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ASSESSMENT OF THE GROUNDWATER POTENTIAL OF THE MIDDEL KOP/ APPLEBY AQUIFER, STELLA DISTRICT, NORTHWEST REGION

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ASSESSMENT OF THE GROUNDWATER POTENTIAL OF THE MIDDEL KOP/APPLEBY AQUIFER, STELLA DISTRICT, NORTHWEST REGION

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND TO THE STUDY

The Department of Water Affairs undertook a large-scale characterisation and mapping of groundwater occurrences of the Kalahari Group towards the end of the twentieth century. During the investigation Mr. Du Toit Appelcryn identified a granite formation in samples taken from a borehole of an area south-east of the town Stella, situated approximately 45 km NNE of Vryburg within the Northwest Province (Figure 1.1). The formation that was not mapped on geological maps of the area subsequently became known as the Appleby granite.

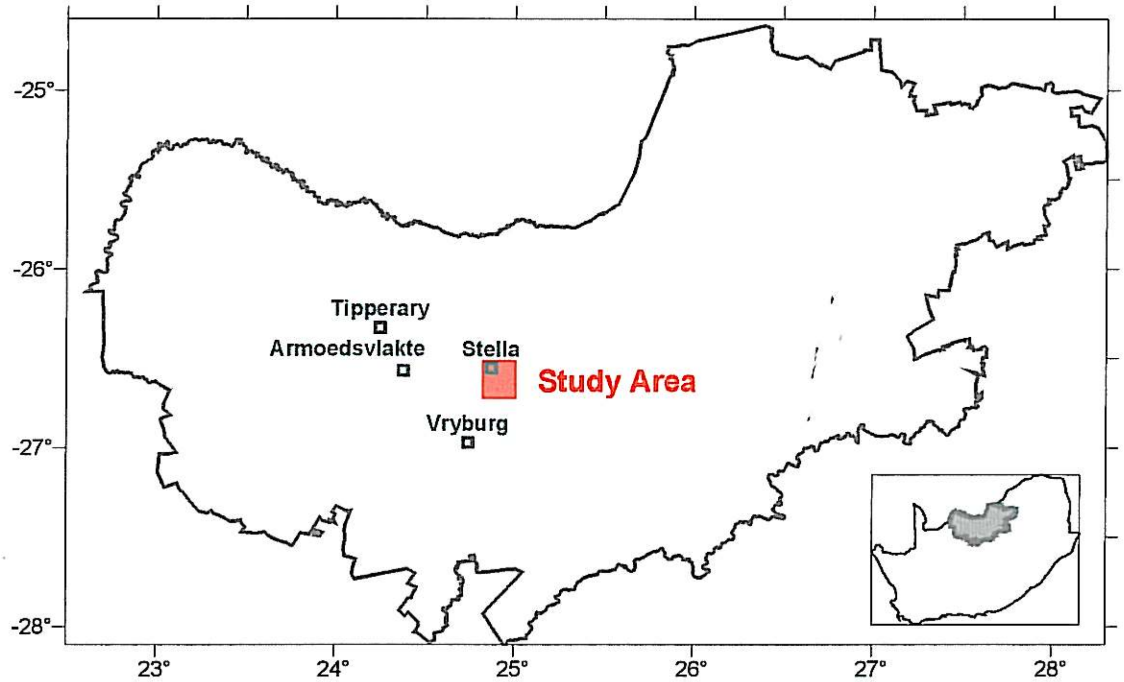

Figure 1.1 Location of the town Stella and the area considered in the investigation described here.

Farmers on the farm Middel Kop situated 5 km southeast of Stella, which is underlain by the Appleby granites, subsequently drilled several boreholes with high yields into the Appleby granites and started to irrigate 10 ha of agricultural land in 1990. The irrigated area steadily increased over the years and covered approximately 171 ha in 2000, an indication that the aquifer is well-developed in the granites. The Middel Kop/Appleby granite aquifer will henceforth be referred to as the *Middel Kop aquifer*.

The crops irrigated from the Middel Kop aquifer, mainly maize, paprika and potatoes create seasonal work opportunities for hundreds of people from the local communities. The rest of the agricultural sector at Stella concentrates largely on cattle farming with small-scale irrigation of lucerne and winter feeds for the cattle.

The town of Stella is a typical rural village with approximately 1 500 residents and no large-scale industries. The town depends entirely on an over-exploited well-field in the nearby Stella aquifer for its supply of water, which is barely able to supply the demands of the town.

The government of the Northwest Province allocated in 1999 a sum of money for the resettlement of approximately 2 000 additional people at Stella. It was thus necessary to locate additional source(s) of water, before continuing with the resettlement plans. The only significant surface water feature in the area is Soutpan that intercepts most of the run-off from the rainstorms over the catchment area, including the Middel Kop aquifer, only to evaporate very quickly. The water in the pan is consequently highly saline and not suitable for human consumption. The only remaining option was thus to look at the groundwater resources of the area.

A previous geophysical and drilling exploration project to try to alleviate the water shortages at Stella, concentrated on the Gold Ridge Formation near which the town is situated. However, the project was abandoned, because of the limited success close to the town and the costs involved in piping water from far-away boreholes.

