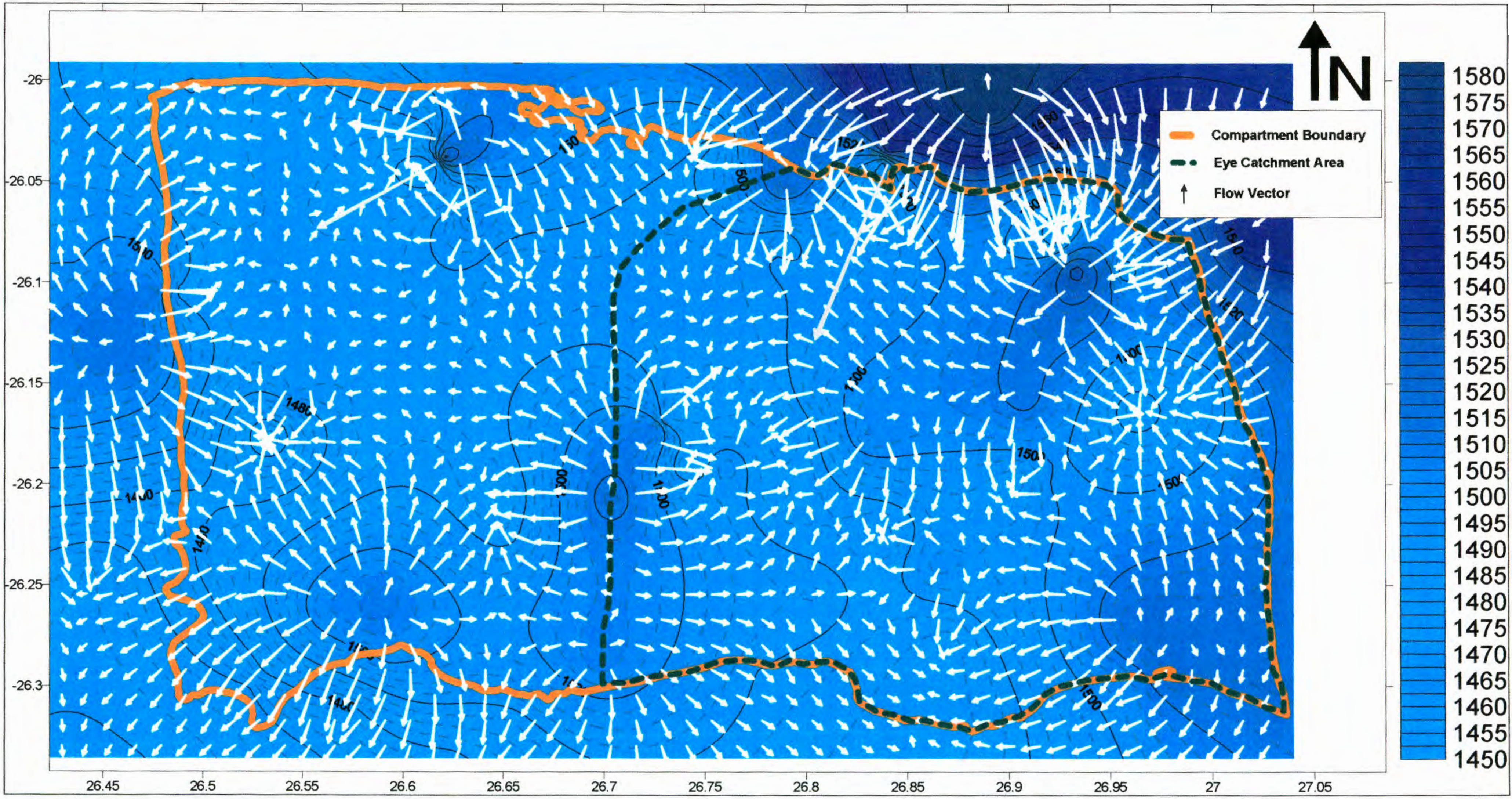


Figure 28: Vector map of the Schoonspruit Dolomitic Compartment water level elevation (mamsl) contours

As a result of the delineation 2 zones have been defined for future groundwater management in the compartment; **Zone A** – the Eastern Dolomitic Eye Catchment and **Zone B** – the Western Dolomitic Compartment; and the names of the properties demarcated to each are listed in APPENDIX B. The 2 zones will be treated separately with regard to groundwater balances as different management principles apply to each.

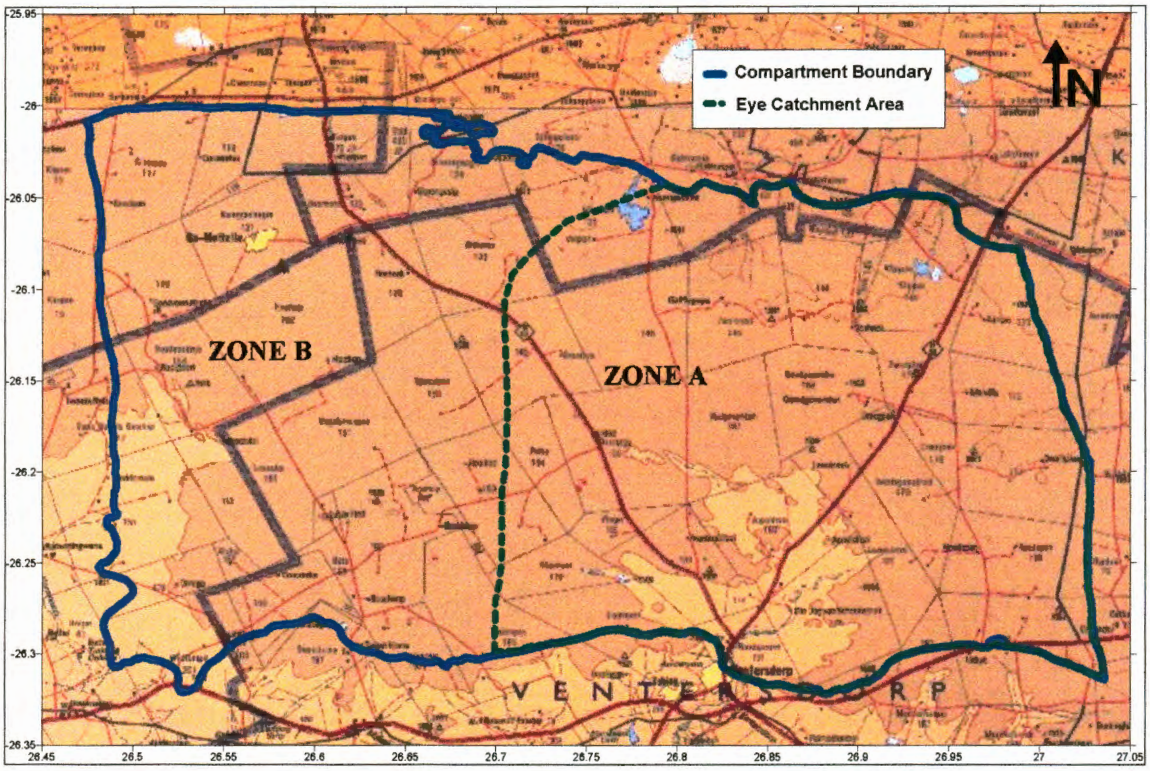


Figure 29: Topocadastral map showing the Schoonspruit Eye catchment area

3.4.4.3 Monitoring Boreholes Versus Springs

Figure 30 and Figure 31 show the groundwater level elevations and depth of the monitoring boreholes close to the Schoonspruit Eye. The Eye's elevation is between 1483.122 and 1484.68 mamsl, but for evaluation purposes it will be taken as 1484 mamsl.

The groundwater levels in the monitoring boreholes show a very flat trend for 2626BB167 & 168, with differences in water levels of 3m from the minimum to the maximum value. Differences in groundwater levels in borehole 2626BD141 are 8m from minimum to maximum value. The groundwater levels have been recovering since 1996.

It can be seen that the groundwater elevation in the boreholes is 5-12m above the elevation of the Eye. This gives rise to a rather big difference in groundwater head between the monitoring boreholes and the Eye.

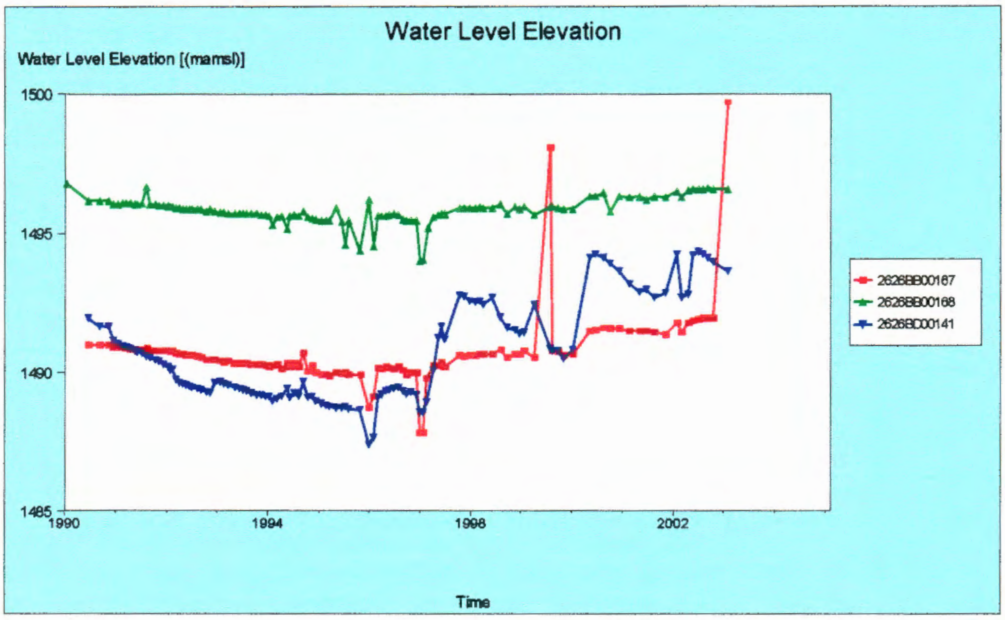


Figure 30: Water level elevation of monitoring boreholes close to the Schoonspruit Eye

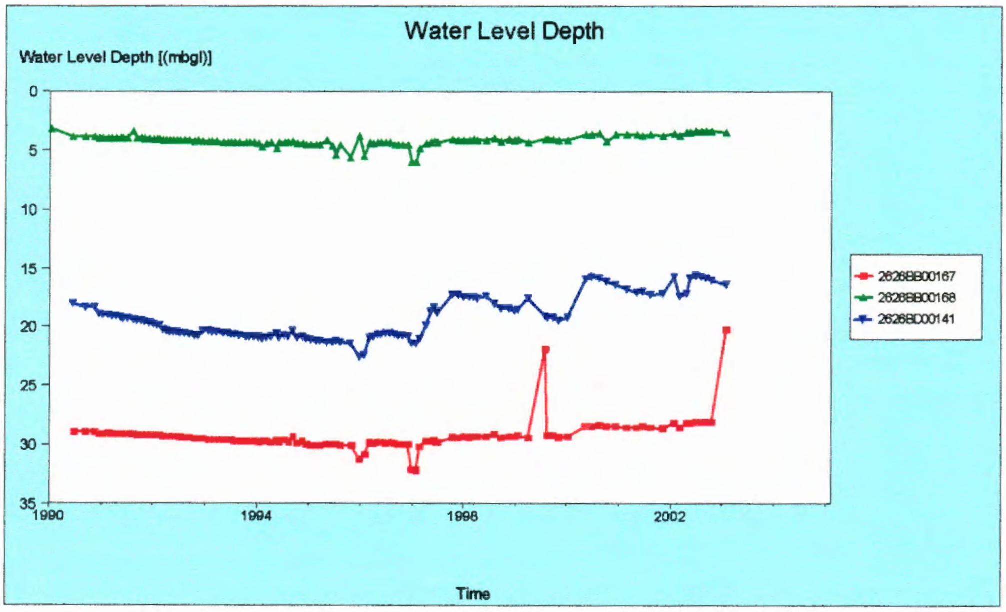


Figure 31: Water level depth of monitoring boreholes close to the Schoonspruit Eye

3.4.5 Groundwater Chemistry

Field measurements of EC were used, in the hydrocensus of Rudolph, 2001, to evaluate the effect of pans on the groundwater regime and to identify areas of recharge and discharge:

- EC values at Vetpan showed a good correlation with EC values in the surrounding boreholes; however, smaller pans did not show the same correlation with their surrounding boreholes.
- Relatively high EC values were measured in the quartzite (120 – 190 mS/m) compared to the dolomite (20 – 52 mS/m). The dense tree growth in the region of the quartzite indicates that evapotranspiration may be contributing to these elevated EC's.
- There is no indication that water quality changes take place when the dolomitic water enters the Ventersdorp Supergroup.

The full water quality analysis is however needed to fully evaluate the differences between evaporation, geological formations and contamination. As part of the field-testing of the hydrocensus by Rudolph, 2001, the following data can be reported (Table 9):

Table 9: Field chemical data (Rudolph, 2001)

	Minimum	Maximum	Average
EC (mS/m)	**12**	**196**	**60**
pH	**6.3**	**9.2**	**7.6**

Darcy Consultants, 2002, summarised the mean chemical composition of the different geological formations in Table 10.

Table 10: Mean chemical composition of geological layers (Barnard, 2000)

Geological Unit	Code	pH	EC mS/m	TDS mg/l	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	Cl mg/l	SO4 mg/l	Talk mg/l	N mg/l	F mg/l	SAR mg/l
FRACTURED AQUIFERS														
Black Reef	**Vbl**	**7.00**	**34.3**	**238**	**28**	**18**	**14**	**2**	**15**	**36**	**98**	**2.8**	**0.2**	**0.5**
KARST AQUIFERS														
Chuniespoort group	**Vh**	**7.60**	**62.9**	**443**	**53**	**35**	**24**	**2**	**38**	**71**	**177**	**5.6**	**0.3**	**0.5**
INTERGRANULAR & FRACTURED														
Pretoria Group	**Vp**	**7.20**	**34.0**	**278**	**29**	**19**	**15**	**2**	**15**	**26**	**125**	**2.9**	**0.3**	**0.6**

As stated by Rudolph, 2001, a detailed water quality analysis is necessary to fully understand the groundwater quality and characteristics in the dolomitic compartment. The analysis consists of diagnostic diagrams, surface plots and the drinking water quality analysis. Water quality data was obtained from the DWAF WMS database and from samples taken in the 2001 hydrocensus.

3.4.5.1 Diagnostic Diagrams

The Piper, Durov, Expanded Durov and SAR diagrams are used for the statistical/graphical analysis. WISH was used for the graphical display of data.

Shown in the figures that follow, is the Piper, Durov, Expanded Durov and SAR diagram, of the groundwater for 1976 and 2001, as well as the Schoonspruit Eye.

3.4.5.1.1 The Piper Diagram

The Piper diagram is a projection of trilinear diagrams onto a diamond shaped field. The two trilinear diagrams consist of the major cations and anions plotted separately on each as percentages. Proportions and not concentrations are plotted in relation to one another. These positions on the trilinear diagrams are then projected to give an indication of certain types of groundwater.

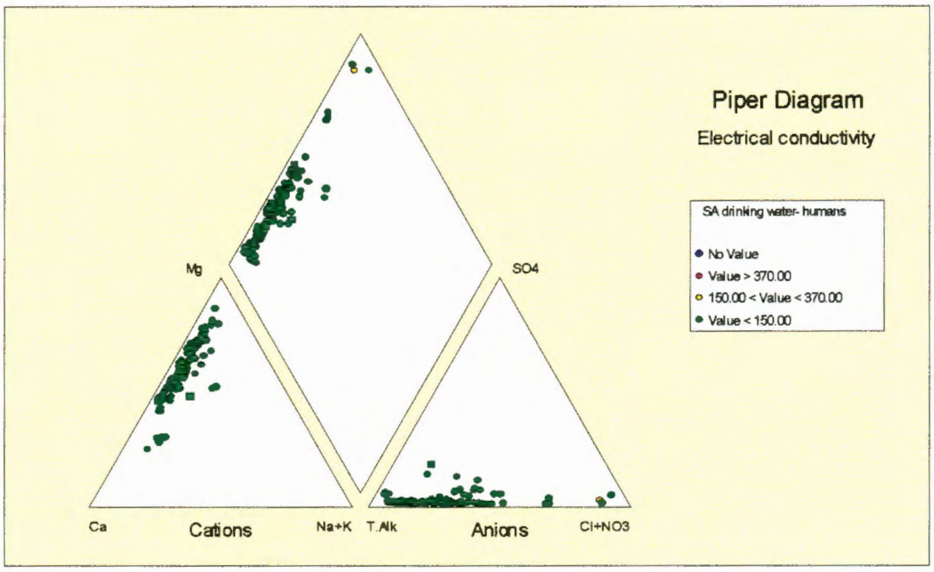


Figure 32: Piper Diagram of the Schoonspruit Dolomitic Compartment for 1976

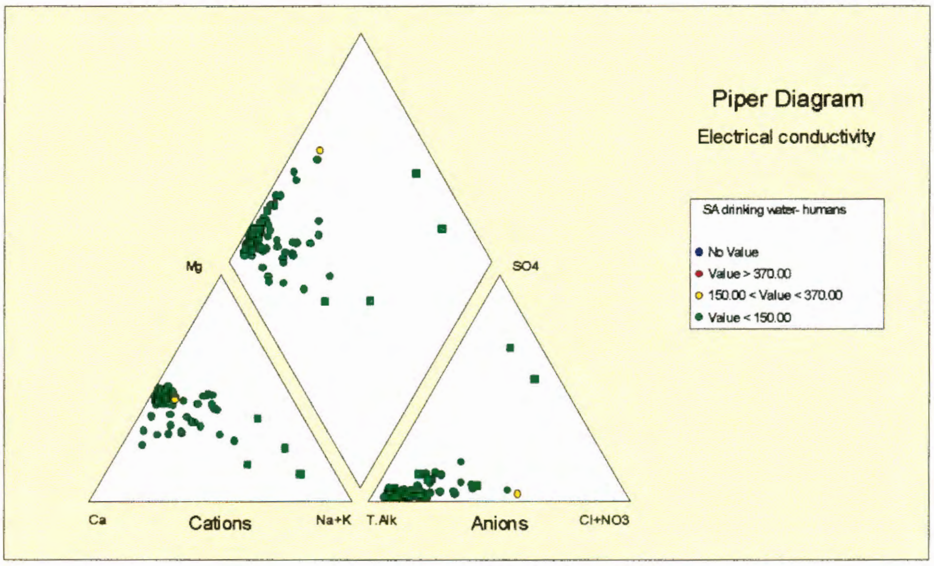


Figure 33: Piper Diagram of the Schoonspruit Dolomitic Compartment for 2001

In Figure 32, the trilinear diagrams of 1976 show the groundwater characteristics varying between Ca^{2+} and Mg^{2+} in the cation field and between HCO_3^- and Cl^- in the anion field. The Piper diagram therefore indicates a variation between recently recharged and old or polluted groundwater. The variation between Ca^{2+} and Mg^{2+} is not typical of a dolomitic water and might be because the introduction of old or stagnant water.

In Figure 33, the trilinear diagrams of 2001 show a correlation of 1:1 between Ca^{2+} and Mg^{2+} (as can be expected) in the cation field and the groundwater characteristic in the anion field as predominantly HCO_3^- with only a few samples shifts towards Cl^-. Two of the samples from pans in the area also show a shift towards SO_4^{2-}. The Piper diagram therefore indicates recently recharged groundwater with some of the pans showing mixed and stagnant water.

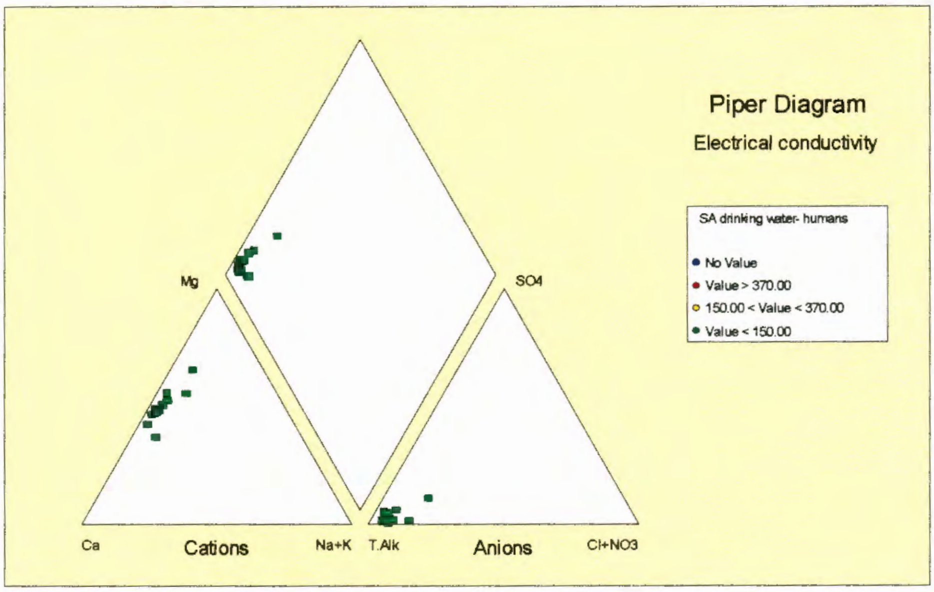


Figure 34: Piper Diagram of the Schoonspruit Eye

Figure 34 shows the Piper diagram of the Schoonspruit Eye and water from this source is classified as recently recharged groundwater with the same characteristics as most of the groundwater in the dolomitic compartment.

3.4.5.1.2 The Durov Diagram

The same plotting criteria were used for the Durov, as for the Piper diagram. However, the fields in the Durov are at right angles and the two points are transposed onto a square field at the point of intersection. The advantage is that two additional rectangular fields can be added, each with a scale displaying an additional parameter of relevance, e.g. pH and EC.

The pH of water in dolomitic aquifers usually falls between 6.5 and 8.9 (Ford & Williams, 1989).

The Durov diagram of 1976, Figure 35, indicates that most of the groundwater in the compartment has a neutral to slightly alkaline pH, ranging between 8 and 9, and a low salinity, ranging between 20 and 100 mS/m with one outlier possibly due to point pollution.

The Durov diagram of 2001, Figure 36, indicates that most of the groundwater in the compartment has a neutral to slightly alkaline pH, plotting mostly higher than 9, and a low salinity, ranging between 20 and 100 mS/m with one outlier, possibly due to point pollution.

The outliers of 1976 and 2001 are not on the same farm and therefore indicate point source pollution or a definite water quality influence on the compartment.

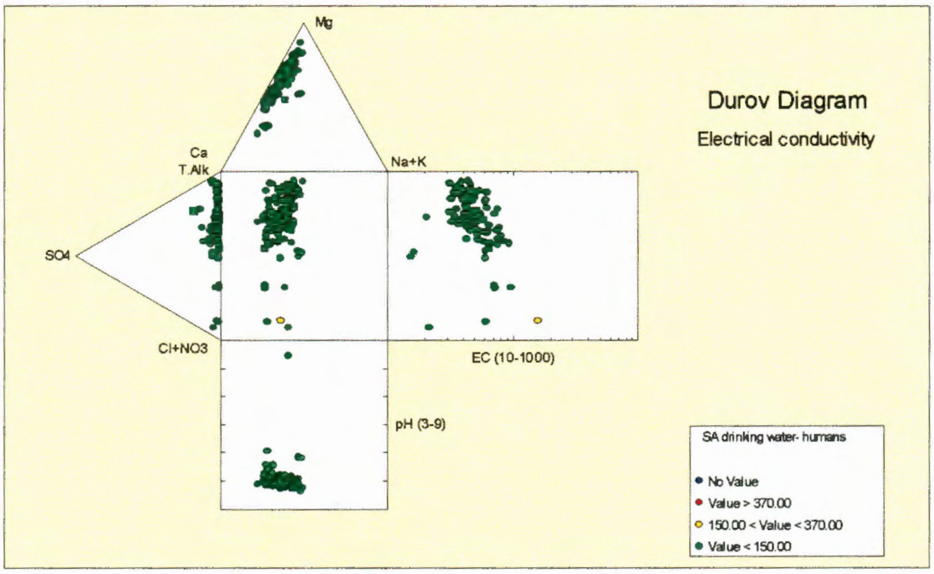


Figure 35: Durov diagram of the Schoonspruit Dolomitic Compartment for 1976

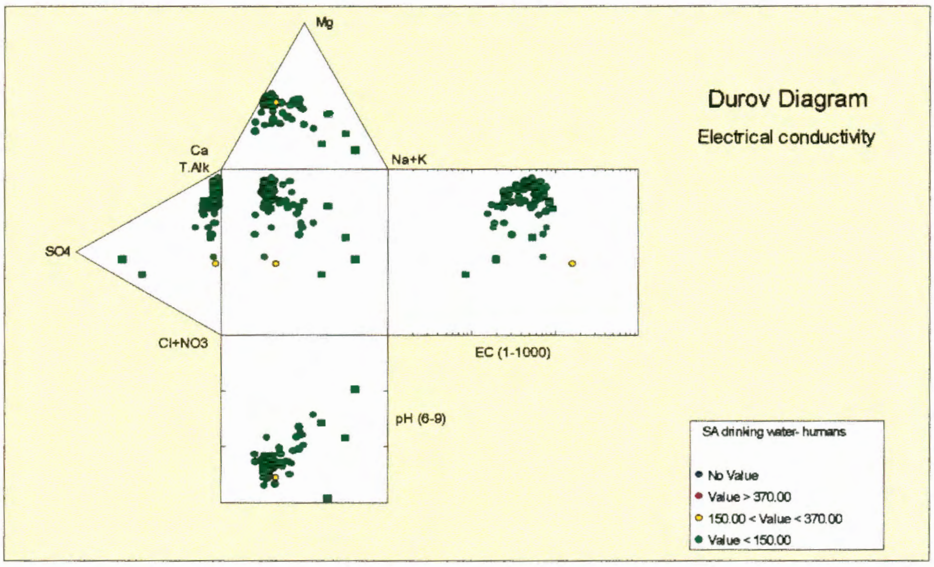


Figure 36: Durov Diagram of the Schoonspruit Dolomitic Compartment for 2001

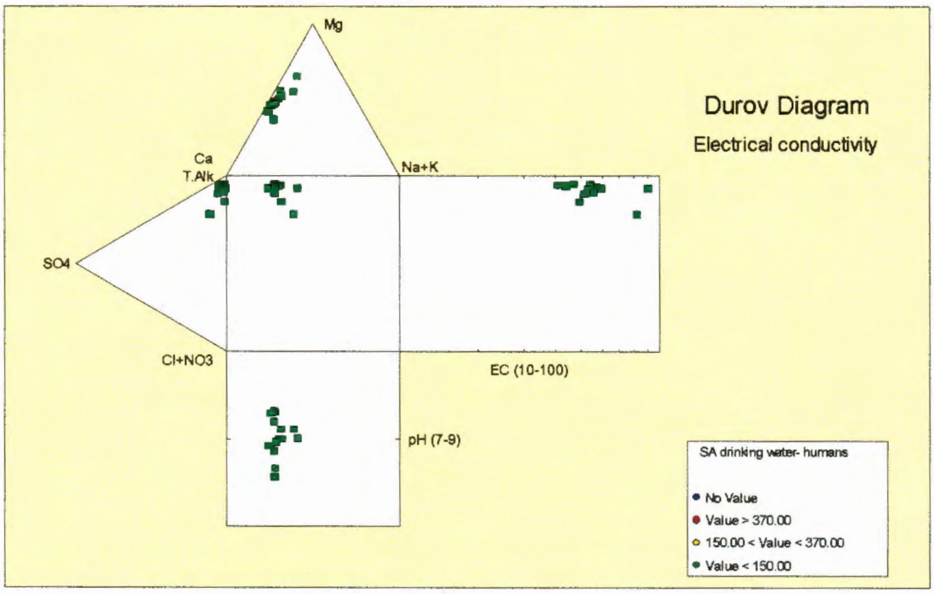


Figure 37: Durov Diagram of the Schoonspruit Eye

The Durov diagram of the Schoonspruit Eye, Figure 37, shows the same trends as the rest of the dolomitic compartment. pH ranges between 7.5 and 8.5 and a low salinity of 40 - 90 mS/m are shown.

3.4.5.1.3 The Expanded Durov Diagram

This diagram uses similar ratio techniques as the Piper to plot the concentrations of the major ions. The only difference is that six triangular diagrams are used, three for cations and three for anions. The ions are plotted in different combinations to form a plot with nine fields for classification. These fields give better splitting than the Piper does and are numbered for explanation purposes as follows:

Table 11: Expanded Durov Field Numbering

1	**2**	**3**
4	**5**	**6**
7	**8**	**9**

The Expanded Durov of 1976, Figure 38, shows most of the groundwater in fields 1 & 2 indicating calcium bicarbonate (field 1: Ca^{2+}, HCO_3^-) and calcium-magnesium bicarbonate (field 2: Ca^{2+}, Mg^{2+}, HCO_3^-) groundwater. Field 1 indicating recently recharged groundwater and field 2 indicates groundwater associated with dolomitic rocks. Some of the samples plot in field 5, indicating no dominant cations or anions and therefore mixing of groundwater may have taken place. The samples plotting in fields 7 and 8 have chloride (Cl^-) as dominant anion and indicate that reverse ion exchange has taken place. This is typical where older water has reacted with the dolomitic rocks or where pollution of groundwater has occurred.

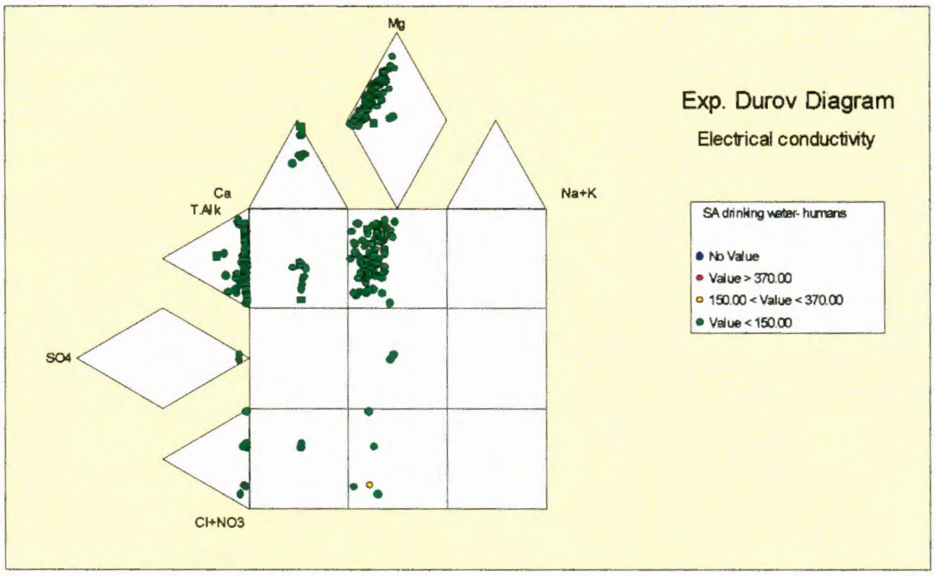


Figure 38: Expanded Durov diagram of the Schoonspruit Dolomitic Compartment for 1976

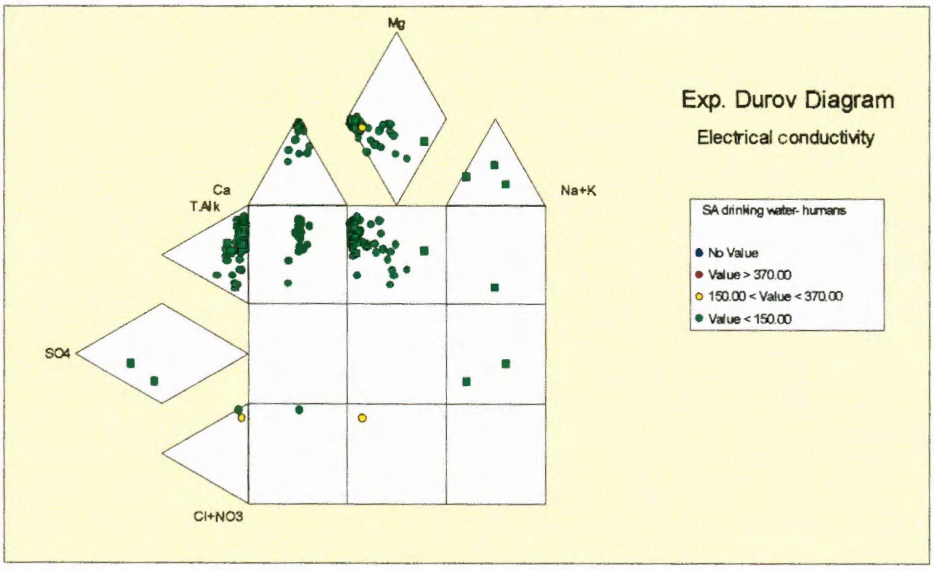


Figure 39: Expanded Durov Diagram of the Schoonspruit Dolomitic Compartment for 2001

The Expanded Durov of 2001, Figure 39, shows once again most of the groundwater in fields 1 & 2, indicating recently recharged groundwater and groundwater associated with dolomitic rocks. Some of the surface water samples plot in field 3 and 6, indicating ion exchange, with sodium (Na^+) and sulphate (SO_4^{2-}) the major ions, therefore mixing of groundwater and surface water may have taken place. The two samples plotting in fields 7 and 8 again, indicate that reverse ion exchange has taken place and older water had reacted with the dolomitic rocks or pollution of groundwater had occurred.

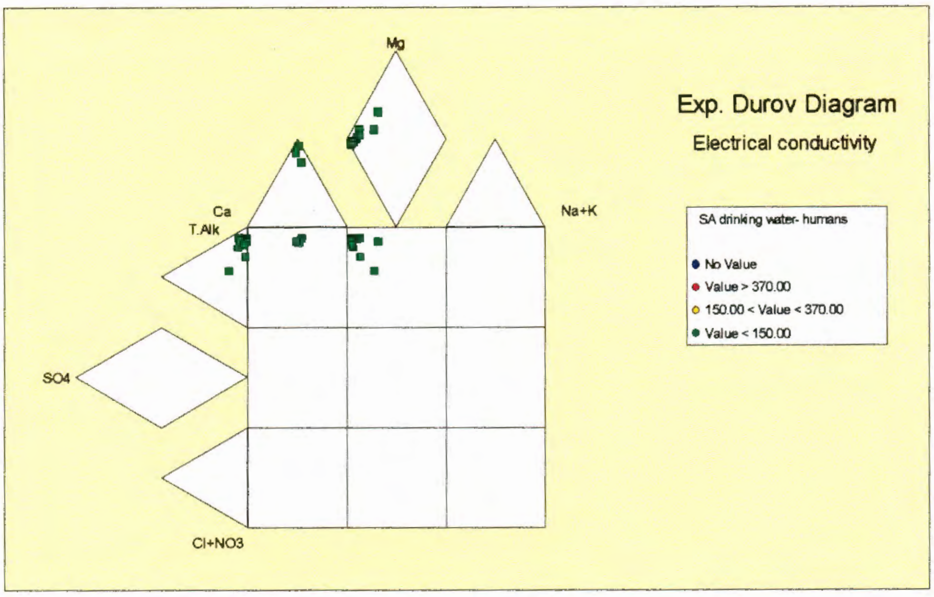


Figure 40: Expanded Durov Diagram of the Schoonspruit Eye

The Expanded Durov of the Schoonspruit Eye, Figure 40, shows the water as recently recharged groundwater associated with dolomitic rocks.

3.4.5.1.4 The SAR Diagram

The **S**odium **A**bsorption **R**ate diagram helps to estimate the ability of water to expel/exchange calcium and magnesium with sodium from topsoil. High SAR values indicate the risk of a displacement of the alkaline earth elements by sodium. There is an additional risk element from water that has a high hydrogen carbonate content but relatively low calcium content, for it already has a higher content ratio of sodium.

In this diagram the water quality is assessed by plotting the total dissolved solids (expressed as electrical conductivity (EC in mS/m)) against the SAR. The resulting 16 fields give an indication of the probability of possible excessive salinity and undesirable ion exchange.

The SAR diagram of 1976 and 2001, Figure 41 & Figure 42, shows groundwater in the dolomitic compartment ranging between classes S1-C1 and S1-C3.

S1 is low-sodium water that can be used with little danger on nearly all soils. Sodium sensitive crops may accumulate injurious concentrations of sodium.

C1 is low-salinity water that can be used on all types of soils.

C2 is medium-salinity water that can be used on soils with adequate drainage, but care should be taken in soils with inadequate drainage.

C3 is high-salinity water that cannot be used on soils that have restricted drainage. With adequate drainage, special management for salinity control may be required.

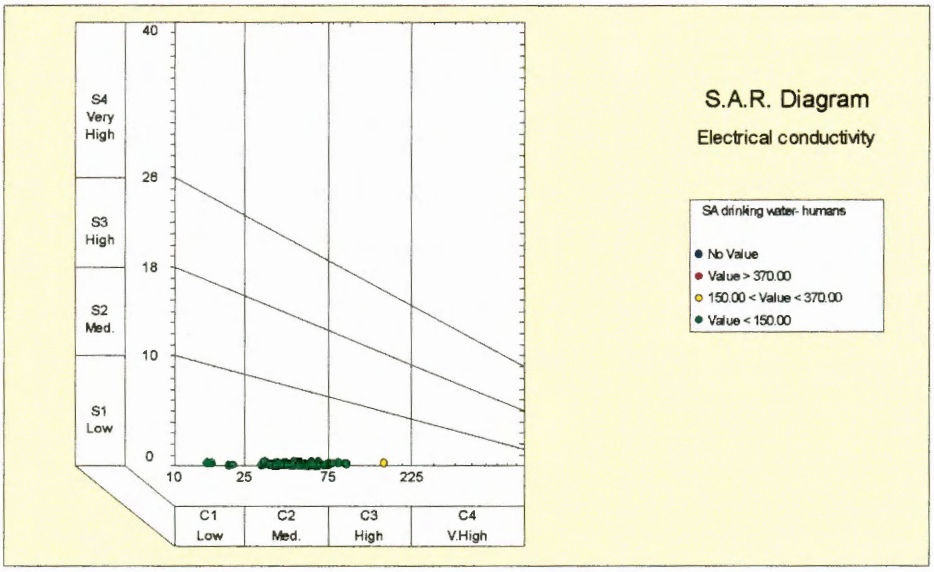


Figure 41: SAR diagram of the Schoonspruit Dolomitic Compartment for 1976

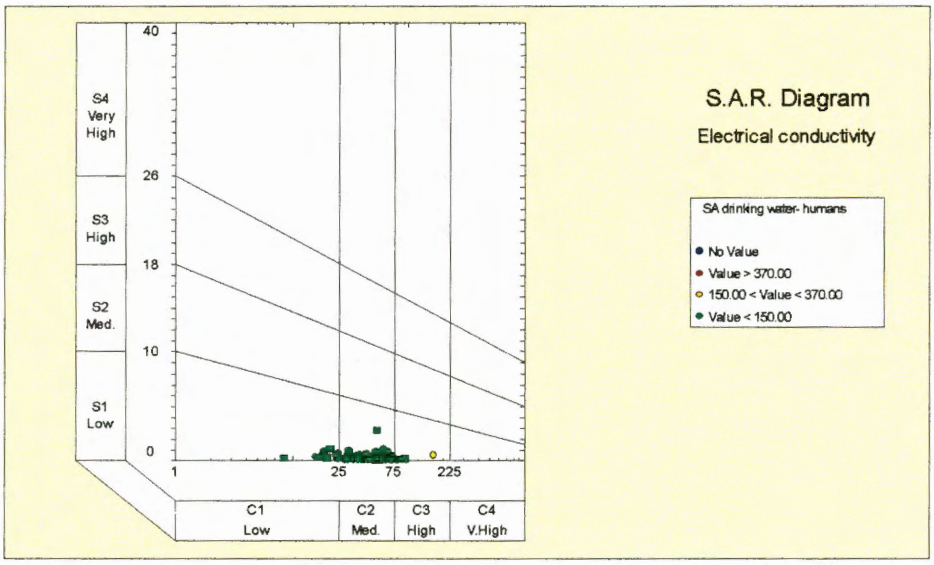


Figure 42: SAR Diagram of the Schoonspruit Dolomitic Compartment for 2001

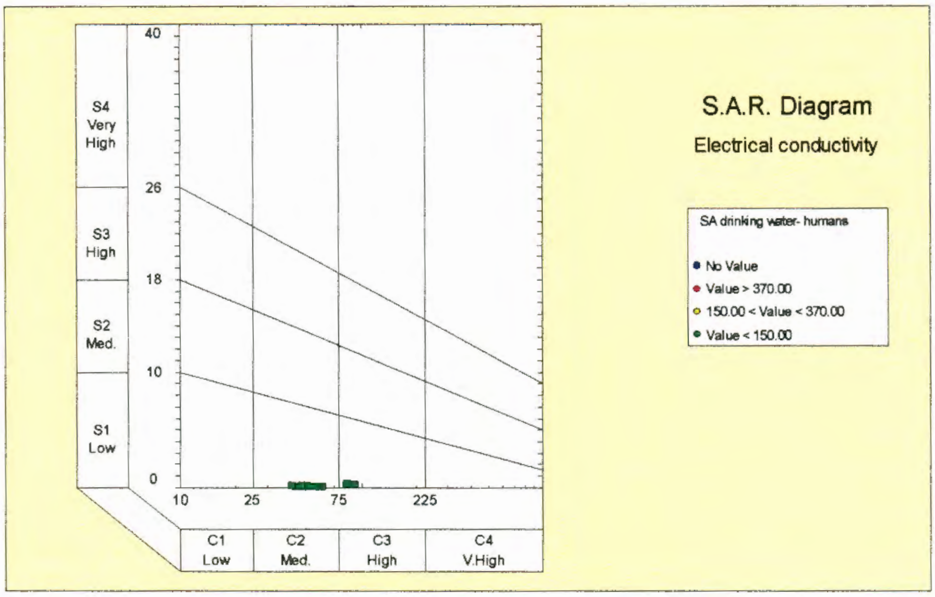


Figure 43: SAR Diagram of the Schoonspruit Eye

The SAR diagram of the Schoonspruit Eye, Figure 43, shows a classification of S1 and ranging between C2-C3 types of water.

The low sodium ratios in the groundwater of the dolomitic compartment indicate a low possibility of ion exchange and therefore a low risk of soil degradation due to irrigation practices. The only care that should be taken while irrigating is ensuring adequate drainage, where clayey soils are present. On average the groundwater in the dolomitic compartment is good quality irrigation water.

3.4.5.2 Surface Plots

These types of plots give an aerial distribution of chemical constituents or concentration gradients, e.g. a spatial plot of electrical conductivity (EC). When element ratios are used, e.g. Stiff diagrams, the different groundwater characteristics is shown in relation to one another and, where pollution has occurred, the extent of the pollution can be determined. Surface plots should always be compared with factors such as geology, recharge areas and rainfall distribution. WISH and Surfer 7.0 was used for the graphical display of data. The ion balance error, Figure 44, shows that for the most part the chemical analyses are reliable with a maximum error of 22% and only 4 error values above 10%.

In the Schoonspruit compartment, the recharge areas and rainfall distribution is fairly constant, and the changes in geology are mostly because of differences in chert content, as well as densities between the different dolomitic layers. The chemical composition of the layers does not differ and it would be expected that the chemical composition of the groundwater in the layers would be the similar. This is observed in Figure 45 to Figure 54.

The spatial plots of the chemical constituents, Figure 45 to Figure 52, show the following:

- EC and pH values are of the same order throughout the compartment, except for borehole WN2 that has an elevated EC concentration of 163mS/m, most probably because of point source pollution from agricultural activities.
- Calcium and magnesium levels are in the same order throughout the compartment except for borehole WN2 that has an elevated Ca concentration of 150mg/l and elevated Mg concentration of 91mg/l.

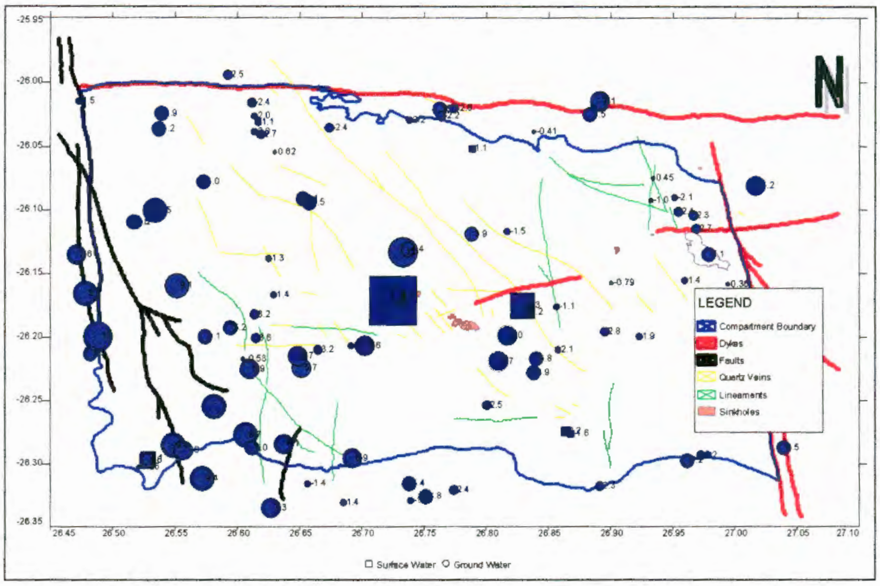


Figure 44: Ion Balance Error for the 2001 Chemical Analysis

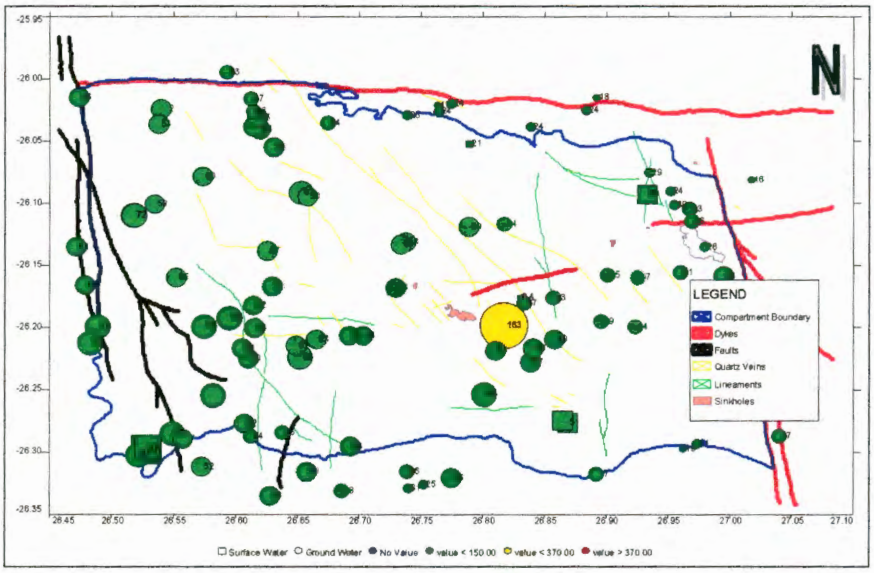


Figure 45: EC of Schoonspruit Dolomitic Compartment: 2001

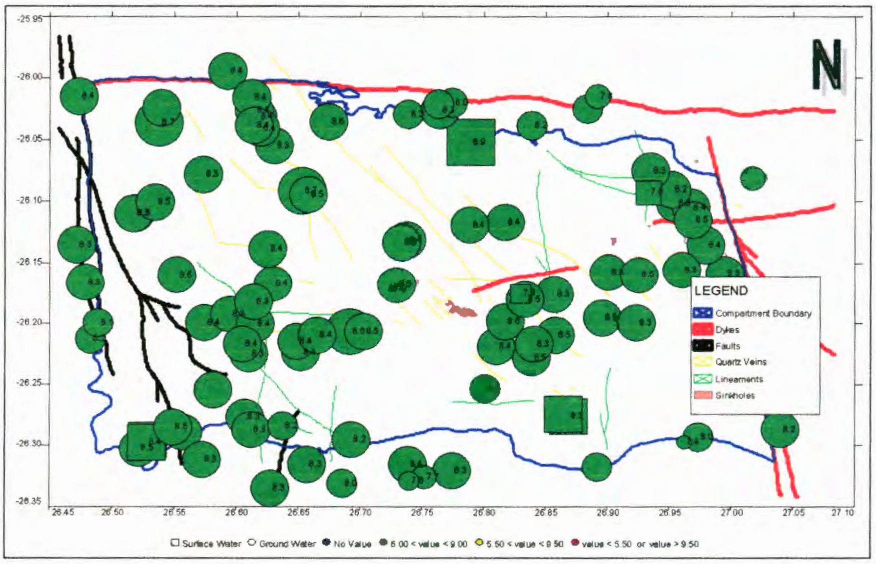


Figure 46: pH of Schoonspruit Dolomitic Compartment: 2001

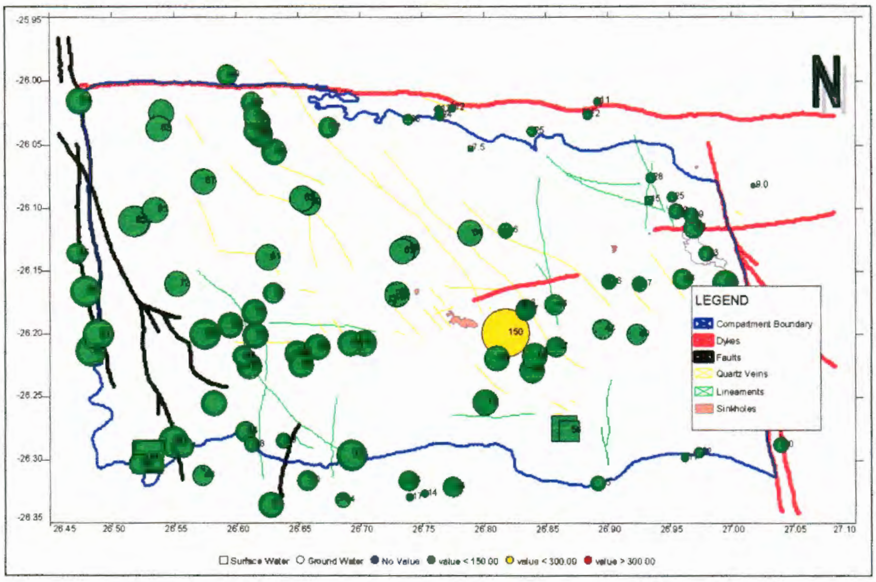


Figure 47: Calcium of Schoonspruit Dolomitic Compartment: 2001

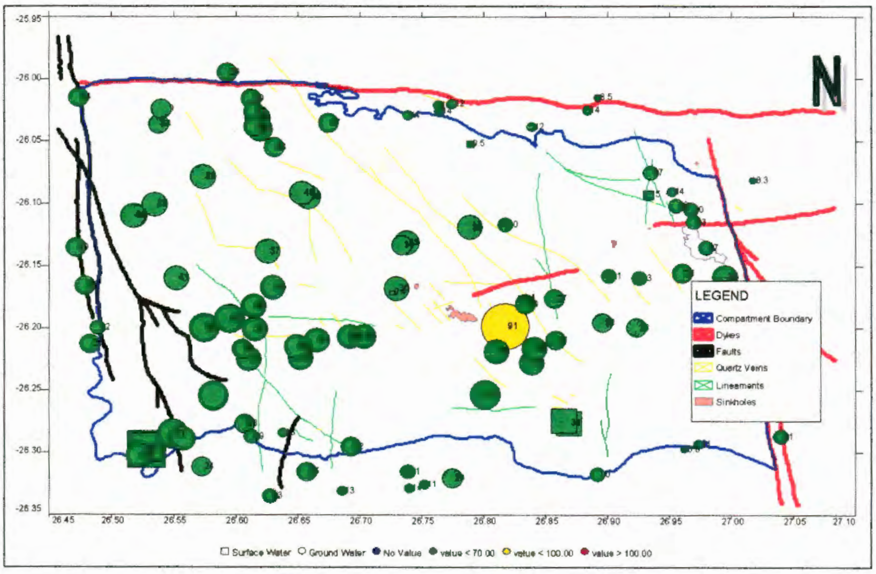


Figure 48: Magnesium of Schoonspruit Dolomitic Compartment: 2001

- Several of the analyses show elevated concentrations of sulphate, although they are still within water quality standards.
- Borehole WN2 and two of the pans in the area has elevated concentrations of sodium and chloride, which can be explained with regard to evaporation in pans, but borehole WN2 once again shows signs of point source pollution.
- Several analyses show elevated concentrations of nitrate, which is mostly related to point source pollution at farmsteads, see section 3.4.5.3, and could be detrimental to the health of small children.
- Aside from the elevated nitrate concentrations, only borehole WN2 has a drinking water quality that has deteriorated to a worse drinking water class than the rest of the boreholes in the compartment.
- It is also obvious that the different dolomitic layers in the compartment do not govern the chemical composition of the groundwater.
- The chemical composition of the Schoonspruit Eye is the same as the groundwater in the compartment.