The relatively large scale irrigation practised on the farm Middel Kop led to the belief that this aquifer may be able to supply the demand of water for Stella. A decision was consequently taken to investigate this aquifer in more detail. The farmers who noted a steady decline in the water levels of the aquifer at the same time approached the Department of Water Affairs and Forestry to help in evaluating of the potential of the aquifer. The area chosen for this study is shown in Figure 1.1.

1.2 OBJECTIVES OF THE STUDY

The importance of groundwater is strongly reflected in the new South African water policy and legislation. All water resources, including groundwater, are now seen as a national asset with the National Government as its custodian to ensure that the resources are protected, developed and managed properly according to principles described in the

National Water Act (Act 36 of 1998). These measures, known as *resource directed measures*, include:

(a) Classification of the resource

(b) Basic human needs and ecological reserve

(c) Resource quality objectives.

This assessment of the Middel Kop aquifer is consequently based on these measures to ensure the comprehensive protection of the resource for future generations. The study was consequently divided into two phases.

The first phase was to determine the potential of the aquifer to supply in the demand for water by the farmers and Stella. This involved a detailed study of the precipitation of the area together with the local and regional drainage characteristics of the area, which is discussed in Chapter 2. This was followed by a study of the geological and geohydrological characteristics of all the aquifers in the area and the area surrounding Stella, as discussed in Chapters 3 and 4 respectively. This information was then used to evaluate the groundwater potential of the area based on the following properties:

(a) The areal extent of the high yielding aquifers in the area.

(b) The fluctuation of groundwater levels with time.

(c) The estimation of recharge

(d) The different applications and volumes of groundwater used in the study area as well as the future needs of Stella.

(e) The groundwater quality and chemical characterisation of the water resources.

(f) The geohydrological boundaries of the aquifer.

The second objective of the study was to protect the resource for the benefit of future generations. This was done by applying the *resource directed measures* by means of an evaluation of the current classification, the reserve and resource quality objectives of the aquifer and are discussed in Chapter 6. The volume of water that is allocatable was determined considering the Reserve, the immediate and future requirements of Stella, as well as Schedule 1 use.

CHAPTER 2

HYDROLOGY

2.1 INTRODUCTION

The water balance in an ecological system is essentially controlled by the four major components of the hydrological cycle of the earth:

(a) Precipitation

(b) Surface run-off

(c) Infiltration

(d) Evapo-transpiration.

It is therefore essential to have a sufficient knowledge of these components when studying the water balance of an ecological system.

One difficulty experienced with the study of the water balance in a given system is the spatial and temporal variability of the components of the hydrological cycle. This is especially the case in semi-arid areas, such as the study area as well as arid areas. For example, a rainfall event close to a borehole may cause a temporary increase in its water level, but the long term behaviour of the water level will be more closely related to the rainfall over the whole area underlain by the aquifer in which the borehole is situated. It is consequently more useful to correlate the water levels in an aquifer with the average precipitation over the aquifer, or its immediate surroundings, rather than individual precipitation events. As shown in Section 2.2, this situation is often forced on the investigator by the absence of suitable precipitation data.

A surface drainage system has two major influences on the water balance of an ecological system. The first is that it can act as sources or sinks of an underlying aquifer, and the second that it can remove water from the system. For this reason the surface drainage systems are often considered as very important in water balance studies. The drainage system can however also affect the groundwater quality of an ecological system significantly. This situation often arises in semi-arid and arid areas where surface channels drain into a depression of the topography to form pans. The water in the pans then slowly evaporates with time and deposits of solids are formed. These solids may slowly migrate to an underlying aquifer. Drainage systems and their importance for the present study are discussed in Section 2.3.

2.2 PRECIPITATION

Precipitation data is available for the farm Middel Kop for the period 1980 to 1996. Current precipitation data in the Stella area is available for the Tipperary and Armoedsvlakte meteorological stations.

In Figure 2.1 the 12-month running average precipitation for the meteorological stations available in the Stella area is shown. The average yearly precipitation of the area is 408 mm per year with recorded low and high yearly precipitation being 180 mm and 788 mm respectively.

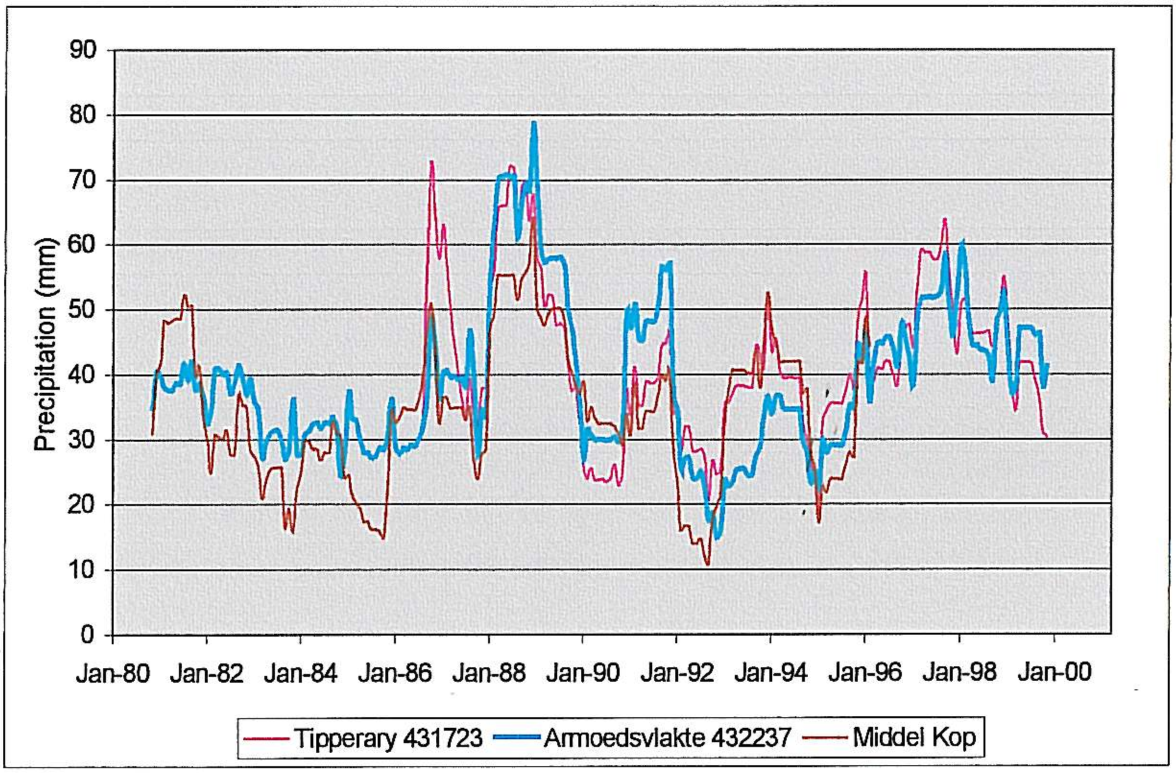

Figure 2.1 Graph representing the 12-month running average precipitation for the meteorological stations in the Stella area.

2.3 SURFACE WATER DRAINAGE

There is no usable surface water available in the Stella area. Some water accumulates in Soutpan after large precipitation events and lasts for a month or two, over which time the water evaporates.

The study area falls within the quaternary drainage region C32 (Dry Harts) (Figure 2.2). The study area is, however, very close to the surface water divide with the D41 drainage region. This limits the potential catchment area available for the generation of run-off and recharge. The only visible drainage channels are from the north towards Soutpan and from Spitskop towards the south, visible as a slight depression in the topography.