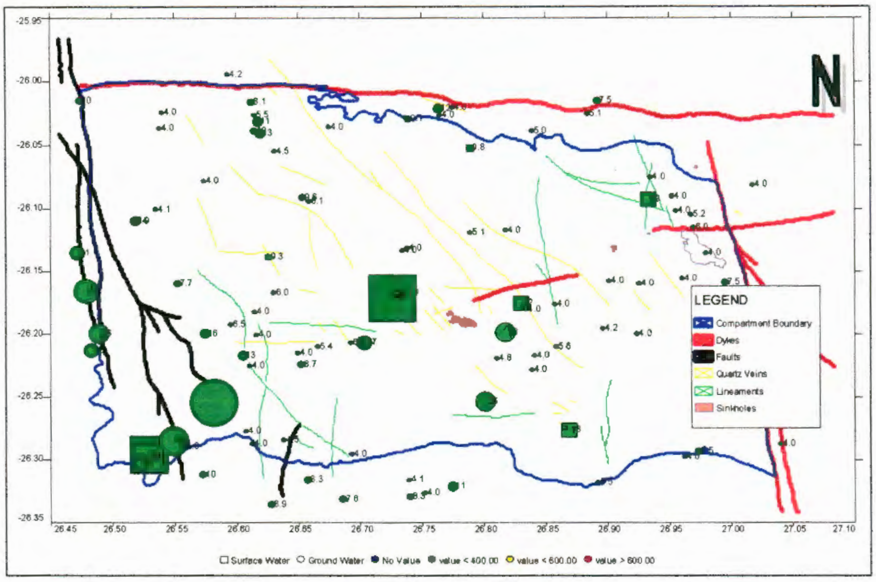


Figure 49: Sulphate of Schoonspruit Dolomitic Compartment: 2001

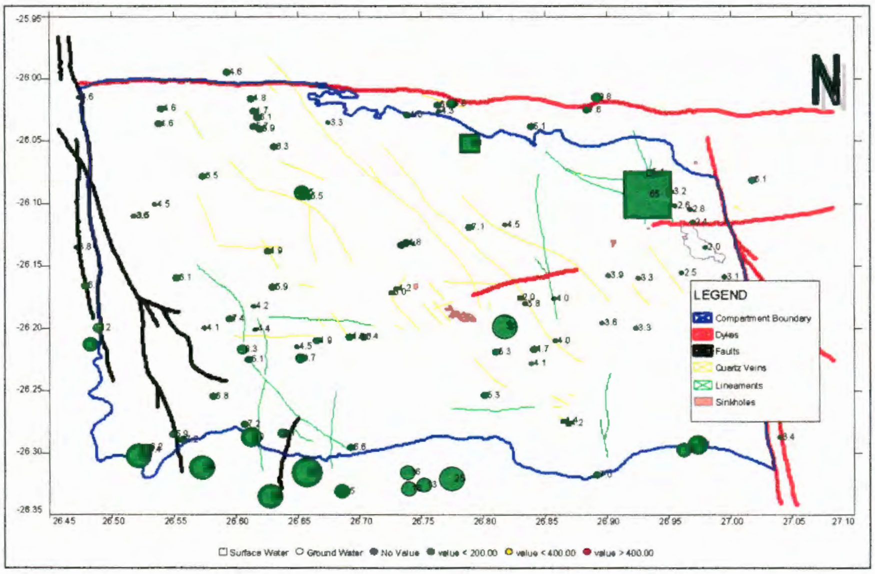


Figure 50: Sodium of Schoonspruit Dolomitic Compartment: 2001

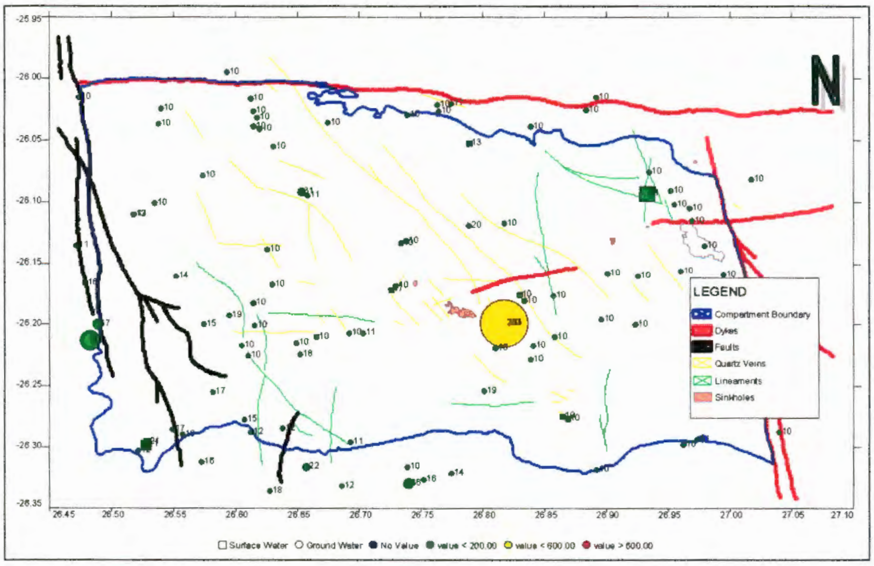


Figure 51: Chloride of Schoonspruit Dolomitic Compartment: 2001

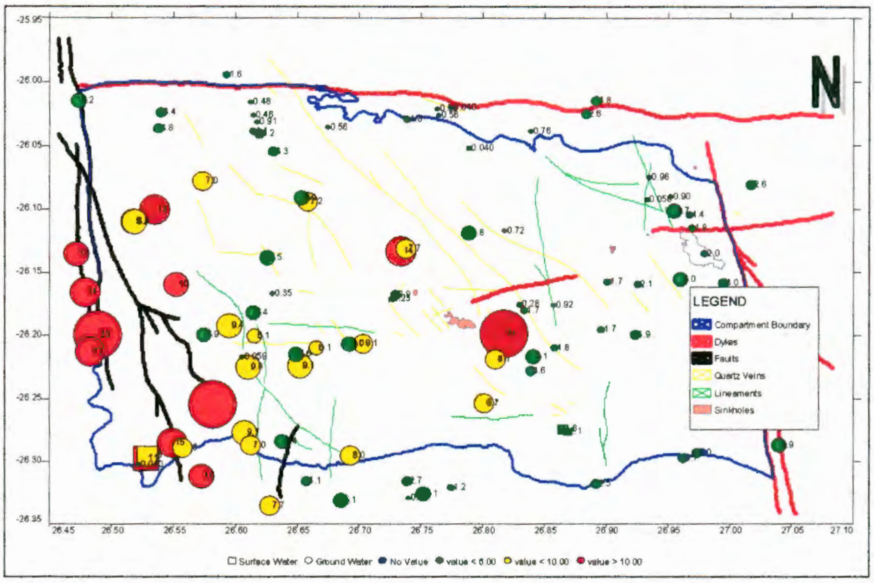


Figure 52: Nitrate of Schoonspruit Dolomitic Compartment: 2001

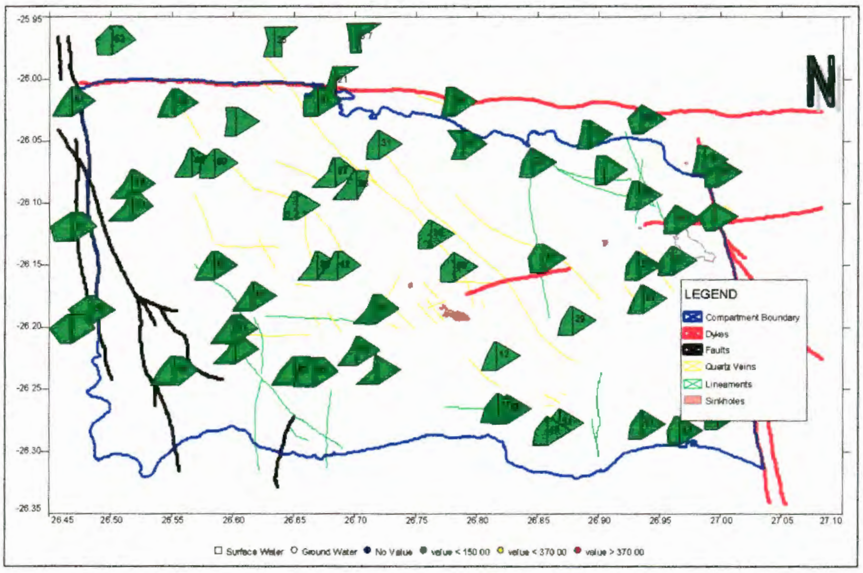


Figure 53: Stiff Diagrams for the Schoonspruit Dolomitic Compartment: 1976/78

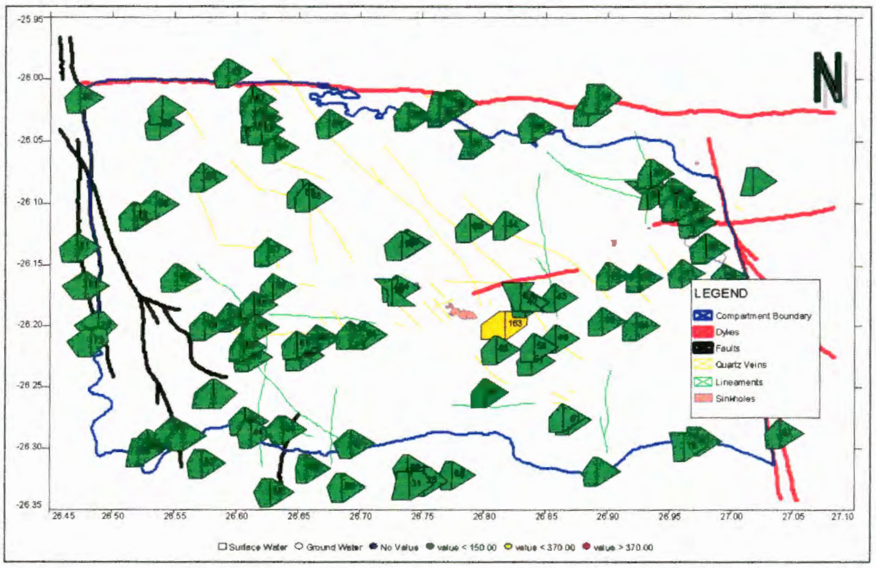


Figure 54: Stiff Diagrams for the Schoonspruit Dolomitic Compartment: 2001

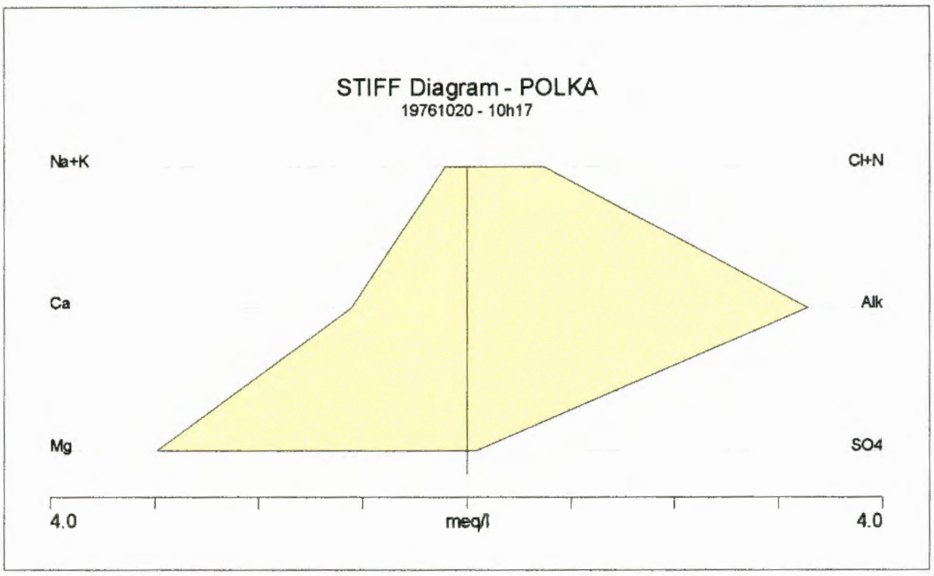


Figure 55: Enlargement of a typical Stiff Diagram for 1976/78

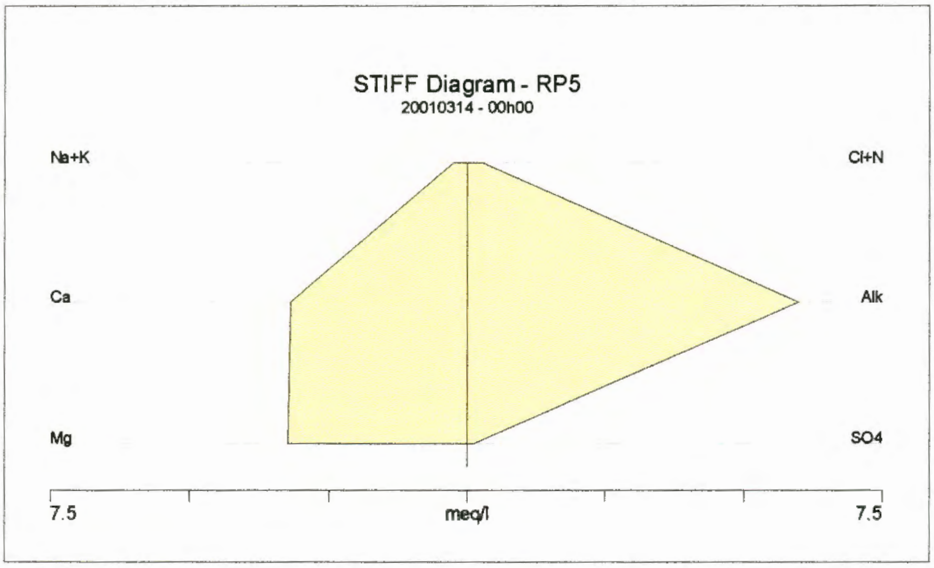


Figure 56: Enlargement of a typical Stiff Diagram for 2001

In a comparison between the Stiff diagrams of 1976 and 2001, Figure 53 to Figure 56, the following is observed:

- The 1976 diagrams are not exactly the same form as the 2001 diagrams. The difference in concentration ratios contributed to the higher magnesium ratios at 1976.
- The 1976 diagrams indicate the same groundwater quality characteristics throughout the compartment.
- The 2001 diagrams indicate the same groundwater quality characteristics throughout the compartment, except for borehole WN2 that has elevated ratios of calcium, magnesium, sodium and chloride.

- Some of the pans also have a different water quality character, but this could be because of surface water evaporation.
- The water quality character of the Schoonspruit Eye mimics the rest of the groundwater in the compartment, confirming that the Eye is dolomitic groundwater.

Table 12 gives the average water quality of the Schoonspruit Eye for the two samples taken during the 2001 hydrocensus:

Table 12: Water Quality of the Schoonspruit Eye

Constituent	Concentration
EC (mS/m)	**53.40**
pH	**8.39**
Total Dissolved Solids (mg/l)	**456.81**
Ca (mg/l)	**58.04**
Mg (mg/l)	**34.98**
SO_4 (mg/l)	**12.10**
Na (mg/l)	**4.29**
Cl (mg/l)	**10.00**
Nitrate - N (mg/l)	**2.43**
F (mg/l)	**0.14**
PO_4 (mg/l)	**0.02**
K (mg/l)	**1.07**
Si (mg/l)	**8.35**
Alkalinity (mg/l)	**270.92**

3.4.5.3 Impacts on Groundwater Quality

Many of the activities common to farmsteads can pollute groundwater, due to the concentration of materials and waste on this relatively small area. Common sources of pollution found around the farmstead include septic tanks, stored fertiliser, silage and pesticides, animal waste and fuel tanks. (Colvin, 2000)

As a pollutant when present in surface water, nitrate may pose a different threat to that in groundwater: (Darcy Consultants, 2002)

- Nitrate (NO_3^-) in surface water is a nutrient that encourages plant growth, choking the water with algae and other aquatic plants, these consume oxygen from the water, especially when they die and decay, and the surface water body can rapidly become eutrophic.
- Since they are very soluble and do not bind to soils, nitrates have a high potential to migrate to groundwater. Because they do not evaporate, nitrates/nitrites are likely to remain in water until consumed by plants or other organisms.

Agricultural activities are a source of diffuse water contamination. The contribution of each farm on a local scale is often fairly small but the contribution on a catchment scale needs to be included in assessing the situation. (Darcy Consultants, 2002)

Conrad et al, (1999) assessed the impact of agriculture on groundwater resources. Nitrate was identified as the most problematic contaminant, especially where sewage sludge application is practised, significantly where intensive animal husbandry (IAH) is practised, while fertiliser application, of greater relevance to agriculture in this region, was also a potential source of high nitrates. Only limited impacts were seen with the application of inorganic fertilisers.

Generally, on a local scale, the areas of intense cultivation are the major contributors in terms of inorganic nitrates. The primary inorganic nitrates, which may contaminate drinking water, are potassium nitrate and ammonium nitrate, both of which are widely used as fertilisers. Where feedlots are operated the contribution of organic nitrates to groundwater contamination can be far more problematic, but for most farming activities, organic nitrate is not a severe problem in South Africa. (Darcy Consultants, 2002)

Figure 57 and Figure 58 shows the spatial distribution of nitrates in the Schoonspruit compartment for the time periods 1976/78 and 2001:

- It is clear that the nitrate concentrations in the compartment have increased from 1976 to 2001.
- The dolomitic groundwater character is the same throughout the compartment and therefore these nitrate occurrences are point source pollution, most probably from septic tanks, feedlots and irrigation fertilisers.
- Care should be taken when using the water for drinking water, especially with regard to children under the age of 6, as elevated nitrates can cause *Blue-baby Syndrome*.
- Increases in nitrate levels could also be problematic for downstream water users. (Darcy Consultants, 2002)

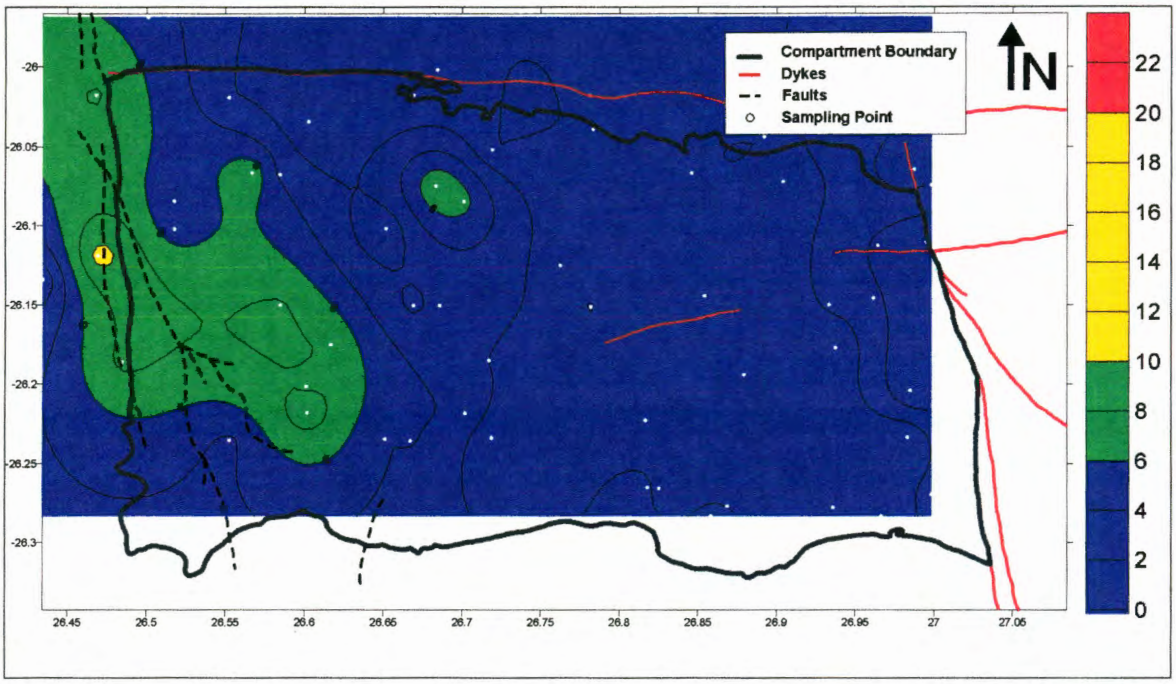


Figure 57: Nitrate as N for the Schoonspruit Dolomitic Compartment: 1976/78

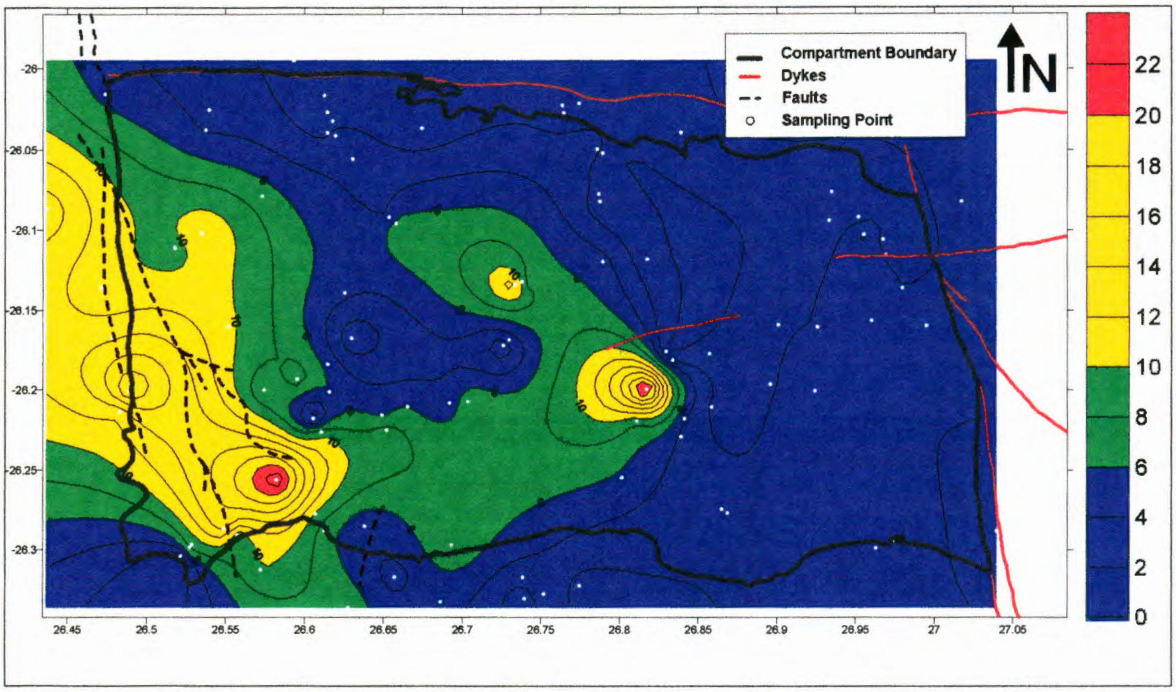


Figure 58: Nitrate as N for the Schoonspruit Dolomitic Compartment: 2001

The contribution of pesticides and herbicides to groundwater contamination is very difficult to quantify on catchment scale and site-specific data relating to likely loading/application volumes and history, soil profile and local geohydrology are required. The run-off contribution of agricultural activities is often a more widespread and problematic phenomenon than infiltration into groundwater. (Darcy Consultants, 2002)

3.4.6 Aquifer Parameters

Aquifer parameters convey the basic characteristics of an aquifer in mathematical terms that can be used in mathematical simulations and numerical modelling. Various factors can be incorporated into these solutions, but the basic parameters construe the following:

3.4.6.1 Transmissivity and Storativity

Table 13: Transmissivity and Storativity values for the Schoonspruit Dolomitic Compartment

SITE ID	Intake Depth (m)	Transmissivity (m^2/d)	*Storativity	Abstraction Rate (l/s)
2527AA00003		1	0.0001	0.2
2626BA00176	72.000	8	0.0001	0.6
2626BA00178	41.000	270	0.0001	1.6
2626BA00179	39.000	500	0.0001	8.0
2626BB00199	24.000	7500		16.0
2626BB00201	30.500	187	0.0001	4.0
2626BB00202	50.000	17	0.0001	0.4
2627AA00135		14	0.0001	2.0
2627AA00137		33	0.0001	1.5

* Storativity values as received from the NGDB – not dependable as described further in the text.

Table 13 shows transmissivity and storativity values as recorded on the NGDB, from pump tests and reported by WA-G. Pumping tests were evaluated with the Theis method for unsteady state flow and the following assumptions is made by this method: the aquifer is confined, homogeneous and the flow to the well is in an unsteady state, it changes with time (Kruseman & de Ridder, 1990). Storativity values is probably not very reliable, as they are all the same and less than one would expect, especially for karst aquifers. Transmissivity values are very variable, between 1 - $7500m^2/d$, because of the variable nature of dolomitic rock. This value depends on whether the boreholes are drilled into a fracture or a solution cavity, therefore homogeneity does not exist and the Theis method cannot be applied. No further pump tests were done for determining aquifer parameters.

Pump tests are expensive and the value of the data that is generated for management in dolomitic areas is very small, as a single borehole's transmissivity and storativity cannot be related to the rest of the compartment, because of the variable nature of the host rock.

3.4.6.2 Recharge

Recharge in the area is high due to soils that are transmissive and areas of karstification, which allow rapid recharge (Darcy Consultants, 2002). Different types of recharge determinations can be used depending on the amount of information available in the dolomitic compartment. Types of methods can be grouped into methods relevant to the unsaturated and saturated zones (Bredenkamp, et.al., 1995):

Unsaturated zone methods	Lysimeter
	Environmental isotopes
	Soil moisture
	Chloride profile
	EARTH-Method (Gehrels & Van der Lee, 1997)
Saturated zone methods	Hydrograph interpretations
	Flow characteristics
	Saturated volume fluctuations
	Cumulative rainfall departure
	Environmental Isotopes (Selaolo, 1998))
	Mathematical modelling
	Geothermal gradients (circulation depth)

The more types used, the higher the confidence level in the recharge value that is obtained, provided that the answers are well correlated. Some of the methods require data that is difficult to obtain and only methods relevant to the area will be described. The software package used for evaluation of data was RECHARGE, developed by Van Tonder & Xu, 2000.

The RECHARGE software uses the average groundwater level from all monitoring boreholes, throughout the aquifer (dolomitic compartment), as the groundwater level to do the simulations from. Thereby integrating the effect of rainfall on the whole system rather than on any specific borehole as such. Singular boreholes can also be evaluated if necessary.

Figure 59 shows the monthly abstraction volumes as used in the water balance methods. Note that these abstraction volumes include abstraction from all boreholes, spring flow volumes from the system, leakages and water consumed by evapotranspiration.

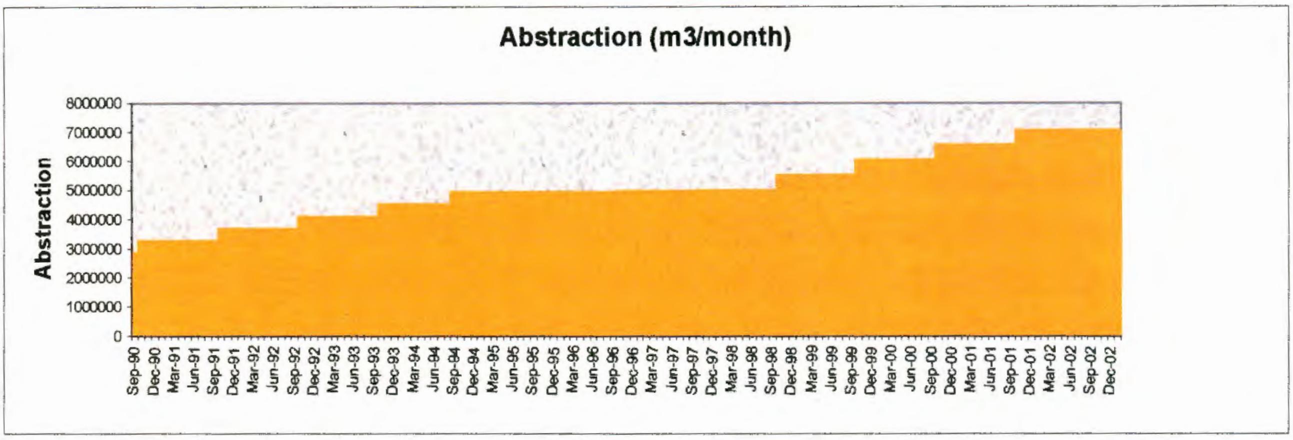


Figure 59: Monthly abstraction values used in estimating the recharge of the Schoonspruit Dolomitic Compartment

3.4.6.2.1 Qualified Guess

Various maps exist which can assist in a first estimate of recharge in an area. Examples include Vegter's map, the Harvest Potential map and the Groundwater Component of Baseflow map. (Van Tonder & Xu, 2001)

Table 16 shows the % recharge from rainfall as derived from different Qualified Guesses.

3.4.6.2.2 Chloride method

Studies carried out by Bredenkamp, et.al., (1995) and Bredenkamp (1993), have shown that the percentage rainfall representing recharge can be derived from the ratio of chloride concentration in rainfall relative to that of the local groundwater. Mathematically the relationship can be expressed as follows:

Equation 6

$$RE\ (\%) = CL_{RAIN}/CL_{GW} * 100$$

Where RE (%) = total percentage recharge of rainfall

CL_{RAIN} = chloride concentration in rainwater

CL_{GW} = chloride concentration in groundwater

Although the chloride concentrations of the soil profile with depth can be used to determine recharge, the chloride-method is applied to the chloride concentration of spring water, as the springs represent the recharge integrated in time and space. A specific requirement is that no chloride should have been added by dissolution of aquifer material, or by contamination or salts contained within the aquifer matrix. The natural hydrological evaporative processes should be the only processes by which the chloride from the rainfall is concentrated. (Darcy Consultants, 2002)

Chloride levels were measured at a rainfall-sampling site and in groundwater samples throughout the compartment, including the Schoonspruit Eye. Figure 60 shows the values and distribution of these chloride values throughout the dolomitic compartment and the rainfall chloride was measured as 0.66 mg/l. Important to note is that all samples were analysed by the same laboratory, the CSIR, as chloride measurements between different laboratories differ because of detection limits of the labs.

The chloride value in Table 12 differs from those in Table 14, as these were analysed by different laboratories. Interesting to note is that the concentrations of the hydrocensus samples' chemical analysis of the Schoonspruit Eye give both chloride values as exactly

10.0 mg/l. This is an indication that the hydrocensus' chloride concentrations might be erroneous.

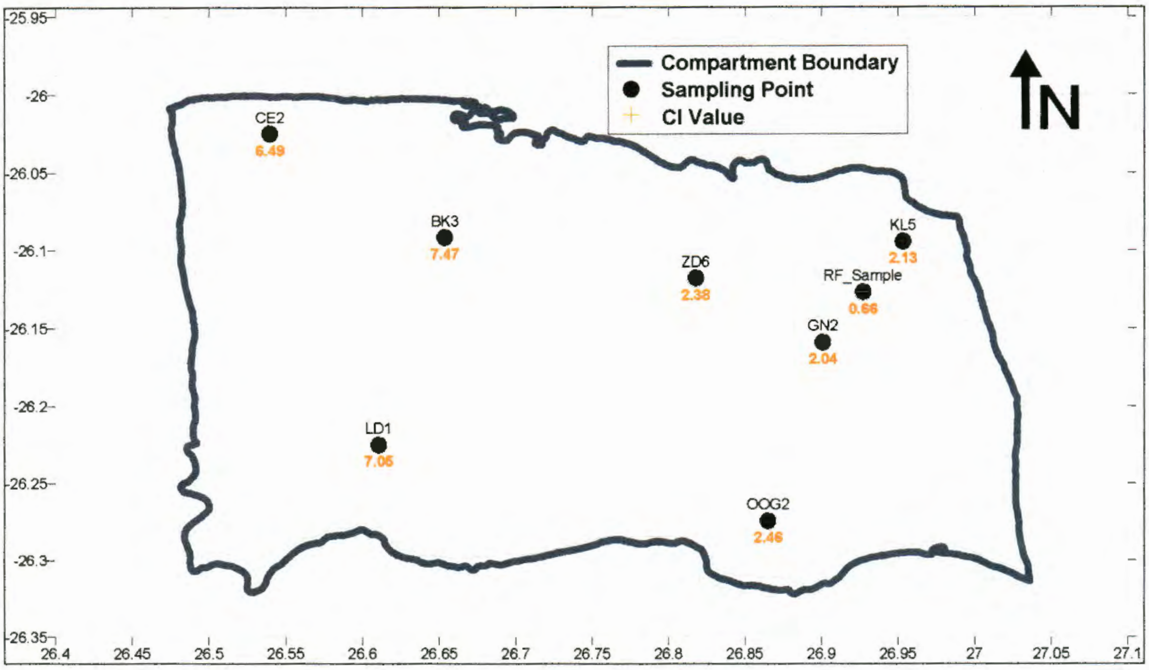


Figure 60: Chloride sampling sites

Table 14 shows the % recharge from rainfall as derived for the different sites with Equation 6.

Table 14: Cl Recharge Estimations

Zone	SiteID	Cl (mg/l)	RF_Cl (mg/l)	Re %	AVE Cl (mg/l)	AVE Re %
A	GN2	2.04	0.66	32.35	**2.25**	**29.47**
	KL5	2.13	0.66	30.99		
	OOG2	2.46	0.66	26.83		
	ZD6	2.38	0.66	27.73		
B	BK3	7.47	0.66	8.84	**7.00**	**9.46**
	CE2	6.49	0.66	10.17		
	LD1	7.05	0.66	9.36		

3.4.6.2.3 EARTH-Method

The Extended Model for Aquifer Recharge and soil moisture Transport through the unsaturated Hardrock (EARTH) method is a lumped parametric model for the estimation of groundwater recharge. The method is a complicated model, taking into account precipitation, interception, evaporation, ponding, soil moisture storage, root uptake, percolation, unsaturated flow, recharge, groundwater level fluctuations and drainage. The general equation is given as (Gehrels & Van der Lee, 1997):

Equation 7

$$S\ dh/dt = R - h/DR$$

Where R = recharge (m^3/month)

S = specific yield

dh/dt = water level head change during one month h = groundwater level

DR = drainage resistance (a lumped, site specific parameter)

The drainage resistance is a measure of the resistance of the saturated zone to flow through it and is inversely proportional to the transmissivity of the saturated zone. Figure 61 shows the simulation of this model on the Schoonspruit Dolomitic Compartment. However, this simulation does not give a particular good fit. The recharge estimate from this simulation should be used with caution.

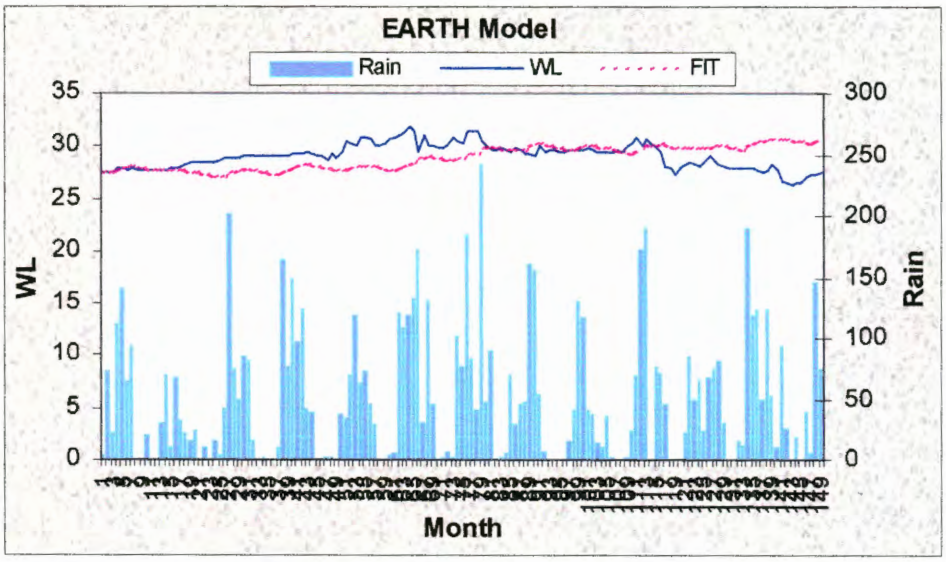


Figure 61: EARTH Model simulation of the Schoonspruit Dolomitic Compartment

Table 16 shows the % recharge from rainfall as derived from the EARTH Model.

3.4.6.2.4 Saturated Volume Fluctuation Method

This method is based on the saturated water balance, therefore taking into account inflows, outflows, recharge and the change in aquifer storage (saturated volume) over time. The method provides a picture of the water level response of the aquifer and the solution is based on Equation 8 (Bredenkamp, et.al., 1995):

Equation 8

$$Q_{INFLOW} - Q_{OUTFLOW} + RE_{TOT} - Q_{ABSTR} = S\Delta V$$

Where RE_{TOT} = total recharge

Q_{ABSTR} = pumpage from the system or spring flows

S = aquifer storativity or specific yield

ΔV = integrated change in saturated storage volume

$Q_{OUTFLOW}$ = lateral flow to lower compartments

Q_{INFLOW} = lateral flow from higher compartment

This method can be used to determine both recharge and storativity. When natural losses like evapotranspiration is not incorporated into the equation, the recharge calculated only represents the effective or exploitable recharge. (Bredenkamp, et.al., 1995)

Figure 62 shows the simulation done for the Schoonspruit Dolomitic Compartment. The storativity was calculated as S, = 0.0225, which indicates a large storage capacity to the volume of 2.25% of the aquifer. This is because of the karstification of the dolomite.

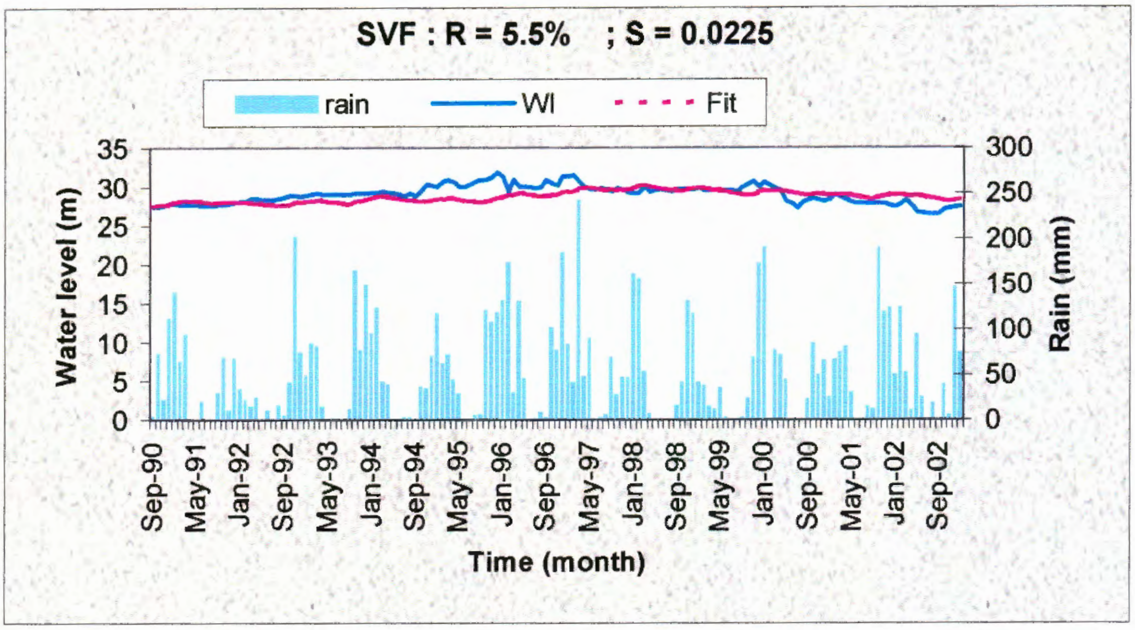


Figure 62: SVF simulation of the Schoonspruit Dolomitic Compartment

Table 16 shows the % recharge from rainfall as derived from the SVF method.

3.4.6.2.5 Equal Volume Method

Recharge can be estimated by means of the rainfall/recharge response of a spring, for its catchment area, from the equal-volume analysis of spring flow (Bredenkamp, 2000). This method is applicable where no change in storage volume (ΔV) has occurred in the system and is shown with Equation 9 (Van Tonder & Xu, 2001). The simulation is shown in Figure 63, indicating the chosen period of equal volume.

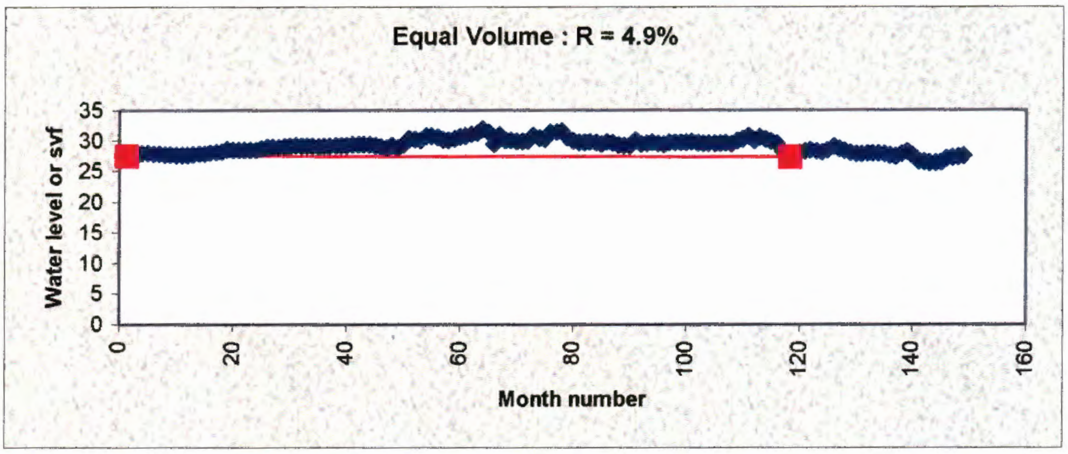


Figure 63: EV simulation of the Schoonspruit Dolomitic Compartment

Equation 9

$$RE_{TOT} = Q_{ABSTR} + E_{VT} + Q_{OUTFLOW} - Q_{INFLOW}$$

Where RE_{TOT} = total recharge

Q_{ABSTR} = pumpage from the system or spring flows

E_{VT} = evapotranspiration losses from the aquifer

$Q_{OUTFLOW}$ = lateral flow to lower compartments

Q_{INFLOW} = lateral flow from higher compartments

Table 16 shows the % recharge from rainfall as derived from the EV method.

3.4.6.2.6 *Cumulative Rainfall Departure Method*

The method is based on the response of groundwater level changes in response to rainfall, but the algorithm was improved to include the water balance as part of the method (Van Tonder & Xu, 2001). This method therefore incorporates the principle that equilibrium develops in an aquifer in time until the average losses equals the average recharge of the system (Bredenkamp, et.al., 1995).

The simulation done in Figure 64 is for the average groundwater level in the compartment and not for a particular monitoring borehole. This method will also be used in the groundwater simulations of the Schoonspruit compartment, section 3.6.1, and the theory are explained in more detail in the particular section.

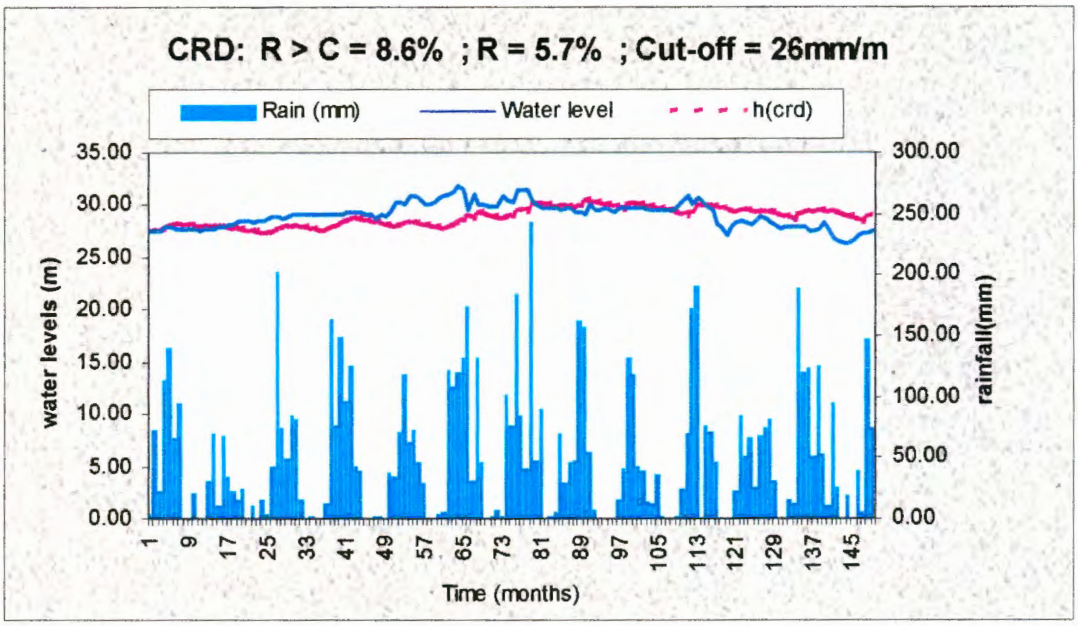


Figure 64: CRD simulation of the Schoonspruit Dolomitic Compartment

The CRD simulation showed a recharge of 8.6% of the rainfall above the threshold of 26mm/m (313mm/a, Bredenkamp & Swartz, 1987). Effective recharge therefore amounts to 5.7% of the total annual rainfall and is summarised in Table 16.

3.4.6.2.7 *Environmental Isotopes*

This method is applicable to the ^{2}H (deuterium) and ^{18}O (Oxygen-18) isotopes and a line is plotted parallel to the local meteoric water line (MWL) representing the displacement of soil moisture. The recharge can be determined as the inverse of the square root of the displacement from this line, Equation 10. (Selaolo, 1998)

Equation 10

$$\Delta\delta = \frac{C}{\sqrt{\mathrm{Re}\,charge}}$$

Where $\Delta\delta$ = δ displacement observed in the $^{2}\delta$-$^{18}\delta$ diagram

C = slope of the line through the inverse of the square root recharge rate

Figure 65 shows the line plotted parallel to the MWL, with ratios used as given in Table 15.

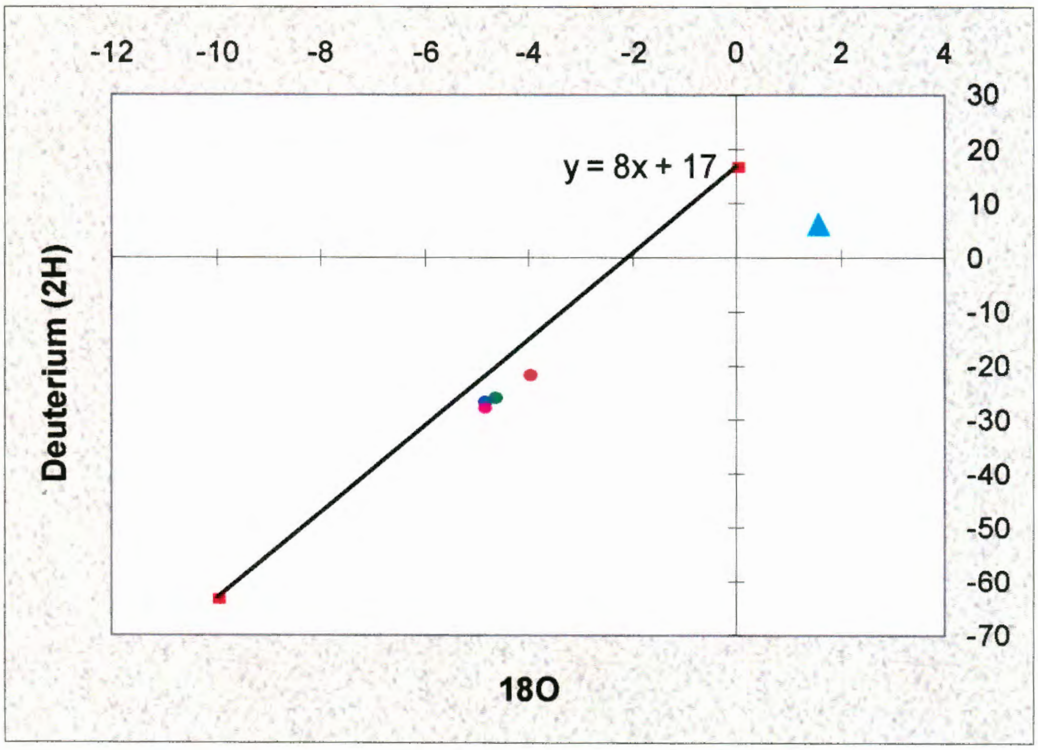


Figure 65: ^{2}H / ^{18}O Environmental Isotopes of the Schoonspruit Dolomitic Compartment

Table 15: Isotope ratios used in Figure 65

Sample	O18	Deuterium
MWL	-10	-63
MWL	0	17
Seawater	1.6	6
Oog2 & KL5	-4.84	-27
CE2 & ZD6	-4.63	-26
GN2	-4.85	-28
BK3	-3.98	-22

Table 16 shows the % recharge from rainfall as derived from the Environmental Isotopes method.

3.4.6.2.8 Geothermal Gradients

This method is used to determine the average depth from which the water at a spring originates, therefore the depth of circulation of groundwater, and is given by Equation 11. (Bredenkamp, et.al., 1995)

Equation 11

$$D_{AV} = (T_{SPRING} + T_{AMBIENT}) / GT_{GRAD}$$

Where D_{AV} = average depth of origin

T_{SPRING} = temperature of spring water

$T_{AMBIENT}$ = temperature of shallow groundwater

GT_{GRAD} = geothermal gradient (°C/100m)

For the Schoonspruit Eye $T_{AMBIENT}$ was taken as 18.9°C, GT_{GRAD} as 0.6°C/100m and T_{SPRING} as 19.9°C. Results on the Eye yielded that the spring emanates from 175mbgl. (Bredenkamp, et.al., 1995)

Keeping the parameters constant and only using recent field measurement of T_{SPRING} = 17.5°C (close to shade) and T_{SPRING} = 20.7°C (in direct sunlight), the equation yielded that the spring emanates from -233mbgl and 300mbgl. This shows the sensitivity of this method to slight changes in temperature measurement or faulty measurements and are therefore not a good method to use if uncertainties regarding data exist.

3.4.6.2.9 Summary

The following table gives a summary of recharge values estimated with the different methods. From this information the most important management decision will be, which value of recharge to use: Does one use the conservative (safe) value, or does one use the high recharge values and risk the aquifer will be over-exploited (mined).

Table 16: Summary of recharge estimates from various methods

Method	mm/a	% of rainfall	Certainty (Very High=5; Low=1)
Cl – Zone A	**182.7**	**29.47**	**4**
Cl – Zone B	**58.65**	**9.46**	**4**
SVF: Equal Volume	**30.3**	**4.9**	**4**
SVF: Fit	**34.1**	**5.5**	**4**
CRD	**35.4**	**5.7**	**4**
Base Flow (minimum Re)	**62.0**	**10.0**	**1**
^{2}H displacement method	**16**	**2.6**	**1**
EARTH Model	**37.2**	**6.0**	**1**
Qualified Guesses:			
Soil	**47.1**	**7.6**	**3**
Geology	**61.0**	**9.8**	**3**
Vegter	**50.0**	**8.1**	**3**
Acru	**20.0**	**3.2**	**3**
Harvest Potential	**40.0**	**6.5**	**3**
Average recharge	39.9	6.4	

The best option is to have a level of certainty assigned to each method, based on the certainty of the input parameters and the certainty of the applicability of the method to the aquifer. Certainties have been assigned to each of the methods used and a weighted approach should be adopted, where recharge estimates in the same ranges have a high weight and the outliers have a lower weight, although they still have an input into the recharge calculations.

By ignoring the low certainty recharge values one can come up with a value that is reliable and useful. Recharge in the Schoonspruit Dolomitic Compartment has been estimated as 6.0% of annual rainfall, amounting to 37.2mm/m and therefore the average volume of 70.68Mm^3/a.

3.4.7 Dolomitic Springs

There are several springs of which the Schoonspruit eye is by far the most productive, although the flow of the eye has decreased over time. This decrease is most likely associated with increased groundwater abstraction, as well as decrease in rainfall.

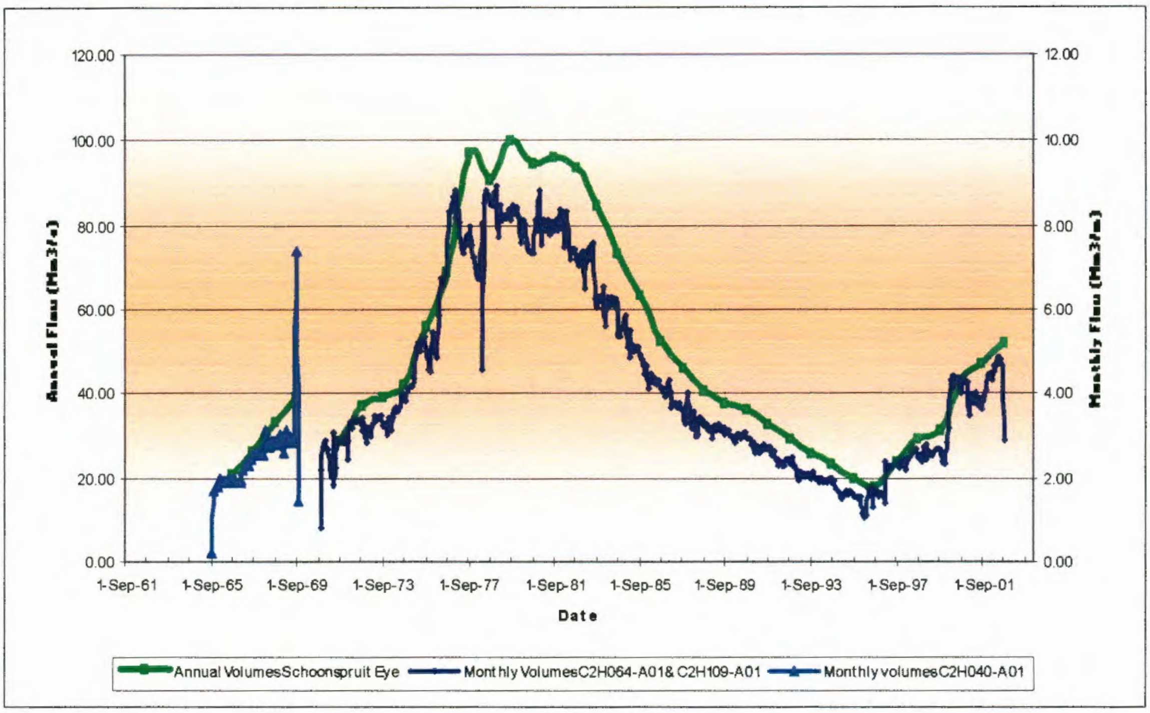


Figure 66: Annual and monthly flow volumes of the Schoonspruit Eye

Figure 66 shows the annual and monthly flows of the Schoonspruit Eye up to September 2002. Annual flows were calculated for hydrological years, starting October and ending September of the following year, e.g. 1-Sep-81 would be flows for October 1980 to September 1981.

It is clear from the flows that an average flow volume, for any given time, would not be an indication of the true situation in the compartment and it is necessary to do an analysis of the effect of rainfall and the lag time effect of recharge through the compartment on the flow of the eye.

3.4.7.1 Rainfall Relationships

To establish the rainfall-spring-flow relationship, it is necessary to estimate the moving average. This method mimics the spring flow of a specific month compared to the average rainfall over the number of preceding months (Bredenkamp, et.al., 1995). This is done by averaging the rainfall over different numbers of months and establishing which has the best fit to the actual data, takimg into account the graph will probably only fit where no impact on the flow has occurred. Equation 12 describes the spring flow relationship to the moving average of rainfall (Bredenkamp, 2000):

Equation 12

$$Q_{I\ \mathrm{spring}} = \rho\ .RF_J + Q_{\mathrm{CONSTANT}}$$

Where $Q_{I\ \mathrm{spring}}$ = spring flow at month I

ρ = fraction of rainfall representing recharge + aerial extent of aquifer

RF_J = average rainfall for preceding months J

Q_{CONSTANT} = constant flow if the average rainfall term is 0

Figure 67 shows a good correlation between rainfall and spring flow up to approximately 1988. After this date significant divergence between the two occur, particularly in the period up to 1996. It is questionable whether the reported flows in this period are in fact as low as indicated by the data and if so, abstraction would be severely impacting on the flow. (Darcy Consultants, 2002)

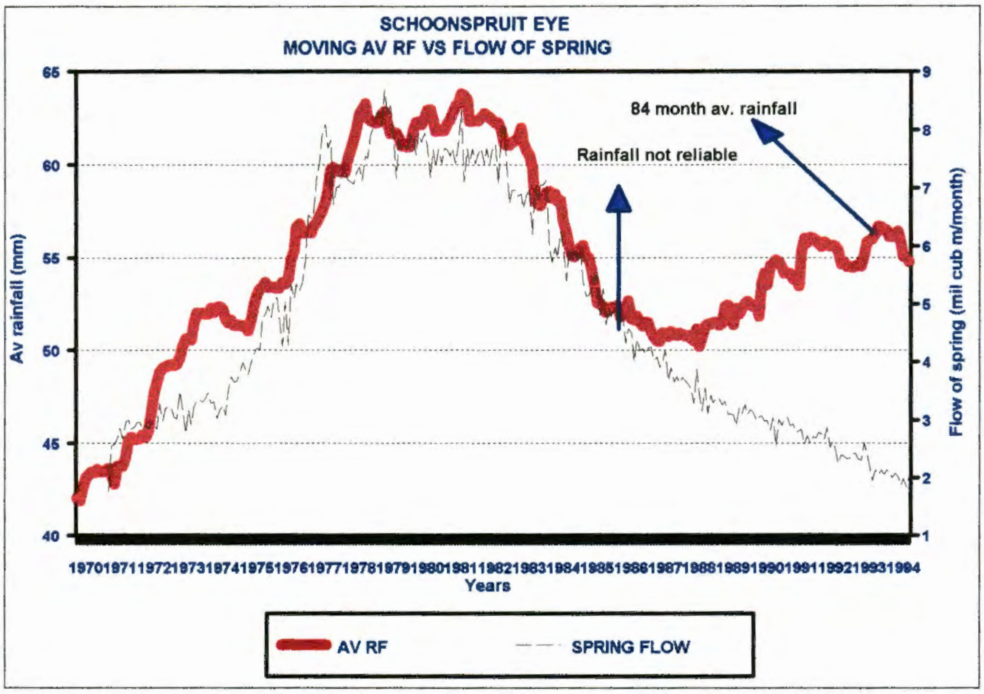


Figure 67: Flow of the Schoonspruit Eye relative to the Moving Average Rainfall over 84 months representing the natural conditions (Bredenkamp & Stephens, 2002)

The moving average of rainfall was evaluated against updated spring flows. Figure 68 shows the moving average of rainfall over 96 months and 120 months using the rainfall data set of Ventersdorp PD, as described in 3.2 Meteorology. It is interesting that the 120 months show a better relationship at an early time than the 96 months, but the 96 months have a better relationship at a late time. This could be due to the system responding slower to recharge after a drought period, because the storage in the system is at a minimum and has to be recharged before the trend is duplicated in surface water outflows.