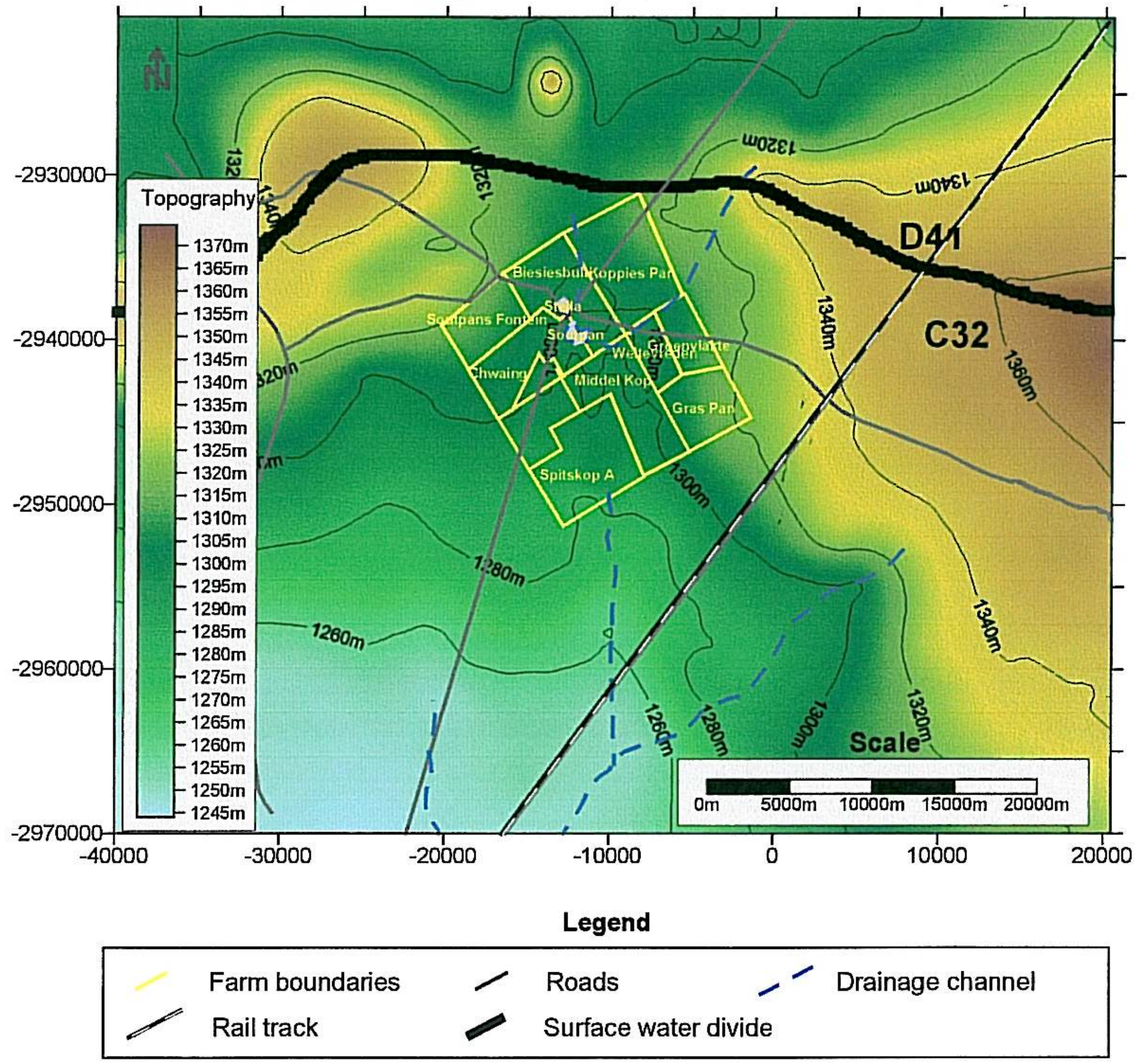

Figure 2.2 Topography in the Stella area giving an indication of the drainage of the area.

2.3.1 Local Drainage

Small pans are scattered all over the Middel Kop granitic aquifer and are visible from the aerial photo of the area (Figure 2.3). During precipitation events where run-off is generated water accumulates in these pans. The small surface pans are visible, especially in the undeveloped areas like the farm Spitskop A. These pans generally do not fill under current weather conditions with losses accounted for only by groundwater infiltration and evaporation. The influence of these pans on the geohydrology is discussed in Section 4.2.1.

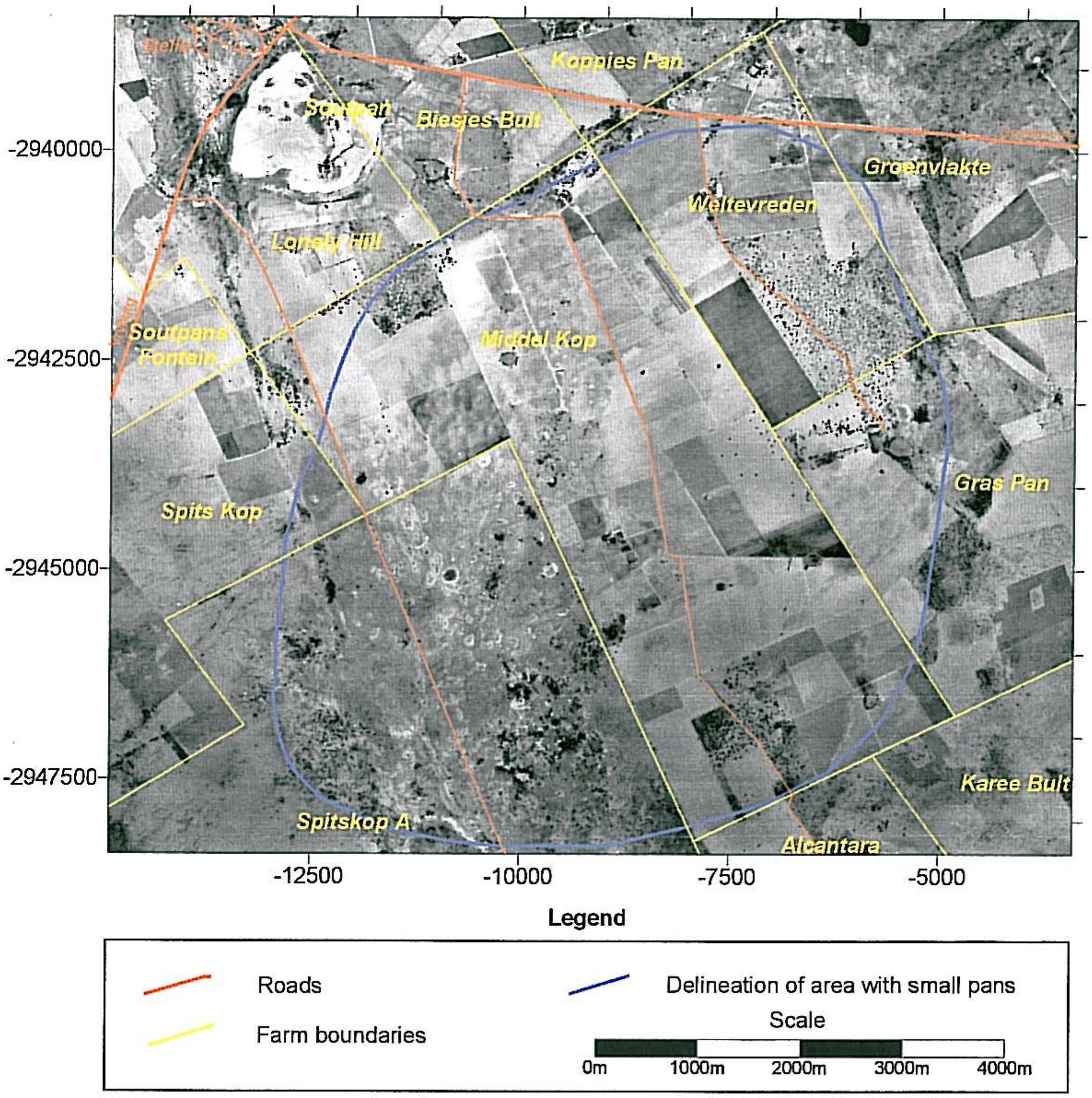

Figure 2.3 Aerial photo showing the delineation of small surface pans found on the Middel Kop aquifer.

During precipitation events, with high enough precipitation in order to generate surface water run-off, the run-off water from the north-east accumulates in the Soutpan south-east of Stella (Plate 2.1). These precipitation events also cause the accumulation of water in the small surface pans that are scattered all over the Middel Kop aquifer (Plate 2.2). The accumulation of water in these different pans results that no surface water contributions are made to any river from the Stella area.

Plate 2.1 Stella Soutpan where all surface water run-off from the north and west accumulates.

Plate 2.2 One of the small pans on the farm Spitskop.

2.4 EVAPO-TRANSPIRATION

The evaporation of water reduces the available water for use from land and water surfaces. Evaporation data from the Armoedsvlakte meteorological station about 50 km west of Stella is available. Open water evaporation from ponds, shallow pans and reservoirs can be estimated using A-pan evaporation and varies from between 223 to 438 mm month^{-1} in summer and 144 to 68 mm month^{-1} in winter (Figure 2.4) for the study area.

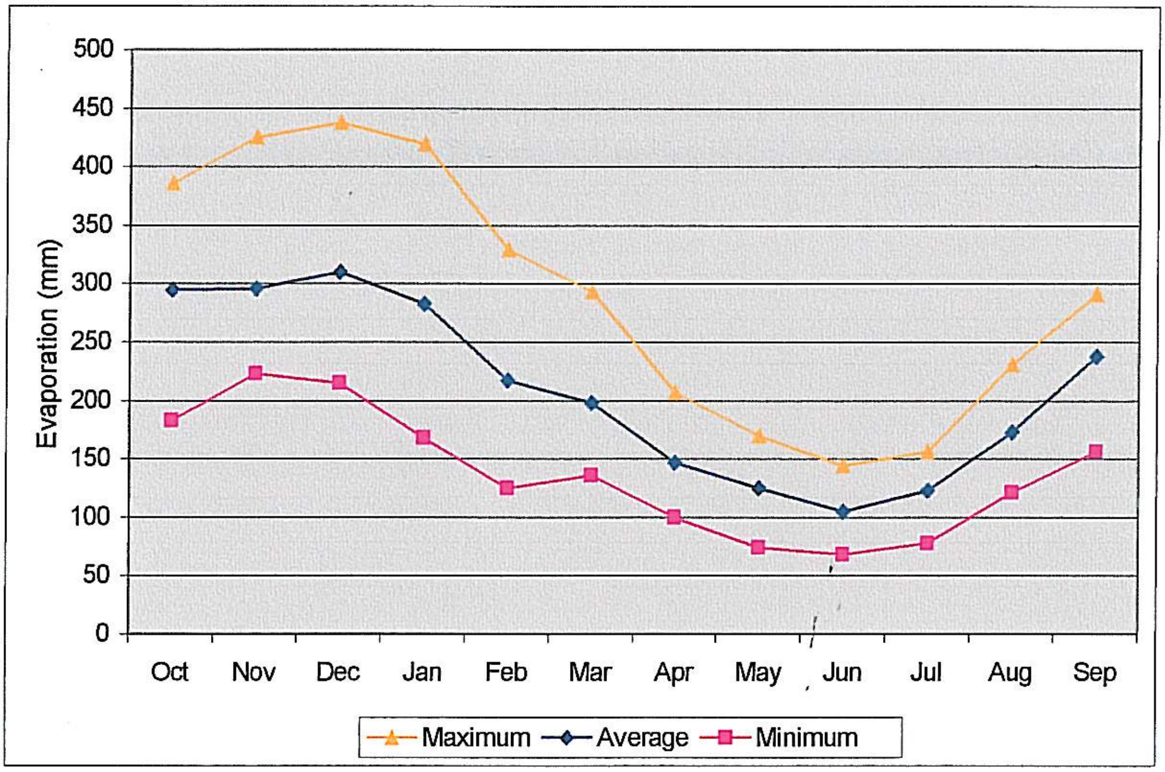

Figure 2.4 Estimated open water evaporation using A-pan evaporation measurements at the Armoedsvlakte meteorological station.

Considering the yearly average rainfall this evaporation is very high and this restricts the occurrence of surface water in the Stella area. Water that does accumulate in the pans after precipitation events will evaporate quite fast. The drainage of this water into the ground will protect it from direct evaporation, but in the case of Soutpan the drainage is poor and this causes a build-up of salts in the pan.