The difference between the moving average periods in Figure 67 (84 months) and Figure 68 (96 & 120 months) is obvious and can be attributed to different rainfall datasets that were used. This demonstrates the importance of a good reliable set of rainfall figures for the whole catchment area.

The difference between the spring flow and the rainfall simulation from the beginning of 1987, Figure 68, is probably due to groundwater abstraction from the compartment increasing. The spring flow was at a low in 1996, after which it has been restored to a degree. It seems that the system shows conditions of higher recharge and more storage when periods of drought and high abstraction is experienced.

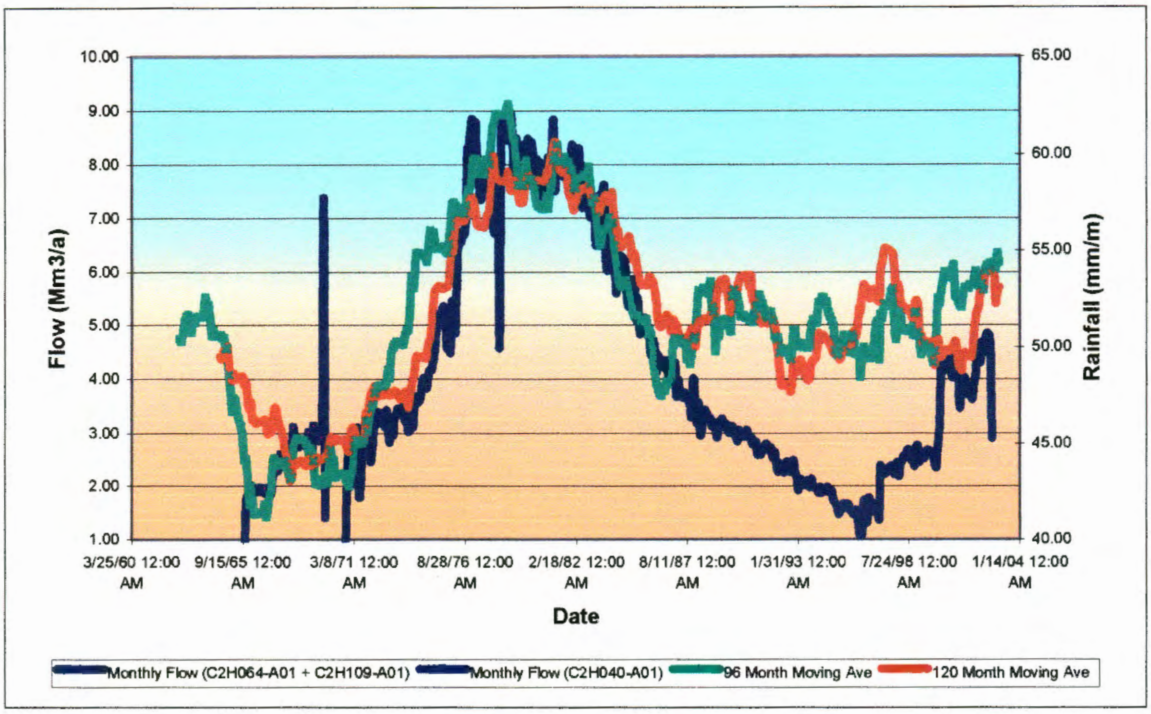


Figure 68: Schoonspruit Flow vs. Rainfall Simulation

3.4.7.2 Recharge to the Schoonspruit Eye

The recharge to the Schoonspruit Eye according to Equation 4 is shown in Figure 69 for the moving averages of rainfall, Figure 68.

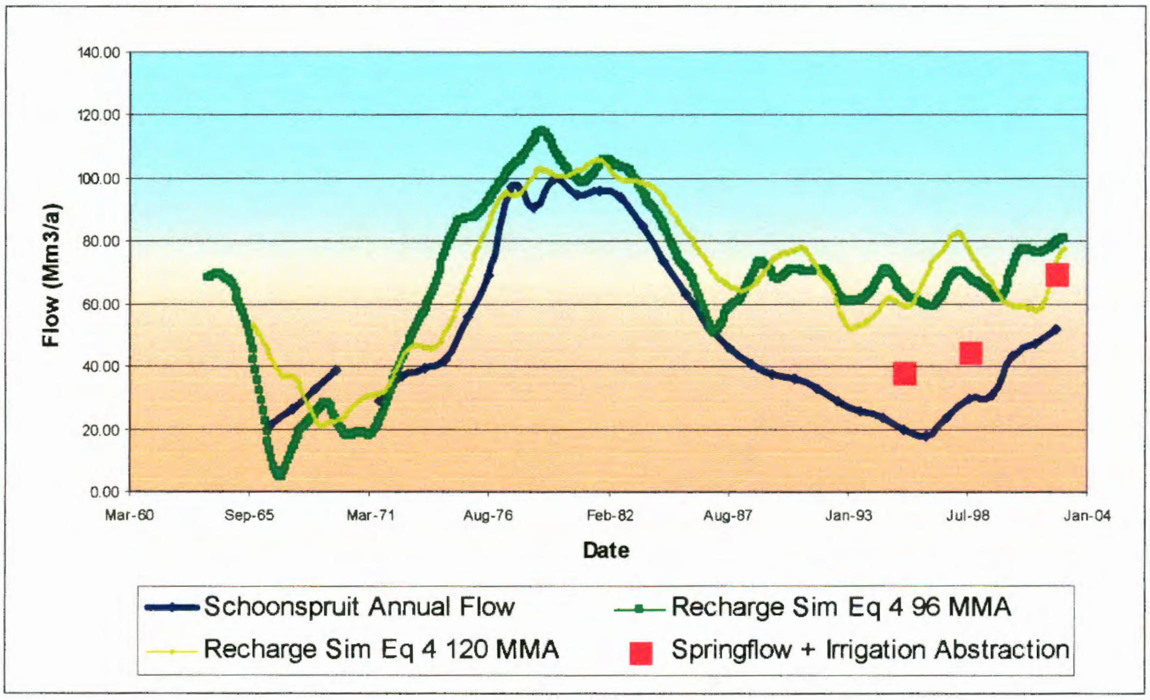


Figure 69: Recharge simulations according to section 2.4.7

Again the difference between the early and late time response is clear. At an early time the 120 months moving average recharge has a better correlation to the spring flow and at a late time the 96 months moving average recharge has a better correlation to spring flow. This is important when deciding during a rainfall cycle which moving average to use for recharge calculations and water balance models, therefore also important for determining allocable volumes for abstractions in the rainfall cycle.

Irrigation abstraction volumes for three different years (1994, 1998 and 2002) have also been added to the spring flow, to see whether it correlates with the estimated recharge. This is true for 2002, as shown in Figure 69, but not for the other years. The abstraction volumes used is only for irrigation abstraction, as calculated by Schoeman & Partners, 2003, and does not include mining abstractions. Mining abstraction could not be determined with the satellite images; however, mining abstractions could not have explained the huge difference that still exists between the estimated recharge and the irrigation volumes added to spring flow. The question arises whether the system has a delayed effect when responding to impacts on it and whether aquifer parameters have changed due to this, to a point where recharge is enhanced when storage is at a minimum.

It is clear that the natural flow of the Schoonspruit Eye has been impacted on and the only factors could be decrease in rainfall and an increase in groundwater abstraction from the compartment. The decrease in rainfall has been taken into account in the recharge estimations and the deviation from the projected flow can only be explained with abstractions from the system. This is explained in more detail in section 3.6.1.

3.5 Water Users

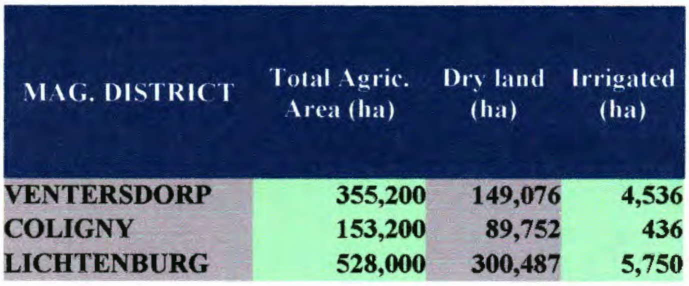
Rudolph, 2001, portrayed the positions and distribution of the different water users in the area in Figure 70. Agricultural (irrigation and stock watering), Mining and Domestic water uses could be distinguished. Most of the area is used for cattle farming and irrigation is concentrated in selected areas due to availability of soil and water. Water used for mining purposes is related to the washing process of diamond diggings and was not considered a major use of water. The total area irrigated from the farms visited amounted to 1600 ha.

3.5.1 Agriculture

Agriculture is one of the most important aspects of the compartment under consideration. Many of the farmers are groundwater users, and several are large-scale users of groundwater. Due to a combination of the suitability of soils and availability of water, there is a high proportion of cultivated land in the area. (Darcy Consultants, 2002)

Data from the Department of Agriculture was obtained, via personal communication with the Agricultural Information Officer in Potchefstroom, for the different municipal area districts and is shown in Table 17. Approximately 52% of the agriculture is dry land agriculture and 1% is irrigated agriculture. It must be emphasized that these figures are for the whole magisterial district and not only the areas pertaining to the dolomitic compartment, but it does give an indication of agricultural practices in the area.

Table 17: Agricultural Information on Different Municipal Areas



MAG. DISTRICT	Total Agric. Area (ha)	Dry land (ha)	Irrigated (ha)
VENTERSDORP	355,200	149,076	4,536
COLIGNY	153,200	89,752	436
LICHTENBURG	528,000	300,487	5,750

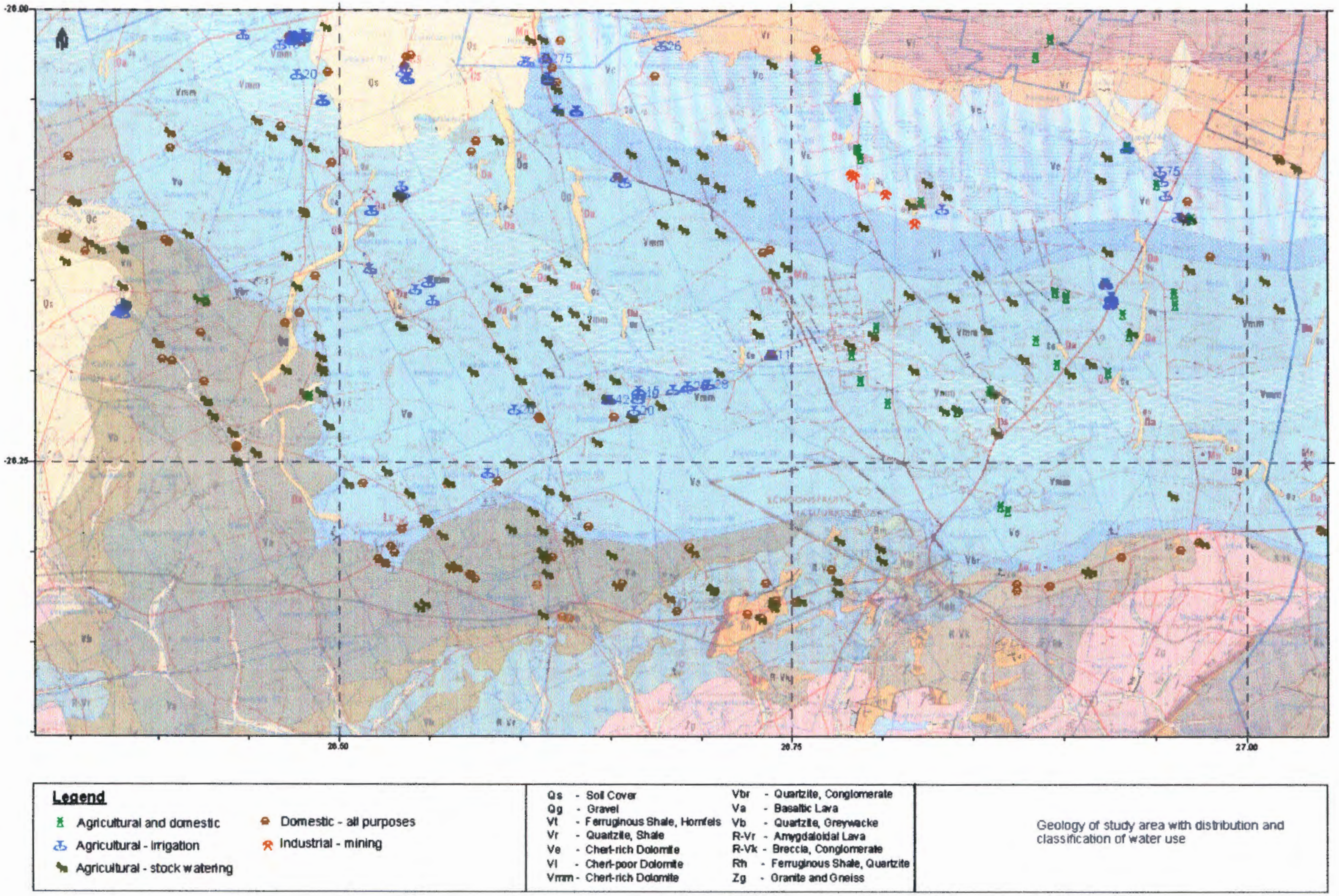


Figure 70: Types of Water Uses on the Schoonspruit Dolomitic Compartment (Rudolph, 2001)

For the Schoonspruit Dolomitic Compartment the following can be said:

- Irrigation in the area was estimated at 22.39 Mm^3/year with another almost 1.8 Mm^3/year for other agricultural practices (Schoeman & Partners, 1996).
- The hydrocensus done by Rudolph, 2001, showed an irrigated area within the study area of 2972 ha.
- An estimated 4200ha is being irrigated, representing only 2% of the total catchment. The total volume abstracted for irrigation, based on information that has been obtained from the farmers, is 60 Mm3/annum, however according to the water requirements of crops and areas that are being irrigated, 32 Mm3/annum is used for irrigation. (Darcy Consultants, 2002)
- Schoeman & Partners, 2003, did the verification study for this area, based on satellite imagery interpretation. For the compartment 3 dates were of importance: 1994 (proclamation date of the water control area), 1998 and 2002. The area used for the study was slightly bigger than the dolomitic compartment and yielded the following figures:
    - Irrigation 1994 (proclamation area only) – 2767.77 ha (22.223 Mm^3/a)
    - Irrigation 1998 – 4138.61 ha (35.781 Mm^3/a)
    - Irrigation 2002 – 5016.96 ha (40.942 Mm^3/a, of which 8.433 Mm^3/a were abstracted from the drainage area of the Schoonspruit Eye and 25.768 Mm^3/a from the rest of the Schoonspruit Dolomitic Compartment. The remaining 6.741 Mm^3/a were from properties not situated on the compartment.)
    - Registered 2002 – 8983.5 ha (50.176 Mm^3/a)

It is clear that the irrigation on the dolomitic compartment is the greater portion of the irrigation in the magisterial districts. The irrigation continued to expand through out the area and the verification of Existing Lawful Use is of utmost importance. Maps of the irrigation, as obtained from the satellite images, are given in APPENDIX C.

3.5.2 Mining

Various diamond diggers exist, abstracting groundwater for washing of gravel. One relatively large operation on the farm Nooitgedacht 131 IP has applied for a licence for a volume of 1.25 Mm^3/a from groundwater. Verification of the other diamond diggers in the area could not be done via satellite interpretation and needs to be confirmed through farm visits.

3.5.3 Domestic

The Ventersdorp area is solely dependent on groundwater either directly, abstraction from boreholes, or indirectly, abstraction out of the Schoonspruit. The town is regarded as an important socio-political indicator in terms of data collated by the Southern District Council, with a population of 32156 (1996) and a population growth of 1.19%. The Ventersdorp Local Municipality indicates an average daily consumption of 16.3, including the four communities within the Ventersdorp Municipal District and on the dolomitic compartment: Ga-Mogopa, Ga-Motlatla, Goedgevonden and Tsêtsê and *Schedule 1 (Nat. Water Act 1998)* water is supplied from groundwater to these communities (Darcy Consultants, 2002).

3.5.4 Downstream

Downstream from the lower weir, there are four water users, which claim water rights from the Schoonspruit Eye. They are Ventersdorp municipality, the Klerksdorp Irrigation Board (IB), the Schoonspruit Governmental Water Scheme and the vlei down stream from the weir. (Darcy Consultants, 2002)

Table 18: Downstream Water Users of the Schoonspruit Eye, (Darcy Consultants, 2002)

Names of User	Annual Demand (million m^3/A)	Loss (%)	Annual release (million m^3/A)
Ventersdorp	3.5	3	3.6
SGWS	18.711	30	26.73
Klerksdorp IB	2.9	30	3.77
Wetlands	2.5		2.5
Total	**27.611**		**36.6**

The total water requirements of the Eye by down stream users are therefore 36.6 m^3/ annum, if the losses are also considered, and 27.611 m^3/ annum, if no losses are allowed. The fact that the flow of the eye has been affected, possibly by irrigation and mining abstraction in the recharge area, is of great concern. If the abstraction is not controlled the water supply of Ventersdorp as well as the irrigation lower down would be seriously threatened and the wetlands below the eye could dry up. Measures to control and manage the groundwater abstraction should therefore be put in place. (Darcy Consultants, 2002)

3.6 Modelling

Simulating the behaviour of dolomitic aquifers by means of 2-D finite element models are difficult and calibration of 3-D models as of yet unsuccessful. The unsatisfactory simulations were attributed to the fact that groundwater levels and spring flows are governed by the hydraulic pressure along fractures and dissolution channels, which can only be partially accommodated in a 2-D model. (Bredenkamp, 2000)

The correlation between surface elevations and groundwater level elevations in 3.4.4.2 shows that the groundwater level elevations do not follow the topography and therefore, Bayesian interpolation is not applicable. This worsens the situation further with regard to numerical modelling, but other methods of reconstructing the natural flow systems do exist.

Groundwater levels in the aquifer can be simulated using different methods, depending on the types of data available. The Moving Average and Cumulative Rainfall Departure (MA and CRD) methods have proven useful, in reconstructing water level fluctuations in both groundwater levels and spring flows dependent on groundwater systems, and are discussed in detail in section 3.6.1. The reconstructed water levels are then used to either fill in gaps in data and/or evaluate quantity related impacts on the aquifer e.g. abstractions. The reliability of both methods depend on the reliability of the rainfall data, averaging the rainfall over an area from different rainfall stations and the lag time between recharge events, the response of the groundwater levels and the effect of abstraction on the system. (Bredenkamp, 2000)

3.6.1 Groundwater Simulations

Spatial interdependence between groundwater levels in an aquifer is a result of the homogeneity of rainfall over the area and the hydraulic conductivity in the aquifer, e.g. large fractures or dissolution channels in dolomitic areas. As a result, responses of recharge and aquifer storativity in the compartment are evened out and these parameters can be used for the compartment, even when derived only from a single borehole. (Bredenkamp, 2000)

Where spring flows are linearly related to the CRD and MA of a rainfall series, and thus also linearly related to the groundwater system from which it is recharged, both the natural flows and the effect of abstraction can be simulated. (Bredenkamp, 2000)

The simulations of the groundwater monitoring borehole levels were done using CRD_MA software (software combining the CRD and MA methods) and Schoonspruit Eye flow were done using MA springflow software currently being developed by Bredenkamp, 2003. The CRD & MA simulations done for the monitoring boreholes are included in APPENDIX D and examples are shown in Figure 71 and Figure 72.

3.6.1.1 Moving Average Method

This method mimics the groundwater level of a specific month to the average rainfall over a number of preceding months (Bredenkamp, et.al., 1995) and is described by Equation 13 (Bredenkamp, 2000):

Equation 13

$$H_I = (b/S)/n.RF_J + F$$

Where H_I = the groundwater level for month I

b = coefficient of rainfall representing recharge

S = aquifer storativity

n = number of months

RF_J = average rainfall for preceding months J

F = inferred depth of aquifer below surface

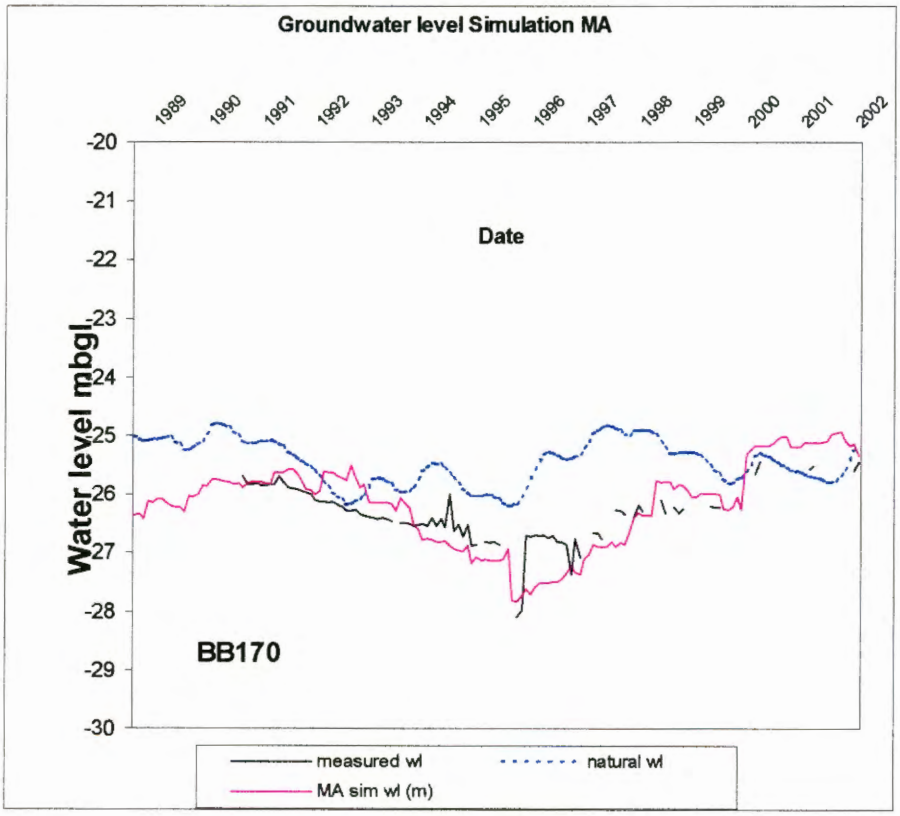


Figure 71: Example of a MA simulation – borehole 2626BB170

3.6.1.2 CRD Method

The groundwater balance can be explained by the concept that equilibrium in an aquifer is established over time between recharge (average gains) and drainage (average losses) and is expressed with Equation 14 (Bredenkamp, et.al., 1995):

Equation 14

$$RF_{AVE} = RO_{AVE} + RE_{AVE} + EVT_{AVE}$$

Where RF_{AVE} = average rainfall

RO_{AVE} = average runoff

RE_{AVE} = average recharge

EVT_{AVE} = average evapotranspiration

The CRD method corresponds to the concept that equilibrium is established in an aquifer over time therefore, matching the groundwater level fluctuations to the cumulative rainfall departure from the average rainfall, can mimic the hydrological balance of an aquifer (Bredenkamp, et. al., 1995). Defining the CRD relationship for different time intervals yields Equation 15 (Bredenkamp, 2000):

Equation 15

$$CRD_I = CRD_{I-1} + RF_I - k.RF_{AVE}$$

Where CRD_I = CRD at month I

CRD_{I-1} = CRD at the month preceding month I

RF_I = rainfall at month I

RF_{AVE} = average rainfall

k = coefficient representing abstraction

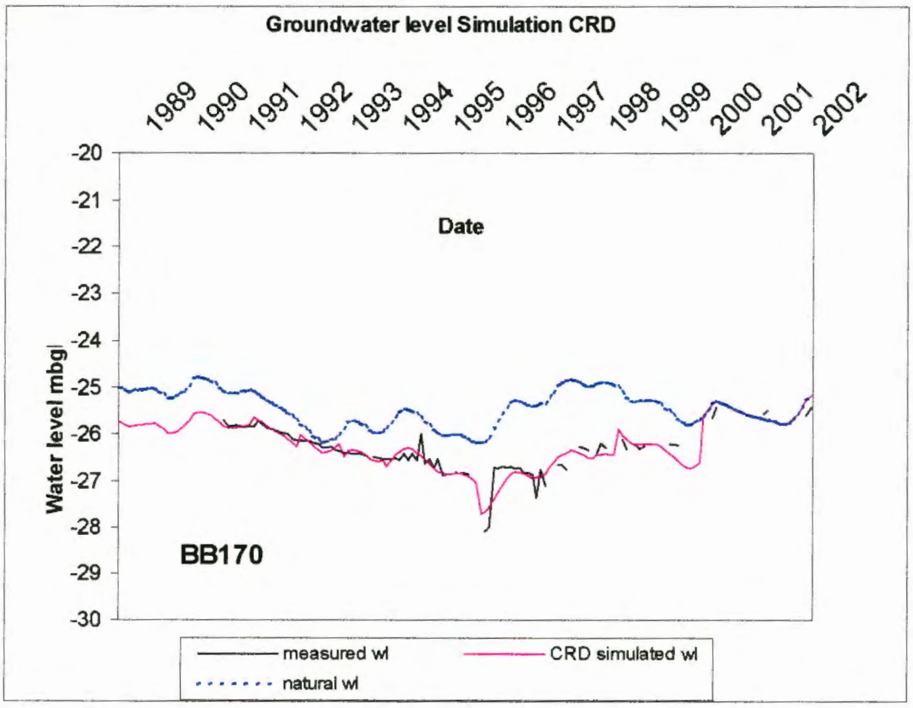


Figure 72: Example of a CRD simulation – borehole 2626BB170

3.6.1.3 Simulations

When doing the CRD_MA software simulations one has to incorporate inflows and outflows (abstractions) and adjust storativity and recharge values to attain the best possible curve to fit the actual groundwater level measurements that was taken. The simulation therefore incorporates the groundwater balance to a degree, although levels and not volumes are of concern. The storativity and recharge values, attributed to the specific borehole's reaction to averaged rainfall over an area, are obtained. In the dolomitic aquifer these values are not as related to fracture flow, since the dolomites characteristics cause variations in groundwater levels to be smoothed over an area. The values are therefore indicative of the aquifer characteristics. Further information gained from these simulations is the effective depth of the aquifer and the threshold values of rainfall before recharge will take place. Table 19 summarise the information as acquired with these simulations.

Table 19: Aquifer parameters determined with the MA & CRD methods

SiteID	Re %	Threshold mm	High Re F %	S	Aq Thick (m)		AVE
2626BB00165	6.00	26.00	30.00	0.025	8.70	ZONE A	
2626BB00166	7.00	26.00	30.00	0.025	10.20		AqTh=8
2626BB00167	5.00	26.00	30.00	0.024	7.30		Re=6
2626BB00168	6.00	26.00	30.00	0.041	5.30		Th=26
2626BB00169	5.80	26.00	30.00	0.023	9.10		HRF=30
2626BB00170	4.10	26.00	30.00	0.023	6.30		S=0.027
2626BD00141	6.00	32.00	30.00	0.025	8.70		
2626AB00051	9.00	24.00	31.00	0.015	21.90	ZONE B	
2626AB00052	9.20	26.00	29.00	0.021	16.00		AqTh=13
2626AB00053	5.30	26.00	30.00	0.025	7.60		Re=7.62
2626AB00054	5.40	25.00	30.00	0.020	9.70		Th=24.33
2626BA00099	8.40	19.00	30.00	0.025	12.20		HRF=30
2626BA00100	8.40	26.00	30.00	0.025	12.30		S=0.023

- Borehole 2626BB168 is close to the origin of the Schoonspruit Eye and the water levels are fairly shallow. Storativity becomes higher and this is the reason why the storativity value is almost double that f the rest of the monitoring boreholes in Zone A.
- Borehole 2626AB051 is close to the western fault system and this would explain why this borehole's storativity differ from the rest of the monitoring boreholes in Zone B.

The simulations have given valuable information for use in regional modelling of the aquifer, as well as information for determining the groundwater balance. However, for proper management of the system one has to refine the relationship between the system's response and the flow of the Schoonspruit Eye.

3.6.1.4 Spring Flow

When relating the CRD relationship to spring flow, Equation 16 can be used to simulate this relationship (Bredenkamp, 2000):

Equation 16

$$Q_{I\ \mathrm{spring}} = J/S.\rho.CRD_I + C_{FLOW}$$

Where $Q_{I\ \mathrm{spring}}$ = spring flow at month I

J = hydraulic coefficient + flow cross section width constant

S = aquifer storativity

ρ = coefficient of rainfall representing recharge

CRD_I = CRD at month I

C_{FLOW} = long term average spring flow around which the flow fluctuates

Various factors can be introduced to simulate different situations, e.g. aerial extent of the aquifer, abstraction from the system or different lag time effects. When the moving average of rainfall is used instead of true rainfall figures one can incorporate the lag time effect of rainfall events and its integration over the aquifer (Bredenkamp, et.al., 1995). When doing the simulation all known parameters are incorporated and the unknown parameters are calibrated to attain the best fit for the spring flow. Figure 73 shows the simulation done for the Schoonspruit Eye, together with abstraction influences, and the calibrated parameters are given in Table 20.

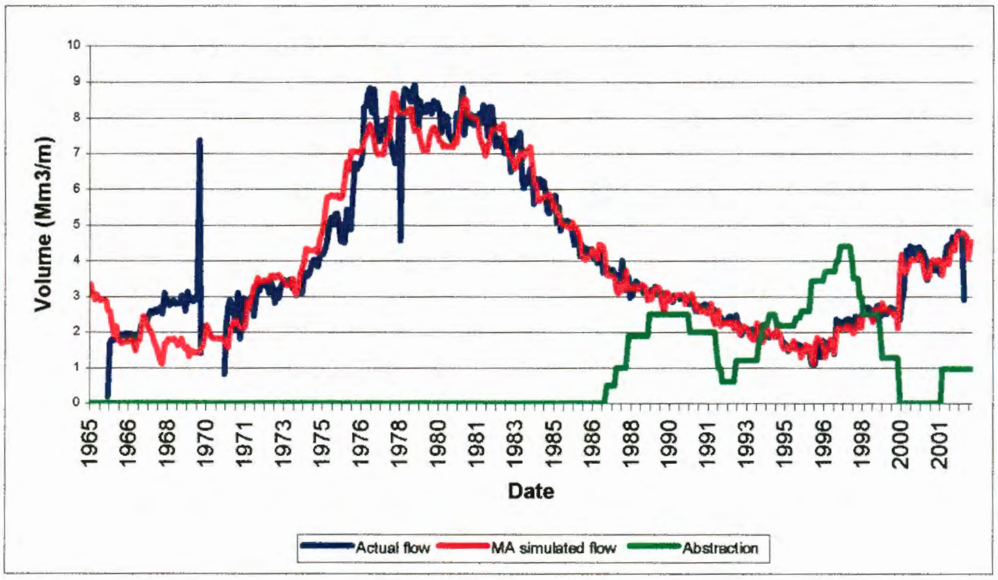


Figure 73: Schoonspruit Eye simulated flow with a 96 Month Moving Average

Table 20: Spring Flow Parameters

Parameter	Value	Explanation
Th_N (mm/m)	26	Monthly rainfall threshold before normal recharge occur
Th_F (mm/m)	43	Monthly rainfall threshold before flood recharge occur
$Re_{N\%}$ (%)	7	Percentage of recharge that occurs with Rf Threshold
$Re_{F\%}$ (%)	44	Percentage of recharge that occurs with Flood Rf Threshold
Area (A)	842	The effective recharge area of the Schoonspruit Eye

These parameters have been incorporated into the spring flow simulation together with the different moving averages of rainfall that affects the flow. The Schoonspruit Eye can be simulated with Equation 17:

Equation 17

$$\text{Schoonspruit Flow } (\text{Mm}^3/\text{m}) = Re_N + Re_F - Abs_{GW}$$

Where Re_N = recharge under normal rainfall events

Re_F = recharge under flood rainfall events

Abs_{GW} = groundwater abstractions from the drainage area (Mm^3/m)

And $Re_N = Re_{N\%}/100 * Rf_{24MMA}/Rf_{120MMA} * (Rf_{96MMA} - Th_N) * A/1000$

$Re_F = Re_{F\%}/100 * (Rf_{FLOOD}) * A/1000$

$Rf_{FLOOD} = IF((Rf_{120MMA} - Th_F)>0, Rf_{120MMA} - Th_F)$

Where $Re_{N\%} = 7$

$Re_{F\%} = 44$

Th_N = 26 mm – recharge threshold

Th_F = 43 mm – flood recharge threshold

A = 842 km^2 – drainage area

Rf_{24MMA} = 24 month moving average of rainfall

Rf_{96MMA} = 96 month moving average of rainfall

Rf_{120MMA} = 120 month moving average of rainfall

The equation therefore amounts to:

Equation 18

$$\text{Schoonspruit Flow } (\text{Mm}^3/\text{m}) = (0.07 * Rf_{24MMA}/Rf_{120MMA} * (Rf_{96MMA} - 26) * 0.842) + (0.44 * (IF((Rf_{120MMA} - 43)>0, Rf_{120MMA} - 43)) * 0.842) - Abs_{GW}$$

Equation 18 will be used in the tool, which will be developed in Chapter 5 section 5.4, for the groundwater management of the Schoonspruit Dolomitic Compartment. The biggest advantage of this method is that abstractions can now be incorporated into the simulation and predictions can be made with long-term predicted rainfall. The effective recharge for the Schoonspruit Eye was determined as 13% for 2002.

3.6.2 Groundwater Balance

Darcy Consultants, 2002 recommended that an accurate and dynamic water balance for the Schoonspruit compartment and a long-term water management strategy should be established. The Saturated Volume Fluctuation (SVF) method is based on the saturated water balance and therefore takes into account inflows, outflows, recharge and the change in aquifer storage (saturated volume) over time. The method gives a picture of the water level response of the aquifer and the solution is based on Equation 8 (Bredenkamp, et.al., 1995). This method will be used to define the groundwater balance for the two zones, Zone A (Eastern Dolomitic Eye Catchment) and Zone B (Western Dolomitic Compartment), using the monitoring boreholes' groundwater levels and recharge and storativity values as obtained through the CRD and MA simulations. For the period September 2001 to September 2002 no change can be observed in the saturated volume and ΔV is equal to 0.

The following summarises the boundary situation as discussed in section 3.4.4.2:

- Inflow into the compartment occurs at the eastern, western and northern boundaries.
- Outflow out of the compartment occurs at the southern boundary, as well as various springs in the south.
- The drainage area of the Schoonspruit Eye does not seem to allow groundwater in this part of the compartment to reach the western side.

Table 21 gives the most current groundwater balance information for each of the two zones. These groundwater balances will also be incorporated into the groundwater management tool as the defining factor in which volumes are allocable and what the flow of the Eye should be for the following year.

Table 21: Groundwater balance information 2002

	Information	Zone A	Zone B
SIZE	AREA (km^2)	840	745
Q_{INFLOW}	Inflow Boundaries (Mm^3/a)	N/A	N/A
$Q_{OUTFLOW}$	Outflow Boundaries (Mm^3/a)	0.245	0.391
	Baseflow Reserve (Mm^3/a)	0.759	0.342
	Eye Flow (Mm^3/a)	52.21	1.6 (3% Polivka, 1987)
	Evapotranspiration Losses (Mm^3/a)	5.783	N/A
Q_{ABSTR}	BHN Reserve (Mm^3/a)	0.047	0.244
	Groundwater Domestic Requirement (Mm^3/a)	1	1

	Information	Zone A	Zone B
SIZE	AREA (km^2)	840	745
Q_{INFLOW}	Inflow Boundaries (Mm^3/a)	N/A	N/A
	Outflow Boundaries (Mm^3/a)	0.245	0.391
	Groundwater Irrigation Abstractions (Mm^3/a)	8.433	25.768
	Groundwater Non-Urban Industry Abstractions (Mm^3/a)	0.140 WARMS	0.086 WARMS
	Groundwater Mining Abstractions (Mm^3/a)	0.164 WARMS	0.115 WARMS
RE_{TOT}	Rainfall (mm)	620	620
	Recharge % (Mm^3/a)	6 31.248	7.67 35.428
$S\Delta V$	S	0.027	0.023
	ΔV	0	0
BALANCE		-37.533	5.882

It is clear that the groundwater balance for the drainage area of the Schoonspruit Eye is not valid as more water was flowing from the eye than was recharged based on the recharge values obtained in section 3.4.6.2. The simulation in section 3.6.1.4 and the groundwater balance for Zone B will be the methods used for determining allocable volumes and predicted flows in the Groundwater Management Tool in section 5.4.

3.7 Monitoring

Monitoring forms an integral part of groundwater protection and is essential for successful long-term management of the area, whenever water forms an important resource or where there are human activities that may generate substances that are harmful to groundwater (Darcy Consultants, 2002). Different types of monitoring are necessary in dolomitic areas, namely water level, water quality, rainfall and spring flow monitoring. Figure 74 shows all types of monitoring points currently active in the Schoonspruit Dolomitic Compartment.

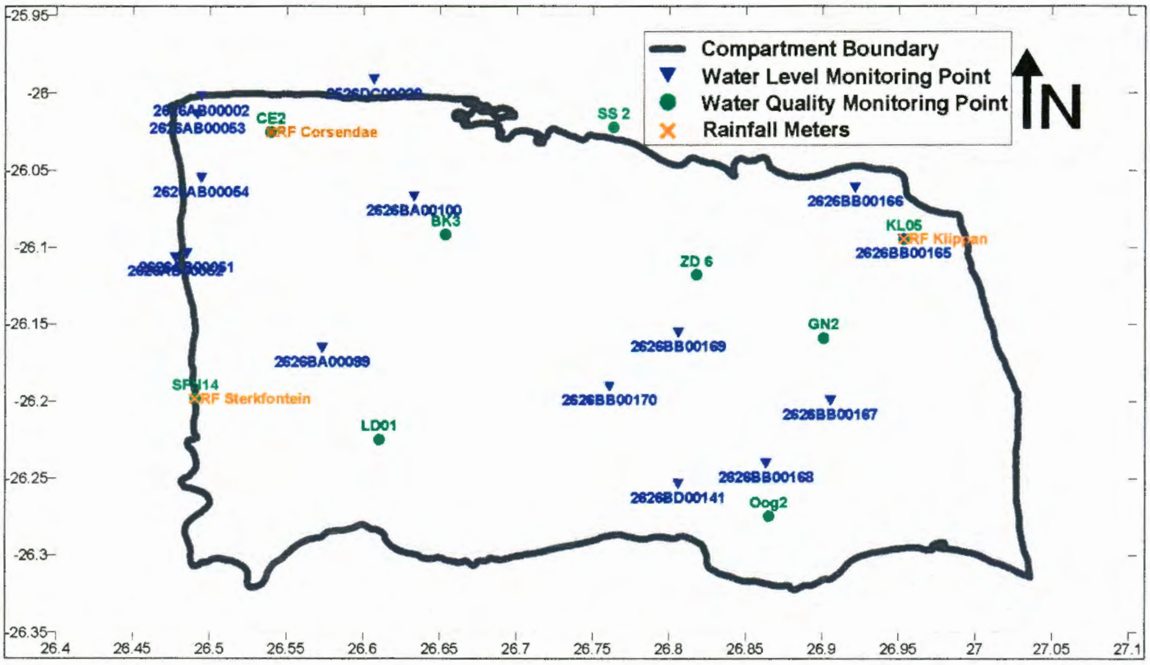


Figure 74: Positions of DWAF monitoring points in the Schoonspruit Dolomitic Compartment

3.7.1 Water Level Monitoring

Water level monitoring is the collection of groundwater depth measurements over time and can be used to obtain water level drawdown, the shape of the water table, groundwater flow directions and recharge relationships with rainfall (Darcy Consultants, 2002). Current monthly water level monitoring seems adequate, but taking the CRD_MA simulations into account the monitoring points can be reduced as follows:

- 2626AB054, since it is in close proximity with 2626AB053, yields the same information and 2626AB053 is closes to another boundary (north) of importance.
- 2626BB165, since this borehole has geological features and abstraction influences that is not indicative of the rest of the compartment. 2626BB166 is in close proximity to this borehole and yields better information related to the dolomitic compartment.

3.7.2 Water Quality Monitoring

Water quality monitoring is the collection of groundwater quality data over time and can be used to determine groundwater characteristics, trends (ambient and contamination), sources of recharge or contamination and the extent and impact of contamination. 9 water quality monitoring points, including the eye, were chosen to obtain a spatial distribution over the compartment on the basis of the water quality analysis in section 3.4.5. Water quality monitoring is being done on a three-monthly base and analysis up to date is given in Table 22.

Table 22: Chemical analysis of July 2003 monitoring run

	ZONE A					ZONE B			
SiteID	GN 2	KL 5	OOG 2	SS 2	ZD 6	BK 3	CE 2	LD 1	SFN14
Long	26.900820	26.953147	26.865024	26.763289	26.817619	26.653441	26.539435	26.610381	26.490505
Lat	26.158924	26.094519	26.274435	26.021882	26.117814	26.091654	26.024974	26.224896	26.198135
Zcoord	1514.370	1536.111	1484.680	1540.424	1512.007	1511.647	1520.503	1522.438	1485.029
Site Type	B	B	F	B	B	B	B	B	B
EC (mS/m)	36	30	44	27	34	54	48	57	78
pH	7,1	7,6	7,0	7,3	7,2	6,9	6,8	6,9	7,0
Alkalinity (mg/l)	166	141	223	107	161	263	241	267	296
Ammonia (mg/l)	<0,21	<0,21	<0,21	<0,21	<0,21	<0,21	<0,21	<0,21	<0,21
Calcium (mg/l)	41	34	57	20	38	72	69	70	99
Chloride (mg/l)	8	7	7	8	7	10	9	10	35
Fluoride (mg/l)	0,14	<0,14	<0,14	<0,14	0,16	0,18	<0,14	0,15	0,18
Magnesium (mg/l)	19	17	27	13,1	19	33	28	34	36
Nitrate – N (mg/l)	<2,3	2,3	2,4	<2,3	<2,3	3,5	3,9	8,5	9,0
Ortho Phosphate (mg/l)	<0,53	<0,53	<0,53	<0,53	<0,53	<0,53	<0,53	<0,53	<0,53
Potassium (mg/l)	1,5	1,0	1,2	2,4	1,6	1,1	1,3	0,9	1,0
Silicon (mg/l)	8,3	10,2	8,5	9,1	75	7,8	9,3	8,7	10,2
Sodium (mg/l)	2,5	<2,2	2,2	5,5	3,3	5,1	3,6	3,3	8,0
Sulphate (mg/l)	<5,2	<5,2	<5,2	7	<5,2	<5,2	<5,2	<5,2	39

3.7.3 Rainfall Monitoring

The use of daily rainfall in dolomitic areas is redundant and monthly rainfall gives reliable simulations when used with groundwater level fluctuations and spring flow simulations. To obtain more representative rainfall data and limit possible spatial variability, it is recommended that monthly rainfall collectors be installed at each long-term groundwater level monitoring borehole. This would greatly reduce uncertainties of rainfall data and improve inputs for other hydrological purposes. (Bredenkamp, 2000)

The positions of the rainfall monitoring devices were chosen randomly to obtain a good spatial distribution, as rainfall over the compartment is considered to be fairly continuous, but in close proximity to current monitoring points. The rainfall monitoring devices consist of rainfall tubes, from which rainfall water samples can be taken, fitted with OTT Thalimedes data loggers, which record hourly rainfall readings. Rainfall monitoring is performed at three-monthly intervals, collecting water samples and downloading data from the loggers. These devices were installed fairly recently and no data from these were available for evaluation at the time of writing.

3.7.4 Spring Flows

Measuring accurate flow volumes of the Schoonspruit Eye is essential in determining relationships between groundwater recharge and flow and the yield of the eye. Due to uncertainties regarding bigger flow cycles and for further calibration of recharge and flow simulations, as well as the dependence of downstream users, monthly flow measurements of the eye must continue.

3.8 Conclusions regarding the Geohydrology

The following conclusions were made with regard to the geohydrological evaluation of the Schoonspruit Dolomitic Compartment:

- The delineation of Polivka, 1987, is a true description of the boundaries of the dolomitic compartment.
- The average rainfall was determined as 52 mm/m or 620 mm/a.
- Rainfall data time series was sufficient to establish good relationships with groundwater level monitoring data.
- The geology of the dolomitic compartment can be described as the Malmani Subgroup, of the Chuniespoort Group, and the Black Reef Formation of the Transvaal Sequence.
- Geological structures such as dykes, faults, quartz veins and karst features are common throughout the area.
- The geohydrological regime is determined by the geological features, of which the Malmani Subgroup is the most prominent water-bearing layer.
- The Eccles and Monte Christo Formations of the Malmani Subgroup have the highest yielding boreholes within the Subgroup.
- The dolomitic compartment is classified with the classification system of Parsons, 1995, as 12 and the protection level is therefore strictly non-degradation in terms of both quantity and quality.
- Groundwater level time series shows that the aquifer has gained significant amounts of recharge as water levels are at the same depth as in 1990, recovering since 1996.
- Groundwater levels do not follow the surface topography, due to chert ridges that are more resistant to weathering.
- The groundwater levels showed that inflow occurs in the east over the NS striking dyke, in the northeast from the Pretoria Group, in the north over the Blaauwbank Dyke and in the west over the NS striking fault system.
- The perched water table referred to in section 2.4.8 is probably because of the topographic differences between the Pretoria Group and the Malmani Subgroup and the slow movement of groundwater through the Pretoria Group.
- Outflow occurs in the southwest towards the southern part of the fault system, in the south over the Black Reef Formation and from springs originating from the compartment.
- Groundwater gradients throughout the compartment are very flat and any abstractions will influence flow directions to a great degree.
- The delineation of the Schoonspruit Eye drainage area has been defined and determined to be 840 km^2.
- Two zones have been defined for further use in groundwater balances and management decisions, Zone A (the drainage area of the eye) and Zone B (the western side of the compartment).
- The groundwater quality is generally of a very good quality and has been shown to be of recently recharged dolomitic water.
- Several boreholes show signs of point source pollution, mainly associated with agricultural contamination.

- Nitrate levels, in some of the boreholes, have reached concentrations higher than the recommended drinking water standards and are of concern to the health of children under the age of 6.
- The Schoonspruit Eye water quality has stayed unaffected and is characterised as recently recharged dolomitic water, confirming that it is only recharged from the dolomitic compartment.
- Transmissivity and storativity values determined from individual boreholes have been shown to be of limited regional applicability, due to the Karst nature of the aquifer.
- Storativity values determined from the CRD and MA methods are integrated over the aquifer and therefore can be used in other simulations or regional numerical models.
- Recharge determined from various methods has proved to be useful and the most important factor governing the groundwater balance in the dolomitic compartment.
- Recharge in the two zones differs from each other, but within each zone is roughly the same.
- The recharge relationship of the spring flow to various monthly averages of rainfall has been defined and is absolutely essential for good groundwater management of the drainage area of the Schoonspruit Eye.
- Water users dependant on the dolomitic groundwater includes domestic users, mining and irrigation farmers.
- The groundwater level simulations with the CRD and MA methods have proven to be unmatched in determining recharge and storativity values from a single borehole, as well as with identifying monitoring boreholes that has been impacted on to such a degree that monitoring in these boreholes should cease.
- The groundwater balance showed that it is good enough for groundwater management in Zone B, but that groundwater management in Zone A should be done with the MA simulation.
- Monitoring in the compartment is sufficient and some of the groundwater level monitoring points can be discontinued.
- Enough information exists for groundwater management to commence and for tools for management and predictions to be developed.

4 GROUNDWATER MANAGEMENT OF THE DOLOMITIC REGIME

The Department of Water Affairs and Forestry (DWAF), as custodian of South Africa's water resources, is responsible for managing the quantity and quality of all water resources. Recent changes by the Department included the National Water Act, Act 36 of 1998 (NWA, 1998), Integrated Water Management (IWM), Integrated Catchment Management (ICM) and Integrated Water Resource Management (IWRM). (Darcy Consultants, 2002)

Groundwater is a strategic resource in South Africa because it occurs widely and it is a cost-effective method of meeting essential domestic water needs. Groundwater is particularly vulnerable to poor management; the major reasons for this being ignorance and a lack of information regarding its occurrence and the importance of its protection. (Lazarus, 1997)

Responsible management of groundwater abstraction and activities in vulnerable areas ensures that groundwater remains a usable resource. If too much groundwater is abstracted or groundwater quality deteriorates as a result of pollution, it will no longer be available as a cost-effective source of water for drinking, stock watering or irrigation. (Colvin, 2000)

Key criteria for the management of groundwater and the allocation of its use should be beneficial use, economic efficiency, equity and protection of the resource base. The groundwater resource base includes its quality, storage for future use and the aquifer matrix integrity and stability. Contributions to spring flow, river baseflow, evapotranspiration and other environmental features are also dependent upon the presence or level of the groundwater table. (Lazarus, 1997)

The following flowchart (developed as part of this research) depict the various groundwater management aspects, with their importance assigned, and can be used as a checklist to see if all necessary steps are understood and have been taken towards the management of the dolomitic aquifer:

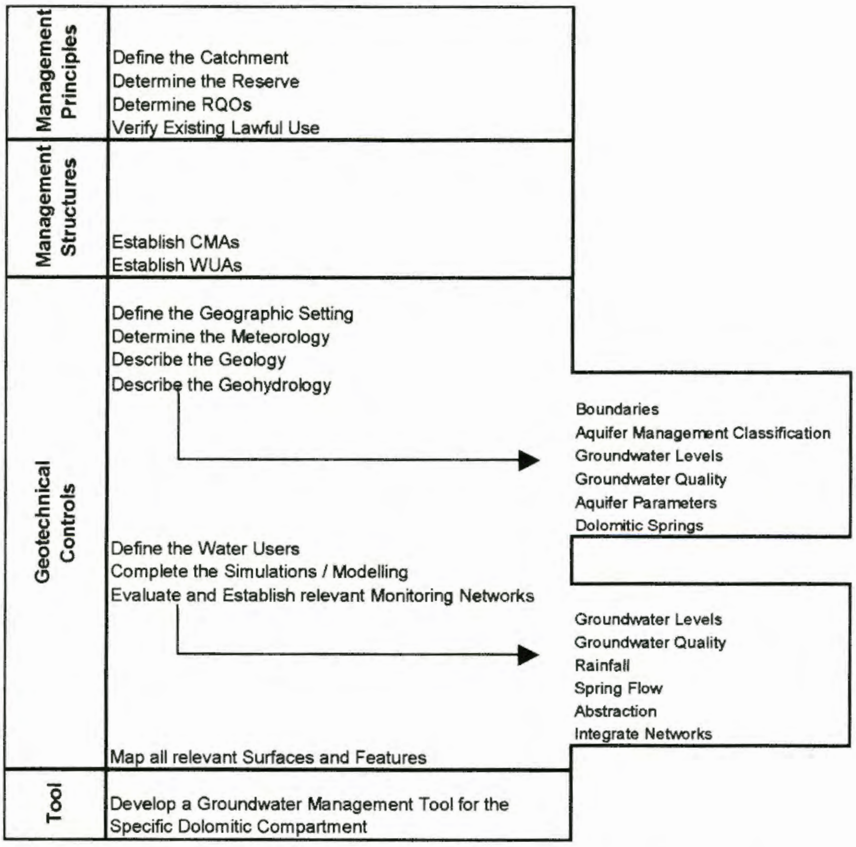


Figure 75: Groundwater Management Aspects Flowchart

4.1 Management Principles

Water resource management is based on principles of equity, optimal use, sustainable use and Integrated Water Resource Management (IWRM). (Parsons et al., 2001) Keeping this in mind, various basic principles of Integrated Water Management (IWM), critical to groundwater management in any dolomitic terrain, needs to be explained.

4.1.1 Integrated Water Resource Management

Integrated Water Resource Management (IWRM) is a philosophy of co-ordinated management of an area's water, land and other resources, to maximise the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems. This aims to promote efficient management of all water resources, and recognises that the various components of the hydrological cycle are intimately linked. (Parsons, et. al., 2001)

Surface water management and groundwater management should be integrated as far as possible, because of the interconnectedness in the hydrological cycle, and is necessary to provide for optimal use of water resources. Groundwater quality and quantity management should be integrated, due to the fact that both forms have the objective of maintaining the resource base through sustainable utilisation. (Lazarus, 1997)

The fact that groundwater is used as a source of water for more than 15-million South Africans, clearly demonstrates the importance of the resource. It is no longer acceptable to manage groundwater in a separate manner and, if it is to be included in IWRM, management of groundwater has to comply with the policy, strategy and practice of general water resource management in South Africa. (Parsons, et. al., 2001)

4.1.2 Integrated Catchment Management

The water resource, at a particular location, is the product of runoff or groundwater recharge that originates in a physiographically defined drainage area, known as a catchment ("local" scale) or basin (large scale). The way humans utilise land inside a catchment has a significant impact on the quality and quantity of the water resource and the aquatic ecosystem reliant upon that resource. In this way the hydrological cycle, land use and the ecosystem are bounded together within a catchment or river basin. Therefore, naturally occurring water can only be managed effectively and efficiently within catchment or river basin boundaries, because of the need to technically account for all aspects of the hydrological cycle, as well as for human interference. Administrative regions within society do not always coincide with water management areas, e.g. provincial & local government boundaries, but by dividing the management process into smaller scales of sub-catchments, it becomes a more people-friendly and manageable process, as residents of a particular area often have a valuable understanding of the local area's problems and solutions. (Darcy Consultants, 2002)

Integrated Catchment Management (ICM) is a process and an implementation strategy to achieve a sustainable balance between utilisation and protection of all environmental resources in a catchment. This involves establishing receiving water quality objectives for rivers in the catchment, based upon requirements of stakeholders and interested and affected parties, and developing catchment management strategies to ensure that these water quality objectives are met. (Darcy Consultants, 2002)

- ☐ The catchment area of the dolomitic compartment needs to be defined and explained as part of the geohydrological study.