The irrigated crops in the Stella area are also affected by the high evaporation potential, as transpiration rates will also be high. As crop yield is a function of the water that is given to the plant (Mottram and De Jager, 1994) the crop water needs in the Stella area are expected to be high.

CHAPTER 3

GEOLOGY OF THE STUDY AREA

3.1 INTRODUCTION

Since groundwater occurs only in the primary and secondary voids of geological formations, the geology of an area plays an important role in the evaluation of its geohydrology. This applies in particular to:

(a) Types of formations present in the area, which control the storage of the water, and

(b) Weathering and fracturing of the formations, which control the recharge of aquifers and the yields of the boreholes.

It is therefore important that particular attention be paid to these characteristics during the evaluation of a groundwater resource.

The study area is largely blanketed by sand of the Kalahari Group, reworked aeolian sand, calcrete and soil and is nearly devoid of outcrops. More attention was consequently paid to sub-outcrops than the superficial cover in the 1:250 000 geology map of the area (Keyser, 1993), see Figure 3.1, in an effort to obtain a better idea of the geology. Some of the geological features that are mapped in the area have little or no effect on the movement and occurrence of groundwater as far as our current understanding of the area is concerned. The geological formations that are important for the geohydrology of the study area include (in ascending order):

(a) The basement granites and gneisses

(b) The Gold Ridge Formation of the Kraaipan Group

(c) The Rietgat and Allanridge Formations of the Ventersdorp Supergroup

(d) Lineaments from aerial photo interpretation

(e) Intrusive post karoo dykes

(f) Tertiary Calcrete

(g) Gordonia Formation of the Kalahari Group

(h) Salt.

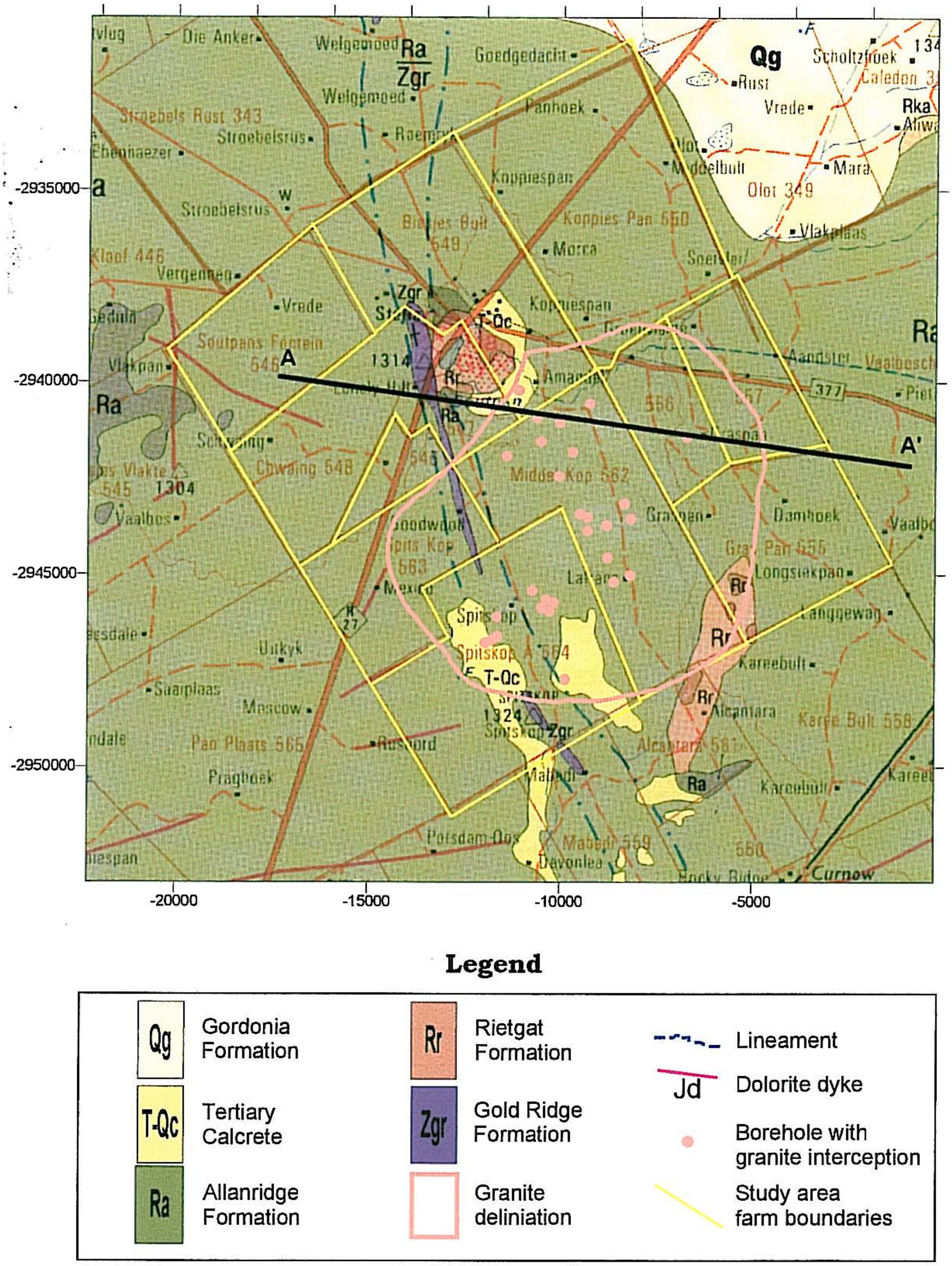

Figure 3.1 The 1:250 000 scale geology map of the study area.

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During geophysical and geohydrological exploration in the Stella area several boreholes were drilled. Most of the boreholes were drilled to evaluate the water bearing properties of the different geological features. These boreholes were therefore not drilled deep enough to evaluate the deep vertical lithology. A geological cross section A-A' indicated in Figure 3.1 is however interpreted from borehole logs to give a better understanding of the geological succession. (Figure 3.2).

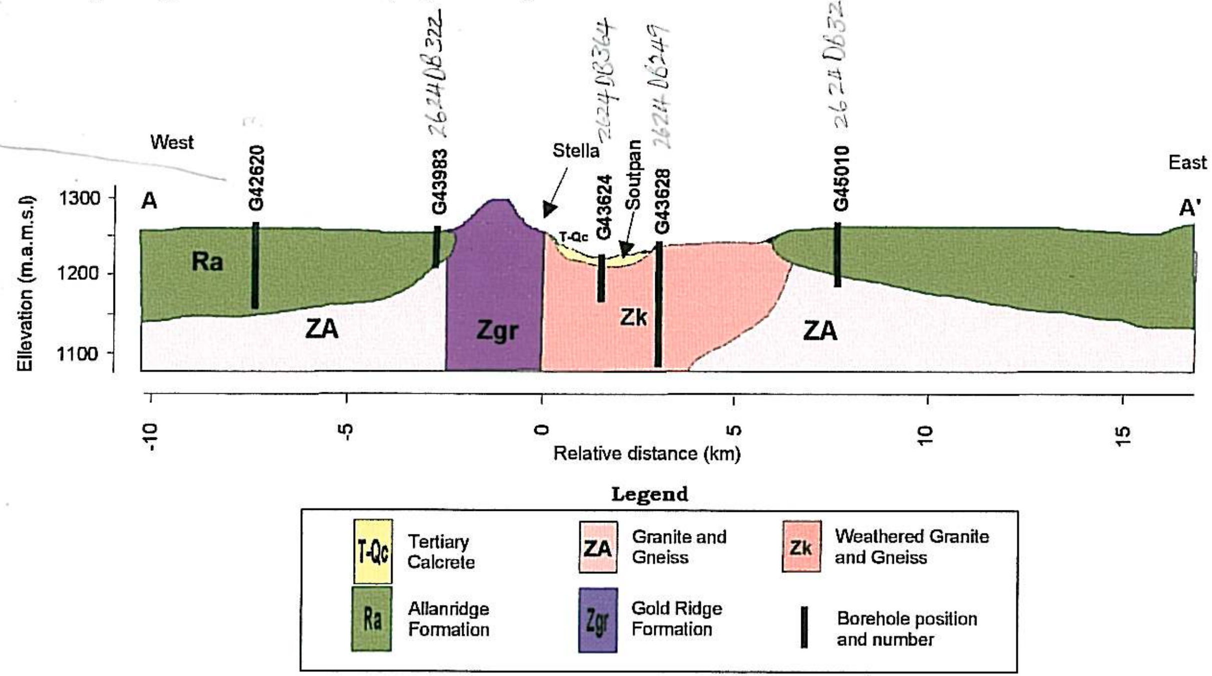


Figure 3.2 Geological cross section A-A' indicated in Figure 3.1.

The main geological properties of these formations are discussed in Section 3.2, while their influence on the geohydrology of the area is discussed in Section 4.2.

3.2 GEOLOGY

3.2.1 Basement Granites and Gneisses

The rocks, considered here as the basement formations, are comprised of migmatite, banded and granitic gneiss, gneiss, granite, amphibolite and schist. The Archaean gneisses are commonly white, grey or pink, medium to coarse grained in texture, and consist of quartz, orthoclase, microcline, oligoclase, muscovite, and in some places biotite, see Plate 3.1. All the granites are foliated and in many places to such a degree that it would be more appropriate to refer to them as gneisses.

The migmatite, banded gneiss, amphibolite and schists may probably represent supra-crustal rocks that were subjected to a high degree of metamorphism and deformation. In some areas extensive quartz intrusions are visible from the borehole camera logs.

Plate 3.1 Basement granite-gneiss samples from a borehole on the farm Middel Kop.