4.1.3 Public Participation

Sustainable water resource management requires the considerations of all users of surface and groundwater in the catchment and a catchment-based authority can most effectively deal with this function. Conflict between competing users should be resolved in the catchment context by an institution consisting of catchment representatives, which take catchment considerations into account. This will allow for the participation of all interested and affected parties. Water courts are inappropriate and inefficient for conflict resolution and should be seen as a last resort. (Lazarus, 1997)

Public awareness is seen as the only permanent guard against degradation of groundwater. Groundwater has a number of important features and characteristics that must be conveyed to decision makers, resource managers and planners and the public, including (Parsons, et. al., 2001):

- It is often present where surface water is not and is therefore an ideal source for small rural communities, villages, small towns and coastal holiday resorts with high summer demands.
- It is usually significantly cheaper to develop and manage than surface water.
- The quality is such that it generally does not require to be treated before distribution.
- It is generally far more environmentally friendly to develop than building dams.
- Groundwater is usually less susceptible to variations in rainfall and periods of drought.

A great need has risen regarding capacity building among the broader groundwater community e.g. graduate programs, graduates currently active in water-related spheres, public and stakeholders involved in IWRM, but outside of the profession. It is necessary to enhance the capacity of these non-specialists with respect to groundwater management, as part of IWRM, and enable institutions to sustain the development of well-qualified water managers. (Parsons, et. al., 2001)

4.1.4 Resource Directed Measures

Groundwater protection and conservation are essential components of groundwater management and relate to both quality and quantity. The NWA, 1998, introduces source and resource based tools to protect and conserve groundwater. Source based includes licensing and authorisations, while resource based measures include Resource Directed Measures and classification. (Parsons, et. al., 2001)

Resource Directed Measures is described by the NWA, 1998, for the protection of the water resource and consist of two mechanisms:

☐ The Reserve

☐ Resource Quality Objectives,

of which the Reserve is critical before allocations can be made.

4.1.4.1 The Reserve

Development of groundwater is not only finding and using new resources, but also the sustainable use of groundwater that has already been developed (current users). Prevention of depletion or damage to the Reserve has high priority in sustainable use, and the risk of over-use must be taken seriously and appropriate management plans formulated (Parsons, et. al., 2001). The Reserve for a water resource is defined by the NWA, 1998, as two components; (1) the water necessary for basic human needs and (2) the water necessary for the ecology.

4.1.4.1.1 The Basic Human Needs Reserve

Basic Human Needs is defined by the DWAF as a volume of water necessary for basic domestic uses and in most areas quantified as 25 l/capita/d.

4.1.4.1.2 The Ecological Reserve

A new concept that was developed as part of water law principles was that of the ecological reserve. It is in essence, the quantity and quality of water necessary to sustain ecosystem function and biotic integrity at a desired state of ecological health, based on management decisions, which determines a balance between environmental and human development needs. Groundwater is part of the total aquatic ecosystem and supports vegetation, springs and baseflow, while recharge is affected by water and land management practices on the surface. Protection of the groundwater resource clearly has a qualitative and quantitative dimension (Lazarus, 1997). The question is not how much groundwater should be reserved for ecological purposes, but rather, how much groundwater can be captured from the natural system for man's use without causing unacceptable damage to the environment (Vegter, 2001).

4.1.4.2 Resource Quality Objectives

Pollution control legislation applies regularly to surface and groundwater, but the application has been largely directed towards surface water, since control measures are reactive. Groundwater control measures needs to be proactive and planned, because of the slow and long-term impacts of pollution. (Lazarus, 1997)

Resource protection essentially determines in what areas and for what purposes abstraction licences should be granted. Groundwater quality management objectives should be in line with surface water management objectives, such as the concepts of fitness for use, optimal management to obtain maximum benefit and the polluter pays principle. (Lazarus, 1997)

MacKay, 1999, defined the Resource Quality Objectives (RQOs) as follows:

RQOs for a water resource are a numerical or descriptive statement of the conditions, which should be met in the receiving water resource, in terms of resource quality, in order to ensure that the water resource is protected. Because they are a statement of water resource quality, and not just water quality, the Objectives have four critical components, to cover each of the aspects of ecological integrity, which are necessary for protection of the Resource Base:

- requirements for water quantity, stated as Instream Flow Requirements (IFR) for a river reach or estuary, or water level requirements for standing water or groundwater. These are determined according to current procedures for assessing IFR;
- requirements for water quality, which are determined on the basis of current guidelines and procedures as set out in the South African Water Quality Guidelines;
- requirements for habitat integrity, which encompass the physical structure of instream and riparian habitats, as well as the vegetation aspects;
- objectives for biotic integrity, which reflect the health, community structure and distribution of aquatic biota. (MacKay, 1999)

While the Reserve is a scientifically calculated volume of water kept apart from water that can be allocated for use, resource quality objectives is a set of standards decided upon by the water users of an area to protect their water resource for sustainable future use. A people orientated approach to water management is sought, where users actively participate in the decision making process (Darcy Consultants, 2002).

4.1.5 Lawful Water Use

It is a commonly held perception that all groundwater is private and subject to individual ownership, somehow beyond the regulatory jurisdiction of the State. The right to use water, in South African law, is determined by the legal status of the water in question. By application of the common law and statutory provisions, groundwater is capable of qualifying as numerous legal categories. (Lazarus, 1997)

The National Water Amendment Act, 1999, classifies the legality of water:

In terms of Section 32 of the National Water Amendment Act, 1999 (Act No. 45 of 1999), an *existing lawful water use* means a water use:

- Which has taken place at any time between 1 October 1996 and 1 October 1998, and which
    - Was authorised under any law which was in force prior to 1 October 1998;
    - Is a stream flow reduction activity contemplated in Section 36(1) of the National Water Act, 1998 (Act No. 36 of 1998); or
    - Is a controlled activity contemplated in Section 37(1) of the NWA, 1998, or
- Which has been declared an existing lawful water use under Section 33 of the National Water Amendment Act, 1999 (Act No.45 of 1999), and which
    - Was authorised under any law which was in force prior to 1 October 1998;
    - Is identified as a stream flow reduction activity in Section 36(1) of the NWA, 1998; or
    - Is identified as a controlled activity in Section 37(1) of the NWA, 1998.

4.1.5.1 Registration & Licensing

Once the legal separation between different sources of water is removed, the allocation mechanism also tends to be unified, although different considerations would be applied to the granting of a licence to abstract groundwater as opposed to surface water. The insistence of a uniform allocation system stems from the principle of IWM and is further necessary to provide for conjunctive use, which may be obtained by granting only one licence for all water abstraction. Therefore, an allocation system that provides for integrated or conjunctive use of surface and groundwater within an integrated management structure must be strived for. (Lazarus, 1997)

Currently all water uses must be registered, irrespective of the legality of the water use, therefore registering a water use does not make it a lawful water use. Licensing takes place were a water user wants to start using water after 1 October 1998, or where a use was registered and verified, according to Section 35 of NWA, 1998, to be unlawful. Licensing is the current mechanism by which allocations of all new water uses on water resources are done.

☐ Verifying all water uses in the area and subsequent registration and licensing of the water users must be a priority and performed as soon as possible, before management can be successful.

4.2 Management Structures

Effective management requires trained and experienced staff, proper planning and data upon which management can be based. Ultimately, the national government is the public trustee of the nation's water resources, but water resource management is to be delegated to regional or catchment level. A key element of the National Water Resource Strategy (NWRS) is the establishment of Catchment Management Agencies (CMAs) that will take over the responsibility of managing water resources in the 19 Water Management Areas (WMAs). (Parsons et al., 2001)

All CMAs will be required to develop and implement catchment management strategies. The nature of aquifer systems requires groundwater management to remain essentially at local level, while research and strategic planning should be undertaken on regional or national level. Local aquifer management includes monitoring of groundwater abstraction, groundwater level fluctuations, groundwater quality changes, rainfall recharge and environmental impacts (e.g. surface subsidence). (Parsons et al., 2001)

Apart from the duty to formulate catchment or sub-catchment water plans, local water resource management institutions should be responsible for the administration and actual implementation of the plans and specifically, the granting of licenses or permits to utilise groundwater in accordance with the plans. The new approach of local level management and the participation of all sectors and the general public in the planning and implementation process will create the stimulus and correct environment for a sustainable management of our vital groundwater resources (Lazarus, 1997).

Devolution of groundwater management functions to the lowest technically competent level should be encouraged, while retaining a strong central authority for overall management of all water resources. The promotion of education and training programmes at local level is a pre-requisite to such a devolved management strategy and structure. Water resource development can only be sustainable if the key functions in this regard are devolved to the regions or areas where the water resources occur and are utilised. (Lazarus, 1997)

The NWA, 1998, provides for three levels of water management (Parsons et al., 2001):

- National Government – The DWAF
- Catchment Management Agencies – CMAs
- Water User Associations – WUAs

Catchment Management Committees is another management structure, which can be utilised to overcome issues like water quality contamination, geohydrological boundaries not following WMA boundaries or resource management between different dolomitic compartments.

Integrated management is best achieved by combining surface and groundwater management institutions and by unifying the allocation mechanism applicable to the two sources. Utilisation management approaches will differ from unit to unit and also between surface and groundwater resources, depending on the resources and demand characteristics in the unit and the resource base that requires protection. (Lazarus, 1997)

☐ Currently National Government and acting CMAs do exist, but WUAs must be established as soon as possible for the smallest manageable dolomitic unit.

4.2.1 National Government

As central authority the DWAF should focus on development of policies and strategies, development or maintenance of databases or information systems, development of tools and guidelines required for implementation. (Parsons et al., 2001)

4.2.2 Catchment Management Agencies

The CMA is responsible for water resource management in the appropriate WMA at regional or catchment level. Sound management of water resources depends on decisions based on facts, and efficient and sustainable use of a catchment's groundwater resources cannot take place without adequate monitoring. The CMA must monitor ambient groundwater levels and quality fluctuations at a catchment level. Monitoring of aquifer response to abstraction and/or contamination on a local or site specific scale must be driven through licence conditions. Information collected should be captured on a database for use and distribution of data. (Parsons et al., 2001)

Until such time that the CMAs are established and functioning, the Minister of the DWAF has delegated these powers and responsibilities to the Regional Offices of the DWAF, with WMAs assigned to the various offices. The Regional Office is therefore responsible for the water resource management within the WMAs assigned to it.

4.2.3 Water User Associations

WUAs should act co-operatively on local level and be encouraged to assist CMAs with joint management of communal aquifers. Guidelines for adequate aquifer management should be established and distributed by the DWAF. Guidelines should cover, among others, sustainable use, abstraction scheduling, pump settings and monitoring requirements. (Parsons et al., 2001)

The functions and responsibilities of the WUAs have been examined and can be defined as follows (Darcy Consultants, 2002):

- Monitoring of hydrological parameters must be carried out to accumulate information on rainfall, water level fluctuations, water quality and abstraction.
- The collation of all relevant geohydrological information in a hands-on database.
- Periodic reassessment of the groundwater situation.
- Making decisions regarding licensing, including enforcing licensing conditions.
- Report to and liase with the water authorities and local interested parties regarding policy matters, the groundwater status complaints and management issues that require a higher level of consultation.

WUAs can be established without all the resource management issues and boundaries being defined. These associations' boundaries, functions and responsibilities can be amended with little trouble, as provision for this has been made in the constitutions, and management agreements can be established, between different associations, as soon as the resource management issues has been defined and before amendments have been approved by the Minister.

4.3 Geotechnical Controls

"In groundwater evaluations the main question of concern to water planners, is whether a specific abstraction could be sustained by an aquifer and what the associated risk of failure would be. Failure could be signified by different criteria, but generally occurs when a specific critical groundwater level or abstraction rate cannot be maintained." (Bredenkamp, et.al., 1995)

The groundwater resources of South Africa differ from that elsewhere in the world, as about 98 % of groundwater is found in fractured, hard rock aquifer systems. These secondary aquifers are more difficult to manage and protect than primary aquifer systems. 18 % of the aquifers in South Africa are classified as major aquifer systems, including dolomitic rocks, and are distinguished by high yielding boreholes producing good quality water (Parsons et al., 2001).

Various geotechnical controls exist which govern the geohydrological regime and which can be defined or determined, with different importance assigned to each. This section aims to provide general instructions in a systematic way, outlining the necessary geohydrological evaluation that needs to be done before meaningful resource management can commence.

4.3.1 Geographic Setting

The geographic setting of an area is easy to define and therefore it must be included It entails information such as where the area is located in the country, which maps to use when visiting or viewing information, as well as geomorphological features that might be of importance. This gives one an understanding of the surface topography and what might have an influence on the groundwater system from the surface. This type of information is available at the DWAF Geomatics Section, Website e.g. DEAT (www.environment.gov.za) and the Surveyor General Offices (www.nsif.org.za). The following should be included:

☐ Province and nearest town. The country can be included if relevant.

☐ Local authority boundaries if relevant.

☐ Topocadastral maps or other relevant maps, e.g. 1:50000 or 1:250000 maps.

☐ Geomorphological features that might be important, e.g. sinkholes.

☐ Type of land cover, which can be obtained on the DTEEA website.

☐ Relevant catchments within which the area falls, e.g. quaternary and primary.

☐ Relevant surface water resources that can be used for orientation.

☐ Other descriptive information.

4.3.2 Meteorology

Rainfall is the most important factor governing the natural system's regional variability in recharge and the associated aquifer response (Bredenkamp, et.al., 1995). A good understanding of the climatic conditions of an area is always essential, especially with regard to groundwater in the dolomitic areas, as rainfall is the source from which recharge originates. The information is also readily available at websites, e.g. DEAT, and meteorological data is available at the South African Weather Buro. Wherever rainfall data time series is insufficient, the rainfall must be extrapolated/patched from other rainfall stations in the vicinity, which show the same rainfall patterns. The following is a list of evaluations that must be completed before groundwater simulations can be done:

☐ Type of rainfall season typical to the area including average rainfall and evaporation.

☐ Minimum and maximum temperatures.

☐ Mean annual precipitation (MAP), and where possible rainfall zones of similar precipitation can be compiled.

☐ A reliable set of monthly rainfall data, with at least 10 years of rainfall data prior to the first groundwater level or spring flow data.

4.3.3 Geology

The geological environment is the governing factor in how the geohydrological regime will respond. Different rocks have different water bearing capabilities and structural features determine flow regimes. Geological information is available in map form at the Council for Geoscience, as geological and geophysical logs on the NGDB and, if it is necessary, one can drill more boreholes in an area where uncertainties exist that needs clarification. A good geological description and understanding of an area before commencing with a geohydrological evaluation is a necessity. It is of utmost importance that the water manager understands the geology of an area before commencing with resource management. The following checklist should be used:

☐ A geological description according to geological maps available.

☐ A geological description from previous reports, including structural features and borehole logs available on the NGDB, focussing on possible geological boundaries.

☐ A geological map compiled from available detail information in reports or electronic form.

☐ A geological cross-section, where enough spatial information is available and where it is necessary.

4.3.4 Geohydrology

The characteristics of karst aquifers depend on controls such as geology, geomorphology, climate and biological controls, as well as the interaction of these controls and the chemical and mechanical processes, whose rates of activity they determine. These factors also control the boundary conditions that exist in the dolomitic terrain. Structural controls, such as joints, fault and bedding planes (dykes or chert sheets), defines preferential pathways for infiltration of rainwater and therefore the dissolution of the dolomite. Permeability, therefore flow, would be greater in layers where more of these controls have caused fissuring or differential solution. (Ford & William, 1989) The geohydrology of the area should be described in general (aquifer types, borehole yields, aquifer parameters) to attain an understanding of the groundwater system and the following checklist should be used:

☐ A geohydrological description according to geohydrological maps available.

☐ A geohydrological description from previous reports including structural controls and data available on the NGDB.

☐ A geohydrological map compiled from available detail information in reports or electronic form.

The dolomitic terrain can be viewed as an open system with input (recharge), output (spring flows and abstraction) and throughput flows, mechanisms and controls. Throughput flows include factors, which dictate the potential flow path, such as effective porosity, storage and storativity, permeability, hydraulic conductivity and transmissivity. These throughput flows would therefore govern the input and output flows. (Ford & William, 1989)

Various relevant parameters are discussed in more detail.

4.3.4.1 Boundaries

Boundary conditions in dolomitic rocks include geological structural features such as dykes, geological contacts and differences in geological layers in the dolomite. Mostly these constitute flow boundaries and have an effect on the direction and velocity of flow in the dolomitic compartment, therefore also compartmentalising the dolomitic region. It is essential to define and understand these flow boundaries, as they have a direct effect on all other determinations, conclusions and assumption one makes:

☐ Boundaries must be described and included in the geohydrological map.

4.3.4.2 Aquifer Management Classification

The starting point of groundwater protection is that groundwater resources should be used within their capacity for renewal, both quantity and quality. However, not all groundwater resources are required to be protected to the same degree. The relative stringency and acceptable risk levels for impact minimisation will depend on the nature of the affected resource. The approach is based on the classification of the resource in terms of their relative importance and vulnerability. (Lazarus, 1997)

Classification of an aquifer system is a means of providing an effective planning tool to facilitate information sharing and decision-making based on simplified knowledge. At a regional scale, application would include allocating groundwater resources, setting water quality standards, defining monitoring requirements, setting controls for groundwater abstraction, setting appropriate levels of groundwater resource protection, setting of licensing conditions, land-use planning, urban zoning and general public education. The classification can also be used to determine the levels of investigation required in order to make decisions and the manpower necessary to be able to manage the system. (Parsons, 1995)

- ☐ The South African Aquifer System Management Classification System according to Parsons (1995) is given in APPENDIX E. The dolomitic aquifer has to be classified before one can decide how important the aquifer is and how much effort should go into the management of the specific dolomitic area.

4.3.4.3 Groundwater Levels

Measuring the groundwater level in an aquifer has a twofold function: (1) to determine the water level at a certain time and (2) to determine the interaction between the groundwater level fluctuations and rainfall fluctuations in an area over time. This is the only way in which one is able to determine the groundwater table surface and how it is responding to rainfall. Groundwater level contours can be used to delineate compartments, as boundary conditions are easily defined where steps in the groundwater table are found. Outflow and inflow boundaries are also determined with the help of groundwater level contours. Groundwater level fluctuations are used to determine aquifer parameters such as recharge and storativity, as well as define the impact abstraction has on the groundwater system. Therefore groundwater level interpretations are essential to the understanding of the groundwater system and the following actions must be performed:

- ☐ Evaluating existing time series data to determine rainfall/water level fluctuation interactions, as well as aquifer parameters.
- ☐ Plotting borehole elevations and the water level elevations of the boreholes against each other, to determine if groundwater levels are following the topographic surface. This is used to determine what kind of interpolation should be used for the contouring of the groundwater levels.
- ☐ Contouring groundwater levels, both elevation and depth below ground level, to determine boundary conditions, inflow and outflow points, the effect of surface water bodies on the system and a piesometric groundwater level map.
- ☐ In dolomitic areas it is essential that elevations of boreholes should be surveyed to at least 10cm accuracy for better interpretation of the water levels in relation to one another.
- ☐ Simulating groundwater level fluctuations with different methods depending on the types of available data. These simulations are included in the groundwater balance simulations and are described in more detail in section 3.6.1.

4.3.4.3.1 Sinkholes

Groundwater levels fluctuate in dolomitic areas, due to differences in rainfall patterns, and whenever this happens a certain risk exists related to the formation of sinkholes, the greater the fluctuation the higher the risk. The fluctuation necessary to cause sinkhole formation can differ between different dolomitic areas and wherever this might be an issue, care should be taken to determine at what level the risk becomes unmanageable and how it should be incorporated into a groundwater management plan.

Pollution from human activities, such as gold and coal mining, can cause Acid Rock Drainage and dissolution of the dolomitic rock is enhanced and the risk of sinkhole formation increases.

- ☐ The risk of sinkhole formation should be quantified and management options should be outlined.

4.3.4.4 Groundwater Quality

Groundwater quality is determined by rainfall and geochemical reactions, which occur in the unsaturated zone, the saturated zone and whenever pollution occurs. The concentrations of substances provide a measure of recharge and its spatial distribution. In areas of similar geology, fingerprinting the groundwater chemistry can help establish where recharge in springs are coming from. (Bredenkamp, 2000)

Karst aquifers are more susceptible to a great range of environmental impacts and subsurface purification is relatively ineffective (Ford & Williams, 1989). Most probably, the only reason why pollution might be concealed, is the great volumes of storage water available for diffusion and therefore dilution. However, it must be understood that groundwater has unique characteristics distinct from surface water, for instance delayed effects of pollution because of slow movement of water, limited assimilative capacity of groundwater, contamination of groundwater is invisible and rehabilitation is difficult, costly and generally ineffective (Lazarus, 1997).

Groundwater quality measurements are used in different types of analysis to understand the groundwater character in the dolomitic compartment. These analyses consist of diagnostic diagrams, spatial analysis and trend analysis, and must be performed to get a good understanding of the chemical character of the groundwater.

- ☐ Diagnostic diagrams would typically consist of Piper, Expanded Durov and Stiff diagrams that use chemical element ratios to plot the different water qualities in different fields, of which each has a different interpretation and meaning.

- ☐ The spatial analysis is used to view and explain the various water qualities over an area in relation to local geology, geomorphology or contamination sources. Wherever applicable these spatial analyses can also be contoured for different times or chemical constituents and interpreted accordingly.

- ☐ Trend analysis is the plotting of the time series of one or more chemical constituents in relation to seasonal rainfall patterns. This gives one an indication of the seasonal variation of chemical constituents compared to rainfall, whether it is ambient trends or contaminated sites.

- ☐ All these types of analyses can be done relative to drinking water quality standards, thereby also determining the fitness for use of the water.

4.3.4.4.1 Environmental Isotopes

Using tracers to delimit catchments, estimate groundwater flow velocities and determine recharge and pollution sources, is a well-developed tool. The main applications of environmental isotopes being to (Ford & William, 1989):

- Provide a signature of the origin of the groundwater type
- Identify mixing of different types of groundwater
- Provide information on through flow velocities and directions

- Provide data on the underground residence time, therefore the age of the water

Isotopic ratios can be changed in a system through fractionation and radioactive decay. Isotopes are then used as tracers of natural waters, but interpretation has to be careful because of external influences (e.g. nuclear testing) onto these isotopic concentrations. (Mazor, 1991)

In natural waters the most important environmental isotopes are:

- Stable isotopes (deuterium & oxygen-18)
- Radioactive isotopes (tritium & carbon-14)

The stable isotopes are used to indicate the kinetic behaviour of water during evaporation or condensation (Mazor, 1991). These can be used for delineating zones within aquifers by contouring areas of similar characteristics.

Radioactive isotopes where used for dating of the groundwater, but after nuclear testing, with artificial introduction of these tracers into the system, dating has become difficult, although it can still be done. (Mazor, 1991)

☐ Environmental isotopes can be used where data is available, as any information is valuable, but care should be taken when doing the interpretations, as various influences could have been introduced onto the system.

4.3.4.4.2 Impacts on Water Quality

Colvin, 2000, identified a borehole as a direct pathway to the aquifer, since a direct link between the surface and saturated zone was established, no infiltration time and therefore reaction time with the soil remain and it often acts as a pathway for pollution. It was stated that high nitrate levels occur naturally in some areas as a result of the local geology and geomorphology, e.g. in the Kalahari and around Prieska, but high nitrate levels in other areas result from agricultural activities, such as fertiliser application, ploughing and livestock effluent irrigation. (Colvin, 2000)

Water users need to be aware of activities on their properties that involve potentially contaminating substances coming into contact with the ground and being leached to the water table by rain or irrigation water (Colvin, 2000). In areas where industrial and mining processes take place, any contaminant from these processes is a potential threat to the groundwater system and these processes should be evaluated and specific pollutants identified e.g. major pollutants in the gold mines are sulphates associated with Acid Rock Drainage, low pH and high heavy metal content (Scott, 1995). A risk rating system was developed by Hodgson, et.al., 2001, which can be used to approximate the risk of pollution from a site, even when little information is available.

Fertilisers from agricultural land are soluble and may be leached to the water table, if not taken up by the crop. The transfer of diesel from a storage tank to vehicles may also cause contamination, if spills occur in an area that has not been sufficiently paved and contained. The possible impacts from agricultural activities and ways to minimise it, is described in more detail in APPENDIX F and are listed as follows: (Colvin, 2000)

- Irrigation
- Fertiliser
- Animal Waste
- Sewage Sludge
- Pesticides and Herbicides

☐ The water quality impacts must be quantified and included in the groundwater management plan for a dolomitic compartment.

☐ Contour maps of nitrate values, as well as other relevant contaminants, must be compiled and reviewed on a continual base.

4.3.4.4.3 Health threats

In areas where industrial and mining pollutants have been identified, the threats of these pollutants to human and animal health should be quantified e.g. sulphate, heavy metals and radioactivity in both gold and coal mining areas.

Nitrate is a common pollutant in agricultural areas and easily dissolved in water, which is why it is likely to leach to groundwater. Nitrate is a concern in drinking water at levels greater than 10mg/l nitrate-nitrogen (NO_3-N), which is equivalent to approximately 45 mg/l as nitrate. At concentrations greater than this, there is an increased risk to infants, of *methahemoglobinaemia*, commonly known as Blue Baby Syndrome. The mortality rate among affected infants is reported to be around 10%. Livestock has been found to be similarly affected, but at higher nitrate concentrations. Nitrate-nitrogen concentrations of 100 - 300 mg/l in livestock water may cause problems if the feed is high in nitrate. There is suspected to be an increased risk of stomach and oesophagus cancer with consumption of nitrate contaminated water and the risk becomes greater if the water is also contaminated with pesticides. Nitrate is therefore the contaminant of most concern. (Colvin, 2000)

☐ If a health threat exists in an area, the threat must be quantified and the users informed accordingly.

4.3.4.5 Aquifer Parameters

Various aquifer parameters can be determined with available data, of which recharge is the most important parameter for groundwater management in dolomitic areas. Only a few parameters are truly useful in groundwater management. The following checklist can be used when determining aquifer parameters:

☐ Transmissivity – optional depending on what its use is e.g. regional numerical modelling.

☐ Storativity – used in most simulations and therefore necessary for a water balance.

☐ Recharge – essential for groundwater management in any dolomitic area. The confidence level at which recharge is determined, will be a function of the importance of the compartment and the availability of data.

4.3.4.5.1 Transmissivity and Storativity

Pump tests are expensive and the value of the data that is generated for management in dolomitic areas is very small. A single borehole's transmissivity and storativity cannot be related to the rest of the compartment, because of the variable nature of the host rock. Storativity values can be obtained with groundwater level simulations and these types of determinations yield a value integrated over an area and are therefore more useful. Storativity values can be obtained with the SVF, CRD and MA methods. Transmissivity values can be obtained with the help of water level contour maps and is therefore also integrated over space and yields a more useful value.

4.3.4.5.2 Recharge

The evaluation of groundwater resources of an area is the first step in managing the resource and recharge estimations are viewed as a key issue in the evaluation (Bredenkamp, et.al., 1995). Recharge is derived from rainfall, or inflows from adjacent geological features, or artificial from recharging boreholes. Floods in river systems can reverse flow directions at springs, if the springs were submerged during the flood. (Ford & William, 1989)

The type of recharge estimations will depend on the types of data available, but it is always recommended to use more rather than fewer methods. Various methods for recharge values can then be compared and where similarities exist, confidence in the recharge estimate will be greater. It is then also the decision of the water manager and water users, whether the recharge should be done at a conservative level or if the aquifer should be exploited. For the dolomitic aquifer the SVF, CRD and MA methods has proven to be invaluable, but it is recommended that all methods be used for the data available and estimates compared with each other to obtain the best recharge estimate for the area. The different methods and types of data necessary is summarised as follows:

4.3.4.5.2.1 Groundwater Chemistry

Recharge in aquifers can be determined through groundwater chemistry, with the chloride ratio method. The reason for this being that chloride is a conservative tracer and only where pollution occurs is the natural concentrations altered. The chloride concentration should therefore only be dependent on the natural, hydrological, evaporative processes. This method expresses the ratio of recharge between the chloride concentration in rainwater and groundwater as a percentage of rainfall. (Bredenkamp, 2000)

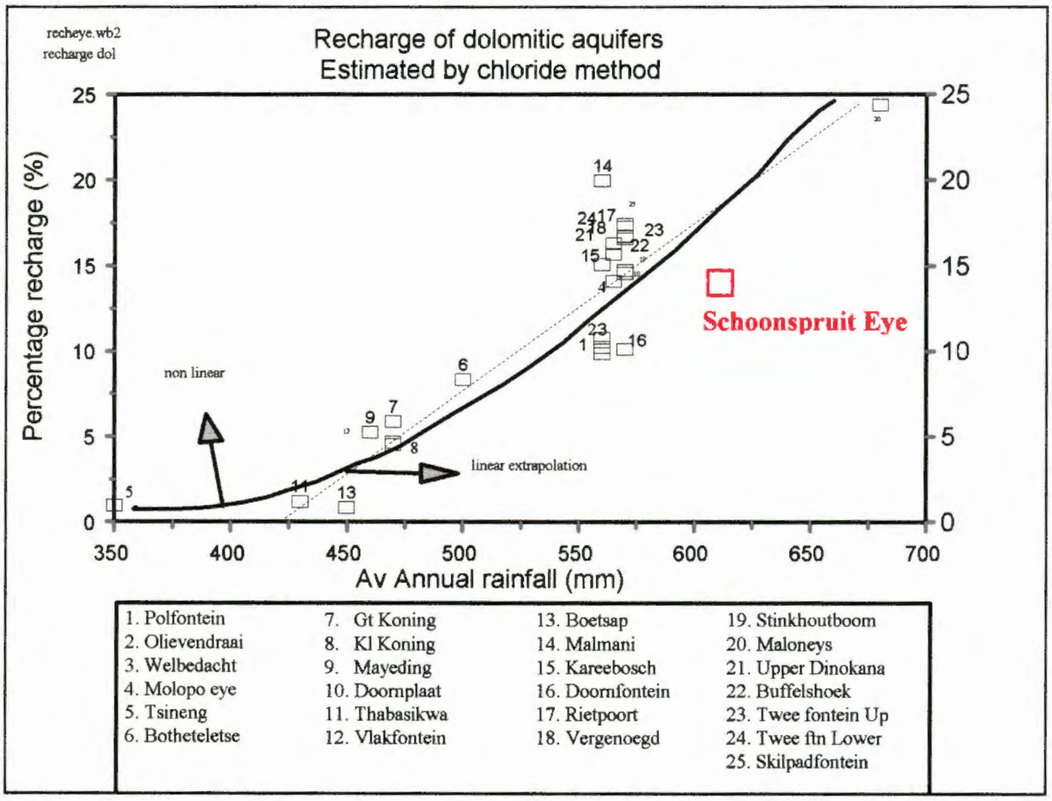


Figure 76: Chloride method recharge values for different dolomitic springs (Bredenkamp, 2000)

Recharge of several dolomitic springs, determined by using the chloride method, is listed in Figure 76. The Schoonspruit Eye effective recharge was determined for the year 2002 as 13% and is shown on the figure. Data needed for this method includes the chloride concentration in both the rainwater and the groundwater in the area.

4.3.4.5.2.2 Moving Average & Cumulative Rainfall Departure

The CRD and MA rainfall methods could simulate the natural flows and effect of abstraction on the natural hydrological response of the system (spring flows) and is a means of assessing the impact of abstraction and rainfall recharge on individual boreholes drilled in fractured and dolomitic aquifers. (Bredenkamp, 2000)

Data needed for these methods include monthly groundwater level series, monthly rainfall series (starting at least ten years prior to the first groundwater levels) and abstraction volumes.

4.3.4.5.2.3 Saturated Volume Fluctuation & Equal Volume Method

The SVF method is based on the saturated water balance and therefore, takes into account inflows, outflows, recharge and the change in aquifer storage (saturated volume) over time. The method gives a picture of the water level response of the aquifer. (Bredenkamp, et.al., 1995)

The EV method can be used to estimate recharge by means of the rainfall/recharge response of a spring to its catchment area, for periods for which the flows are equal at the beginning and end of the period. (Bredenkamp, 2000)

Spatial integration of individual boreholes will give you an integration of recharge over the area. This is applied by balancing the input and output of the saturated water budget over time, and a good reliable set of groundwater level data is necessary for this method. One drawback of this method is that abstraction from the aquifer for the time series has to be known. Natural losses, outflows from springs, pumping from groundwater and differences between lateral inflows and outflows can be zero for aquifers in equilibrium. (Bredenkamp, 2000)

Data needed for this method include monthly groundwater level series, inflows and outflows and monthly abstraction volumes.

4.3.4.5.2.4 Environmental Isotopes

The stable isotopes, hydrogen ($^2H/^1H$) and oxygen ($^{18}O/^{16}O$), are used to indicate the kinetic behaviour of water during evaporation or condensation. The ratios are referenced against Standard Mean Ocean Water (SMOW). When these stable isotopes in rainwater are compared to the ratios of the isotopes in groundwater, an indication of the recharge origin (place) can be determined. (Bredenkamp, 2000)

The Tritium, ^3H, profile method has been tested and used for recharge estimations in dolomitic areas. Advantages, of the method, include that storativity values do not influence the determinations, it is a tracer that is integrated over an area, the character of the soil is undisturbed and point values can be integrated to represent an area. Disadvantages include the fact that present concentrations are almost undetectable, uncertainties with regard to losses of concentration in the soil exist, recharge values from the method possibly constitutes a minimum recharge value for the area and it is difficult to sample. (Bredenkamp, 2000)

^{14}C isotopes are inappropriate to use for recharge estimates in carbonate rocks in South Africa, because Transvaal aged carbon exist in the rock and therefore in the groundwater analyses. This old carbon has already decayed radioactively and the ratios of carbon introduced by rainfall against that in the groundwater is reduced, resulting in a lower recharge value.

Data needed for these methods include isotope concentrations in rainwater and groundwater, as well as reference data for the specific area.

4.3.4.6 Dolomitic Springs

In dolomitic areas the springs that originate on the compartments are solely dependent on the compartment for surface water flow, as dolomitic areas are generally flat and all rainfall either infiltrate or evaporates. Runoff from these areas is minimal and discharge from the system takes place at topographic low points. In many instances downstream users are dependent upon this flow and the rainfall/flow relationship should be determined and the effect of abstractions from the compartment on the spring flow quantified. Where water quality is an issue, this should also be included in a monitoring network. The following actions should be taken with regard to socio-economic important springs in a dolomitic area:

☐ Determine the rainfall/flow relationship and catchment area of the spring with the MA, CRD, SVF and EV methods of simulation.

☐ Determine the water quality for the spring and as a result, its fitness for use.

☐ Determine the recharge to the spring and therefore, a flow simulation based on rainfall.

☐ Determine the impact of groundwater abstractions from the compartment upon the flow of the spring and therefore, the impact on surface water users.

☐ Include monthly spring flow measurements and water quality analysis in the monitoring network, where applicable.

4.3.5 Water Users

All water users dependant on the dolomitic compartment must be clearly defined, to achieve a good understanding of all stakeholders that might be impacted on by management decisions. Water users of concern in most dolomitic compartments include:

- Domestic
- Local Authorities
- Agricultural
- Mining
- Wetlands dependent on flow and their importance
- Surface water users dependent on spring flows

☐ Water users must be defined and the legality of the uses determined.

4.3.6 Modelling

Mathematical models are tools in the analysis of groundwater systems, but should not be seen as an answer to an end. It is a tool used for multiple purposes, such as: (Vegter, 2001)

- Providing a framework for organising hydrological data
- Attaining a consistent qualitative understanding of the hydrological system.
- Quantifying the properties and behaviour of that system.
- Allowing quantitative prediction of the response to externally applied stresses.

Models are quantitative approximations of complex natural phenomena and cannot be performed without sound qualitative and conceptual information about the hydraulic and geological properties of the groundwater system. (Vegter, 2001)

4.3.6.1 Groundwater Balance Simulations

Groundwater levels and spring flows can be simulated to a higher degree of certainty than any 2D or 3D numerical model. These simulations give valuable information regarding aquifer characteristics and impacts on the aquifer e.g. volumes of groundwater abstracted from the recharge area. These simulations are therefore one of the key components of groundwater management in the dolomitic areas and also one of the key components of the groundwater management tool. The groundwater balance is dependent on all inflows and outflows in a dolomitic compartment and therefore, every factor that could influence the groundwater flows in the aquifer. The SVF method can be used to determine the groundwater balance for the aquifer.

☐ Groundwater level and spring flow simulations must be performed before the groundwater management tool is developed.

4.3.7 Monitoring

Monitoring of water resources is probably the most critical factor with regard to groundwater management and must be geared towards satisfying management information needs, e.g. resource quality objectives (RQO 's). These needs include status and trends, effluent discharges, waste loads, impact assessment, unused or underused resources, health of the aquatic environment, situation analysis and auditing of the resource for both quality and quantity. (Parsons & Tredoux, 1993)

The hydrological cycle is a complex interactive system, which can have simplified relationships between variables over long time series (Bredenkamp, 2000). Establishing a monitoring station or network must be based on the importance of the aquifer, the use, e.g. urban or economic, sustainability expressed as recharge and current monitoring stations in operation. Current monitoring stations should always be evaluated according to importance and use before a new station is established. The objectives and criteria for each station should also be clearly defined in the monitoring program for future use by water managers. Closing a station should be according to the same criteria as establishing one. (Bredenkamp, 2000)

Increasing cost of monitoring forced network designers to reconsider their approach to a systems approach, in order to meet needs and objectives in a cost-effective manner, thereby looking at the objectives of the monitoring, conceptualising what is needed, designing and implementing networks properly and reporting and evaluating information generated. The type of monitoring depends on the specific purpose or objective of monitoring and the scale of monitoring. (Parsons & Tredoux, 1993)

The following scales of monitoring were identified:

- Local scale
- Regional or provincial scale
- National scale
- International scale

For the management of the dolomitic compartment only local and regional monitoring is necessary. The objectives of a regional monitoring network can be classified as resource classification and quantification, resource planning, resource protection and detection of pollution (Parsons & Tredoux, 1993). The objectives of a local monitoring network being pollution control and compliance to standards set by a governing authority.

A monitoring network design depends primarily on the purpose of the measurements and a good spatial distribution of monitoring stations is necessary. In general 6-9 well-spaced stations per aquifer would be representative and the number would be governed by the importance of the aquifer. (Bredenkamp, 2000)

Priority areas, geohydrological considerations and available resources will define the exact location of monitoring stations. Four components of technical considerations of a monitoring system requires further review (Parsons & Tredoux, 1993):

- Station selection – has the greatest impact on the development of a monitoring network. This includes the total number of boreholes that should be included, whether existing boreholes will suffice and whether specialised boreholes need to be drilled and whether depth is a consideration.
- Sampling protocol – this is to attain consistency in monitoring and representivaty of samples. This will typically include office preparation and equipment, field sampling procedures and sample transportation and hand over.
- Laboratory analysis – suitable laboratory is a great factor in the quality of data.
- Quality control – responsibility of the data manager (*CMA & WUA*).

Reliable measurements of groundwater levels, groundwater quality and rainfall seem to be the most important variables to be monitored. A reduction in the spatial variability is more important than measurement intervals more frequent than monthly; therefore stations of different variables should be close to one another to reduce uncertainties in evaluation of the data. Flow measurements and water quality of springs is also essential, as this represents the cumulative effect of groundwater over the catchment area of the spring. (Bredenkamp, 2000)

The monitoring network in a dolomitic compartment must include the following stations:

☐ Groundwater level monitoring
☐ Groundwater quality monitoring
☐ Rainfall monitoring
☐ Spring flow monitoring
☐ Abstraction monitoring (*WUA*)

4.3.7.1 Groundwater level monitoring

Groundwater level monitoring is the collection of groundwater level data over time and can be used to determine aspects such as seasonal fluctuations, rainfall/recharge relationships, aquifer parameters, abstraction impacts on the aquifer, groundwater flow directions and the groundwater balance for the aquifer. This is probably the most important monitoring requirement in dolomitic terrains, as no groundwater management can be done without this information.

Various methods, such as the CRD and MA methods, of interpreting this data have been developed and refined for the South African dolomitic aquifers in the last few years and essential information will be gained when analysing existing data by means of these methods. However, it is of utmost importance that a good spatial distribution of monitoring points over the dolomitic compartment exists, as different boundary conditions might influence the groundwater differently in separate parts of the compartment.

Groundwater levels should be monitored monthly and the monitoring stations chosen away from abstraction boreholes. Data loggers can also be used to record hourly water levels for research purposes, where this is practical. The monitoring points should be surveyed, with at least 10cm accuracy, with regard to position and especially the elevation.

4.3.7.2 Groundwater quality monitoring

Groundwater quality monitoring is the collection of groundwater quality data over time and can be used to determine groundwater quality characteristics, such as ambient (background) trends and contamination impacts. Ambient analysis includes seasonal groundwater quality changes over time and with rainfall events, background water quality for the dolomitic compartment, as well as groundwater quality in relation to spatial distribution. Contamination impact analysis includes identification of pollution sources, as well as the impact of pollution on the system over time.

Ambient quality monitoring points should be chosen where no impacts on the aquifer system exist, while contamination impacts should be monitored as close as possible to the pollution point source. Care should be given to take groundwater flow directions into account when choosing a site, as a current ambient site over time might become an impacted site if pollution is moving towards it. Similarly, a pollution plume is governed by the groundwater flow direction and therefore a site chosen in the opposite flow direction from the source will not fulfil its purpose. In the dolomitic areas one should not be focussing on boreholes only, as springs that flow from the compartments can also effectively be defined as groundwater features. Springs forming the origin of important surface water sources should be included as monitoring points in the groundwater quality network.

Groundwater quality constituents to be monitored for include, field measurements and laboratory analyses, and will be dependent on the types of use in the compartment (Parsons & Tredoux, 1993). The most important hydrochemical constituents to measure for in rural areas are the total dissolved solids (TDS) and nitrate, as these are usually the first to increase with domestic and agricultural pollution (Colvin, 2000). For mining areas various constituents are potential pollutants, e.g. gold mining areas sulphates are usually the biggest contributor to pollution, and constituents should be chosen according to the type of mining occurring on the dolomites. The same rules apply to the industry sector that applies to the mining sector. Eight simple steps by Colvin (2000) should be followed to obtain a worthwhile groundwater sample and is listed in APPENDIX G. Chemical constituents in a proper analysis should include those necessary for diagnostic diagrams, as well as those pertinent to specific users or pollution impacts in the dolomitic compartment.

Groundwater samples in dolomitic terrains should be taken from monthly to six monthly, depending on the type of monitoring. Compliance monitoring must be done monthly, while three monthly monitoring should be sufficient for aquifer contamination impacts, until sufficient data has been obtained to prove that less monitoring is sufficient. Ambient trends can be monitored three monthly until a good reliable set of data is acquired, showing seasonal trends, after which the monitoring can be reduced to six monthly.

4.3.7.3 Rainfall monitoring

Rainfall monitoring stations are easy to set up and combine with groundwater level monitoring stations, as rainfall over an area is generally similar in trend. The most important feature of the rainfall station site selection is a good spatial coverage of the area in order that simulations of the groundwater level fluctuations can be refined. Before establishing a new rainfall station it is also necessary to take existing rainfall stations of the South African Weather Bureau into account.

The rainfall station should be used for monitoring rainfall volumes as well as taking rainfall samples for chemical analysis. Rainfall volumes should preferably be monitored on an hourly base with a data logger, wherever groundwater levels are recorded hourly with a data logger. Rainfall samples can be taken three monthly, whenever the data logger is serviced.

4.3.7.4 Spring flow monitoring

Spring flow volumes, from dolomitic compartments, are essential information necessary for interpretation of flow characteristics from the compartment and recharge estimations for the recharge area of the spring. Wherever springs flow from dolomitic compartments, decisions should be made regarding the importance of larger as well as smaller springs. This will then determine whether or not a certain spring is monitored or not. Monitoring of monthly flow volumes is recommended and sufficient for most interpretations.

4.3.7.5 Abstraction monitoring

Volumes of groundwater abstracted from the system are essential for accurate simulations of the groundwater flow in the aquifer, as well as for groundwater balances and predictions. This type of data should be available on the same frequency as the spring flow data and monthly volumes should be sufficient for simulations. However, for abstraction control purposes monthly abstraction volumes might not be sufficient and frequency of monitoring might need to be weekly or even daily. The control and monitoring function will be with the WUA.

4.3.7.6 Integration of monitoring networks

Wherever possible, the different monitoring points should be integrated into the same monitoring plan and monitoring network. This is not only pertaining to the station locations, but where possible, more than one purpose should be assigned for a monitoring point.

4.3.8 Mapping

Decision-makers and managers often complain that hydrogeologists seldom present information that can be readily understood by the layman and they fail to provide clear guidance with respect to groundwater resources. The gap has recently been narrowed with the publication of national and regional scale hydrogeological maps, but the focus needs to shift towards providing more detailed information, as well as providing data and information by electronic means. (Parsons et al., 2001)

The first step in resource management and allocation is the objective assessment of the resource. Basic facts about catchment limits and drainage networks, as well as a quantitive estimate of annually renewable water are necessary. Various maps can then be produced and the detail on these maps must take into account the variation in expertise of its users. Detail on maps may include karst features throughout the area, rainfall distribution, available water, water quality, pollution and vulnerability to pollution. Essential maps to an area include:

☐ A geological map depicting all relevant geological features and boundaries, therefore also depicting the extent of the dolomitic compartment.

☐ A geohydrological map with the most important geotechnical controls and monitoring stations depicted on the map.

☐ A topocadastral map with all relevant geohydrological and institutional boundaries.

☐ A map within the management tool, with the recharge zones delineated, so that allocable volumes can be linked to the map.

4.4 A First Order Groundwater Management Tool

The basic principle of a first order tool is to include the essential mechanism in an understandable format, which will be used by the most basic groundwater manager, e.g. the Groundwater User Association. Inputs into the tool must be straightforward and outputs easily usable and controlled by mechanisms that cannot be changed by a layman. However, should new information come to light, it should just as easily be modified, by CMA professionals, to include refined techniques, parameters or simulations.

Developing a groundwater management tool is dependent upon which geotechnical controls are **essential** to the management of the dolomitic compartment and which controls are only beneficial. Therefore the tool cannot be developed before the geohydrological evaluation has been complete and all essential controls have been defined and determined. Beneficial controls do not have to be included, but if the data is available and if it will be collected in future, it should be included, in order that the tool becomes even more useful.

Essential input controls in the dolomitic compartment include:

- The Reserve
- The groundwater balance and all related simulations, including recharge to the compartment or response units within the compartment.
- Groundwater quality issues defined where applicable.
- Data inputs to these controls include:
  - Groundwater level measurements over time.
  - Spring flow measurements over time.
  - Monthly rainfall data for a time series ten years prior to the first groundwater level or spring flow measurements.
  - Groundwater abstractions or allocations, either to the Reserve or water users.
  - Groundwater quality data for the compartment where applicable.

Beneficial input controls in the dolomitic compartment include:

- Resource Quality Objectives, which have to be defined through Public-Participation.
- The general fitness for use of the water quality over the area.
- Pollution impacts upon the compartment.
- The management class of the aquifer, which have to be defined through Public Participation.
- Numerical modelling, if a useful model can be achieved.
- Data inputs to these controls include:
  - Resource Quality Objectives as was defined through Public Participation.
  - Groundwater quality data for the compartment.
  - Modelling parameters

The different controls have to be integrated into a software package, e.g. MS Excel, and where applicable, links must be established to existing software packages, e.g. Recharge software and CRD_MA simulations. Programming new software is not essential, as management can be done by means of hard copies of the groundwater balance and simulations, but automating management tools is recommended for ease of use.

Outputs from the groundwater management tool can also be divided into essential and beneficial outputs.

Essential outputs from the tool include:

- Groundwater balances for various zones in the compartment.
- Annual recharge volumes and therefore allocable volumes in the compartment.

- Spring flow simulations for predictions from predicted rainfall, also used for determining allocable volumes for both groundwater and surface water users.
- A classification of the groundwater quality based on the standards for the use of the water on the compartment.

Beneficial outputs from the tool include:

- A warning system if the Resource Quality Objectives are not met.
- A contour map of identified contaminants showing movement of pollution plumes.
- The management class of the aquifer incorporated into the system of allocable volumes.
- A numerical model showing flow directions in the compartment based on monthly groundwater levels.

The development of the Schoonspruit Groundwater Management Tool will be described in detail in section 5.4 and it is recommended that other tools follow the same model.

5 GROUNDWATER MANAGEMENT OF THE SCHOONSPRUIT DOLOMITIC COMPARTMENT

Chapter 5 is the combination of all work that has been done in Chapters 2 to 4 and was done as an example of how to use the methodology as described in Chapter 4. An explanation of the development of the MS Excel-based groundwater management tool is also included in this chapter. This tool is probably the most important item to come out of this thesis, as groundwater management in the Schoonspruit Dolomitic Compartment can now commence on a scientifically founded tool. In the sections that follow an assessment of the actions required for dolomitic management, as applied to the case study, is given.

5.1 Management Principles

- ☑ The catchment area of the dolomitic compartment has been defined and the geohydrological regime explained in great detail.
- ☑ The Reserve has been determined preliminary, but it is foreseen that a more detailed Reserve determination is necessary.
- ☒ Resource Quality Objectives have not been set.
- ☒ The verification of all water uses in the area and subsequent registration and licensing of the water users has been initiated but not completed. This is seen as a priority and must be performed as soon as possible.

5.2 Management Structures

- ☑ The Free State Regional Office of the DWAF is the acting CMA for the Schoonspruit Dolomitic Compartment.
- ☒ The draft constitution of the Ventersdorp-Dolomite WUA has been submitted for approval by the Minister of Water Affairs & Forestry, but it as not been approved as yet.

Through the Model Constitution of the Ventersdorp-Dolomite Water User Association, 2003, the WUA has applied for certain aims, functions and delegated powers from the Minister of the DWAF. These are listed in APPENDIX H, but the most important ones pertaining to groundwater management are listed below:

- To exercise control and management over the use of water from and on the Schoonspruit Dolomitic Compartment.
- To prevent water from any water resource and/or waterworks being wasted.
- To protect the Schoonspruit Dolomitic Compartment as groundwater resource.
- To prevent any unlawful use.
- To prevent any unlawful act likely to reduce the quality of water in any water resource or waterworks.
- To manage, regulate and conserve the abstraction of water from the Schoonspruit Dolomitic Compartment.
- To investigate and record water level readings.
- To suspend or reduce the abstraction of water from waterworks or water resources under its control.

- Issue directives for water use to cease and enforce those directives issued.

The area of operation of the Ventersdorp-Dolomite Water User Association is included as maps in APPENDIX I. This includes the Schoonspruit Dolomitic Compartment as delineated by Polivka, 1987, as well as areas of runoff that could have a negative influence on recharge should surface runoff be blocked by structures such as dams.

A Water Research Commission study, to determine the best institutional arrangements for groundwater management in the dolomitic areas, has been initiated. The aim of the project is to develop institutional arrangements for the sustainable and equitable management of groundwater in the dolomitic terrains of the North West Province, South Africa. The problem is that the dolomitic aquifer is divided between three WMAs (therefore CMA's), and structures needs to be set in place to address trans-boundary management (including international obligations) within the principles of equity and sustainability. These institutions also need a sound understanding of the geohydrology of the aquifer, the ecology dependant on the resource and the social, cultural and institutional dynamics of the area. (Bredenkamp & Stephens, 2002)

Institutional arrangements were defined as the:

- Principles, objectives and institutional approach for groundwater management
- Overall institutional structures and implementing agencies
- Roles, responsibilities and functions of implementing agencies
- Requirements and support needed to ensure functioning institutions

The project was divided into different phases of which phase 1 (Situation Analysis: Desktop) has been completed and phase 2 (Situation Analysis: Field Research) is currently in progress. (Bredenkamp & Stephens, 2002)

Phase 1 of the study gives a detailed outline of the legislative framework within which this groundwater management should take place, explaining the Water Act, 1956, descriptions of groundwater and the National Water Act, Act 36 of 1998, policy goals with regard to source directed control and resource directed measures. Different legislation and issues pertaining to sustainable groundwater management was discussed. It was noted that groundwater management would focus on meeting basic human needs, maintaining resource integrity and allocating groundwater for economic development equitably. On the smallest groundwater management scale it has been proposed that each of the five main dolomitic compartments form a WUA including all interested and affected parties. (Bredenkamp & Stephens, 2002)

Of particular significance to the establishment of a WUA for the Schoonspruit area is that a valuable database of basic information on ownership, properties and boreholes has to be put in place. (Darcy Consultants, 2002)

5.3 Geotechnical Controls

5.3.1 Geographic Setting

☑ The province and nearest towns have been defined.

☒ Local authority boundaries have not been included, as only one local authority is dependant on the compartment for water supply to a town.

☑ Topocadastral maps have been added to delineate the area.

☑ Geomorphological features were included in the geology section.

☑ Type of land cover has been described in general, as background information.

☒ The catchment areas have not been defined.

☑ The Schoonspruit is the most relevant surface water resource pertaining to the area and have been mentioned.

☒ No extra descriptive information was given for the area.

5.3.2 Meteorology

☑ Rainfall season typical to the area, including average rainfall and evaporation, has been defined in detail.

☒ Minimum and maximum temperatures have not been included.

☑ Mean annual precipitation (MAP) and homogeneous rainfall zones have been compiled.

☑ A reliable set of monthly rainfall data, with at least 10 years of rainfall data prior to the first groundwater level or spring flow data, have been obtained.

5.3.3 Geology

☑ Geological descriptions according to geological maps have been described.

☑ A geological description from previous reports, including structural features and borehole logs available on the NGDB, focussing on possible geological boundaries was obtained.

☑ A detailed geological map was compiled.

☒ A geological cross-section has not been done.

5.3.4 Geohydrology

☑ A geohydrological description according to geohydrological maps has been described.

☑ A geohydrological description from previous reports, including structural controls and data available on the NGDB, was obtained.

☑ A detailed geohydrological map was compiled.

5.3.4.1 Boundaries

☑ Boundaries was described and included in the geohydrological map.

5.3.4.2 Aquifer Management Classification

☑ The Schoonspruit Dolomitic Compartment has been classified as an aquifer that should be managed strictly non-degrading.

5.3.4.3 Groundwater Levels

☑ Time series data have been evaluated and water level response to rainfall, as well as aquifer parameters, determined.

☑ It was determined that the groundwater levels do not follow topography and Kriging interpolation was recommended for contouring the groundwater levels.

☑ The groundwater levels was contoured and boundary conditions, inflow and outflow points determined.

☑ The elevations of boreholes in the Schoonspruit Dolomitic Compartment was surveyed to 10cm accuracy.

☑ Groundwater level fluctuations were simulated in detail with the SVF, CRD and MA methods. These simulations were included in the groundwater balance.

5.3.4.3.1 Sinkholes

☒ The risk of sinkhole formation has not been quantified and management options could not be outlined.

5.3.4.4 Groundwater Quality

☑ Diagnostic diagrams were done for the compartment and the groundwater character was described.

☑ The spatial analysis was done for nitrate, as this constituent's concentrations has elevated since 1976.

☒ Trend analysis has not been done, as time series groundwater quality data does not exist at the moment, and therefore, the seasonal variation of chemical constituents compared to rainfall have not been determined.

☑ The quality analyses were done taking drinking water standards into account, as the compartment is widely used for drinking water purposes.

5.3.4.4.1 Environmental Isotopes

☑ Environmental isotope analyses have been included in the evaluation.

5.3.4.4.2 Impacts on Water Quality

☑ Nitrate contamination is the greatest potential water quality impact.

☑ Contour maps of nitrate values were compiled for two different timeframes.

5.3.4.4.3 Health threats

☑ The threat of nitrate on human health has been described and should be relayed to the groundwater users.

5.3.4.5 Aquifer Parameters

☑ Transmissivity values exist, but are of no use and no further values were determined.

☑ Storativity values have been determined for both zones in the compartment.

☑ Recharge estimates have been determined, using all available data.

5.3.4.6 Dolomitic Springs

☑ The rainfall / spring flow relationship and catchment area of the spring was determined using the MA method of simulation.

☑ The water quality for the spring was determined.

☑ Recharge to the spring was determined based on spring flow simulations.

☑ The impact of groundwater abstractions from the compartment upon the flow of the spring was determined.

☑ Monthly spring flow measurements are currently being done.

5.3.5 Water Users

☑ Water users on the compartment were defined as domestic, local authorities, agricultural, mining, wetlands and surface water users.

☒ Determining the legality of the uses is still pending.

5.3.6 Modelling

5.3.6.1 Groundwater Balance Simulations

☑ Groundwater level and spring flow simulations were performed for use in the groundwater management tool.

5.3.7 Monitoring

☑ Groundwater level monitoring is adequate.

☑ Groundwater quality monitoring is adequate.

☑ Rainfall monitoring is adequate.

☑ Spring flow monitoring is adequate.

☒ Abstraction monitoring has not been initiated, e.g. for the time being satellite images can be used, but an official from the WUA should be performing this function.

5.3.8 Mapping

☑ A detailed geological map depicting all relevant geological features and boundaries, therefore also depicting the extent of the dolomitic compartment, has been compiled.

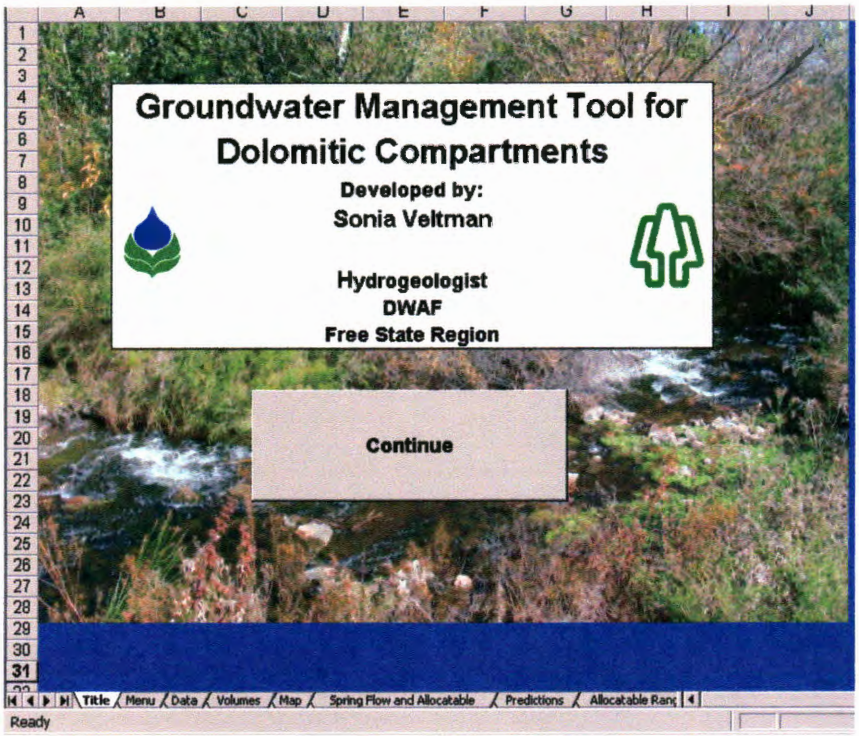
☑ A detailed geohydrological map has been compiled, but the most important geotechnical controls and monitoring stations needs to be added to the map.

☒ A detailed topocadastral map with all relevant geohydrological and institutional boundaries is still lacking.

☑ A map, with the recharge zones delineated, so that allocable volumes can be linked to the map, is available for use within the groundwater management tool.

5.4 The Schoonspruit Groundwater Management Tool

The Schoonspruit Groundwater Management (SGM) Tool is one of the most important deliverables of this thesis, as groundwater managers of the relevant CMAs and WUAs need to be capacitated to perform the most basic groundwater balances and simulations. The development of this tool will be discussed simultaneously with the appropriate figures, Figure 77 to Figure 85, as obtained from the actual tool.



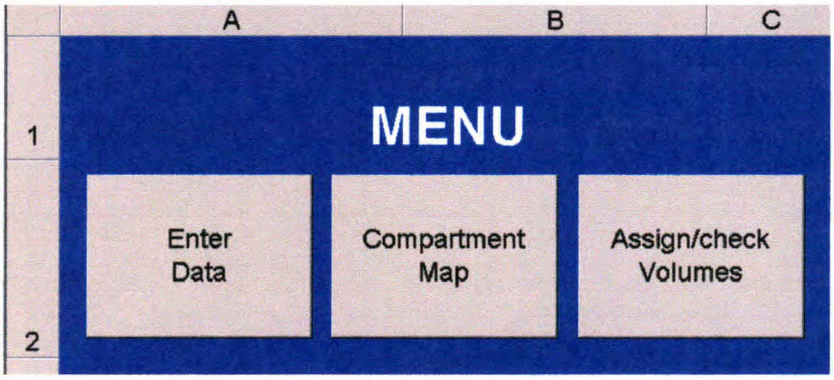
Groundwater Management Tool for Dolomitic Compartments

Developed by:
Sonia Veltman

Hydrogeologist
DWAF
Free State Region

Figure 77: Title page of the SGM Tool

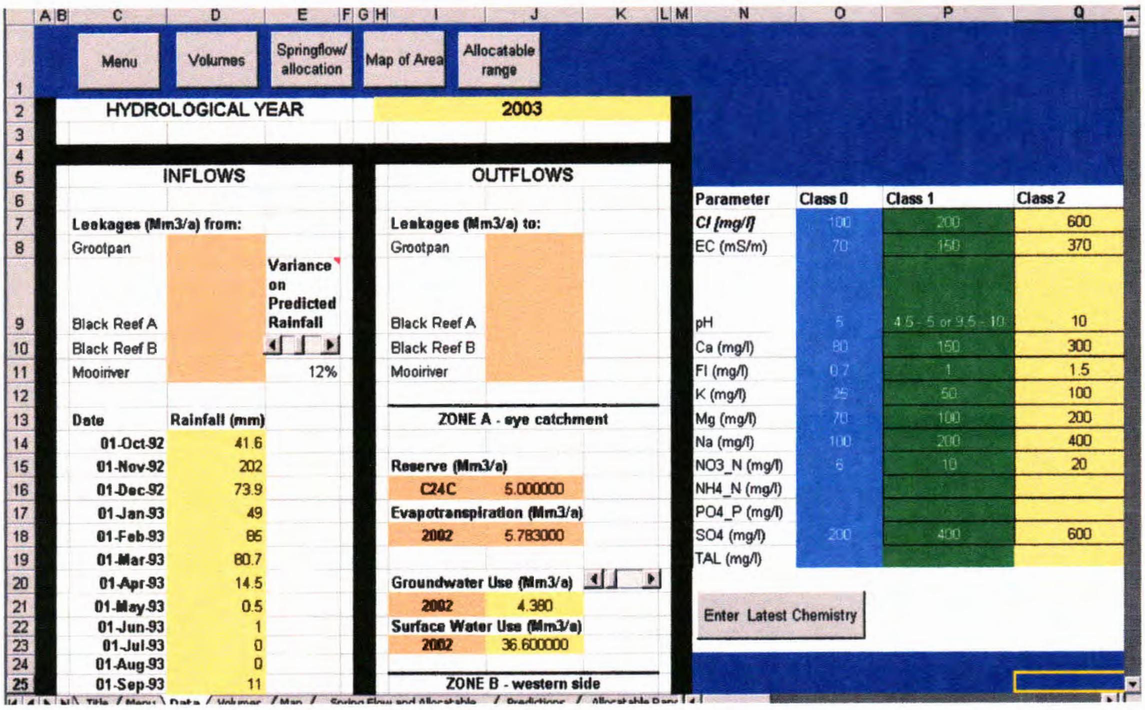
Figure 77 shows the Title page of the Tool as information page only and a navigational button exist to move to the next sheet, the Menu sheet. Figure 77 also shows tabs of all the other sheets in the Tools.



MENU

Figure 78: Menu of the SGM Tool

Figure 78 shows the Menu sheet from which one can navigate to different sheets in the Tool. The "Enter Data" button navigates to the Data sheet, the "Compartment Map" button to the Map sheet and the "Assign/check Volumes" button to the Volume sheet. This is a navigational sheet only and which pathways are inserted here, is up to the developer.



HYDROLOGICAL YEAR 2003

INFLOWS

Leakages (Mm3/a) from:
Grootpan
Black Reef A
Black Reef B
Mooirivier

Variance on Predicted Rainfall 12%

Date	**Rainfall (mm)**
01-Oct-92	41.6
01-Nov-92	202
01-Dec-92	73.9
01-Jan-93	49
01-Feb-93	86
01-Mar-93	80.7
01-Apr-93	14.5
01-May-93	0.5
01-Jun-93	1
01-Jul-93	0
01-Aug-93	0
01-Sep-93	11

OUTFLOWS

Leakages (Mm3/a) to:
Grootpan
Black Reef A
Black Reef B
Mooirivier

ZONE A - eye catchment

Reserve (Mm3/a)
C24C 5.000000
Evapotranspiration (Mm3/a)
2002 5.783000
Groundwater Use (Mm3/a)
2002 4.380
Surface Water Use (Mm3/a)
2002 36.600000

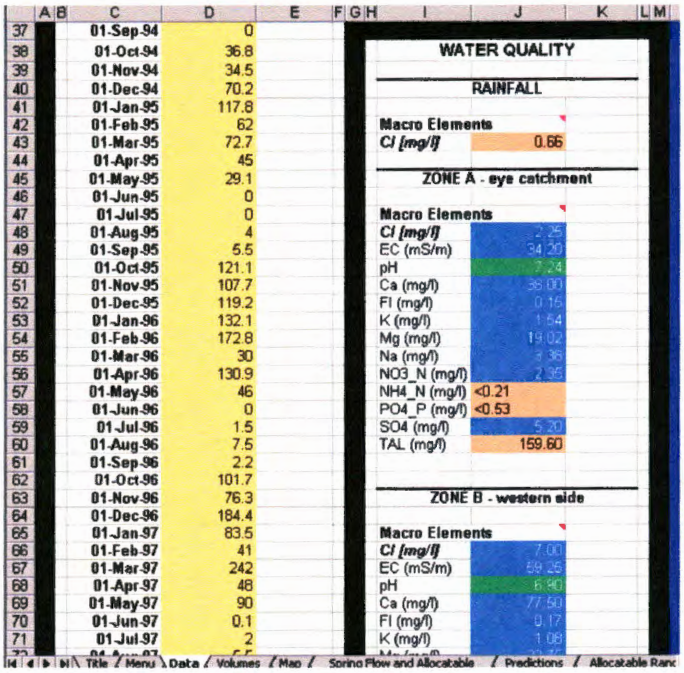
ZONE B - western side

Parameter	**Class 0**	**Class 1**	**Class 2**
Cl (mg/l)	100	200	600
EC (mS/m)	70	150	370
pH	5	4.5 - 5 or 9.5 - 10	10
Ca (mg/l)	80	150	300
Fl (mg/l)	0.7	1	1.5
K (mg/l)	25	50	100
Mg (mg/l)	70	100	200
Na (mg/l)	100	200	400
NO3_N (mg/l)	6	10	20
NH4_N (mg/l)			
PO4_P (mg/l)			
SO4 (mg/l)	200	400	600
TAL (mg/l)			

Figure 79: Data sheet of the SGM Tool - Quantity

Figure 79 & Figure 80 show the Data sheet of the Tool, pertaining to the input cells of the groundwater quantities and qualities. Data input is done in the yellow and orange cells, yellow being compulsory data inputs and orange being optional data inputs. The optional data is helpful if it is available, but the simulations are not dependent on these cells to run. Navigational buttons to other sheets and data entry points can also be seen and these are again done at the discretion of the developer, for ease of use.

Included in Figure 79 is the Drinking Water Quality Classes for the different parameters and these are dependent on groundwater quality inputs, as shown in Figure 80.



01-Sep-94	0
01-Oct-94	36.8
01-Nov-94	34.5
01-Dec-94	70.2
01-Jan-95	117.8
01-Feb-95	62
01-Mar-95	72.7
01-Apr-95	45
01-May-95	29.1
01-Jun-95	0
01-Jul-95	0
01-Aug-95	4
01-Sep-95	5.5
01-Oct-95	121.1
01-Nov-95	107.7
01-Dec-95	119.2
01-Jan-96	132.1
01-Feb-96	172.8
01-Mar-96	30
01-Apr-96	130.9
01-May-96	46
01-Jun-96	0
01-Jul-96	1.5
01-Aug-96	7.5
01-Sep-96	2.2
01-Oct-96	101.7
01-Nov-96	76.3
01-Dec-96	184.4
01-Jan-97	83.5
01-Feb-97	41
01-Mar-97	242
01-Apr-97	48
01-May-97	90
01-Jun-97	0.1
01-Jul-97	2

WATER QUALITY

RAINFALL

Macro Elements	
Cl (mg/l)	0.66

ZONE A - eye catchment

Macro Elements	
Cl (mg/l)	2.25
EC (mS/m)	34.20
pH	7.24
Ca (mg/l)	38.00
Fl (mg/l)	0.16
K (mg/l)	1.54
Mg (mg/l)	19.02
Na (mg/l)	3.36
NO3_N (mg/l)	2.35
NH4_N (mg/l)	<0.21
PO4_P (mg/l)	<0.53
SO4 (mg/l)	5.20
TAL (mg/l)	159.60

ZONE B - western side

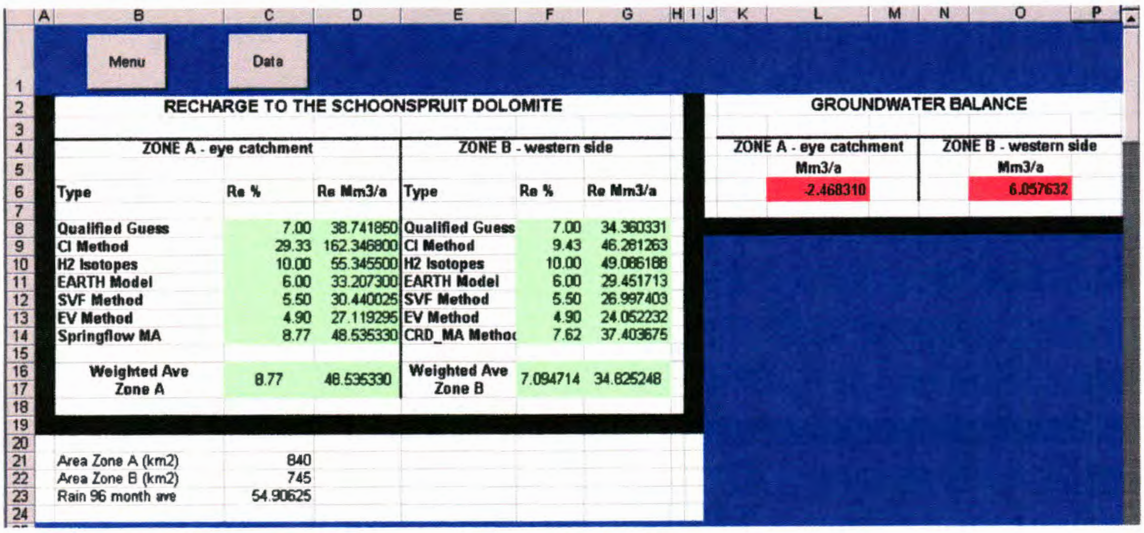
Macro Elements	
Cl (mg/l)	7.00
EC (mS/m)	59.25
pH	6.90
Ca (mg/l)	77.50
Fl (mg/l)	0.17
K (mg/l)	1.08

Figure 80: Data sheet of the SGM Tool - Quality

Data inputs into the Data sheet include the following:

- Rainfall data for the 10 years prior to the current hydrological year, as well as predicted rainfall;
- Volumes (Mm^3/a) for the different zones, of inflow and outflow leakages, the Reserve, evapotranspiration, groundwater use and surface water use needs;
- Groundwater quality data for rainfall, the different zones and the Schoonspruit Eye.

Groundwater use include all abstractions from the subsurface e.g. domestic, irrigation and mining. A scroll button controls the groundwater use volume and it should be changed with this button. A scroll button for the variance (level of certainty) has been added for the predicted rainfall data and this certainty is then taken into account in the allocable volume graph and ranges.



RECHARGE TO THE SCHOONSPRUIT DOLOMITE

ZONE A - eye catchment			ZONE B - western side		
Type	Re %	Re Mm3/a	Type	Re %	Re Mm3/a
Qualified Guess	7.00	38.741850	Qualified Guess	7.00	34.360331
CI Method	29.33	162.346800	CI Method	9.43	46.281263
H2 Isotopes	10.00	55.345500	H2 Isotopes	10.00	49.086188
EARTH Model	6.00	33.207300	EARTH Model	6.00	29.451713
SVF Method	5.50	30.440025	SVF Method	5.50	26.997403
EV Method	4.90	27.119295	EV Method	4.90	24.052232
Springflow MA	8.77	48.535330	CRD_MA Methoc	7.62	37.403675
Weighted Ave Zone A	8.77	48.535330	Weighted Ave Zone B	7.094714	34.825248

Area Zone A (km2)	840
Area Zone B (km2)	745
Rain 96 month ave	54.90625

GROUNDWATER BALANCE

ZONE A - eye catchment Mm3/a	ZONE B - western side Mm3/a
-2.468310	6.057632

Figure 81: Volume sheet of the SGM Tool

Figure 81 shows the Volume sheet of the Tool, which is basically a groundwater balance sheet dependent on the data inputs from the Data sheet. On the Volume sheet, the recharge estimates from the different methods have been added and weighed against a certainty factor and an average recharge value can be obtained for the specific zone.

Zone A has not been weighed, but the effective recharge value determined from the MA simulation for that specific year has been incorporated, as the simulation yields the best groundwater balance information for the drainage area of the eye.

Recharge estimates from the different methods for Zone B has been weighed between 1 and 5 as follows:

Table 23: Recharge estimate weights

Type	Weight
Qualified Guess	3
Cl Method	4
H2 Isotopes	1
EARTH Model	1
SVF Method	4
EV Method	3
CRD_MA Method	4

- The ^2H isotopes yielded very little recharge for a dolomitic aquifer and the EARTH method simulation did not attain a very good fit, therefore a weight of 1 was assigned to these methods.

- The Qualified Guess and the EV methods was assigned a 3, because expert knowledge has been put into these methods, so they cannot be disregarded, but the evaluations on the Qualified Guesses might be outdated and the EV could only be fit for a portion of the time series data.
- The Cl, SVF and CD_MA methods have proven to be very good methods for determining recharge and a weight of 4 have been assigned to them.

The groundwater recharge volume for each zone was then determined with the weighted averages of recharge, the 96 month average of rainfall and the size of the area pertaining to each of the zones. The groundwater balance takes into account the volume of recharge, inflows and outflows, abstractions and surface water demands.

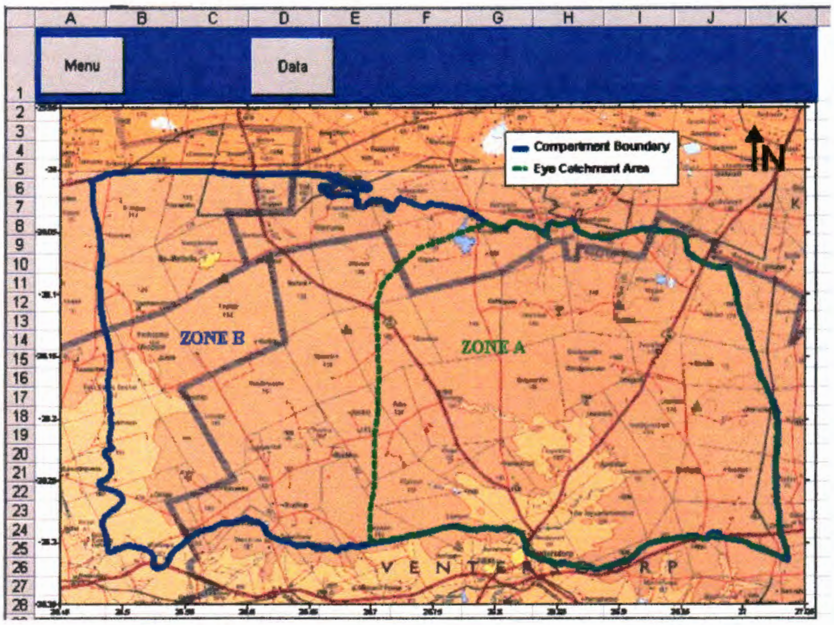


Figure 82: Map sheet of the SGM Tool

Figure 82 shows the map of the Schoonspruit Dolomitic Compartment with the two zones as they have been delineated in section 3.4.4. This sheet is for orientation purposes and to determine in which zone a property's abstraction falls and to which should it be assigned.

Figure 83 shows the Prediction sheet of the Tool and it is on this sheet that all the calculations for the simulation of the Schoonspruit Eye flow, therefore allocable volumes from Zone A, is done. The equation for this simulation has been described in section 3.6.1.4. as Equation 18 and is shown as follows:

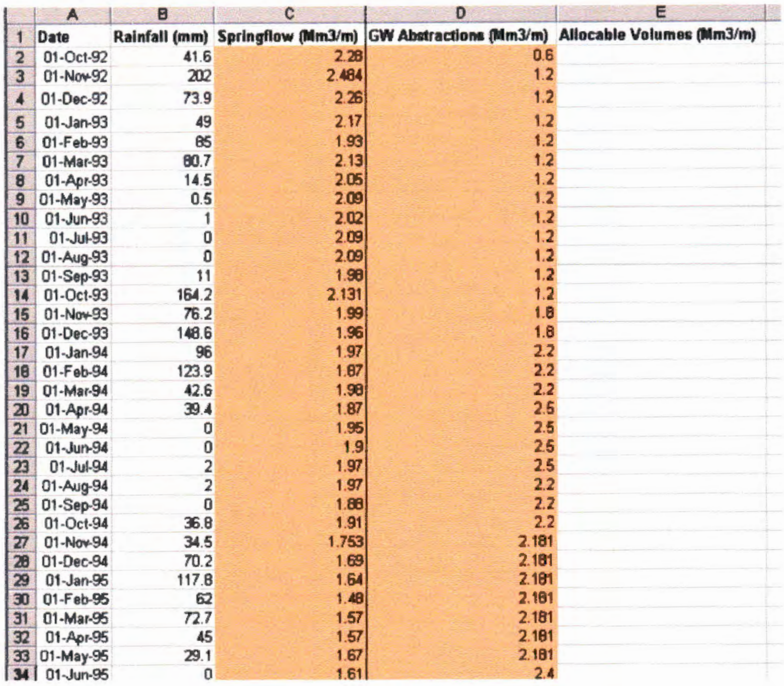
$$\text{Schoonspruit Flow (Mm}^3\text{/m)} = (0.07 * Rf_{24MMA}/Rf_{120MMA} * (Rf_{96MMA} - 26) * 0.842) + (0.44 * (IF((Rf_{120MMA} - 43) > 0, Rf_{120MMA} - 43)) * 0.842) - Abs_{GW}$$

It is clear that to use an equation like this will probably be confusing if it is not split up into different smaller equations in different columns. Four columns were assigned for determining the effective monthly rainfall figures used in the equation namely:

- 24 Month Rf AVE (mm/m) – the 24 month moving average of rainfall
- 96 Month Rf AVE (mm/m) – the 96 month moving average of rainfall
- 120 Month Rf AVE (mm/m) – the 120 month moving average of rainfall
- Flood Rf (mm/m) – the flood rainfall events, this is done with an IF statement

The Simulated Flow (Mm3/m) is then determined using the spring flow equation as only rainfall values, and not equations, are now incorporated. Input data to this sheet is obtained from the Data sheet.

Allocable Volumes are determined with the simple equation of subtracting surface water demand from the simulated flow, as this has already taken into account current groundwater use.



	A	B	C	D	E
1	Date	Rainfall (mm)	Springflow (Mm3/m)	GW Abstractions (Mm3/m)	Allocable Volumes (Mm3/m)
2	01-Oct-92	41.6	2.28	0.6	
3	01-Nov-92	202	2.484	1.2	
4	01-Dec-92	73.9	2.26	1.2	
5	01-Jan-93	49	2.17	1.2	
6	01-Feb-93	85	1.93	1.2	
7	01-Mar-93	80.7	2.13	1.2	
8	01-Apr-93	14.5	2.05	1.2	
9	01-May-93	0.5	2.09	1.2	
10	01-Jun-93	1	2.02	1.2	
11	01-Jul-93	0	2.09	1.2	
12	01-Aug-93	0	2.09	1.2	
13	01-Sep-93	11	1.98	1.2	
14	01-Oct-93	164.2	2.131	1.2	
15	01-Nov-93	76.2	1.99	1.8	
16	01-Dec-93	148.6	1.96	1.8	
17	01-Jan-94	96	1.97	2.2	
18	01-Feb-94	123.9	1.87	2.2	
19	01-Mar-94	42.6	1.98	2.2	
20	01-Apr-94	39.4	1.87	2.5	
21	01-May-94	0	1.95	2.5	
22	01-Jun-94	0	1.9	2.5	
23	01-Jul-94	2	1.97	2.5	
24	01-Aug-94	2	1.97	2.2	
25	01-Sep-94	0	1.88	2.2	
26	01-Oct-94	36.8	1.91	2.2	
27	01-Nov-94	34.5	1.753	2.181	
28	01-Dec-94	70.2	1.69	2.181	
29	01-Jan-95	117.8	1.64	2.181	
30	01-Feb-95	62	1.48	2.181	
31	01-Mar-95	72.7	1.57	2.181	
32	01-Apr-95	45	1.57	2.181	
33	01-May-95	29.1	1.67	2.181	
34	01-Jun-95	0	1.61	2.4	

Figure 83: Prediction sheet of the SGM Tool

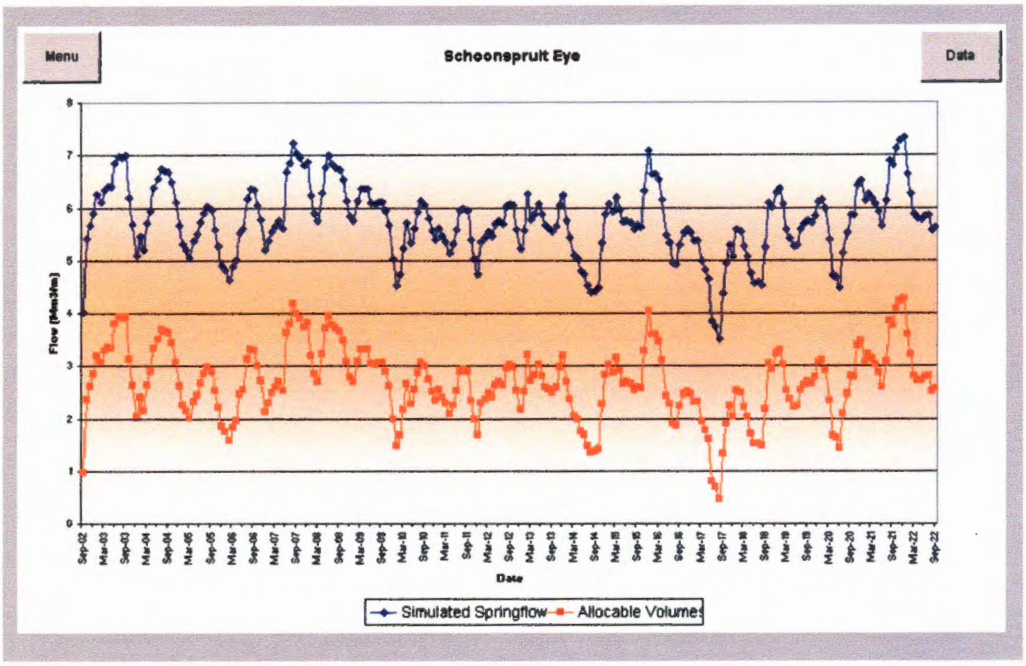


Figure 84: Spring flow and allocable volume graph of the SGM Tool

Figure 84 & Figure 85 shows the spring flow and allocable volume graph and the range of allocable volumes with different certainties assigned to the predicted rainfall. Graphs are plotted from data generated in the Prediction sheet.

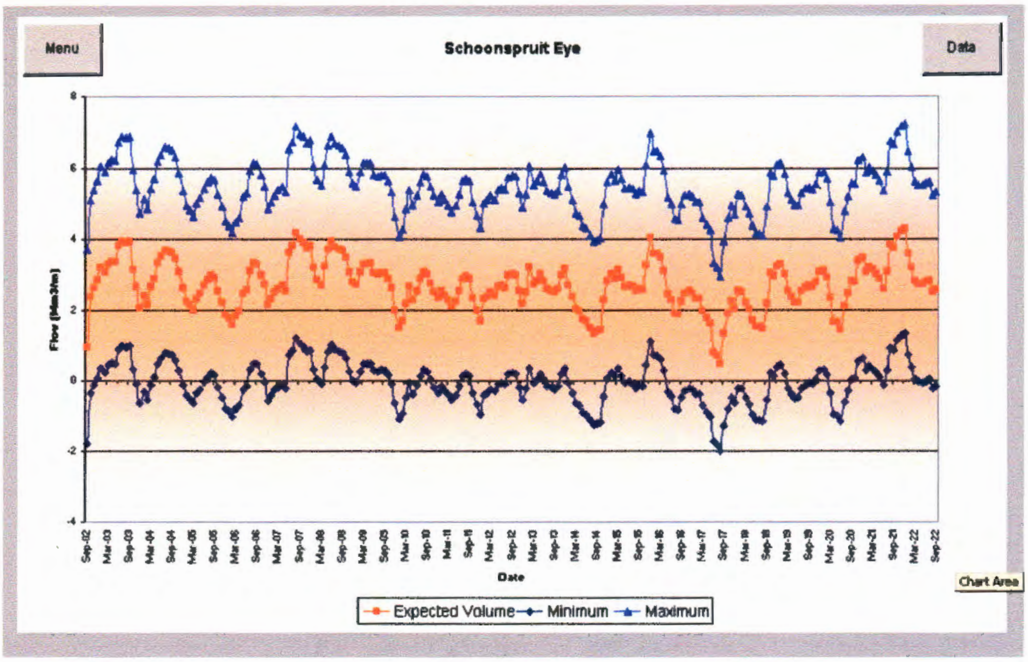


Figure 85: Allocable volume range graph of the SGM Tool

5.5 Conclusions regarding Groundwater Management

The following conclusions were made with regard to groundwater management in the Schoonspruit Dolomitic Compartment:

- Data and information in the area is sufficient to commence with groundwater management of the dolomitic compartment.
- Verification of the lawful water users in the area is of utmost importance, before management of the resource will be successful.
- A useable tool was developed, which should lighten the burden of decision making for groundwater managers.

6 CONCLUSIONS AND RECOMMENDATIONS

In Chapter 1, this thesis proposed to use the principle of *prior conceptual model explanation (PCME)* by LeGrand & Rosen, 2000, as base to developing a technical methodology towards groundwater management in dolomitic terrains. The Schoonspruit Dolomitic Compartment was used, as case study, to evaluate the aquifer with current information, test the developed methodology on and to develop a technical groundwater management tool, using the data available and the developed methodology.

The following sections outline the conclusions and recommendations deducted from the different actions performed to achieve the end result.

6.1 Geohydrological Assessment

The aim of the geohydrological assessment was the use of the PCME approach, basic geohydrological principles and previous studies to evaluate the current status of the aquifer. This was done in Chapters 2 and 3 with a description of current information and an evaluation of new information and data. The following conclusions are made with regard to the geohydrological assessment:

- Available reports on the Schoonspruit Dolomitic Compartment provided very valuable information regarding geology, geohydrology and water uses.
- Aquifer characteristics were defined, with the Malmani Subgroup being the most productive aquifer, as well as the most sustainable with regard to long-term groundwater supply.
- The delineation of Polivka, 1987, is a true reflection of the Schoonspruit dolomitic aquifer boundaries.
- The Schoonspruit dolomitic aquifer was classified with the classification system of Parsons, 1995, as strictly non-degradation in terms of both quantity and quality.
- The dolomitic compartment has an extent of 1585 km^2, of which the drainage are of the Schoonspruit Eye is on the order of 840 km^2.
- Four separate communities, several farmers and mining operations are dependant on the dolomitic compartment for water, abstracting groundwater directly from boreholes situated on the compartment.
- Abstraction from groundwater on the compartment is impacting the aquifer and the flow of the Schoonspruit Eye.
- The Schoonspruit Eye is dependent on the dolomitic compartment for flow.
- The Ventersdorp Municipality and two irrigation boards are dependent on this eye flow for surface water flow and executing their lawful water use.
- The flow of the eye can be simulated using various methods of which the MA method has proven to be the most effective.
- High rainfall events have an enormous positive effect on the recharge to the compartment, as no runoff occurs and evaporation and evapotranspiration is the only factors influencing infiltration.
- Groundwater quality in the compartment is generally good, with only point source pollution occurring due to agricultural practices.
- Nitrate levels are reaching concentrations above 10mg/l N in some of the boreholes and are a health concern related to children under the age of 6.

- Inflow and outflow boundaries were determined and confirmed with the use of groundwater level contour maps, with inflow occurring in the east, northeast, north and west and outflow occurring in the south and southwest.
- Two zones were defined for use in groundwater management within the compartment, Zone A (drainage area of the eye) and Zone B (western dolomitic aquifer).
- Groundwater levels and rainfall data are a critical input into most simulations and evaluations, of which the SVF, CRD and MA methods give the best simulations for determining natural water levels and various aquifer parameters.
- Aquifer parameters determined by the SVF, CRD and MA methods are integrated over the compartment and can be used in other simulations or regional numerical models.
- Recharge is the most important factor governing the groundwater balances in the aquifer.
- The rainfall/recharge relationship for the flow of the Schoonspruit Eye has been defined and is absolutely essential for good groundwater management of the drainage area of the eye.
- Groundwater balances for Zone A must be done with the MA method and for Zone B with the average weighted recharge for the aquifer.
- Monitoring in the compartment is sufficient and the most critical parameter in future assessments.
- The geohydrological information is critical to the development of a conceptual model and cannot be duplicated without enormous expenses.
- Enough information exists for groundwater management to commence and for a groundwater management tool to be developed.

The following recommendations are made with regard to the geohydrological assessment:

- Volumes of inflow and outflow over the flow boundaries should be determined for refinement of the groundwater balances.
- Monitoring should continue as described in section 3.7 and abstraction monitoring should be implemented as soon as possible.
- A groundwater management plan needs to be established for the Schoonspruit Dolomitic Compartment.
- Resource Quality Objectives should be set for the two zones during the Public Participation phase of establishing a groundwater management plan for the dolomitic compartment.
- Verification of Existing Lawful Use should be completed as soon as possible to determine exact volumes of abstraction from the system.

6.2 Technical Methodology

The aim of the technical methodology was to provide a technical framework, which could easily be extrapolated and applied to other dolomitic areas. This was achieved in Chapter 4 and tested in Chapter 5 against information from Chapters 2 and 3. The following conclusions are made with regard to the technical methodology:

- A flowchart was developed, figure 72, for ease of use when assessing dolomitic areas for the purpose of groundwater management.

- The methodology distinguished between essential and supplementary information needed for groundwater management in dolomitic areas.
- An overview was given with regard to the legal and institutional principles that should be applied in such areas.
- A detailed description was given with regard to the geotechnical controls that govern the groundwater flow and characteristics in dolomitic areas.
- The basic principles governing the development of a groundwater management tool was outlined, with input and output parameters defined.

The following recommendations are made with regard to the technical methodology:

- The methodology be used and tested against other dolomitic areas.
- The tool should be developed towards groundwater management in the Schoonspruit Dolomitic Compartment.

6.3 Groundwater Management Tool

The aim of the groundwater management tool was to provide a first order technical tool, which is a practical and workable tool, for use by the WUA in determining allocable volumes. This was outlined in Chapter 4 and developed in Chapter 5 with information from Chapters 2 and 3. The following conclusions are made with regard to the groundwater management tool:

- Input and output parameters as outlined in Chapter 4 was used and proven to be sufficient for defining quantity and quality concerns in the Schoonspruit Dolomitic Compartment.
- Allocable volumes can be determined for the two zones using predicative rainfall data.
- The Schoonspruit Eye can be simulated using predicative rainfall data with the following equation:

$$\text{Schoonspruit Flow } (Mm^3/m) = (0.07 * Rf_{24MMA}/Rf_{120MMA} * (Rf_{96MMA} - 26) * 0.842) + \\ (0.44 * (IF((Rf_{120MMA} - 43) > 0, Rf_{120MMA} - 43)) * 0.842) - Abs_{GW}$$

- The drinking water quality classes were introduced, as a useful parameter, as part of an early warning system where drinking water quality is of concern.
- The tool is sufficient to continue with groundwater management in the dolomitic compartment.
- Verification of the lawful users is of utmost importance for groundwater management to be successful.
- The tool is a practical and useable tool for all groundwater managers and planners.

The following recommendations are made with regard to the groundwater management tool:

- Groundwater management should commence at once and the tool tested against annual data.
- Verification of lawful water uses should continue and be completed as soon as possible.
- The tool should be tested and applied to other dolomitic areas.

6.4 Extrapolation to Other Dolomitic Areas

Water managers and planners in other dolomitic areas need to follow the steps, as outlined in the Technical Methodology, in order to achieve a situation where the necessary information and data is sufficient to successfully implement groundwater management and planning in their respective areas.

It is necessary to perform a geohydrological assessment of the area with current information and data before any new projects are initiated, thereby eliminating the possibility of duplication of work, as well as attaining a thorough understanding of how the system functions. If information or data is lacking, initiate the proper studies to solve the issues. When the aquifer characteristics and parameters have been defined, as outlined in the methodology, one can assimilate the necessary information and formulas into a workable groundwater management tool.

The Technical Methodology is the framework within which these assessments must be done, while the Geohydrological Assessment and development of the Technical Tool can be used as examples of the research methodology to be used and the goals to be attained.

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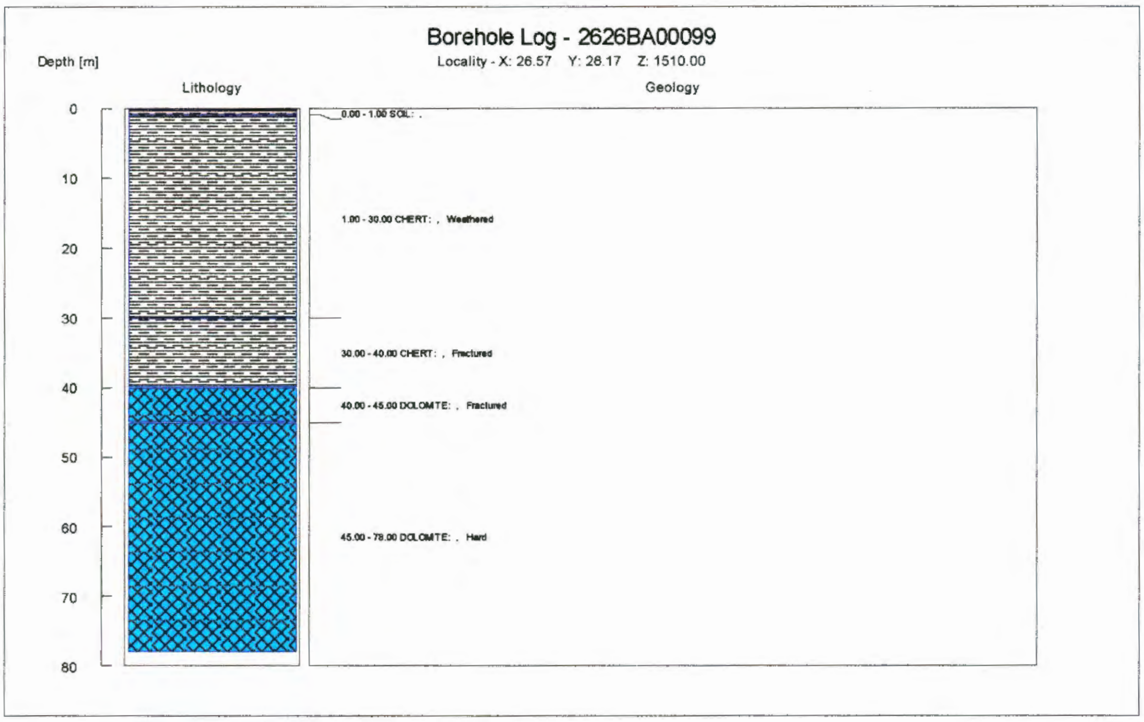
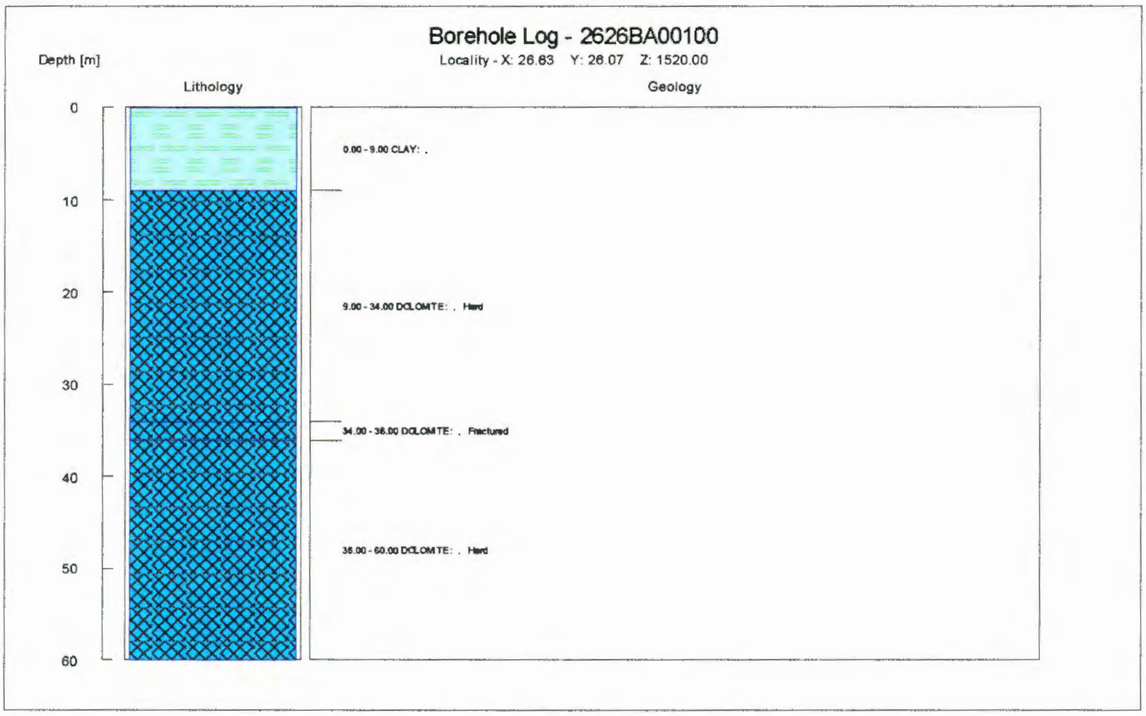
APPENDICES

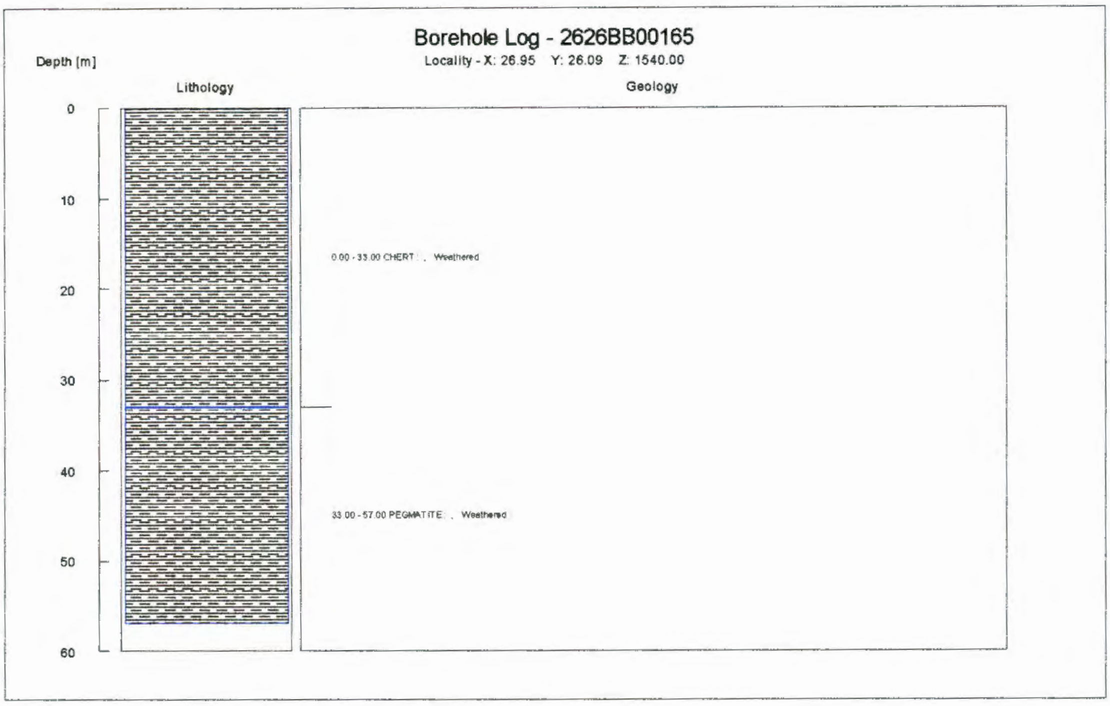
8 APPENDIX A

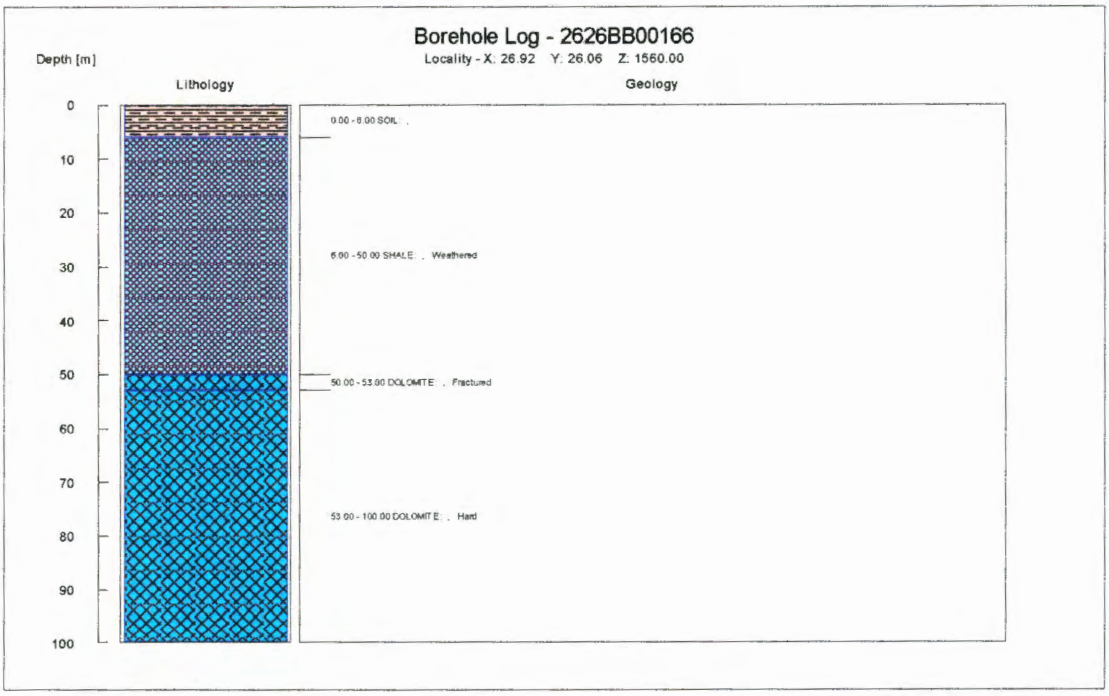
GEOLOGICAL BOREHOLE LOGS

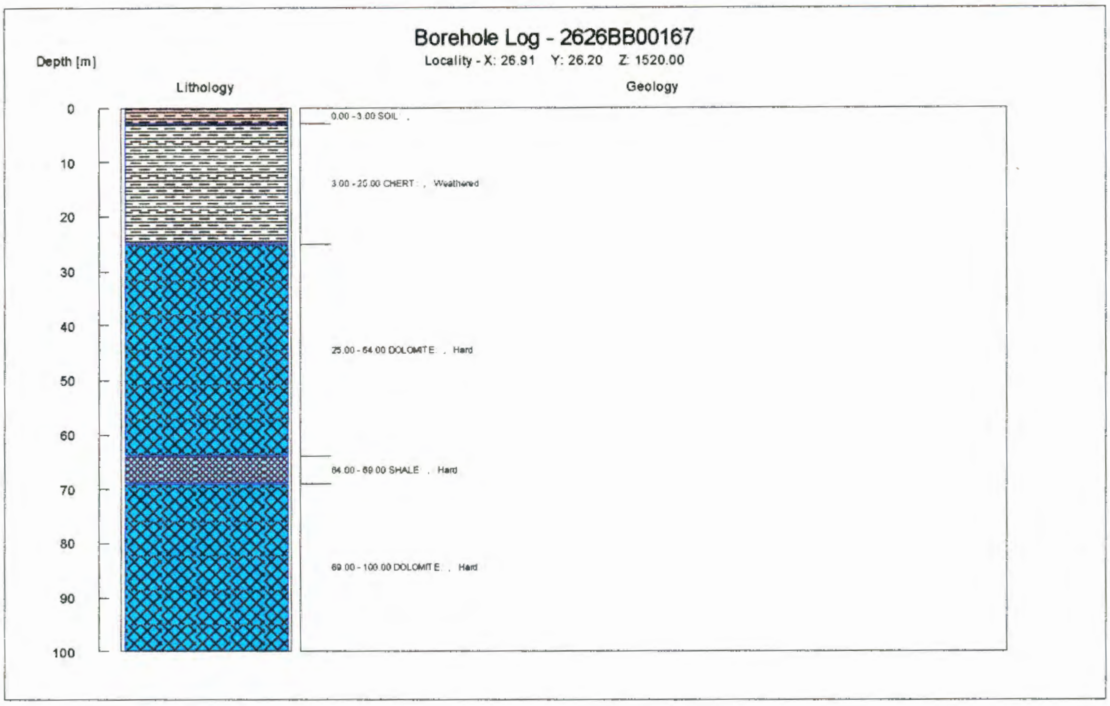
MONITORING BOREHOLE LOGS:

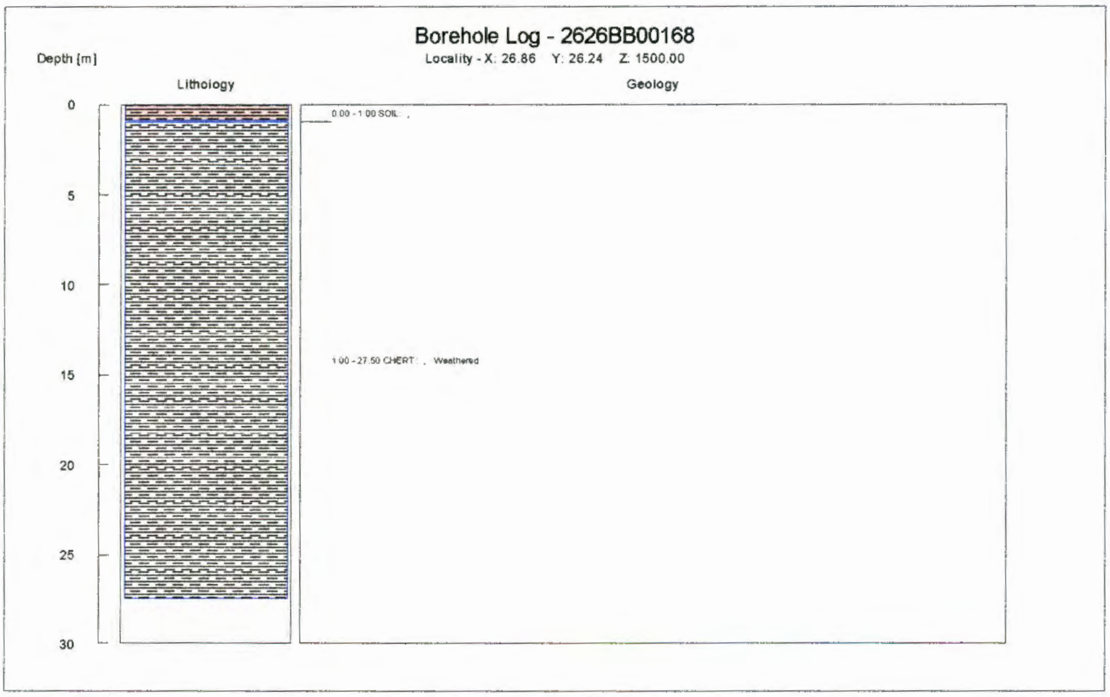


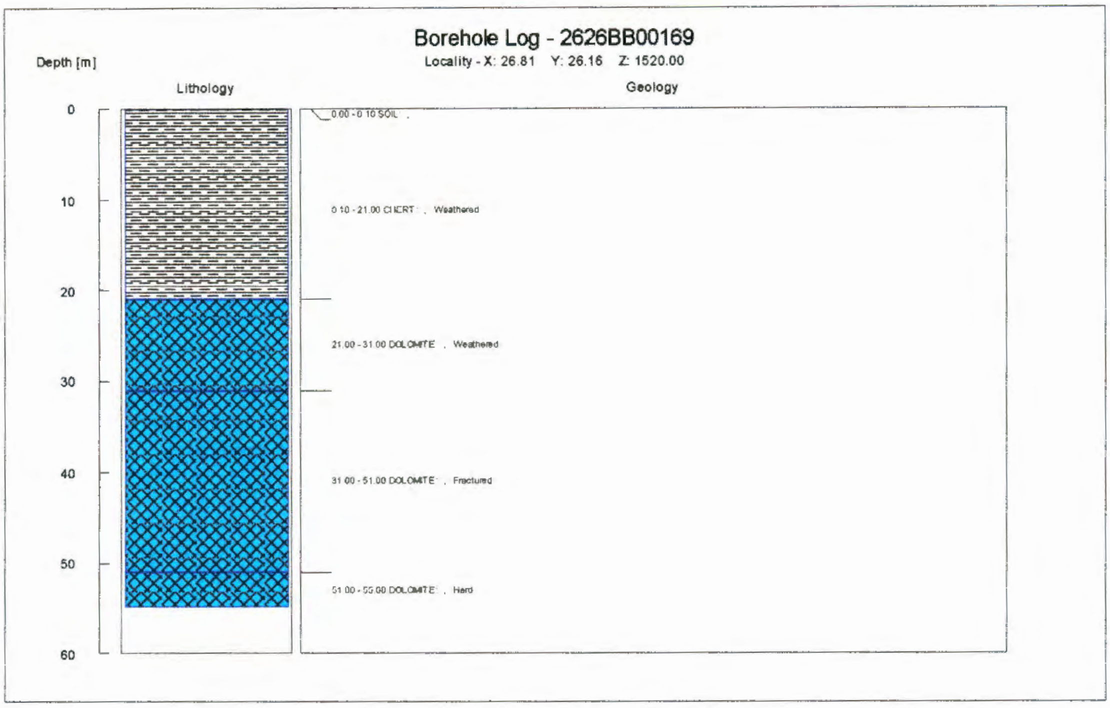


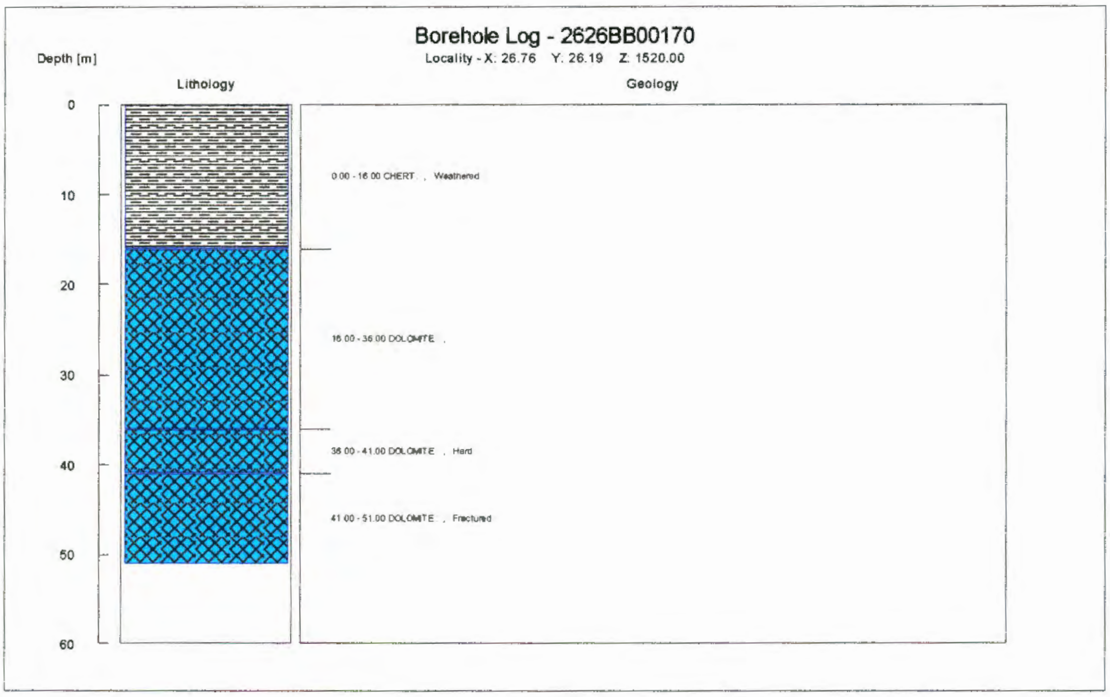

Borehole Log - 2626BB00165
Locality - X: 26.95 Y: 26.09 Z: 1540.00
Depth [m]
Lithology
Geology
0
10
20
30
40
50
60
0.00 - 33.00 CHERT : , Weathered
33.00 - 57.00 PEGMATITE : , Weathered

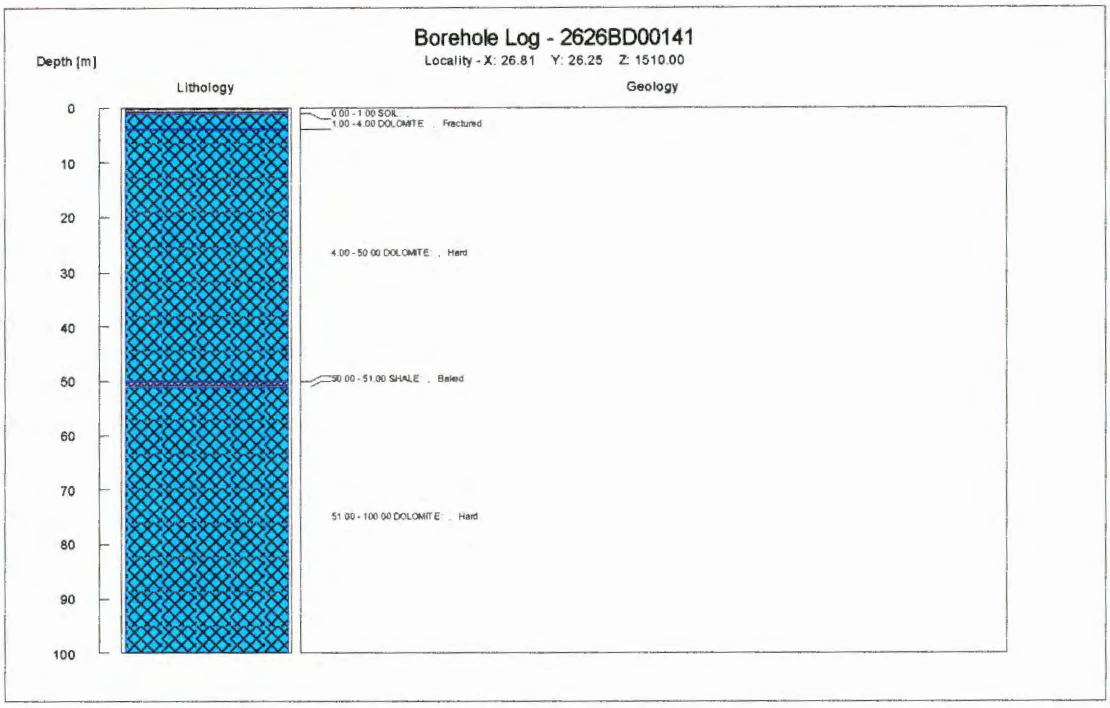

Borehole Log - 2626BB00166
Locality - X: 26.92 Y: 26.06 Z: 1560.00
Depth [m]
Lithology
Geology
0
10
20
30
40
50
60
70
80
90
100
0.00 - 6.00 SOIL : ,
6.00 - 50.00 SHALE : , Weathered
50.00 - 53.00 DOLOMITE : , Fractured
53.00 - 100.00 DOLOMITE : , Hard


Borehole Log - 2626BB00167
Locality - X: 26.91 Y: 26.20 Z: 1520.00
Depth [m]
Lithology
Geology
0
10
20
30
40
50
60
70
80
90
100
0.00 - 3.00 SOIL : ,
3.00 - 25.00 CHERT : , Weathered
25.00 - 64.00 DOLOMITE : , Hard
64.00 - 69.00 SHALE : , Hard
69.00 - 100.00 DOLOMITE : , Hard

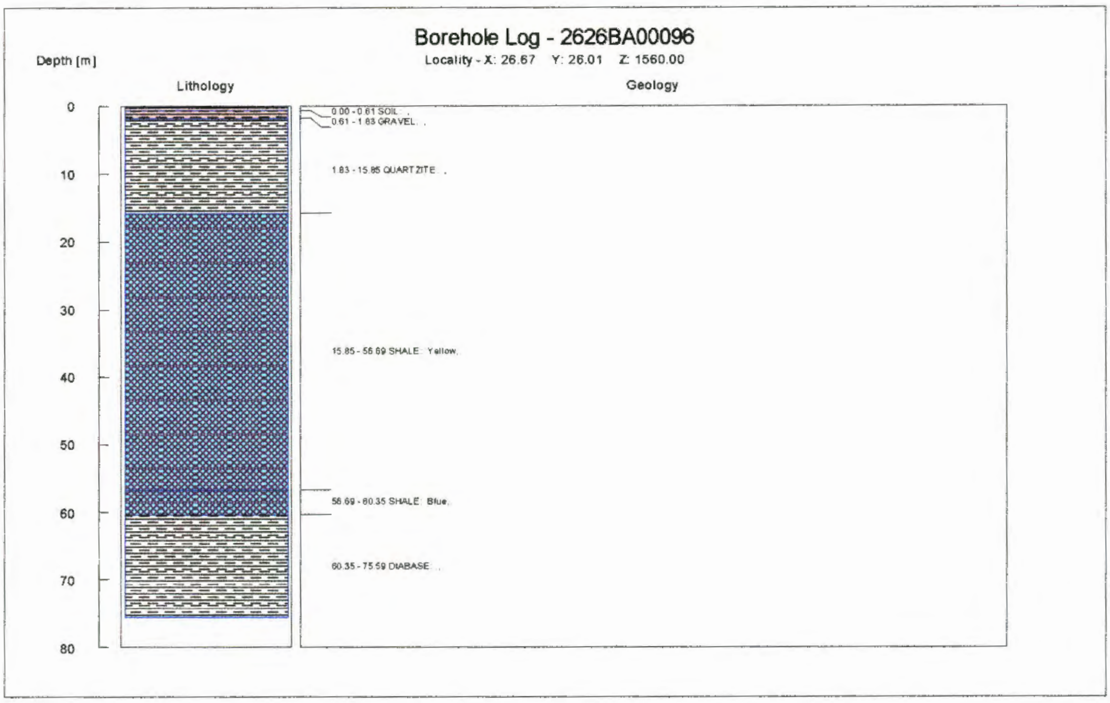

Borehole Log - 2626BB00168
Locality - X: 26.86 Y: 26.24 Z: 1500.00
Depth [m]
Lithology
Geology
0
5
10
15
20
25
30
0.00 - 1.00 SOIL : ,
1.00 - 27.50 CHERT : , Weathered

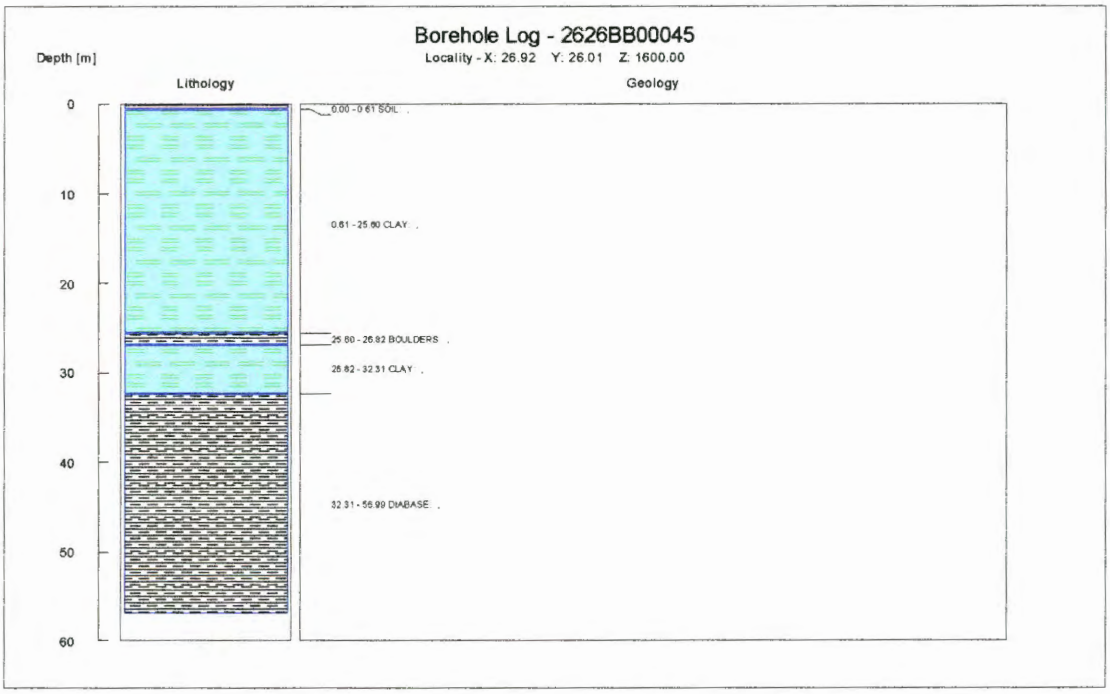

Borehole Log - 2626BB00169
Locality - X: 26.81 Y: 26.16 Z: 1520.00
Depth [m]
Lithology
Geology
0
10
20
30
40
50
60
0.00 - 0.10 SOIL ,
0.10 - 21.00 CHERT , Weathered
21.00 - 31.00 DOLOMITE , Weathered
31.00 - 51.00 DOLOMITE , Fractured
51.00 - 55.00 DOLOMITE , Hard

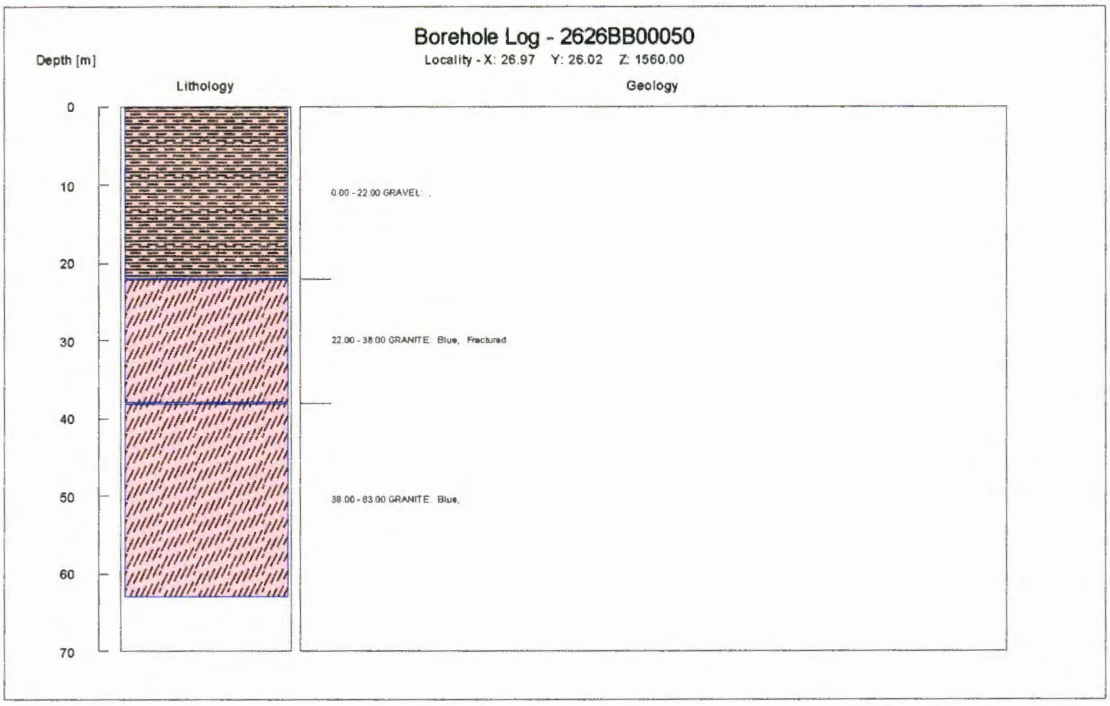

Borehole Log - 2626BB00170
Locality - X: 26.76 Y: 26.19 Z: 1520.00
Depth [m]
Lithology
Geology
0
10
20
30
40
50
60
0.00 - 16.00 CHERT , Weathered
16.00 - 36.00 DOLOMITE ,
36.00 - 41.00 DOLOMITE , Hard
41.00 - 51.00 DOLOMITE , Fractured

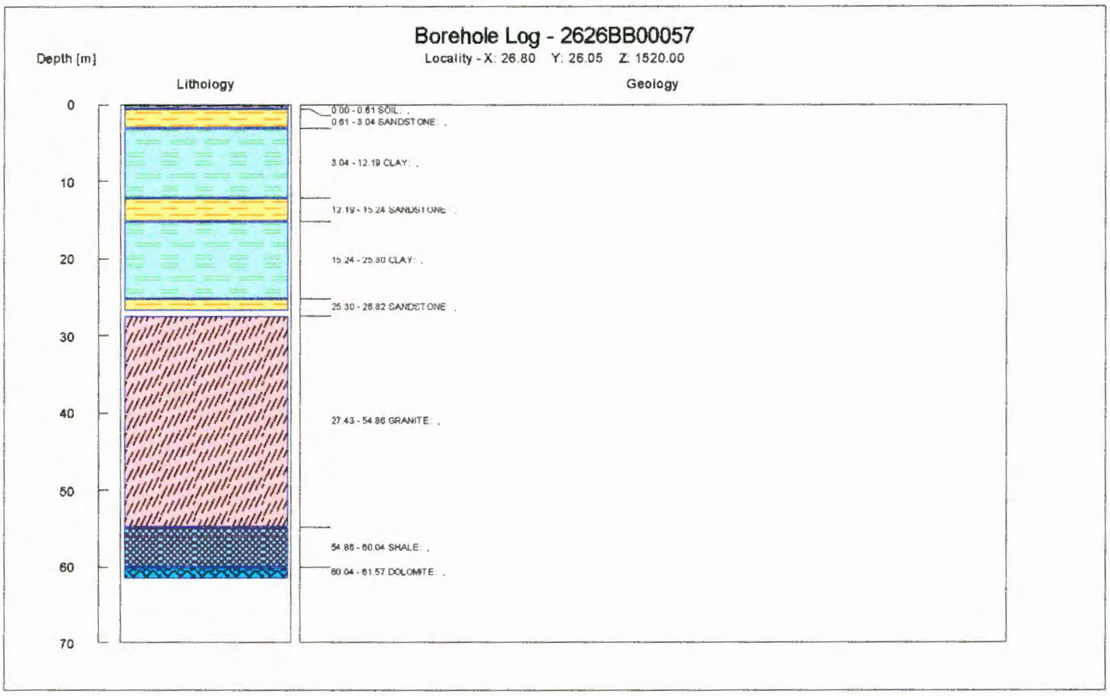

Borehole Log - 2626BD00141
Locality - X: 26.81 Y: 26.25 Z: 1510.00
Depth [m]
Lithology
Geology
0
10
20
30
40
50
60
70
80
90
100
0.00 - 1.00 SOIL: ,
1.00 - 4.00 DOLOMITE: , Fractured
4.00 - 50.00 DOLOMITE: , Hard
50.00 - 51.00 SHALE: , Baked
51.00 - 100.00 DOLOMITE: , Hard

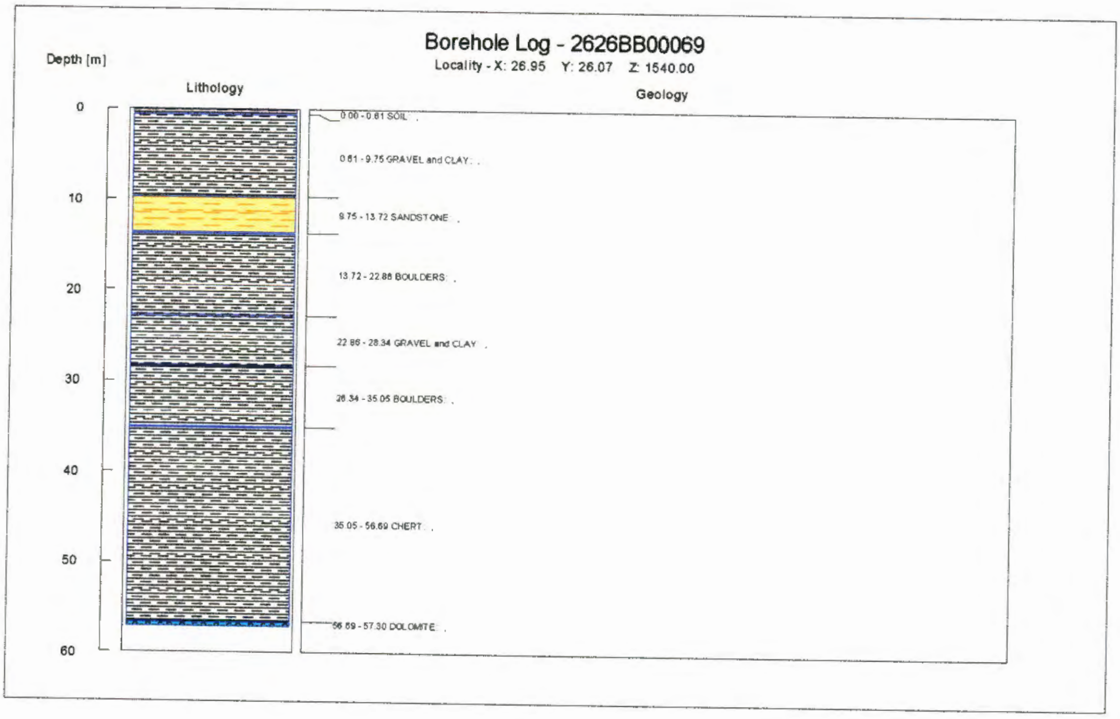
BOUNDARY BOREHOLE LOGS:

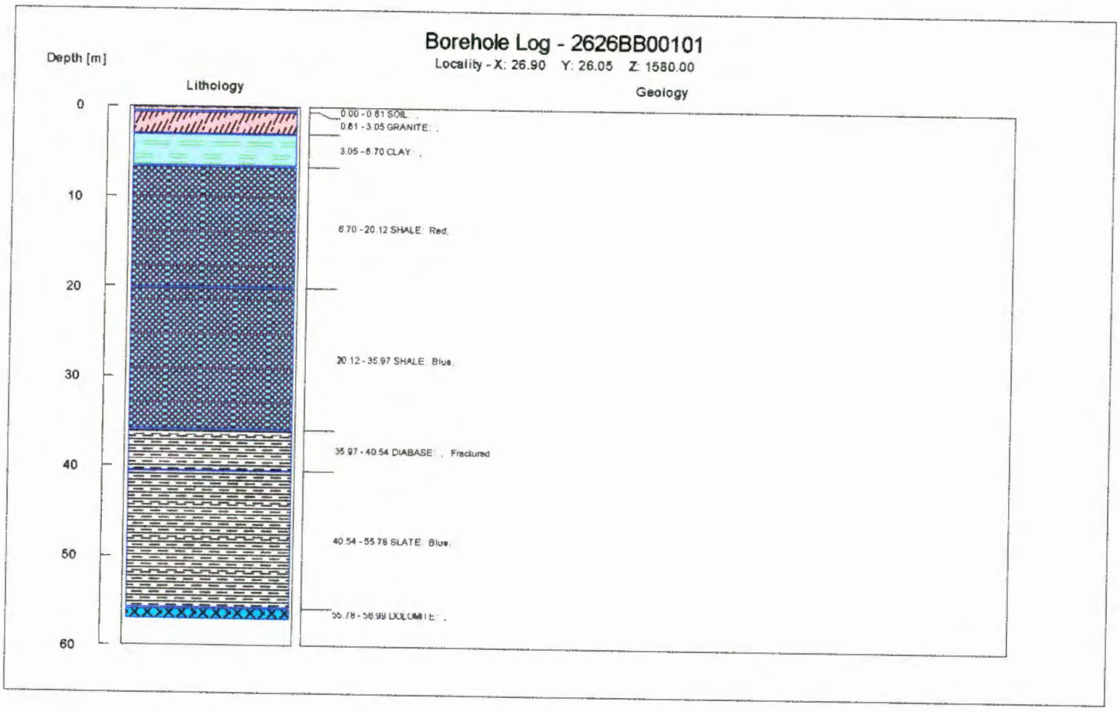


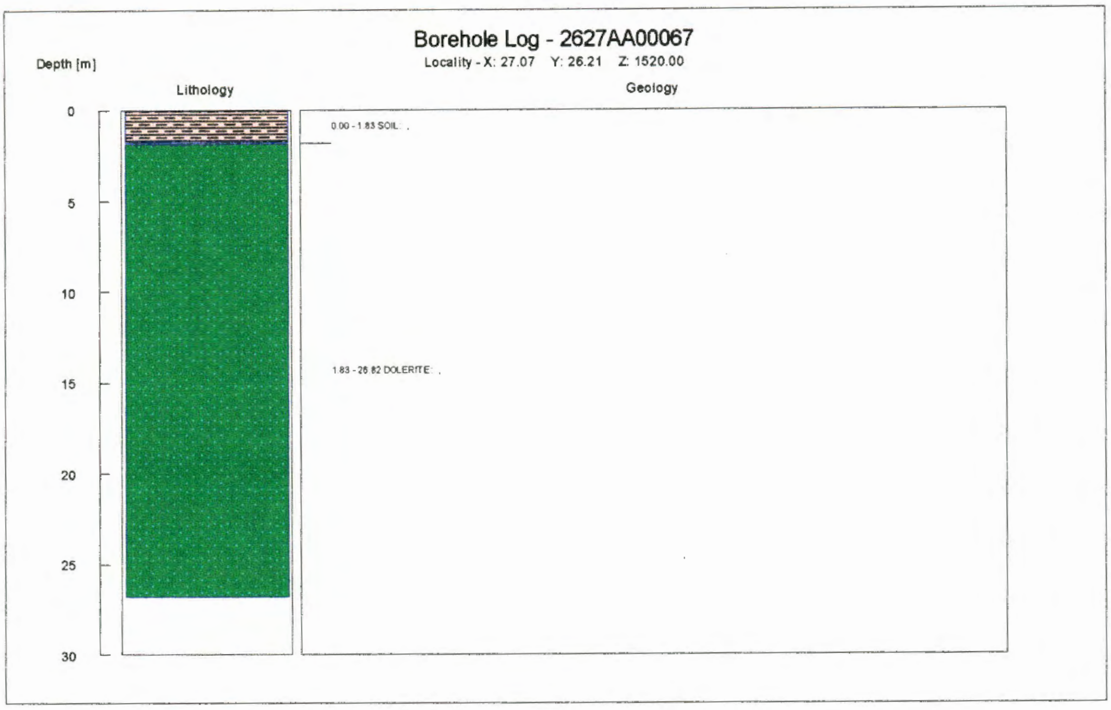


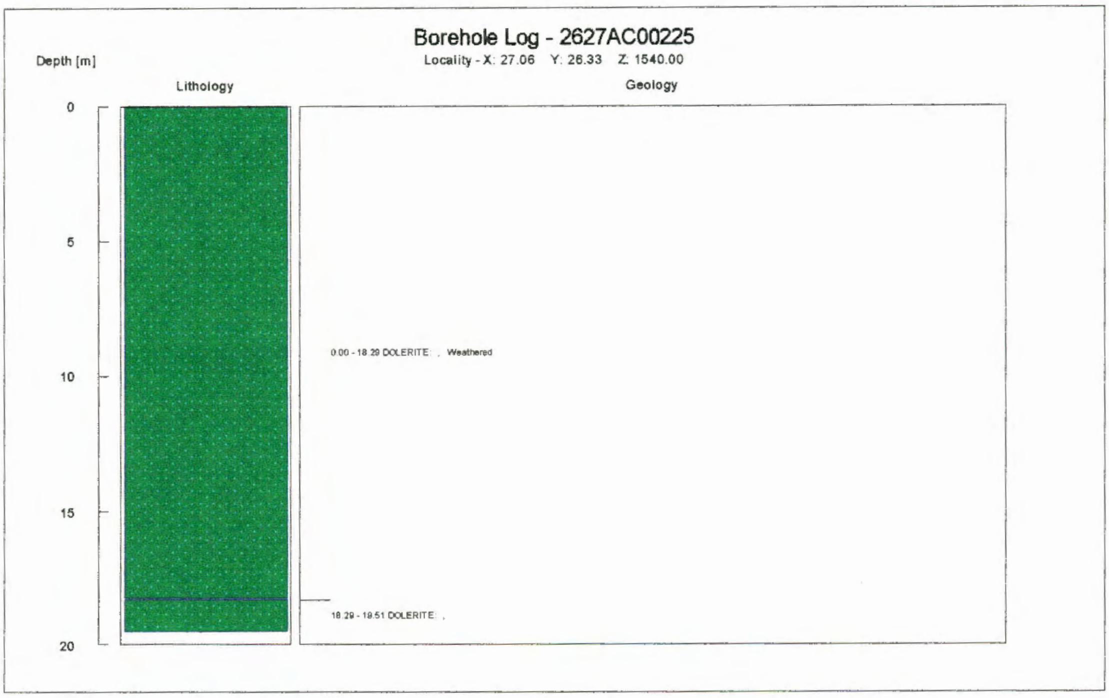

Borehole Log - 2626BB00050
Locality - X: 26.97 Y: 26.02 Z: 1560.00
Depth [m]
Lithology
Geology
0
10
20
30
40
50
60
70
0.00 - 22.00 GRAVEL: ,
22.00 - 38.00 GRANITE: Blue, Fractured
38.00 - 63.00 GRANITE: Blue,

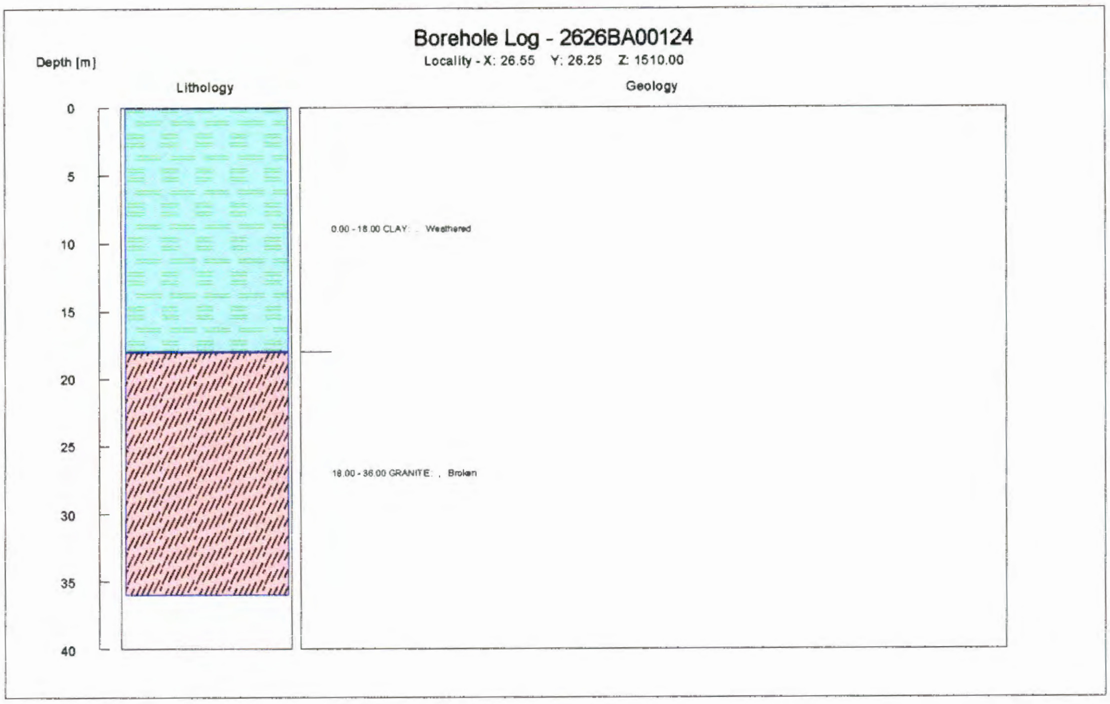

Borehole Log - 2626BB00057
Locality - X: 26.80 Y: 26.05 Z: 1520.00
Depth [m]
Lithology
Geology
0
10
20
30
40
50
60
70
0.00 - 0.61 SOIL: ,
0.61 - 3.04 SANDSTONE: ,
3.04 - 12.19 CLAY: ,
12.19 - 15.24 SANDSTONE: ,
15.24 - 25.30 CLAY: ,
25.30 - 26.82 SANDSTONE: ,
27.43 - 54.86 GRANITE: ,
54.86 - 60.04 SHALE: ,
60.04 - 61.57 DOLOMITE: ,


Borehole Log - 2626BB00069
Locality - X: 26.95 Y: 26.07 Z: 1540.00
Depth [m]
Lithology
Geology
0
10
20
30
40
50
60
0.00 - 0.61 SOIL: .
0.61 - 9.75 GRAVEL and CLAY: .
9.75 - 13.72 SANDSTONE: .
13.72 - 22.86 BOULDERS: .
22.86 - 28.34 GRAVEL and CLAY: .
28.34 - 35.05 BOULDERS: .
35.05 - 56.69 CHERT: .
56.69 - 57.30 DOLOMITE: .

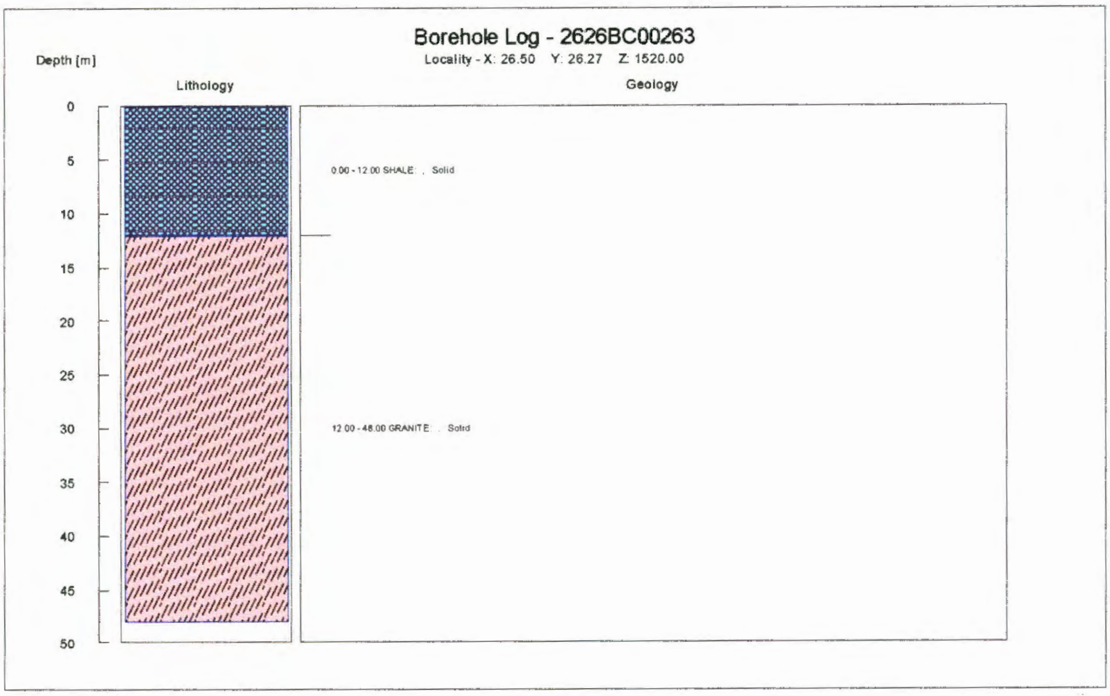

Borehole Log - 2626BB00101
Locality - X: 26.90 Y: 26.05 Z: 1580.00
Depth [m]
Lithology
Geology
0
10
20
30
40
50
60
0.00 - 0.61 SOIL: .
0.61 - 3.05 GRANITE: .
3.05 - 6.70 CLAY: .
6.70 - 20.12 SHALE: Red,
20.12 - 35.97 SHALE: Blue,
35.97 - 40.54 DIABASE: , Fractured
40.54 - 55.78 SLATE: Blue,
55.78 - 56.99 DOLOMITE: .


Borehole Log - 2627AA00067
Locality - X: 27.07 Y: 26.21 Z: 1520.00
Depth [m]
Lithology
Geology
0
5
10
15
20
25
30
0.00 - 1.83 SOIL: ,
1.83 - 26.82 DOLERITE: ,

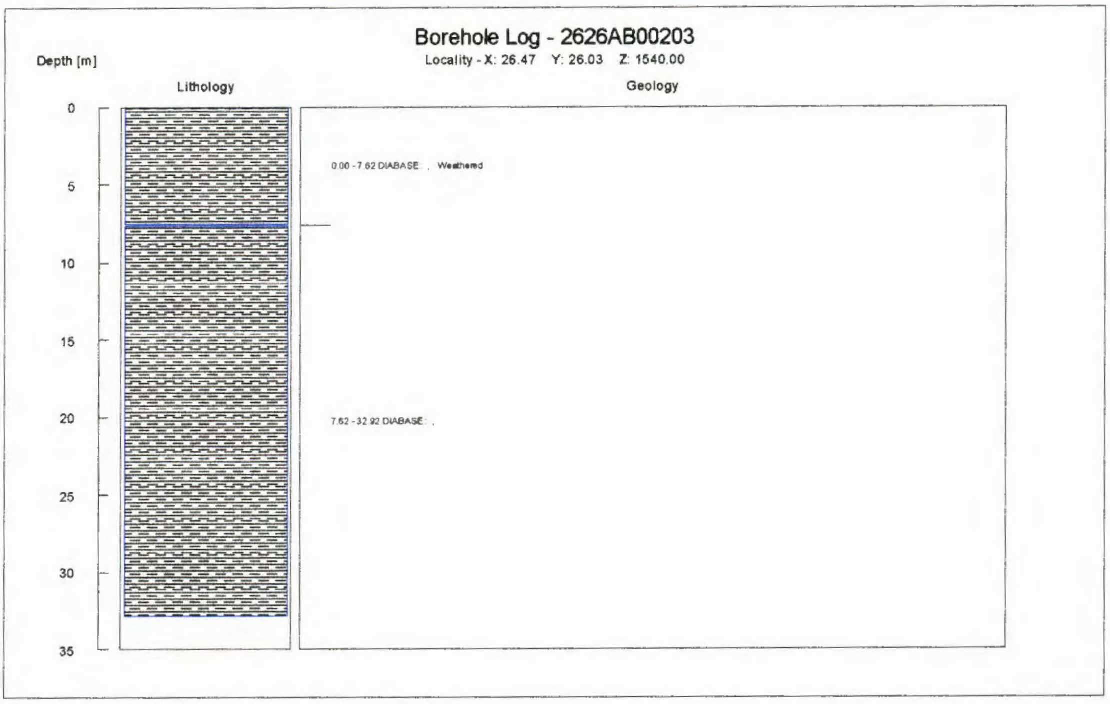

Borehole Log - 2627AC00225
Locality - X: 27.06 Y: 26.33 Z: 1540.00
Depth [m]
Lithology
Geology
0
5
10
15
20
0.00 - 18.29 DOLERITE: , Weathered
18.29 - 19.51 DOLERITE: ,

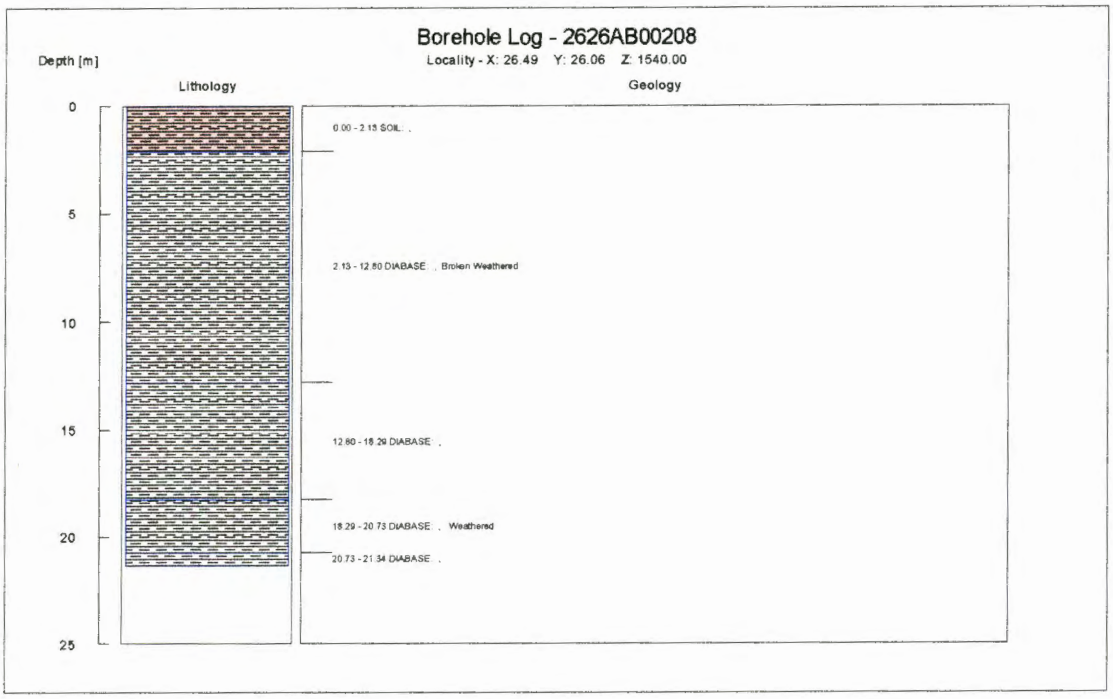

Borehole Log - 2626BA00124

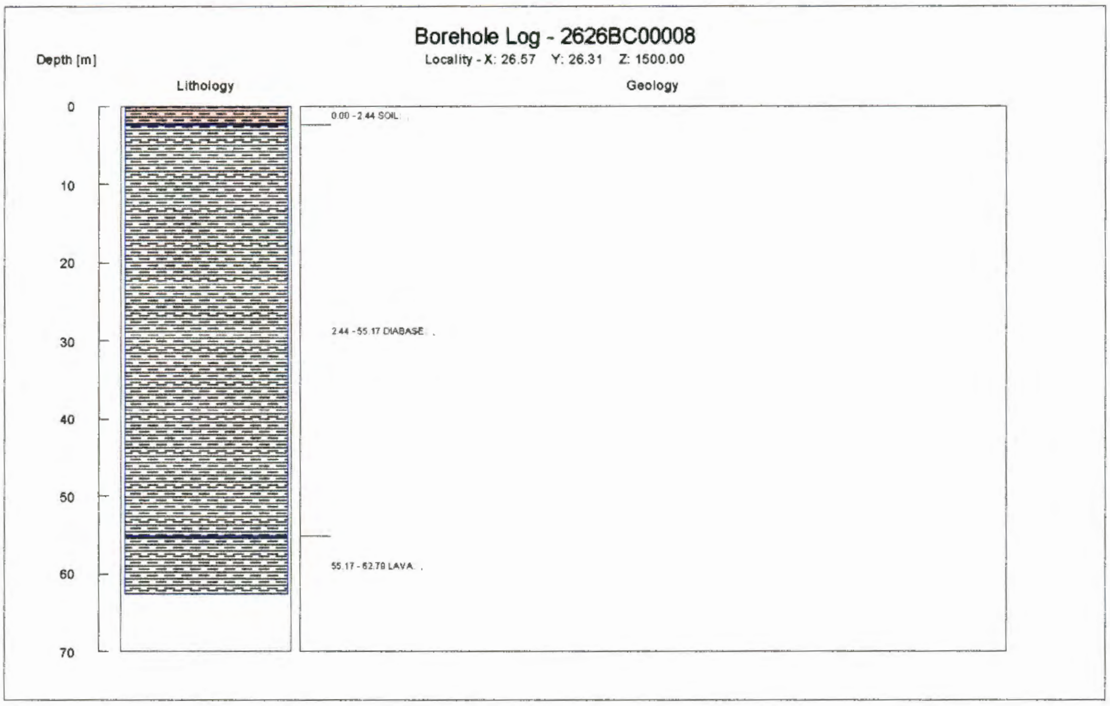
Locality - X: 26.55 Y: 26.25 Z: 1510.00

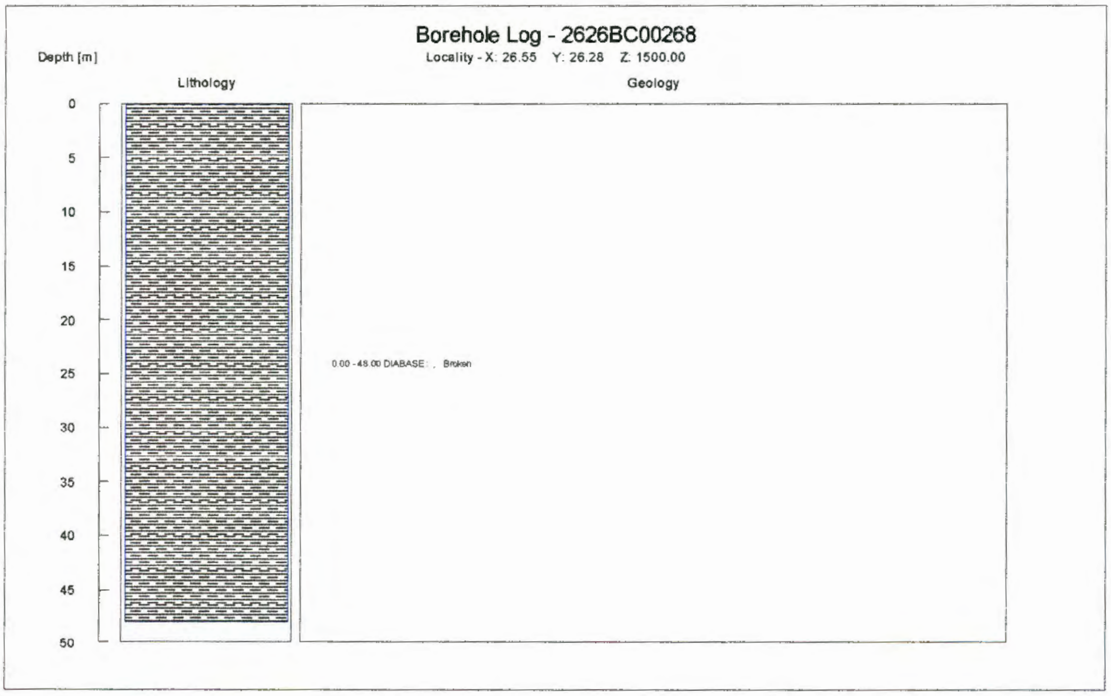

Borehole Log - 2626BC00263

Locality - X: 26.50 Y: 26.27 Z: 1520.00


Borehole Log - 2626AB00203
Locality - X: 26.47 Y: 26.03 Z: 1540.00
Depth [m]
Lithology
Geology
0
5
10
15
20
25
30
35
0.00 - 7.62 DIABASE: , Weathered
7.62 - 32.92 DIABASE: ,


Borehole Log - 2626AB00208
Locality - X: 26.49 Y: 26.06 Z: 1540.00
Depth [m]
Lithology
Geology
0
5
10
15
20
25
0.00 - 2.13 SOIL: ,
2.13 - 12.80 DIABASE: , Broken Weathered
12.80 - 18.29 DIABASE: ,
18.29 - 20.73 DIABASE: , Weathered
20.73 - 21.34 DIABASE: ,


Borehole Log - 2626BC00008
Locality - X: 26.57 Y: 26.31 Z: 1500.00
Depth [m]
Lithology
Geology
0
10
20
30
40
50
60
70
0.00 - 2.44 SOIL: ,
2.44 - 55.17 DIABASE: ,
55.17 - 62.78 LAVA: ,


Borehole Log - 2626BC00268
Locality - X: 26.55 Y: 26.28 Z: 1500.00
Depth [m]
Lithology
Geology
0
5
10
15
20
25
30
35
40
45
50
0.00 - 48.00 DIABASE: , Broken

9 APPENDIX B

LISTS OF FARM NAMES

A.1. The Schoonspruit Dolomitic Compartment as delineated by Polivka, 1987

A.2. Catchment Area of the Schoonspruit Eye as delineated by Kotze, 1994

A.3. 1995 Proclamation Farms captured by Schoeman & Partners, 1996

A.4. Demarcated Zones for the 2 Groundwater Management Areas

A.1. The Schoonspruit Dolomitic Compartment as delineated by Polivka, 1987

Almoro 173 IP
Alpha 152 IP
Appeldraai 182 IP
Beta 159 IP
Boschhoek 129 IP
Boschhoek 144 IP
Boschkop 160 IP
Boschkop 165 IP
Bruidegomskraal 179 IP
Bultfontein 132 IP
Cecilia's Home 200 IP
Cheyne 171 IP
Concordia 199 IP
Corsindae 118 IP
Doornkop 166 IP
Doornkop 372 IP
Doornpan 193 IP
Doornpan 195 IP
Doornplaat 177 IP
Droogpan 178 IP
Dunbar 119 IP
Goedgevonden 169 IP
Goedvooruitzicht 120 IP
Grootbos 149 IP
Grootpan 117 IP
Grootvlei 161 IP
Hartebeestlaagte 146 IP
Holgat 63 IP
Houtkop 152 IP
Kaallaagte 136 IP
Kafferskraal 153 IP
Kerkgrond 133 IP
Kerkgrond 141 IP
Klippan 13 IP
Klippan 140 IP
Klippan 15 IP
Klipstraat 192 IP
Kwaggaslaagte 121 IP
Leeuwkraal 181 IP
Leliefontein 138 IP
Lucky Find 158 IP
Makokskraal 203 IP
Melville 175 IP
Modderfontein 187 IP
Nagel 168 IP
Nooitgedacht (Vetpan) 131IP
Oog van Schoonspruit 186IP
Omega 156 IP
Palmietfontein 189 IP
Polka 164 IP
Ray 134 IP
Roodekop 163 IP
Roodepan 180 IP
Roodepoort 191 IP
Roodepoortjie 154 IP
Schaapplaats 126 IP
Scherpdoorn 162 IP
Schoongezicht 124 IP
Speculatie 150 IP
Sterkfontein 155 IP
Sweethome 197 IP
Thorn 143 IP
Twee Buffels Geschiet 42 IP
Uitkyk 184 IP
Veld 480 IP
Ventersdraai 176 IP
Ventersdraai 183 IP
Vlieger 185 IP
Vogelstruispan 151 IP
Wayland 137 IP
Welgevonden 167 IP
Wildfontein 201 IP
Witkrans 130 IP
Wolvepan 196 IP
Ystervarklaagte 135 IP
Zwartplaat 170 IP
Zwartrand 123 IP
Zwartrand 145 IP

Oatlands 79 IQ
Ryedale 75 IQ
Syferfontein 81 IQ
Wildebeestlaagte 72 IQ
Wolvengat 2 IQ

Boshoff 452 JP
Kwaggasnek 485 JP
Mooibult 481 JP
Mooilaagte 483 JP
Renosterfontein 494 JP
Rietpan 479 JP
Veld 480 JP
Vlakpan 476 JP

A.2. Catchment Area of the Schoonspruit Eye as delineated by Kotze, 1994

Almoro 173 IP
Appeldraai 182 IP
Beta 159 IP
Boschhoek 129 IP
Boschhoek 144 IP
Boschkop 165 IP
Bultfontein 132 IP
Bruidegomskraal 179 IP
Doornpan 195 IP
Doornkop 166 IP
Doornplaat 177 IP
Goedgevonden 169 IP
Grootbos 149 IP
Grootvlei 161 IP
Hartebeestlaagte 146 IP
Houtkop 152 IP
Kaallaagte 136 IP
Kerkgrond 133 IP
Klippan 140 IP
Klipstraat 192 IP
Kwaggaslaagte 121 IP
Leeuwkraal 181 IP
Leliefontein 138 IP
Lucky Find 158 IP
Nooitgedacht (Vetpan) 131 IP
Polka 164 IP
Ray 134 IP
Roodepan 180 IP
Roodekop 163 IP
Roodepoort 191 IP
Schaapplaats 126 IP
Schoongezicht 124 IP
Speculatie 150 IP
Thorn 143 IP
Uitkyk 184 IP
Ventersdraai 176 IP
Ventersdraai 183 IP
Vlieger 185 IP
Vogelstruispan 151 IP
Wayland 137 IP
Welgevonden 167 IP
Witkrans 130 IP
Wolvepan 196 IP
Ystervarklaagte 135 IP
Zwartplaat 170 IP
Zwartrand 123 IP
Zwartrand 145 IP

Wolvegat 21 IQ

Mooilaagte 483 JP
Rietpan 428 JP
Rietpan 479 JP
Veld 480 JP

A.3. 1995 Proclamation Farms captured by Schoeman & Partners, 1996

Almoro 173 IP
Appeldraai 182 IP
Beta 159 IP
Boschhoek 129 IP
Boschhoek 144 IP
Boschkop 160 IP
Boschkop 165 IP
Bultfontein 132 IP
Bruidegomskraal 179 IP
Cheyne 171 IP
Doornpan 195 IP
Doornkop 166 IP
Doornplaat 177 IP
Droogpan 178 IP
Goedgevonden 169 IP
Grootbos 149 IP
Grootvlei 161 IP
Hartebeestlaagte 146 IP
Houtkop 152 IP
Kaallaagte 136 IP
Kerkgrond 133 IP
Kerkgrond 141 IP
Klippan 140 IP
Klipstraat 192 IP
Kwaggaslaagte 121 IP
Leeuwkraal 181 IP
Leliefontein 138 IP
Lucky Find 158 IP
Melvill 175 IP
Nagel 168 IP
Nooitgedacht (Vetpan) 131 IP
Oog Van Schoonspruit 186 IP
Polka 164 IP
Ray 134 IP
Roodepan 180 IP
Roodekop 163 IP
Roodepoort 191 IP
Schaapplaats 126 IP
Scherpdoorn 162 IP
Schoongezicht 124 IP
Speculatie 150 IP
Thorn 143 IP
Uitkyk 184 IP
Ventersdraai 176 IP
Ventersdraai 183 IP
Vlieger 185 IP
Vogelstruispan 151 IP
Wayland 137 IP
Welgevonden 167 IP
Witkrans 130 IP
Wolvepan 196 IP
Ystervarklaagte 135 IP
Zwartplaat 170 IP
Zwartrand 123 IP
Zwartrand 145 IP

Wolvegat 21 IQ

Mooibult 481 JP
Mooilaagte 483 JP
Rietpan 479 JP
Veld 480 JP

A.4. Demarcated Zones for the 2 Groundwater Management Areas

ZONE A

Almoro 173 IP
Appeldraai 182 IP
Boschhoek 144 IP
Bruidegomskraal 179 IP
Bultfontein 132 IP
Doornkop 166 IP
Doornpan 193 IP
Doornpan 195 IP
Doornplaat 177 IP
Droogpan 178 IP
Goedgevonden 169 IP
Grootbos 149 IP
Hartebeestlaagte 146 IP
Kaallaagte 136 IP
Kerkgrond 128 IP
Kerkgrond 133 IP
Kerkgrond 141 IP
Klippan 140 IP
Klipstraat 192 IP
Leeuwkraal 181 IP
Leliefontein 138 IP
Melville 175 IP
Modderfontein 187 IP
Nooitgedacht(Vetpan) 131 IP
OogvanSchoonspruit 186 IP
Palmietfontein 189 IP
Polka 164 IP
Ray 134 IP
Renosterfontein 494 JP
Roodekop 163 IP
Roodepan 180 IP
Roodepoort 191 IP
Thorn 143 IP
Uitkyk 184 IP
Ventersdraai 176 IP
Ventersdraai 183 IP
Vlieger 185 IP
Wayland 137 IP
Welgevonden 167 IP
Witkrans 130 IP
Ystervarklaagte 135 IP
Zwartplaat 170 IP
Zwartrand 145 IP
Oatlands 79 IQ
Ryedale 75 IQ
Wolvengat 2 IQ
Wildebeestlaagte 72 IQ

ZONE B

Alpha 152 IP
Beta 159 IP
Boschhoek 129 IP
Boschkop 160 IP
Boschkop 165 IP
Cecilia's Home 200 IP
Cheyne 171 IP
Concordia 199 IP
Corsindae 118 IP
Doornpan 195 IP
Dunbar 119 IP
Goedvooruitzicht 120 IP
Grootbos 149 IP
Grootpan 117 IP
Grootvlei 161 IP
Houtkop 152 IP
Kafferskraal 153 IP
Klippan 13 IP
Klippan 15 IP
Klipstraat 192 IP
Kwaggaslaagte 121 IP
Lucky Find 158 IP
Nagel 168 IP
Nooitgedacht(Vetpan) 131 IP
Polka 164 IP
Roodekop 163 IP
Roodepoortjie 154 IP
Schaapplaats 126 IP
Scherpdoorn 162 IP
Schoongezicht 124 IP
Speculatie 150 IP
Sterkfontein 155 IP
Sweethome 197 IP
Twee Buffels Geschiet 42 IP
Vogelstruispan 151 IP
Wildfontein 201 IP
Witkrans 130 IP
Wolvepan 196 IP
Zwartrand 123 IP
Kwaggasnek 485 JP
Mooihult 481 JP
Mooilaagte 483 JP
Rietpan 479 JP
Veld 480 JP

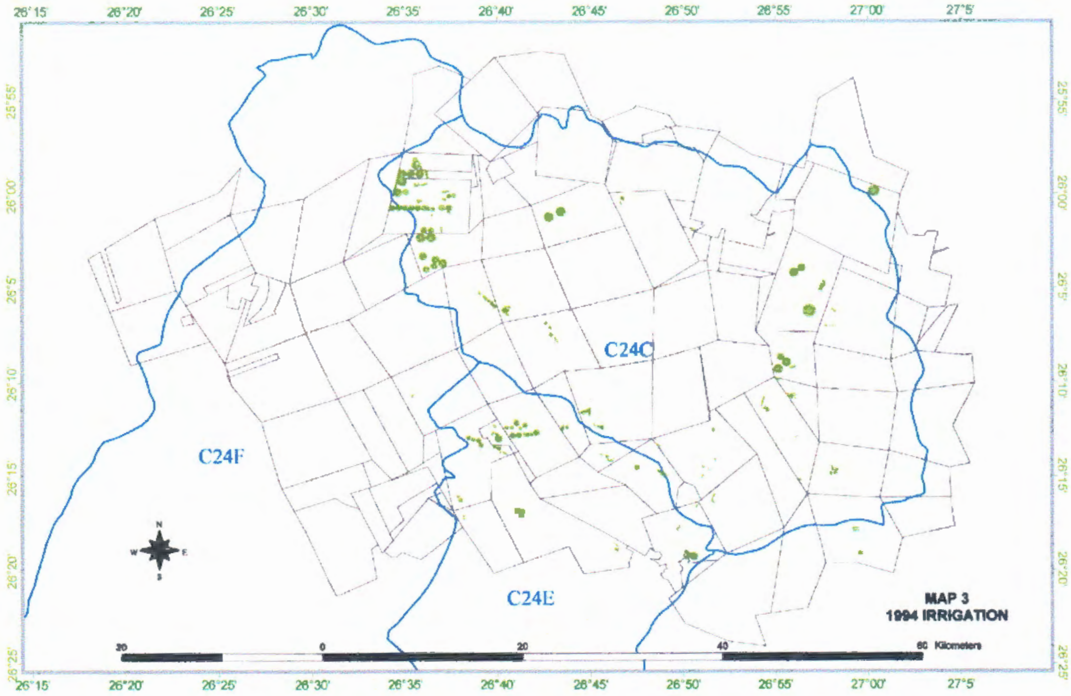
A.4. Continue

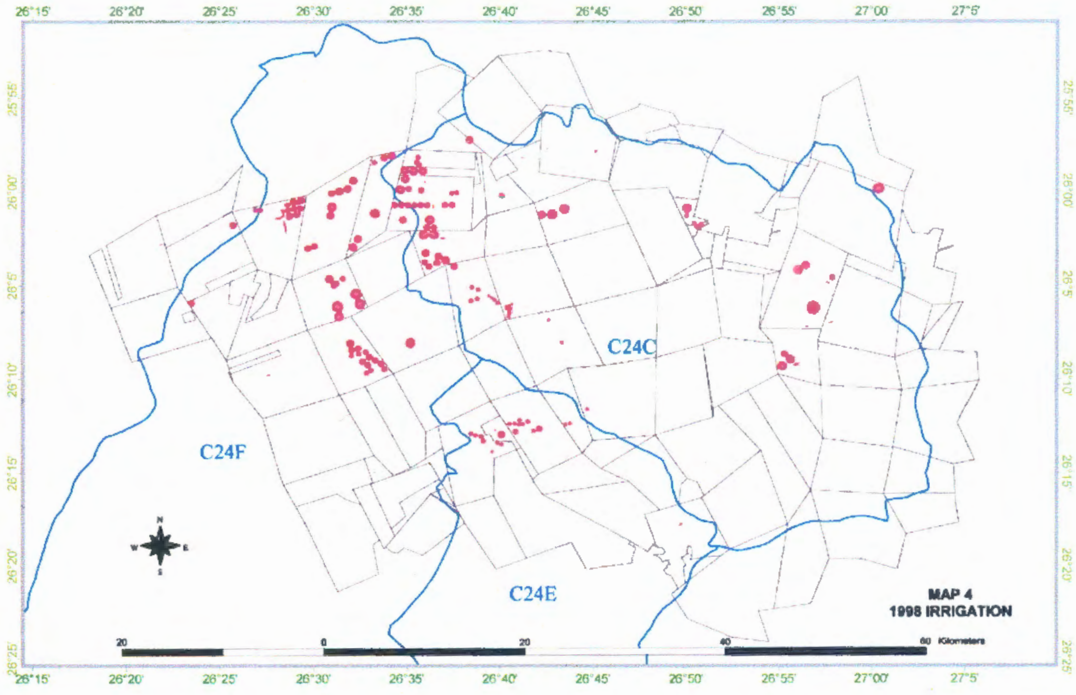
THE FOLLOWING FARMS OVERLAP BETWEEN THE TWO ZONES:

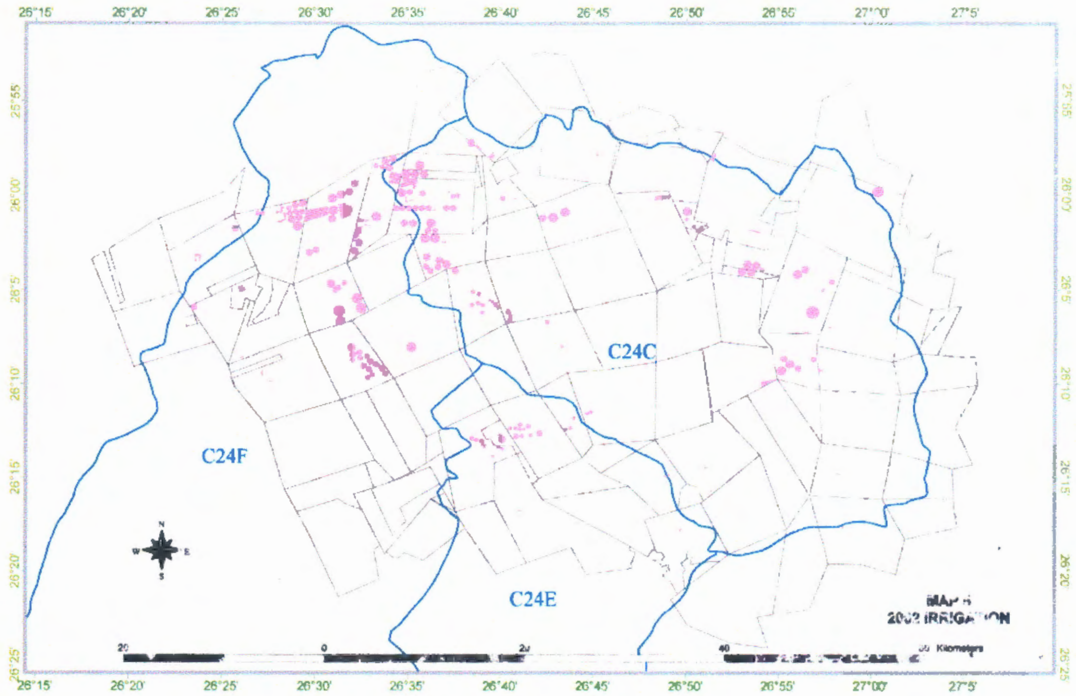
Doornpan 195 IP
Grootbos 149 IP
Klipstraat 192 IP
Nooitgedacht(Vetpan) 131 IP
Polka 164 IP
Roodekop 163 IP
Witkrans 130 IP

10 APPENDIX C

MAPS OF IRRIGATION IN THE SCHOONSPRUIT DOLOMITIC COMPARTMENT FOR THE DIFFERENT DATES PERTAINING TO THE VERIFICATION OF EXISTING LAWFUL USE (Schoeman & Partners, 2003)


26°15'
26°20'
26°25'
26°30'
26°35'
26°40'
26°45'
26°50'
26°55'
27°00'
27°5'
25°55'
26°00'
26°5'
26°10'
26°15'
26°20'
26°25'
C24C
C24F
C24E
N
W
E
S
MAP 3
1994 IRRIGATION
20
0
20
40
60 Kilometers

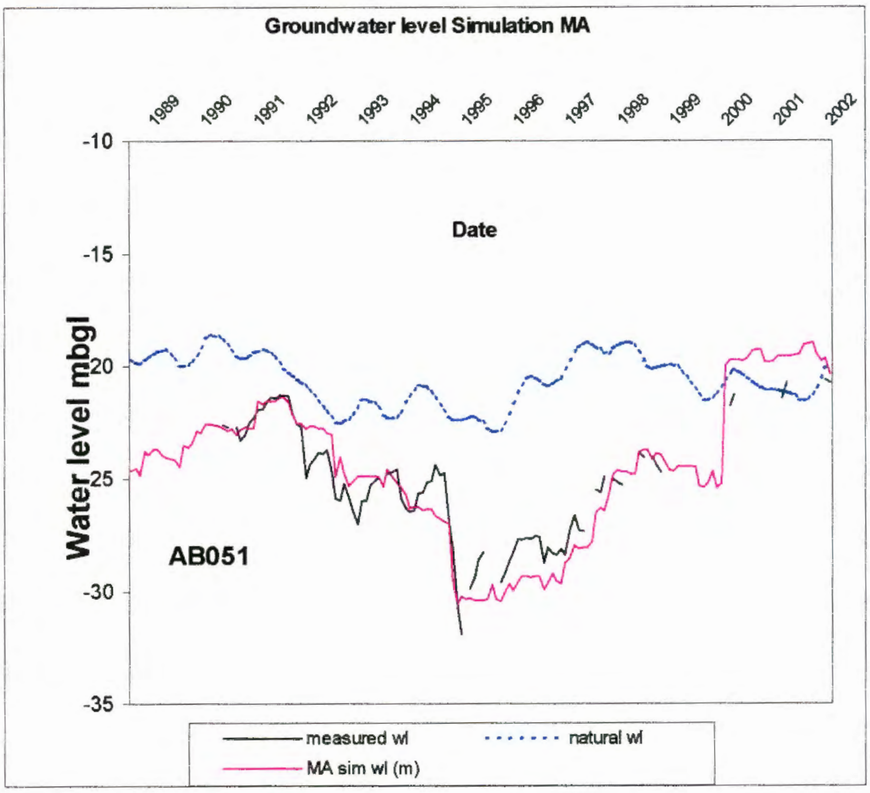

26°15'
26°20'
26°25'
26°30'
26°35'
26°40'
26°45'
26°50'
26°55'
27°00'
27°5'
25°55'
26°00'
26°5'
26°10'
26°15'
26°20'
26°25'
C24C
C24F
C24E
N
W
E
S
MAP 4
1998 IRRIGATION
20
0
20
40
60 Kilometers

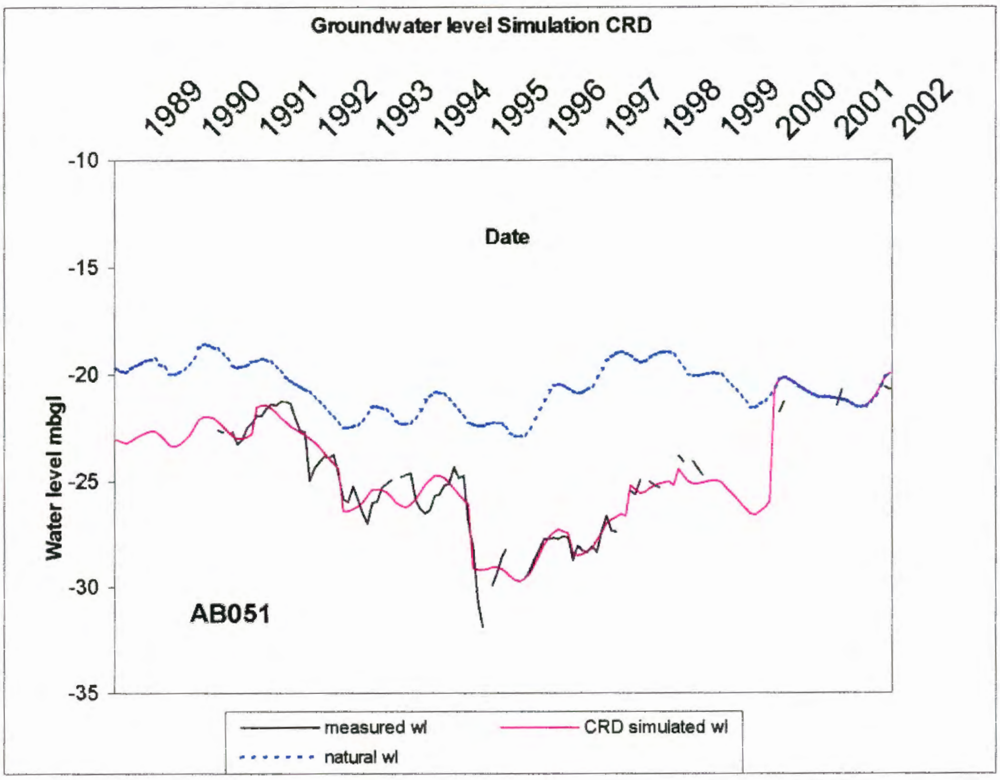

26°15'
26°20'
26°25'
26°30'
26°35'
26°40'
26°45'
26°50'
26°55'
27°00'
27°5'
25°55'
26°00'
26°5'
26°10'
26°15'
26°20'
26°25'
C24F
C24C
C24E
N
W
E
S
MAP 5
2002 IRRIGATION
20
0
20
40
60 Kilometers

11 APPENDIX D

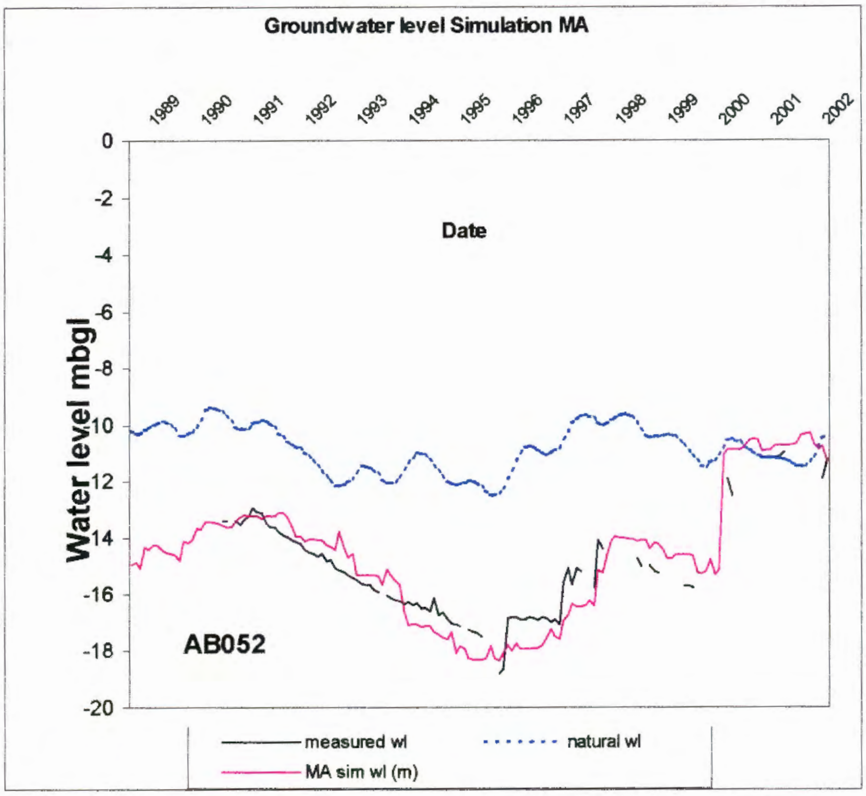
THE MA AND CRD SIMULATIONS FOR THE DIFFERENT WATER LEVEL MONITORING BOREHOLES

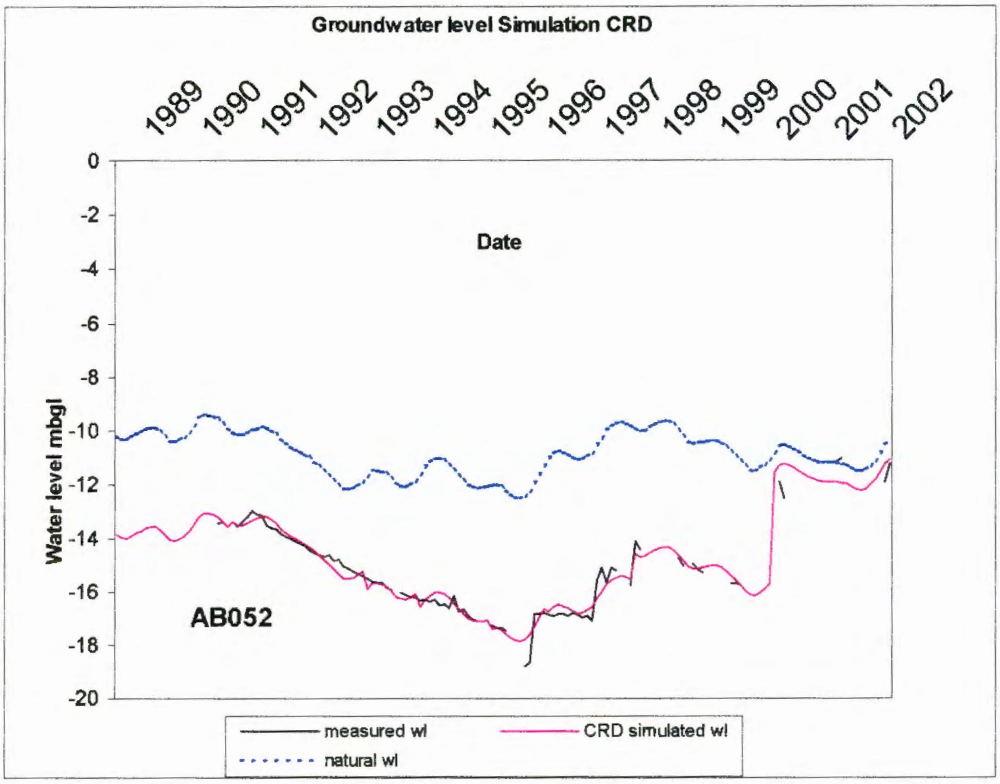
2626AB051


Groundwater level Simulation MA
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
-10
-15
-20
-25
-30
-35
Water level mbgl
Date
AB051
measured wl
natural wl
MA sim wl (m)

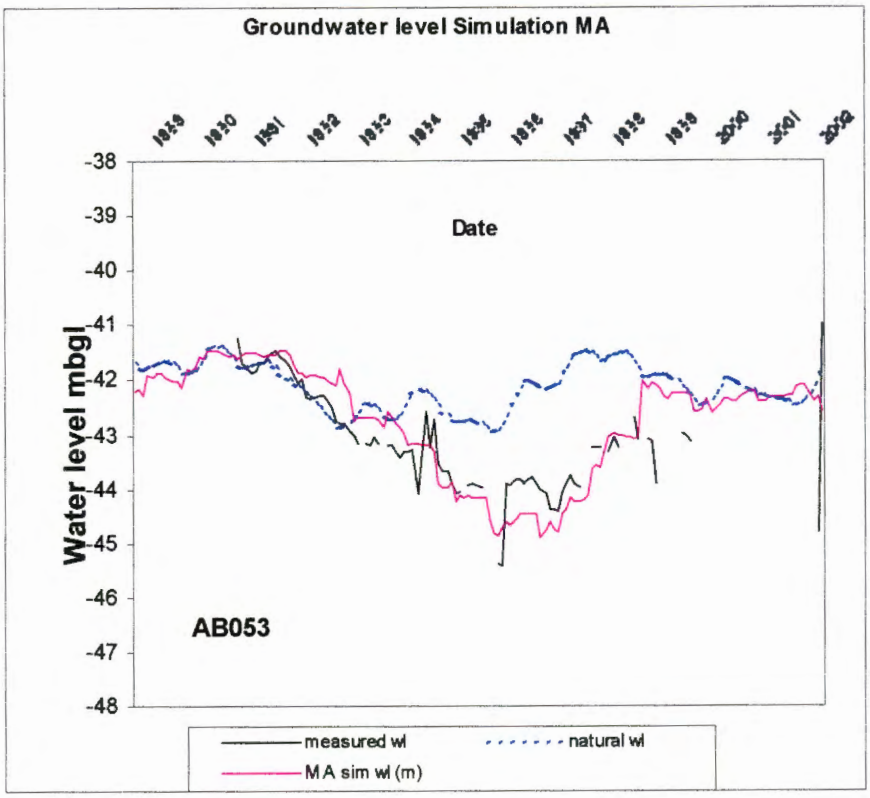

Groundwater level Simulation CRD
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
-10
-15
-20
-25
-30
-35
Water level mbgl
Date
AB051
measured wl
CRD simulated wl
natural wl

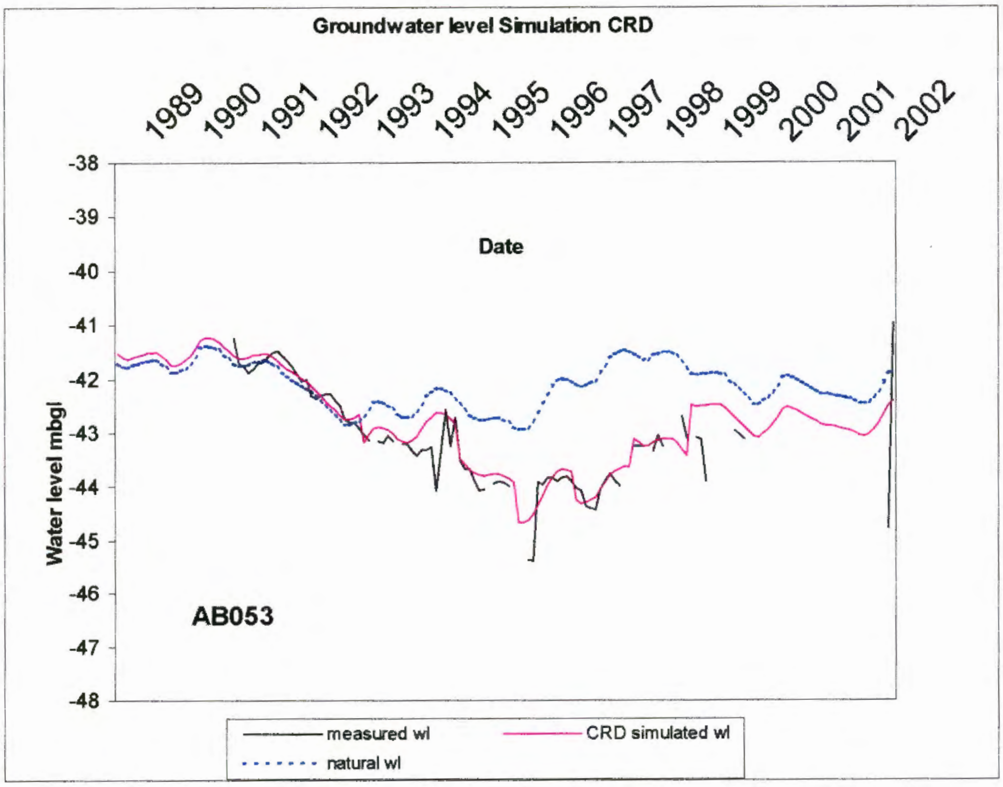
2626AB052


Groundwater level Simulation MA
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
Date
Water level mbgl
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
AB052
measured wl
natural wl
MA sim wl (m)

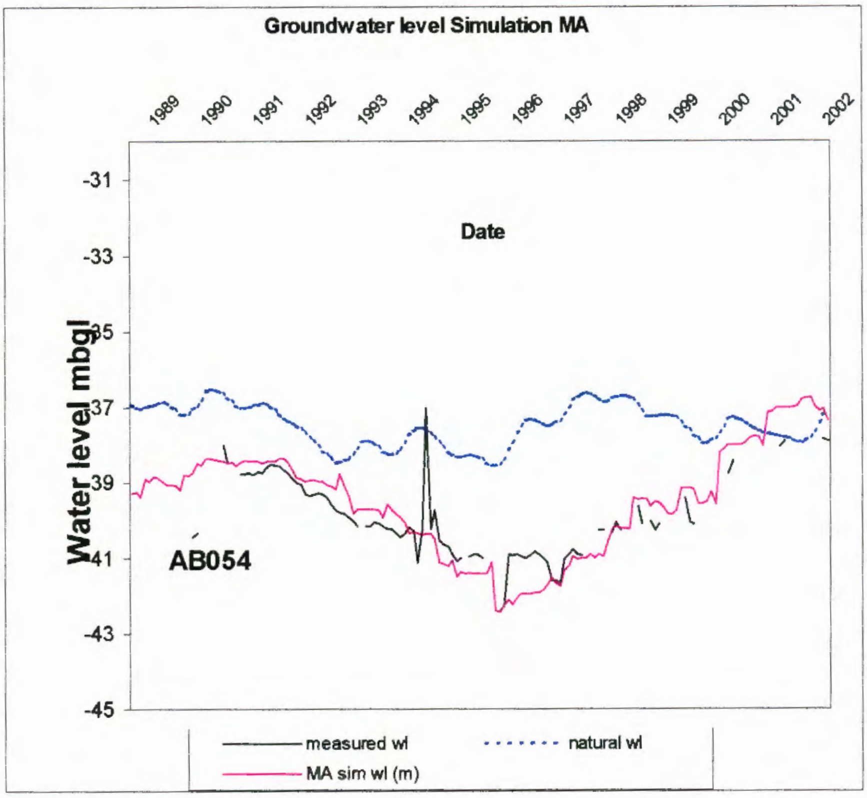

Groundwater level Simulation CRD
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
Date
Water level mbgl
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
AB052
measured wl
CRD simulated wl
natural wl

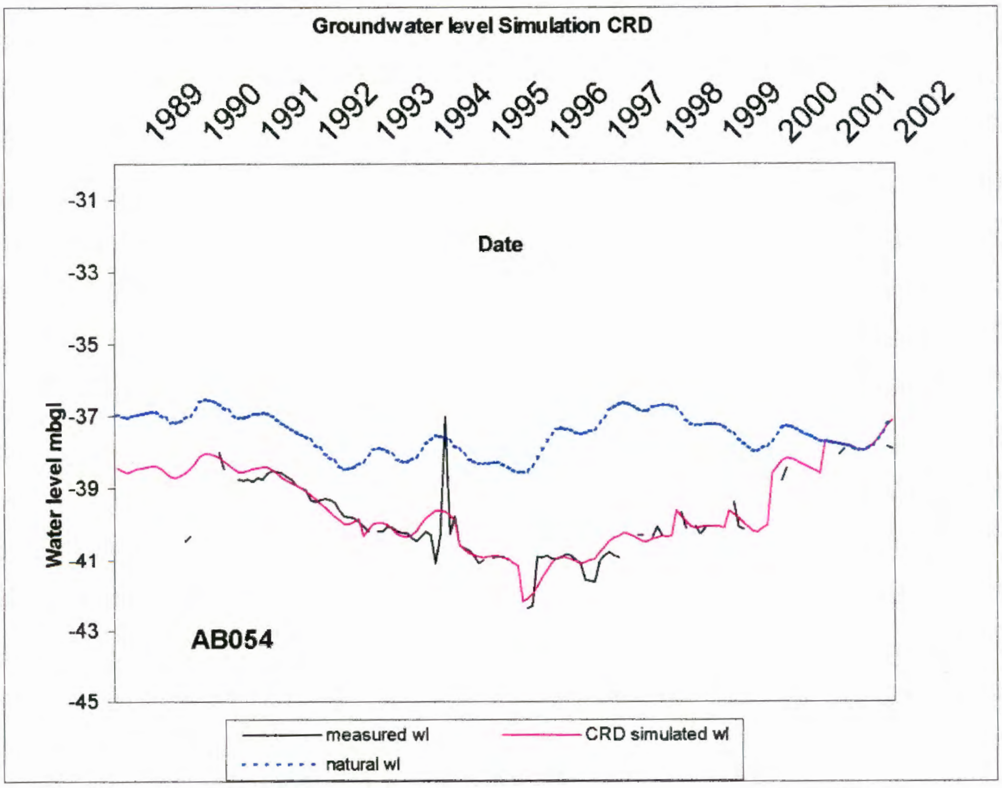
2626AB053


Groundwater level Simulation MA
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
Date
Water level mbgl
-38
-39
-40
-41
-42
-43
-44
-45
-46
-47
-48
AB053
measured wl
natural wl
MA sim wl (m)

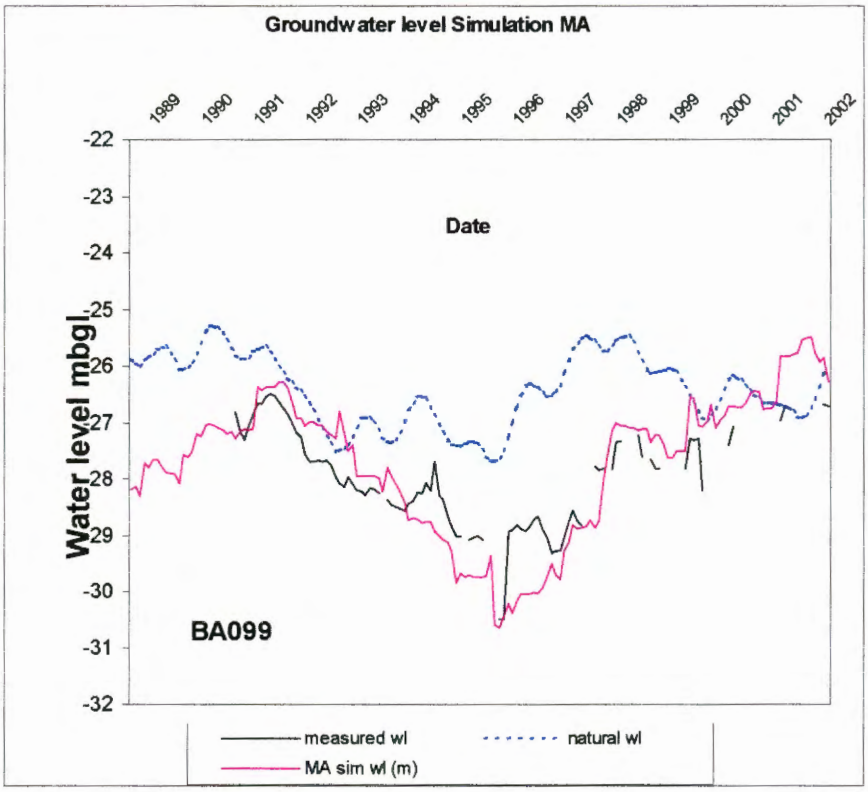

Groundwater level Simulation CRD
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
Date
Water level mbgl
-38
-39
-40
-41
-42
-43
-44
-45
-46
-47
-48
AB053
measured wl
CRD simulated wl
natural wl

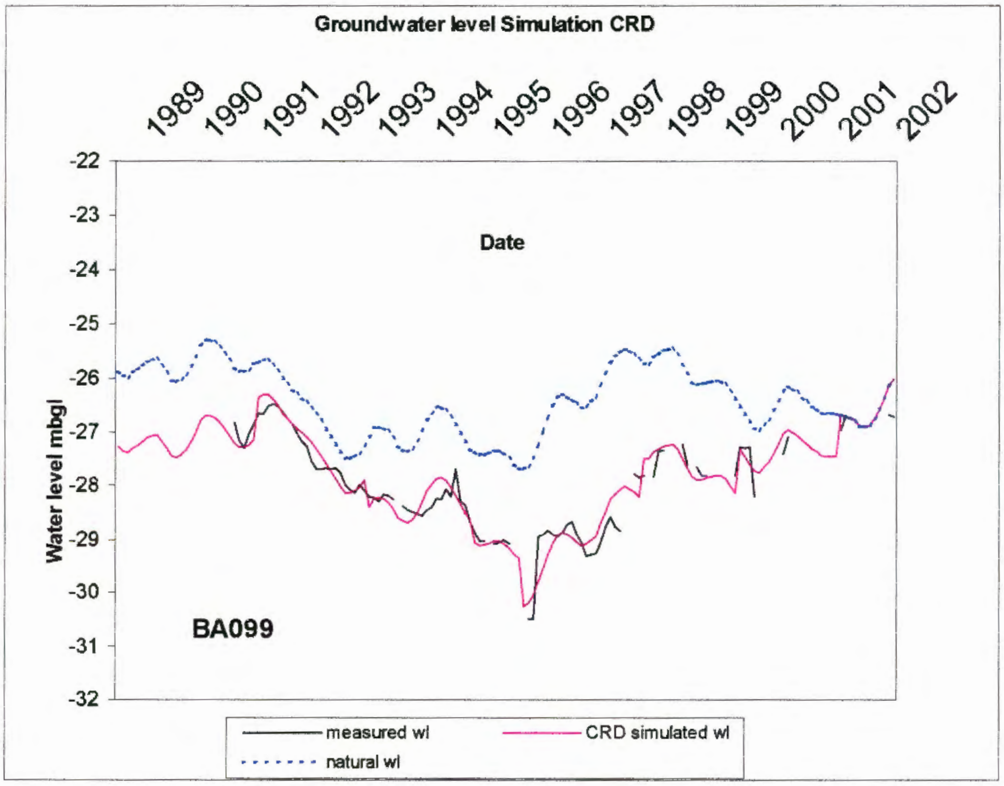
2626AB054


Groundwater level Simulation MA
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
Date
Water level mbgl
-31
-33
-35
-37
-39
-41
-43
-45
AB054
measured wl
natural wl
MA sim wl (m)

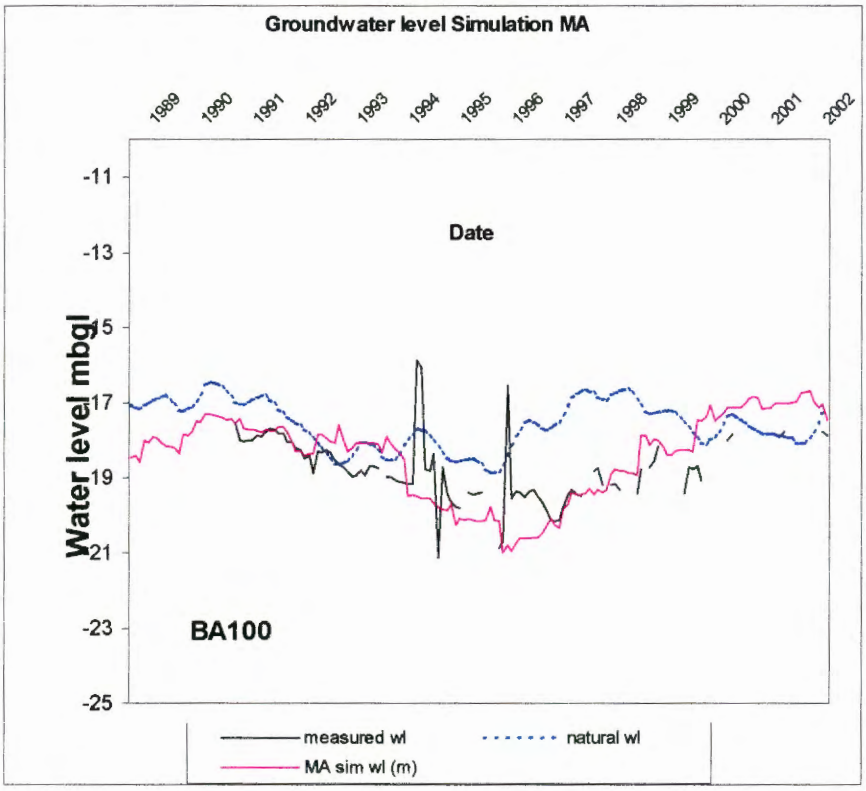

Groundwater level Simulation CRD
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
Date
Water level mbgl
-31
-33
-35
-37
-39
-41
-43
-45
AB054
measured wl
CRD simulated wl
natural wl

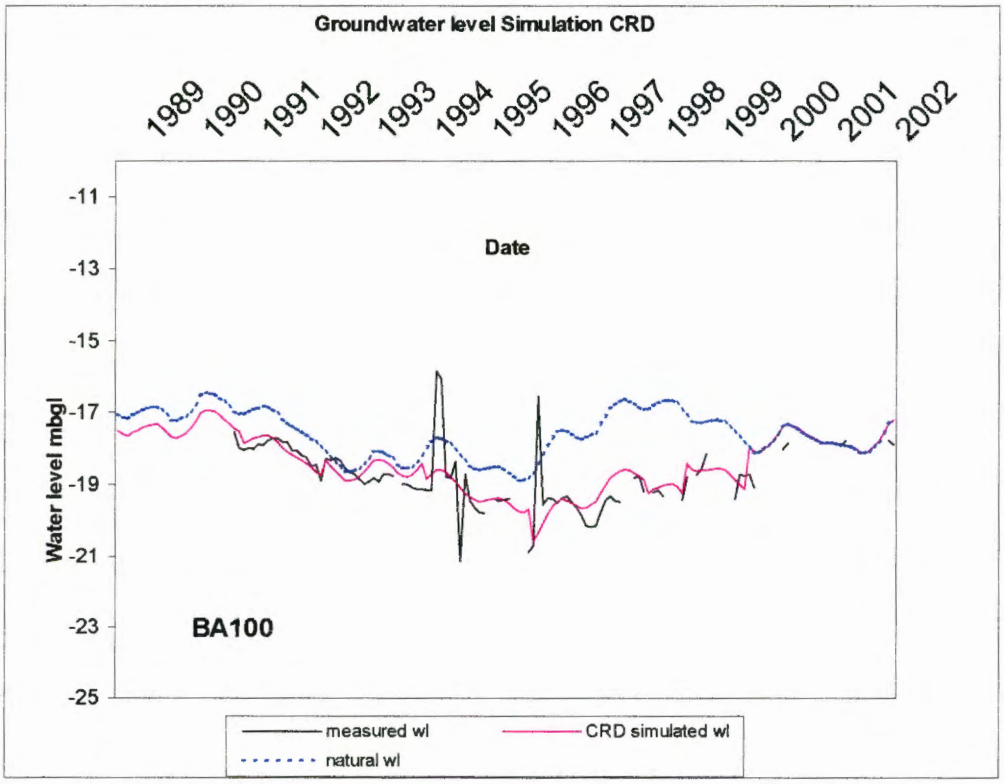
2626BA099


Groundwater level Simulation MA
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
Date
Water level mbgl.
-22
-23
-24
-25
-26
-27
-28
-29
-30
-31
-32
BA099
measured wl
natural wl
MA sim wl (m)

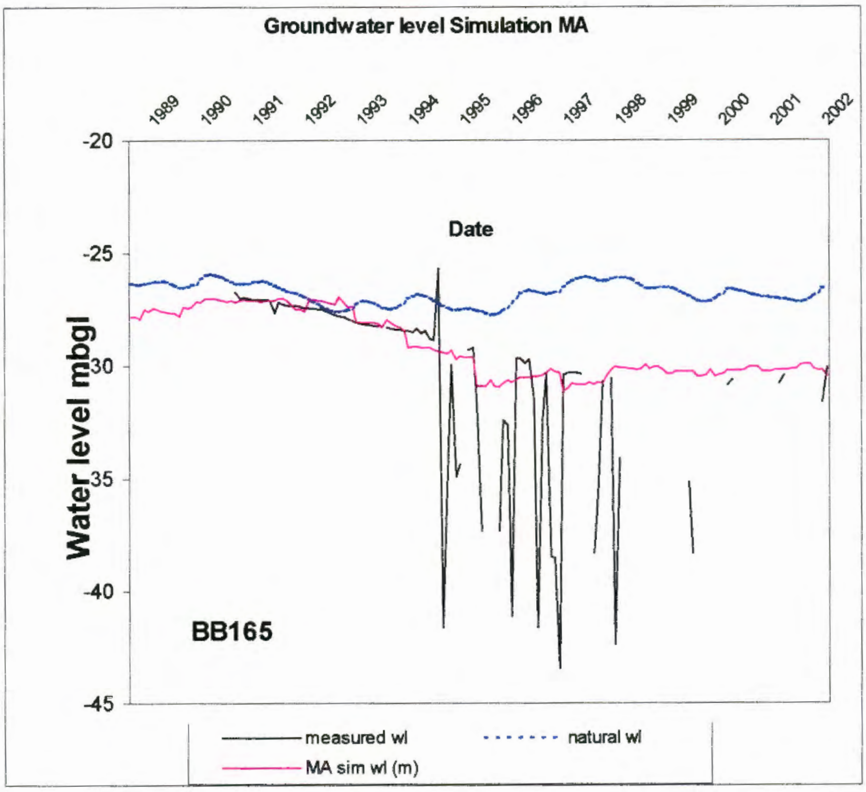

Groundwater level Simulation CRD
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
Date
Water level mbgl
-22
-23
-24
-25
-26
-27
-28
-29
-30
-31
-32
BA099
measured wl
CRD simulated wl
natural wl

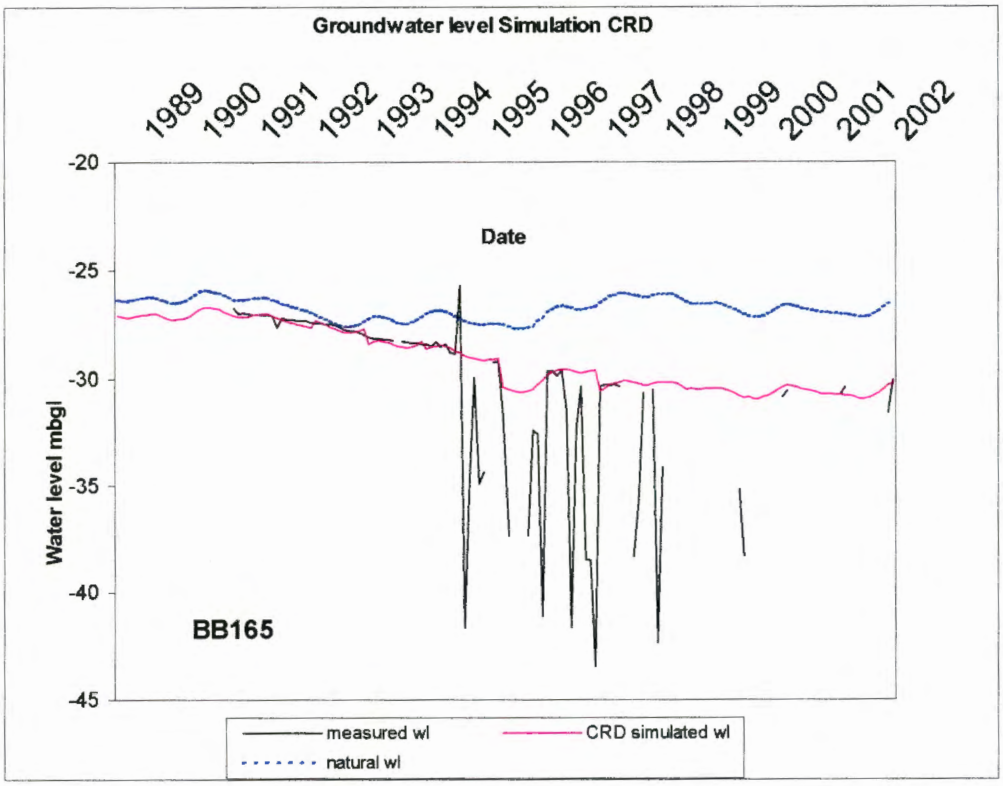
2626BA100


Groundwater level Simulation MA
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
Date
Water level mbgl
-11
-13
-15
-17
-19
-21
-23
-25
BA100
measured wl
natural wl
MA sim wl (m)

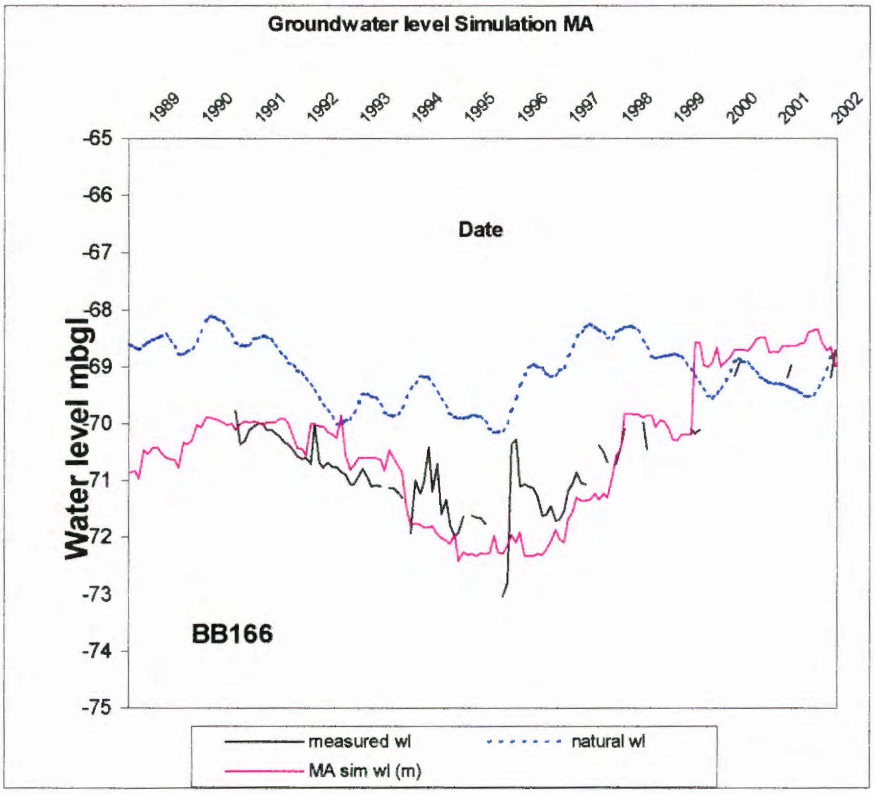

Groundwater level Simulation CRD
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
Date
Water level mbgl
-11
-13
-15
-17
-19
-21
-23
-25
BA100
measured wl
CRD simulated wl
natural wl

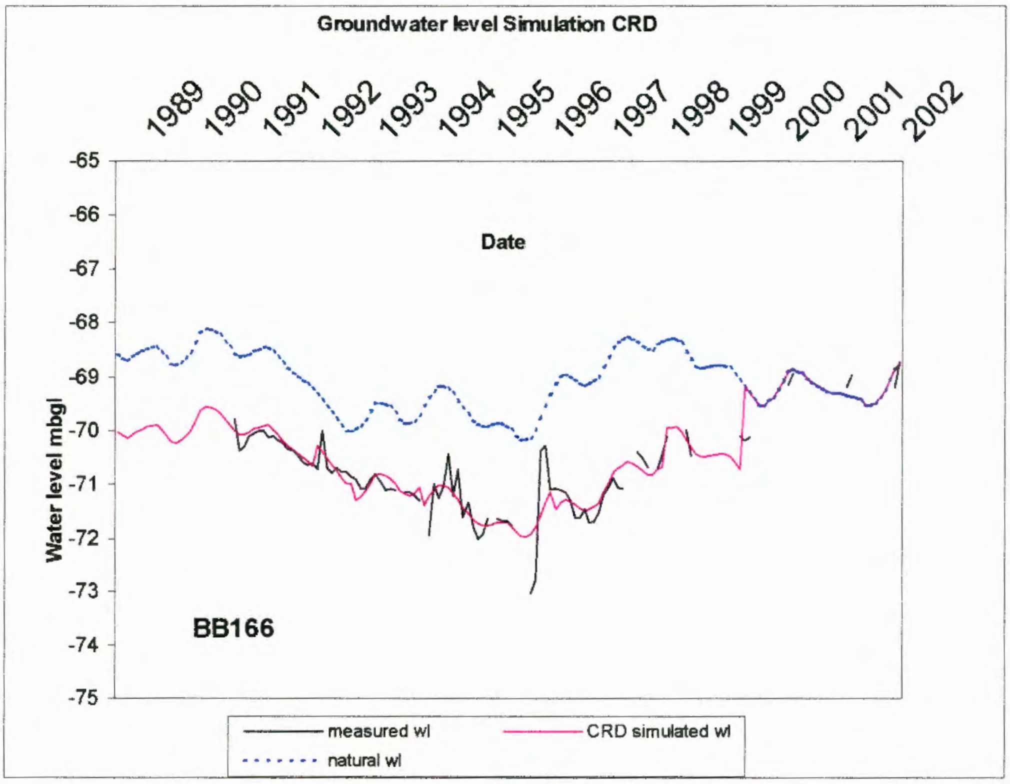
2626BB165


Groundwater level Simulation MA
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
Date
-20
-25
-30
-35
-40
-45
Water level mbgl
BB165
measured wl
natural wl
MA sim wl (m)

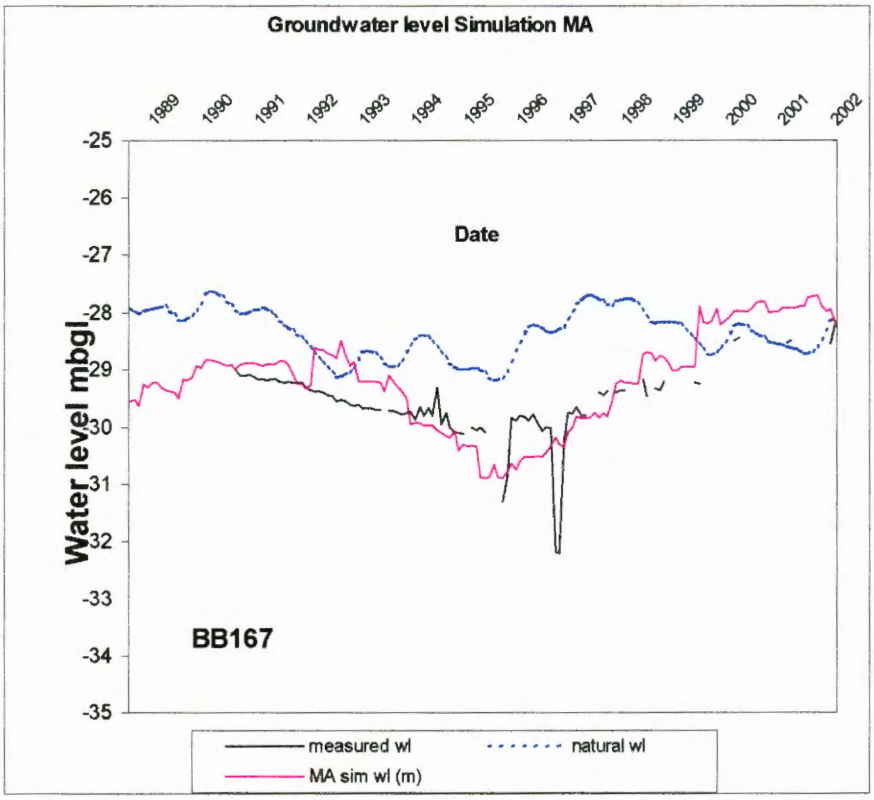

Groundwater level Simulation CRD
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
Date
-20
-25
-30
-35
-40
-45
Water level mbgl
BB165
measured wl
CRD simulated wl
natural wl

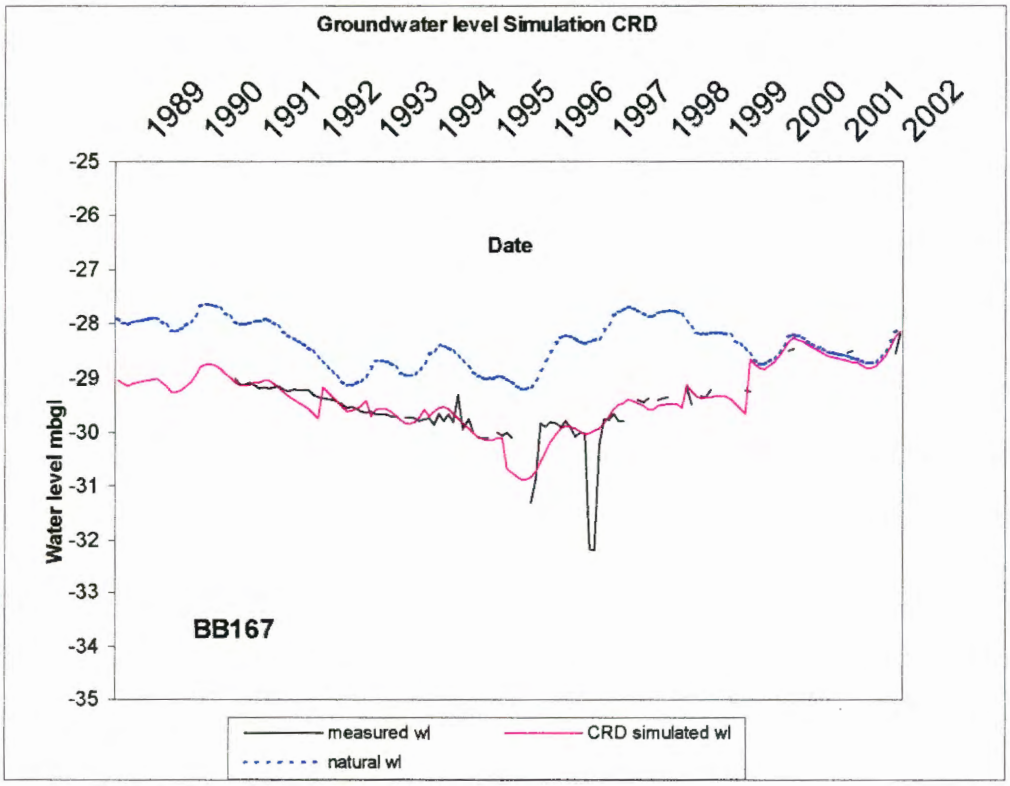
2626BB166


Groundwater level Simulation MA
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
-65
-66
-67
-68
-69
-70
-71
-72
-73
-74
-75
Water level mbgl
Date
BB166
measured wl
natural wl
MA sim wl (m)

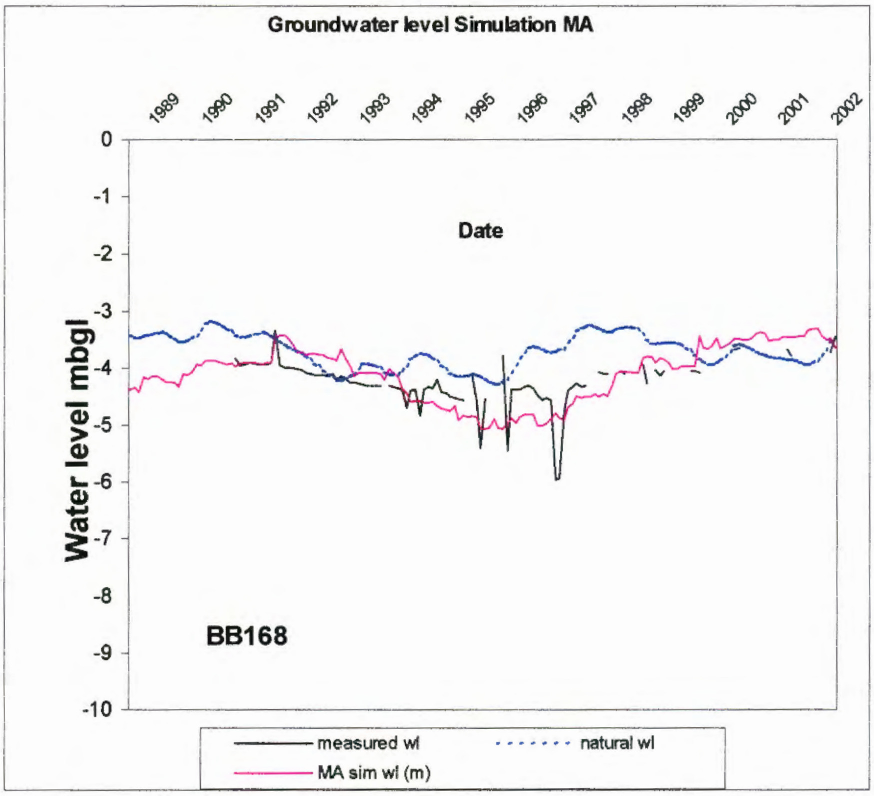

Groundwater level Simulation CRD
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
-65
-66
-67
-68
-69
-70
-71
-72
-73
-74
-75
Water level mbgl
Date
BB166
measured wl
CRD simulated wl
natural wl

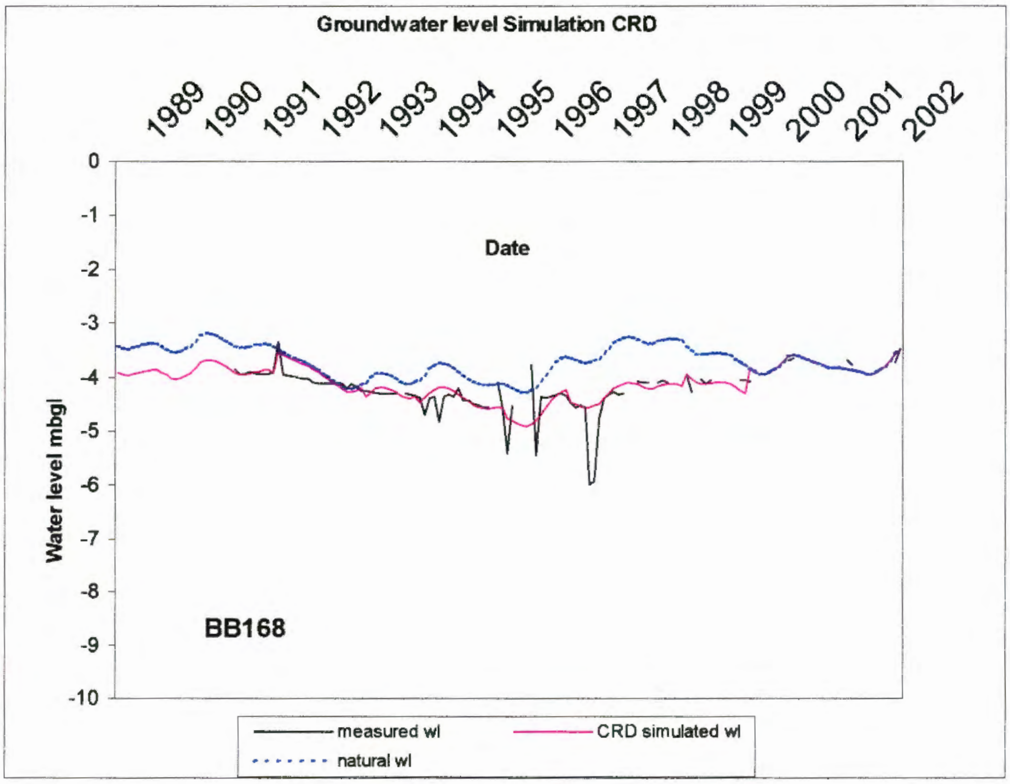
2626BB167


Groundwater level Simulation MA
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
Date
Water level mbgl
-25
-26
-27
-28
-29
-30
-31
-32
-33
-34
-35
BB167
measured wl
natural wl
MA sim wl (m)

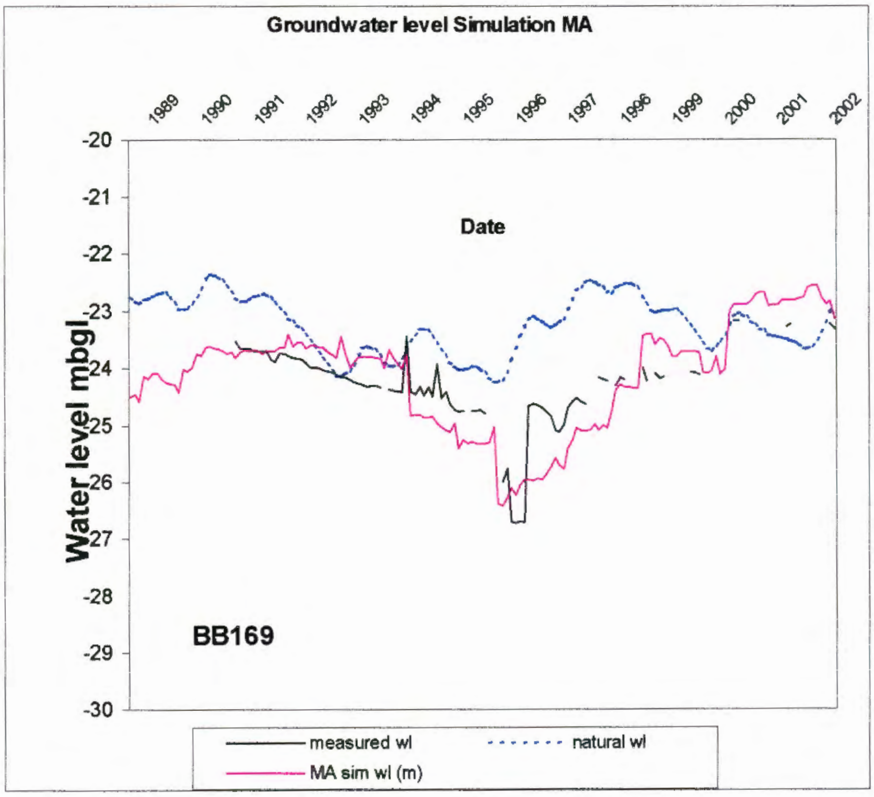

Groundwater level Simulation CRD
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
Date
Water level mbgl
-25
-26
-27
-28
-29
-30
-31
-32
-33
-34
-35
BB167
measured wl
CRD simulated wl
natural wl

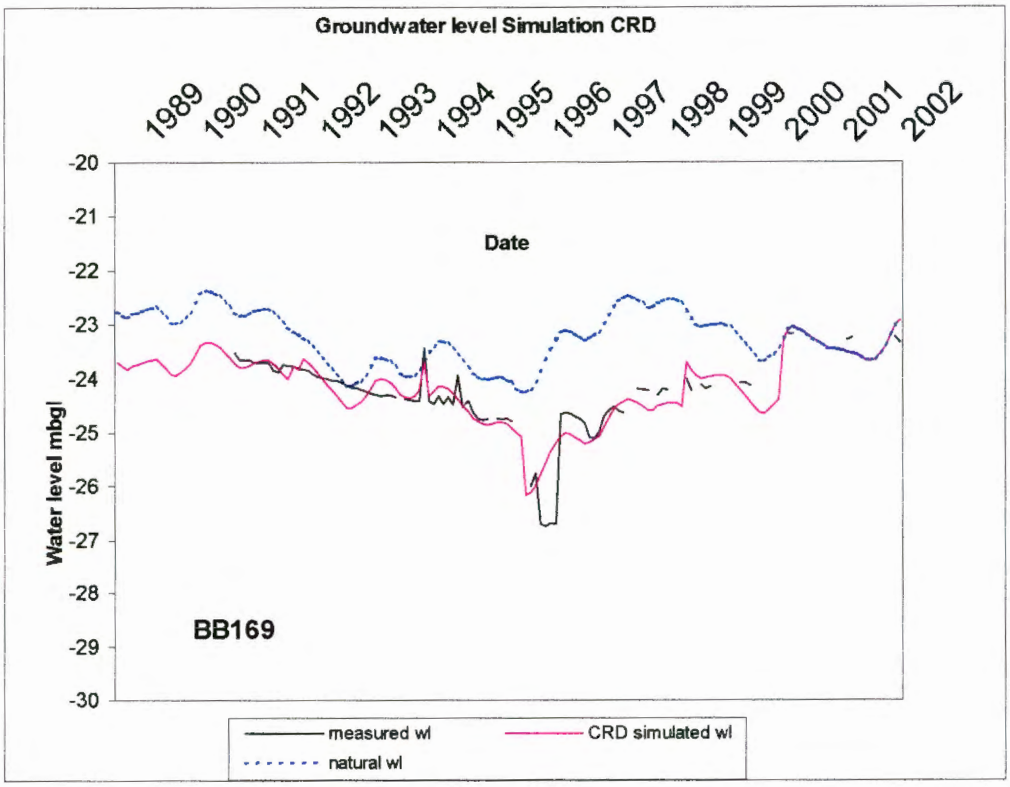
2626BB168


Groundwater level Simulation MA
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
Date
Water level mbgl
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
BB168
measured wl
natural wl
MA sim wl (m)

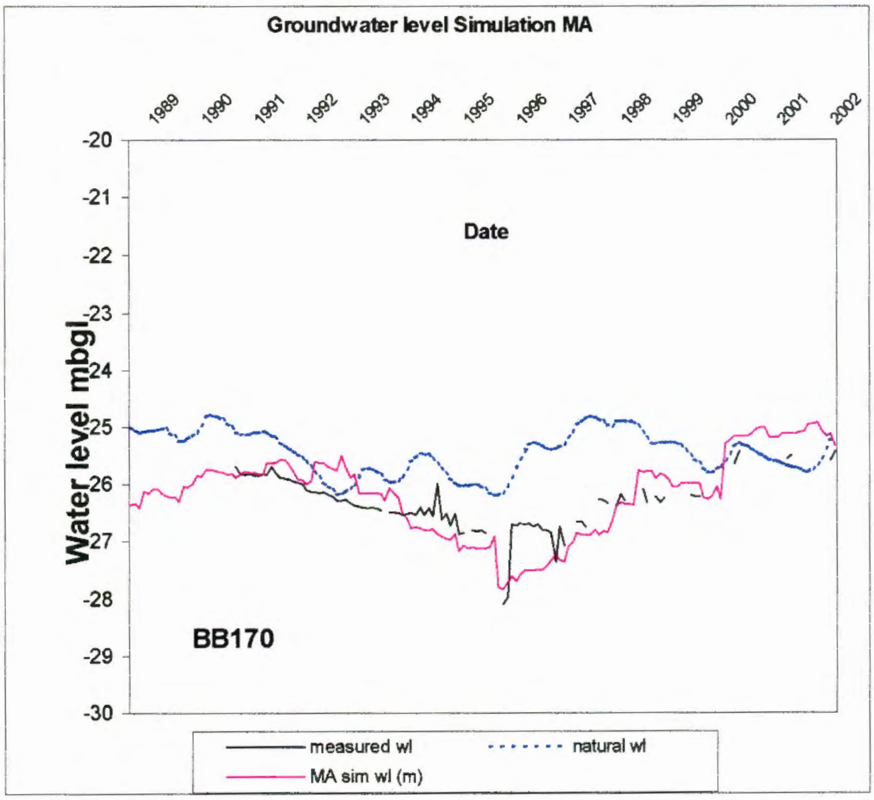

Groundwater level Simulation CRD
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
Date
Water level mbgl
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
BB168
measured wl
CRD simulated wl
natural wl

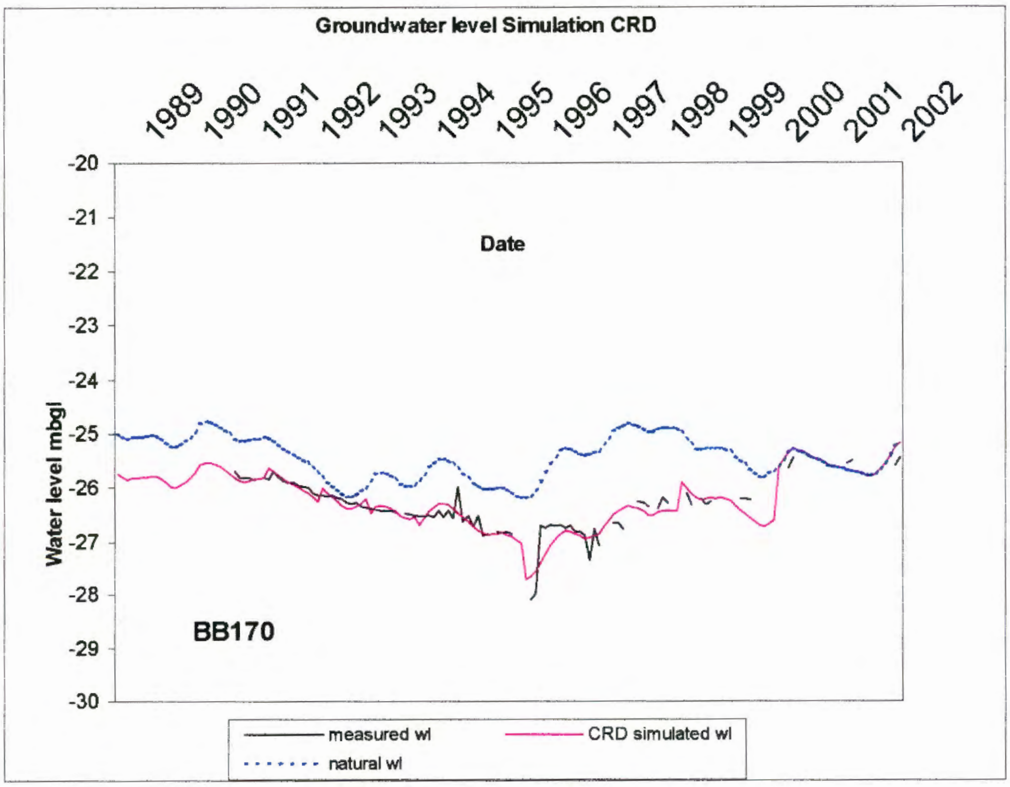
2626BB169


Groundwater level Simulation MA
1989
1990
1991
1992
1993
1994
1995
1996
1997
1996
1999
2000
2001
2002
Date
Water level mbgl
-20
-21
-22
-23
-24
-25
-26
-27
-28
-29
-30
BB169
measured wl
natural wl
MA sim wl (m)


Groundwater level Simulation CRD
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
Date
Water level mbgl
-20
-21
-22
-23
-24
-25
-26
-27
-28
-29
-30
BB169
measured wl
CRD simulated wl
natural wl

2626BB170


Groundwater level Simulation MA
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
Date
Water level mbgl
-20
-21
-22
-23
-24
-25
-26
-27
-28
-29
-30
BB170
measured wl
natural wl
MA sim wl (m)


Groundwater level Simulation CRD
1989
1990
1991
1992
1993
1994
1995
1996
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1998
1999
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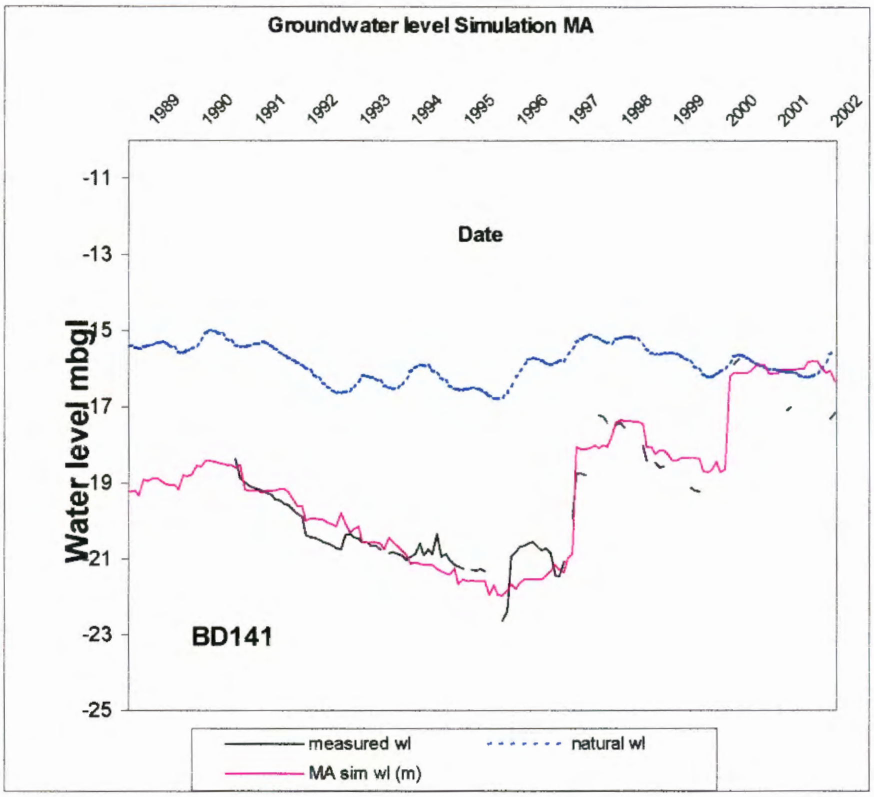
2001
2002
Date
Water level mbgl
-20
-21
-22
-23
-24
-25
-26
-27
-28
-29
-30
BB170
measured wl
CRD simulated wl
natural wl

2626BD141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1990
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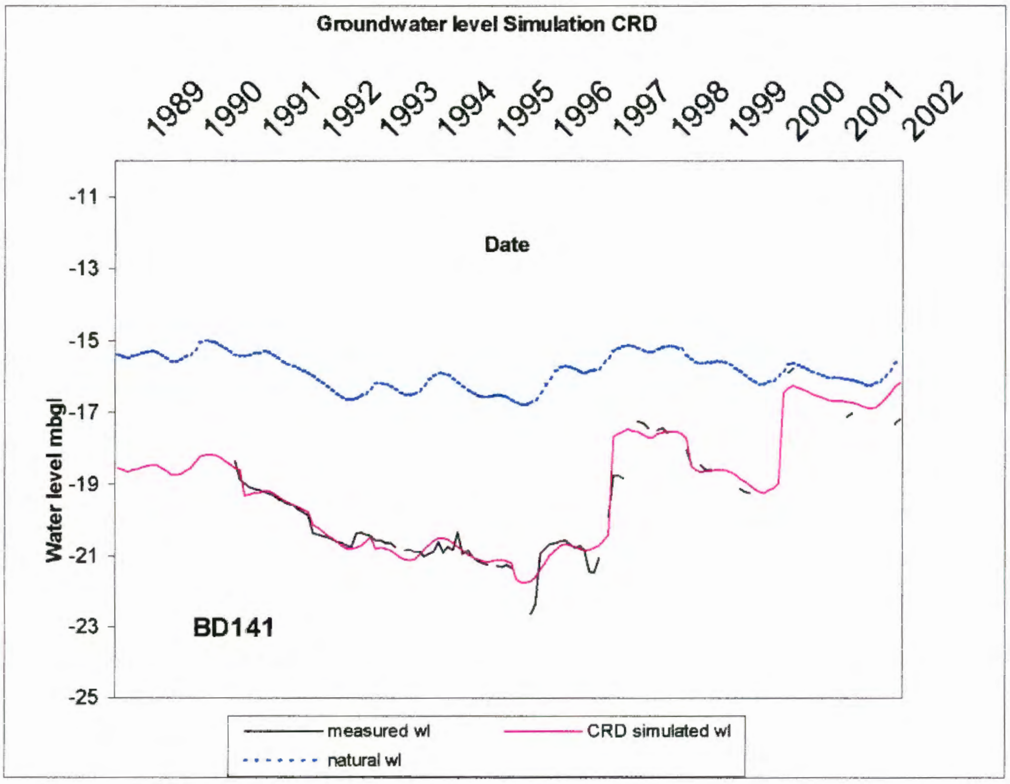
Date
Water level mbgl
-11
-13
-15
-17
-19
-21
-23
-25
BD141
measured wl
natural wl
MA sim wl (m)


Groundwater level Simulation CRD
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Date
Water level mbgl
-11
-13
-15
-17
-19
-21
-23
-25
BD141
measured wl
CRD simulated wl
natural wl

12 APPENDIX E

THE SOUTH AFRICAN AQUIFER SYSTEM MANAGEMENT CLASSIFICATION

Parsons (1995)

The South African Aquifer System Management Classification

Five major classes present the South African Aquifer System Management Classification: (Parsons, 1995)

Sole Source Aquifer System

Major Aquifer System

Minor Aquifer System

Non- Aquifer System

Special Aquifer System

The definitions of the Aquifer Systems being as follows: (Parsons, 1995)

Sole Source "An aquifer which is used to supply 50% or more of domestic water for a given area, and for which there are no reasonable alternative sources available should the aquifer be impacted upon or depleted."

Major "Highly permeable formations, usually with a known or probable presence of significant fracturing (or high porosity). They may be highly productive and able to support large abstractions for public supply and other purposes. Water quality is generally very good."

Minor " Fractured or potentially fractured rocks which do not have a high primary permeability, or other formations of variable permeability. Aquifer extent may be limited and water quality variable. Although these aquifers seldom produce large quantities of water, they are important both for local supplies and in supplying base flow to rivers."

Non-Aquifer "Formations with negligible permeability that are generally regarded as not containing groundwater in exploitable quantities. Water quality may also render these aquifers unusable. However, groundwater flow does take place and needs to be considered when assessing the risk associated with persistent pollutants."

Special "An aquifer designated as such by the Minister of Water Affairs & Forestry, after due process.

The weighting and rating approach was followed for defining the different classes. This can be seen in Table 24 and a second variable was introduced, which can be based on usage or aquifer vulnerability. These two ratings are then multiplied to give the Groundwater Quality Management Index (GQM Index), and can be seen in Table 25. (Parsons, 1995)

Table 24: Ratings for the aquifer quality management classification system (Parsons, 1995)

AQUIFER SYSTEM MANAGEMENT CLASSIFICATION		AQUIFER VULNERABILITY CLASSIFICATION	
Class	**Points**	**Class**	**Points**
Sole Source Aquifer System	6	High	3
Major Aquifer System	4	Medium	2
Minor Aquifer System	2	Low	1
Non-aquifer System	0		
Special Aquifer System	0-6		

Table 25: Appropriate level of groundwater protection required (Parsons, 1995)

GQM INDEX	LEVEL OF PROTECTION
<1	Limited protection
1-3	Low Level protection
3-6	Medium level protection
6-10	High level protection
>10	Strictly non-degradation

The GQM Index therefore gives the relative level of protection required for the aquifer, upon which management decisions should be made.

The scale of interest and the information available for the resource, should guide the application of this system and a degree of flexibility is necessary. Special status, however, should only be designated to an aquifer after careful consideration of the facts and consequences of such a decision, and a full EIA is necessary in these circumstances. (Parsons, 1995)

13 APPENDIX F

IMPACTS ON WATER QUALITY

Irrigation

The main impacts of irrigation on groundwater are: (Colvin, 2000)

- Increased salinity, e.g. salt in irrigation water or mobilisation of salts in unsaturated zone.
- Declining water levels where groundwater is used to irrigate.
- Rising water levels where surface water is used, sometimes to the point of waterlogging the surface.
- Leaching of other agricultural contaminants, such as nitrate from fertiliser and pesticides.

Soil and groundwater salinization is the most common problems. Irrigation water always contains some salt. Evapotranspiration will consume some of the water but not the salt, thereby concentrating salt in the remaining soil water. The source of salts leached to the groundwater may not be the salt in irrigation water, but salts occurring naturally in the soil. Declining water levels occur in areas where the groundwater abstracted is not sustainable and means that groundwater are being abstracted faster than it can be replenished. There is a far higher risk of groundwater contamination in irrigated areas with significant percolation to the water table. (Colvin, 2000)

Salinization of soils should be minimised by reducing over-irrigation and leakages from dams or canals, application of better quality irrigation water, artificial drainage in areas of poor drainage and the choice of land and land development could also play a role. (Conrad et al, 1999)

Fertilisers

Carbon, hydrogen and oxygen are required for plant growth and are usually abundant in the atmosphere, soil and water. Nitrogen, phosphorus and potassium are also essential for plant growth, but become depleted in soil that supports intensive crop farming. The main risk to groundwater from the use of fertilisers is nitrate contamination. Nitrate is the most soluble nutrient supplied by inorganic fertilisers and therefore the most likely to be leached to the water table. (Colvin, 2000)

A good system for fertiliser application is necessary to minimise its impacts on seepage to groundwater. Such a system should include factors such as: when the crop requires fertiliser and at what rates. This requires working out the nitrogen balance for a crop and can be a complicated procedure. Direct contamination of the borehole can occur when the fertiliser is mixed within 15m of the borehole and applied within 50m of the borehole. These actions should always be performed further than the specified distances from the borehole. (Conrad et al, 1999)

Animal waste

The main environmental impact of intensive animal husbandry (IAH, e.g. feeding stalls and battery farming) is the large volume of animal waste that is produced, concentrated in a limited area. Nitrate is the most widespread groundwater contaminant associated with IFE. Nitrogen contained in urea, ammonium and the organic matter in manure is converted to nitrate under certain conditions in the soil. This may then be leached to vulnerable groundwater during periods of rainfall or irrigation. Animal effluents typically have TDS levels of 3000 – 15000 mg/l. This is much higher than the TDS of fresh groundwater; therefore an increase in salinity will be seen with contamination. The high levels of nutrients contained in animal wastes lead to an increase in the biological oxygen demand (BOD) of the water and disrupts the balance of aquatic ecosystems. Micro-organisms are present in animal excreta, but do not usually represent a major risk to groundwater quality, because of the long retention time in soils and the organisms are 'sieved' by the soil. However, where fractures or cracks exist, or where the soil is very sandy with little clay and organic matter, micro-organisms may reach the water table. (Colvin, 2000)

IAH (intensive animal husbandry) can be minimised by harnessing natural processes, such as self-sealing of effluent ponds or lagoons because of the accumulation of solids and clogging of pores by bacterial cells and fine organic matter. Where self-sealing is not possible, such as in areas of coarse sands, fractures or fissures, artificial linings are required for effluent ponds and lagoons. (Conrad et al, 1999)

In the case of feedlots, an impermeable layer of manure and clay may form, and care should be taken not to remove this layer when removing excess manure. Correct siting of feedlot pads with good storm water drainage also minimises its impacts to a great extent. (Conrad et al, 1999)

Leaching from urine patches on pastures is also a significant contributor in seepage to groundwater and therefore the carrying capacity of a pasture should not be exceeded. General good practice includes maintaining a grass or plant buffer between IAH and surface water features, where effluent manure should be kept away from the buffer zone. (Conrad et al, 1999)

Sewage sludge

Sewage sludge is a semi-solid waste produced by the treatment of wastewater. It is used in many countries as a soil conditioner and fertiliser. Sludge also provides some essential micro-nutrients (zinc, copper, molybdenum, iron and manganese) most of which are not common in fertilisers. The main hazards to human and livestock are the introduction of potentially toxic substances and pathogenic micro-organisms to the food chain. Nitrate is the most common groundwater contaminant from sludge. Nitrogen is found in sludge as part of organic matter and as ammonium. Heavy metals and phosphorus are not very soluble and tend to accumulate in the soil. Pathogenic micro-organisms are usually killed off during treatment of the sludge or when they are exposed to sunlight. (Colvin, 2000)

The maximum rate of sludge application is given as 8t(dry mass)/ha/a and where heavy metals are introduced this rate should be diminished. Sludge should also not be applied to soils with a pH of less than 6 and application to agricultural land should be according to crop requirements. (Conrad et al, 1999)

Pesticides & herbicides

Other contaminants of concern are pesticides and herbicides. Pesticides are toxic compounds used to control weeds (herbicides), insects (insecticides), fungi, algae, etc. Pesticides tend to be highly toxic, therefore the maximum allowable concentrations (2ppb or 2μg/l) recommended for drinking water is very low. Contamination occurs both from the large areas of application and from point sources, where pesticides are spilt or disposed of. Very few laboratories in South Africa have the capacity to analyse water samples for pesticides. Careful management is required both in the field and where pesticides are stored and handled. (Colvin, 2000)

Pesticides and herbicides should never be over-applied and the recommended dosages used. Spray equipment should be calibrated regularly. During cooler, dryer periods it may even be possible to attain the same effectiveness with a lower dose. Rain wash the material to the ground and application before heavy rainfall should be avoided. The same distances of mixing and application from the borehole apply, as with fertiliser application. Pesticide and herbicide containers and excess mixtures should be disposed of responsibly at a licensed facility. (Conrad et al, 1999)

14 APPENDIX G

STEPS TO FOLLOW TO OBTAIN A GROUNDWATER SAMPLE

Colvin (2000)

Steps to follow to obtain a groundwater sample

Eight simple steps should be followed to obtain a worthwhile groundwater sample (Colvin, 2000):

- Choose your laboratory – make sure it is reputable, carries out SABS analyses and preferably takes part in the national accreditation scheme.
- Confirm with the laboratory the tests you would like to have carried out, how much sample they require, whether they will supply you with sterile sampling bottles and when they can receive them.
- The borehole should be pumped for at least half an hour to obtain a sample, which is representative of water in the aquifer, not water that is standing in the well.
- The sample should be taken as close to the wellhead as possible, preferably at the wellhead and certainly not from a storage tank where it will mix with standing water.
- For TDS and nitrate analyses, collect one litre of water in containers that have been rinsed several times with the water to be sampled.
- For microbiological analyses it will be necessary to obtain a sterilised sample jar from the laboratory. Do not touch the inside of the container or its lid, as this will introduce microbes to the sample.
- Once the samples have been taken, keep them in a fridge or cool box with freezer blocks.
- Submit the samples to a laboratory within 24 hours if possible.

15 APPENDIX H

AIMS, FUNCTIONS AND DELEGATED POWERS APPLIED FOR BY THE VENTERSDORP_DOLOMITE WUA

AIMS

The objects of the Association in the area of operation are:

(a) to exercise control and management over the use of water from and on the Schoonspruit – Dolomitic Compartment. The control and management will take place according to entitlements as set out in Article 28 of the Water Act (Act 54 of 1956) and Articles 22(1) and 32(a) of the National Water Act (Act 36 of 1998) (see Annexure A 1.1);

(b) to see to it in general that water is abstracted and used according to entitlements as set out in Article 22(2);

(c) should there be a need, the institution and/or continuation of sub-areas, each with its own management committee to manage the domestic matters of the sub-area;

(d) to exercise cost accounting from the user and/or user groups;

(e) to realize the total grant and accounting of costs;

(f) differentiated determination of costs according to extraction method;

(g) to promote co-operation with neighbouring Water User Associations or private individual subterranean water users.

FUNCTIONS

The principal functions to be performed by the association in its area of operation are:

(a) to prevent water from any water resource and waterworks being wasted – for purposes of this constitution boreholes, dams, pipelines, pumps, all irrigation systems as pivots, dripper lines and net houses will be regarded as waterworks;

(b) to protect the Schoonspruit Dolomitic Compartment as underground water source;

(c) to prevent any unlawful water use;

(d) to remove or arrange to remove any obstruction unlawfully placed in a watercourse or waterworks;

(e) to prevent any unlawful act likely to reduce the quality of water in any water resource or waterworks;

(f) to exercise general supervision over water resources and waterworks;

(g) to manage and regulate the flow of any watercourse or waterworks by –

  (1) clearing its channel;

  (2) reducing the risk of damage to the land in the event of floods;

  (3) changing a water course back to its previous course where it has been altered through natural causes;

(h) to manage, regulate and conserve the abstraction of water from the Schoonspruit Dolomitic Compartment

  (i) to investigate and record –

    (1) the water level readings of boreholes in the area of operation of the water resource;

    (2) the times when; and

    (3) the place where water may be used by any person entitled to use water from a water resource or waterworks.

(j) to construct, purchase or otherwise acquire, manage, operate and maintain waterworks considered to be necessary for-

  (1) draining land and

  (2) supplying water to land for irrigation or other purposes;

(k) to establish the equitable division, distribution and use of water from a water resource and to regulate it according to the relevant water use entitlements, by erecting and maintaining devices, or requiring members to erect and maintain devices at their own expenses, for –

  (1) measuring of water levels and dividing; or

  (2) controlling total abstraction rates/volumes from boreholes in the Schoonspruit Dolomitic Water Resource;

(l) to suspend or reduce the abstraction of water from waterworks or water resources under its control in so far as it is needed for the execution of any of the functions or for reasons required for the proper operation and protection of the water work and water resource;

(m) The entitlements of this Association and its members as currently registered are the status quo, although it do not establish any rights, and are only negotiable if a exhaustive completed water management plan is submitted which will serve as basis for any further negotiation to ensure members of the Association of equitable division of available water;

(n) To urge this Association and its members to be sensitive towards management practices in respect of conservation and sustainability of the source and finally the application thereof.

The Association may perform functions other than its principal functions only if it is not likely –

(a) to limit the Associations capacity to perform its principal functions; and

(b) to be to the financial prejudice of itself or its members.

Other functions of the Association can include:

(a) The provision of management services, training and other supportive services to-

  (1) Water service institutions;

  (2) Rural communities;

  (3) Water users and

  (4) Emerging farmers (men as well as women).

(b) Agreement of co-operation can be established with the Klerksdorp Irrigation Board and the Schoonspruit Water User Association.

APPLICATION FOR POWERS AND COMPETENCIES, WHICH CAN POSSIBLY BE DELEGATED, TO WATER USER ASSOCIATIONS

The following is a list of powers and competencies, which are being referred to in the National Water Act, 1998, which can possibly by application be delegated to Water User Associations regarding only their operational areas:

1) Article 53(1): To notify in writing a person who contravenes –

(a) any provision of Chapter 4 of the Act;

(b) a requirement set or directive given by the responsible authority under chapter 4 of the Act; or

(c) a condition which applies to any authority to use water, direct that person, or the owner of the property in relation to which the contravention occurs, to take any action specified in the notice to rectify the contravention, within the time (being not less than two days) specified in the notice or any other longer time allowed by the responsible authority.

2) Article 53(2): If the action is not taken within the time specified in the notice, or any longer time allowed, the responsible authority may -

(a) carry out any works and take any other action necessary to rectify the contravention and recover its reasonable costs from the person on whom the notice was served; or

(b) apply to competent court for appropriate relief.

3) Article 54(1): Subject to subsections 54(3) and 54(4), a responsible authority may by notice to any person entitled to use water under this Act suspend or withdraw the entitlement if the person fails -

(a) to comply with any condition of the entitlement;

(b) to comply with this Act; or

(c) to pay a charge which is payable in terms of Chapter 5.

4) Schedule 3

Item 2: A Water User Association may –

(a) manage and monitor permitted water use within its water management area;

(b) conserve and protect the water resources and resource quality within its water management area;

(c) subject to the provisions of the Act, develop and operate a waterwork in the furtherance of its functions;

(d) do anything necessary to implement catchment management strategies within its water management area; and

(e) by notice to a person taking water, and after having given that person a reasonable opportunity to be heard, limit the taking in terms of Schedule 1.

Item 3: Subject to sub-items 3(2), 3(5) and 3(6) a water user association may make rules to regulate water use.

Item 4(1): A water user association may require in writing that a water user –

(a) install a recording or monitoring device to monitor storing, abstraction and use of water;

(b) establish links with any monitoring or management system to monitor storing, abstraction and use of water; and

(c) keep records on the storing, abstraction and use of water and submit the records to the water user association.

Item 4(2): If the water user fails to comply with a requirement of item 4(1), a water user association may undertake the installation or establishment of such links and recover any reasonable cost from that water user.

Item 5(1): A water user association may, by written notice to the owner or person in control of a waterwork, require that person to collect and submit particular information within the period specified to enable the water user association to determine whether that waterwork is constructed, maintained and operated in accordance with the Act.

Item 5(2): Subject to Item 5(3), a water user association may direct the owner or person in control of a waterwork at the owner's own cost and within a specified period, to

(a) undertake specific alterations to the waterwork;

(b) install a specific device; or

(c) demolish, remove or alter the waterwork or render the waterwork inoperable in a manner specified in the directive.

Item 5(4): If the owner fails to comply with a directive, to

(a) undertake the alterations;

(b) install the device; or

(c) demolish, remove or alter the waterwork or render the waterwork inoperable, and recover any reasonable costs from the person to whom the directive was issued.

Item 6(1): In case of a water shortage within its operational area and subject to Item 6(2) and Item 6(3) of Schedule 3, by notice in the Gazette or by written notice to each of the water users in the area who are likely to be affected –

(a) limit or prohibit the use of water;

(b) require any person to release stored water under that person's control;

(c) prohibit the use of any waterwork and

(d) require specified water conservation measures to be taken.

Item 6(4): If the owner or person in control of a waterwork contravenes a notice issued under sub-item (1), to –

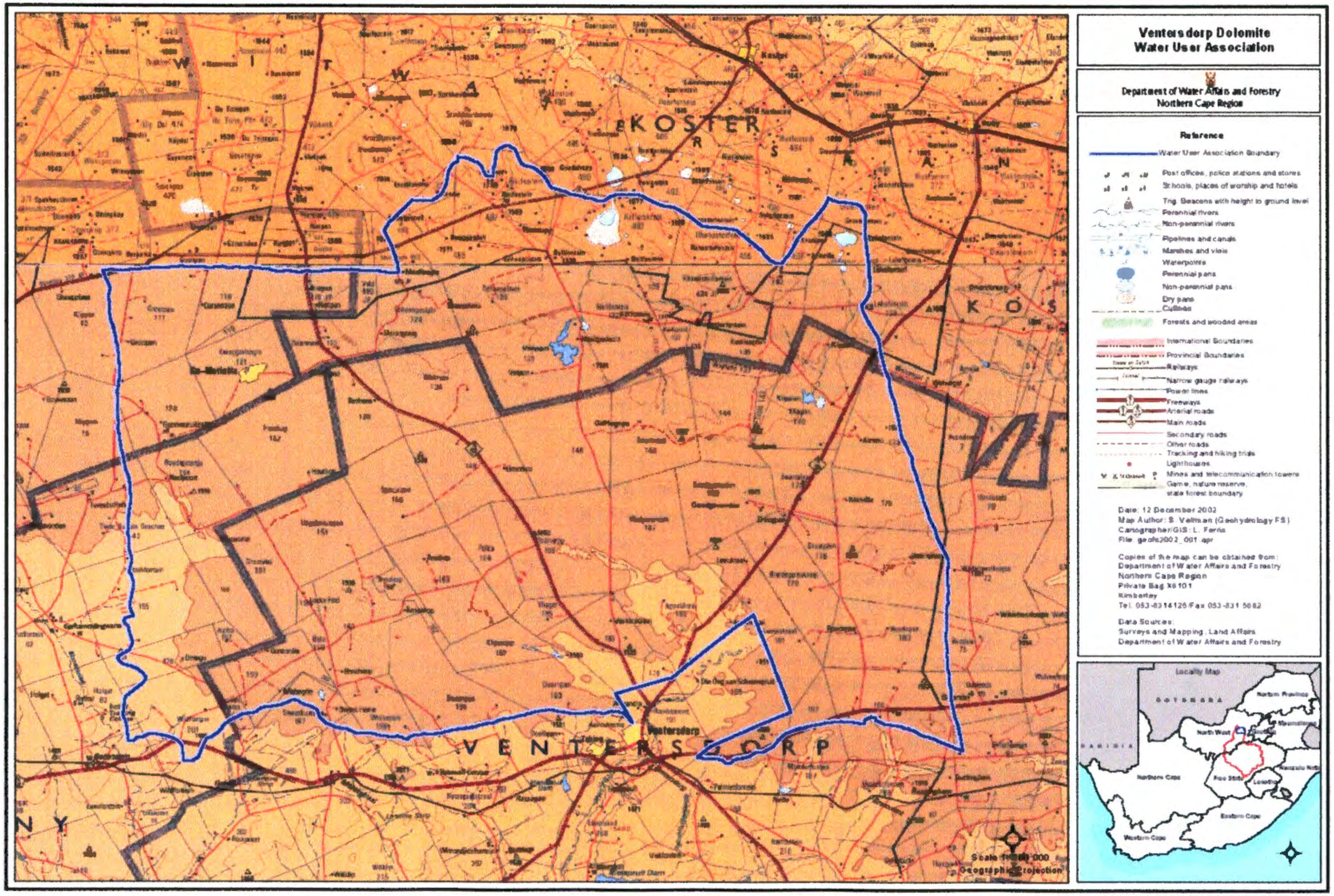
(a) modify, or require the owner of the waterwork to modify the waterwork so that it cannot be used to take more water than that allowed for in the notice; or

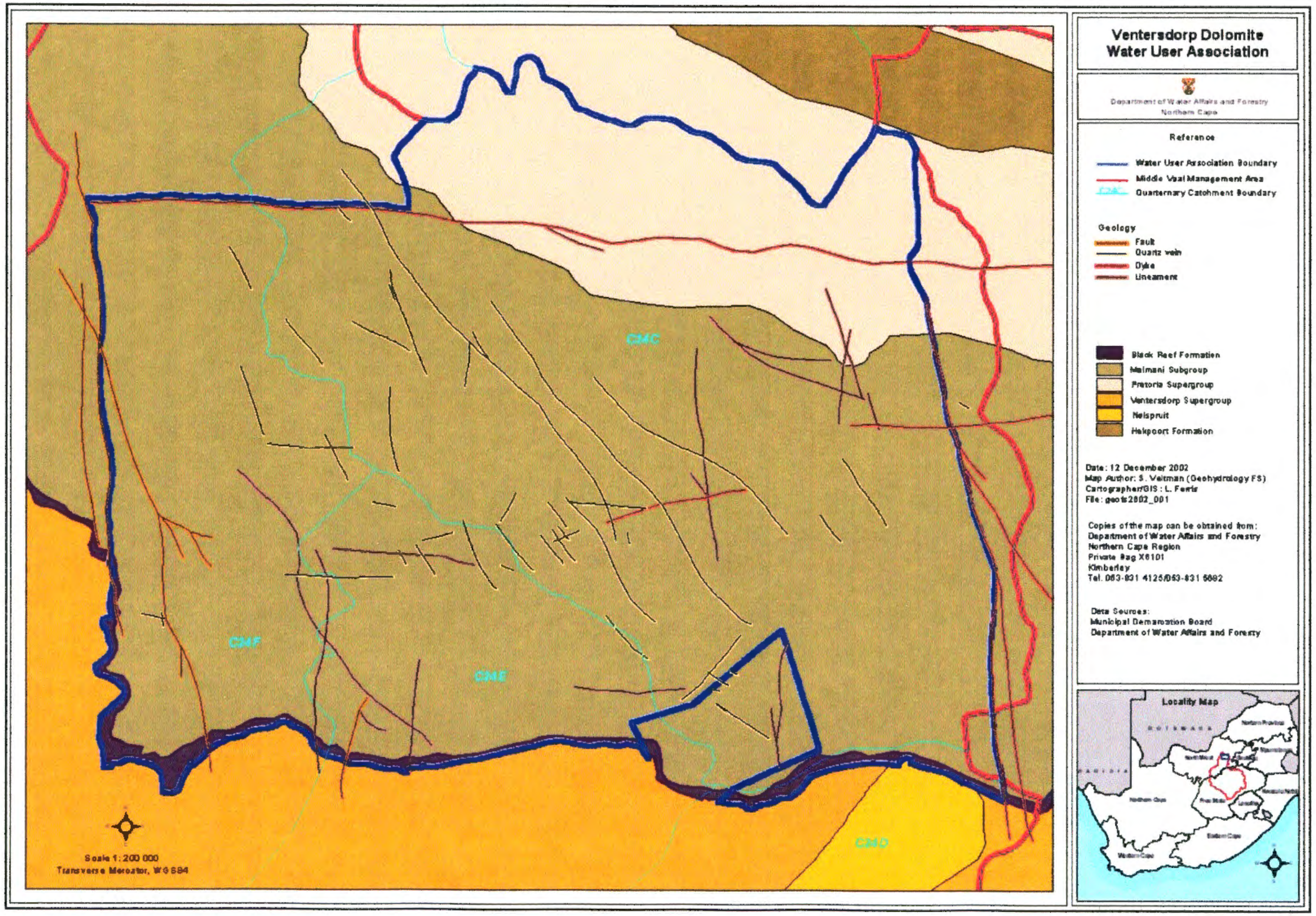
(b) remove the waterwork or require the owner to remove the waterwork if the notice contains a prohibition on the use of that waterwork.

Item 6(5): To recover any reasonable costs from the owner incurred by it in acting under sub-item 6(4).

16 APPENDIX I

AREA OF OPERATION OF THE VENTERSDORP_DOLOMITE WUA


Ventersdorp Dolomite
Water User Association
Department of Water Affairs and Forestry
Northern Cape Region
Reference
Water User Association Boundary
Post offices, police stations and stores
Schools, places of worship and hotels
Trig. Beacons with height to ground level
Perennial rivers
Non-perennial rivers
Pipelines and canals
Marshes and vleis
Waterpoints
Perennial pans
Non-perennial pans
Dry pans
Cutlines
Forests and wooded areas
International Boundaries
Provincial Boundaries
Railways
Narrow gauge railways
Power lines
Freeways
Arterial roads
Main roads
Secondary roads
Other roads
Tracking and hiking trials
Lighthouses
Mines and telecommunication towers
Game, nature reserve,
state forest boundary
Date: 12 December 2002
Map Author: S. Veltman (Geohydrology FS)
Cartographer/GIS: L. Ferris
File: geofs2002_001.apr
Copies of the map can be obtained from:
Department of Water Affairs and Forestry
Northern Cape Region
Private Bag X6101
Kimberley
Tel. 053-8314126/Fax 053-831 5682
Data Sources:
Surveys and Mapping, Land Affairs
Department of Water Affairs and Forestry
Locality Map
BOTSWANA
NAMIBIA
Northern Province
Mpumalanga
North West
Gauteng
Northern Cape
Free State
KwaZulu Natal
Lesotho
Eastern Cape
Western Cape
KOSTER
VENTERSDORP
Ventersdorp
Koster
Geographic Projection


Ventersdorp Dolomite
Water User Association
Department of Water Affairs and Forestry
Northern Cape
Reference
Water User Association Boundary
Middle Vaal Management Area
C24C
Quarternary Catchment Boundary
Geology
Fault
Quartz vein
Dyke
Lineament
Black Reef Formation
Malmani Subgroup
Pretoria Supergroup
Ventersdorp Supergroup
Nelspruit
Hekpoort Formation
Date: 12 December 2002
Map Author: S. Veltman (Geohydrology FS)
Cartographer/GIS: L. Ferris
File: geots2002_001
Copies of the map can be obtained from:
Department of Water Affairs and Forestry
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Private Bag X6101
Kimberley
Tel. 053-831 4125/053-831 5692
Data Sources:
Municipal Demarcation Board
Department of Water Affairs and Forestry
Locality Map
BOTSWANA
NAMIBIA
Northern Province
North West
Northern Cape
Free State
Lesotho
Eastern Cape
Western Cape
C24C
C24D
C24E
C24F
Scale 1:200 000
Transverse Mercator, WGS84

Abstract

The thesis proposed to use the principle of *prior conceptual model explanation (PCME)* by LeGrand & Rosen, 2000, as base to develop a technical methodology towards groundwater management in dolomitic terrains, with the development of a groundwater management tool. The Schoonspruit Dolomitic Compartment was used as case study to evaluate the aquifer with current information, test the developed methodology on and develop a technical groundwater management tool. A phased approach was adopted with a geohydrological assessment of the study area as phase 1 and the development of a technical methodology and the development of the groundwater management tool as phase 2.

The aim of the geohydrological assessment was the use of the PCME approach, basic geohydrological principles and previous studies to evaluate the current status of the aquifer. This was done with a description of current information and an evaluation of new information and data.

The Schoonspruit Dolomitic Compartment is a dolomitic aquifer situated to the North and Northwest of the town Ventersdorp in the Northwest Province, South Africa. The compartment has been named after the Schoonspruit Eye, which is dependent on the compartment for flow. The Schoonspruit Eye, in turn, is the sole reason why the Schoonspruit has a constant flow and provides a municipality and two surface water irrigation boards with surface water all year round.

Several water users abstract groundwater from the compartment impacting on the flow of the Schoonspruit Eye. With the proclamation of The National Water Act, Act 36 of 1998, groundwater was seen as a resource that needed management and, although very little information existed in most cases, Regional Offices of the DWAF, had to start taking decisions, based on sound scientific principles, as to allocable volumes from the groundwater resources.

The Schoonspruit dolomitic regime were defined, aquifer characteristics determined, groundwater quality quantified and recharge/rainfall relationships of groundwater levels and spring flow determined with the saturated volume fluctuation (SVF), moving average (MA) and cumulative rainfall departure (CRD) methods. Two zones were identified as groundwater management units in the compartment and groundwater balances for the two zones defined. The spring flow simulation equation was determined for use in all simulations related to the drainage area of the Schoonspruit Eye.

The aim of the technical methodology was to provide a technical framework, which could easily be extrapolated and applied to other dolomitic areas. The methodology distinguished between essential and supplementary information needed for groundwater management in dolomitic areas.

A flowchart was developed, as blueprint, when assessing dolomitic areas for the purpose of groundwater management, an overview given with regard to the legal and institutional principles that should be applied in such areas, a detailed description given with regard to the geotechnical controls that govern the groundwater flow and characteristics in dolomitic areas and the basic principles governing the development of a groundwater management tool outlined, with input and output parameters defined.

The aim of the groundwater management tool was to provide a first order technical tool, which is practical and workable, for use by the Water User Association in determining allocable volumes. Input and output parameters used were proven to be sufficient for defining quantity and quality issues in the Schoonspruit Dolomitic Compartment.

Allocable volumes can be determined for the 2 zones and the Schoonspruit Eye flow simulated, with the MA method, using predicative rainfall data and the drinking water quality classes were introduced, as part of an early warning system, where drinking water quality is of concern.

Opsomming

Die thesis gebruik die beginsels van *prior conceptual model explanation (PCME)* van Legrand & Rosen, 2000, as basis om 'n tegniese metodologie te ontwikkel rakende grondwater bestuur in dolomitiese omgewings, asook die ontwikkeling van 'n grondwater bestuurstoestel. Die Schoonspruit Dolomitiese Kompartement was gebruik as gevalle studie om die akwifeer te evalueer met bestaande inligting, die metodologie op te toets en die tegniese grondwater bestuurstoestel te ontwikkel. Die thesis is in fases gedoen met die geohidrologiese ondersoek as fase 1 en die ontwikkeling van die tegniese metodologie en bestuurstoestel as fase 2.

Die doel van die geohidrologiese ondersoek was om die PCME benadering, basiese geohidrologiese beginsels en vorige studies te gebruik in 'n evaluasie van die huidige toestand van die akwifeer. Dit is bereik deur 'n beskrywing van bestaande inligting en die evaluasie van nuwe inligting en data.

Die Schoonspruit Dolomitiese Kompartement is 'n dolomitiese akwifeer wat Noord en Noordwes van die dorp Ventersdorp geleë is in die Noordwes Provinsie, Suid-Arika. Die kompartement is vernoem na die Schoonspruit Oog, wat afhanklik is van die kompartement vir oppervlak water vloei. Die Schoonspruit Oog is ook die rede hoekom die Schoonspruit 'n konstante vloei het en 'n munisipaliteit en twee oppervlak water besproeïngsskemas oppervlak water regdeur die jaar het.

Verskeie water gebruikers onttrek grondwater uit die kompartement en impakteer sodoende op die vloei van die Schoonspruit Oog. Met die proklamasies van die Nasional Waterwet, Wet 36 van 1998, is grondwater erken as 'n bron wat bestuur moes word en, alhoewel min inligting omtrent sekere areas bestaan het, moes Streeks Kantore van die DWAF begin besluite neem rakende beskikbare volumes vanaf grondwater bronne, gebaseer op wetenskaplike feite.

Die Schoonspruit dolomitiese omgewing is gedefinieer, akwifeer kenmerke bepaal, grondwater kwaliteit gekwantifiseer en aanvulling/reënval verhoudings van grondwater vlakke en fontein vloeie bepaal, met die versadigde volume fluktuasie (SVF), bewegende gemiddelde (MA) en kumulatiewe reënval afwyking (CRD) metodes. Twee sones is identifiseer as grondwater bestuurseenhede in die kompartement en grondwater balanse vir beide is bepaal. Die fontein simulasie vergelyking is bepaal, vir gebruik in alle simulasies wat met die dreinerings area van die Schoonspruit Oog te doen het.

Die doel van die tegniese metodologie was om 'n tegniese raamwerk te verskaf, wat maklik ekstrapoleer en toegepas kan word op ander dolomitiese areas. Die metodologie onderskei tussen noodsaaklike en opsionele inligting wat benodig word vir grondwater bestuur in dolomiete.

'n Vloeidiagram is ontwikkel as konsepmodel wanneer dolomitiese areas ondersoek word vir grondwater bestuurs doeleindes, 'n oorsig is gegee rakende wetlike en institusionele beginsels wat toegepas moet word, 'n gedetailleerde beskrywing is gegee van geotegniese kontroles wat grondwater vloei in sulke areas beheer en die kenmerke van dolomitiese areas en die basiese beginsels van die grondwater bestuurs toestel is verduidelik, met die invoer en produk parameters gedefinieer.

Die doel van die grondwater bestuurstoestel was om 'n eerste orde tegniese toestel te voorsien, wat prakties en werkbaar is, vir gebruik deur die Water Gebruikers Vereniging, vir die bepaling van beskikbare volumes vir water toekennings. Daar is bewys dat invoer en produk parameters voldoende is om die probleme rondom kwaliteit en kwantiteit in die kompartement te definieer.

Beskikbare volumes in die twee sones kan bepaal word en die Schoonspruit Oog fontein vloei simuleer word, met die MA metode, deur gebruik te maak van voorspelde reënval data. Die drinkwater kwaliteit klasse is in ag geneem, as deel van 'n vroeë waarskuwings stelsel, in areas waar drinkwater kwaliteit van belang is.