3.2.2 Gold Ridge Formation

The Gold Ridge Formation consists mainly of banded ironstones with sub-ordinate interbedded schists and amphibolites. The banded ironstone forms a prominent north-south stretching ridge, consisting of alternating chert and magnetite bands and laminae. The schists are fine grained and highly weathered. The formation was at some stage subjected to lateral compressional forces causing some isoclinal overfolding and the formation of pseudo-bedded rocks. The folding was probably accompanied by localised shearing, which led to the development of tectonic breccias. The formation also contains a significant number of quartz veins such as the one shown in Plate 3.2. Some of the veins are highly deformed in places, which suggests that the veins formed before and after the shearing.

Plate 3.2 Banded ironstone and quartz veining observed in a road cut through the Gold Ridge Formation.

3.2.3 Rietgat Formation

The rocks of the Rietgat Formation in the Zoetlief area consist of a mixture of tuffaceous and clastic sediments that dip at (6°-25°) to the south. Tuffs and tuffaceous sediments prevail at the base of this sequence, while the top consists mainly of tuffaceous sedimentary rocks and quartzites. Ripple marks on the exposed bedding planes of the tuffaceous units, see Plate 3.3, indicate that the deposition of the tuffaceous material was reworked by fluvial processes. At Stella the Rietgat Formation consists of greenish or dark grey arkosic quartzite, micaceous flagstone, siltstone, shale and amygdaloidal lava. The sedimentary rocks dip at a low angle to the south.

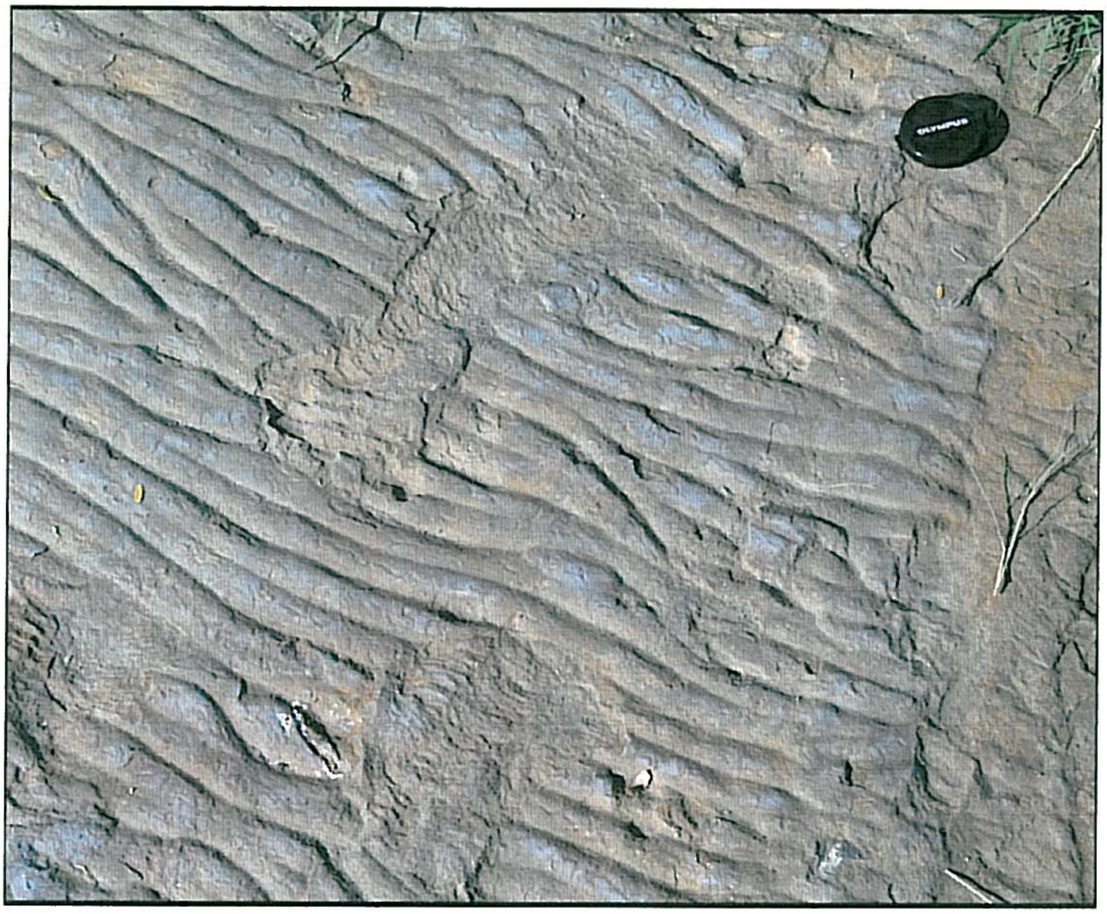


Plate 3.3 Ripple marks on the bedding plane of the sedimentary deposits near Soutpan.

3.2.4 Allanridge Formation

The Allanridge Formation underlies an extensive area of the Vryburg 1:250 000 geological map. The dark-green lava, which is by far the most prominent unit in the Allanridge Formation, represents the major part of the Ventersdorp Supergroup in the area. The lava is fine to medium grained in texture and the plagioclase and augitite in it have been replaced by secondary minerals. The lavas in the Stella area have an amygdaloidal structure, see Plate 3.4. The amygdale infilling minerals consist of calcite, various forms of silica, zeolites or indefinite hydrated ferro-magnesian silicates.

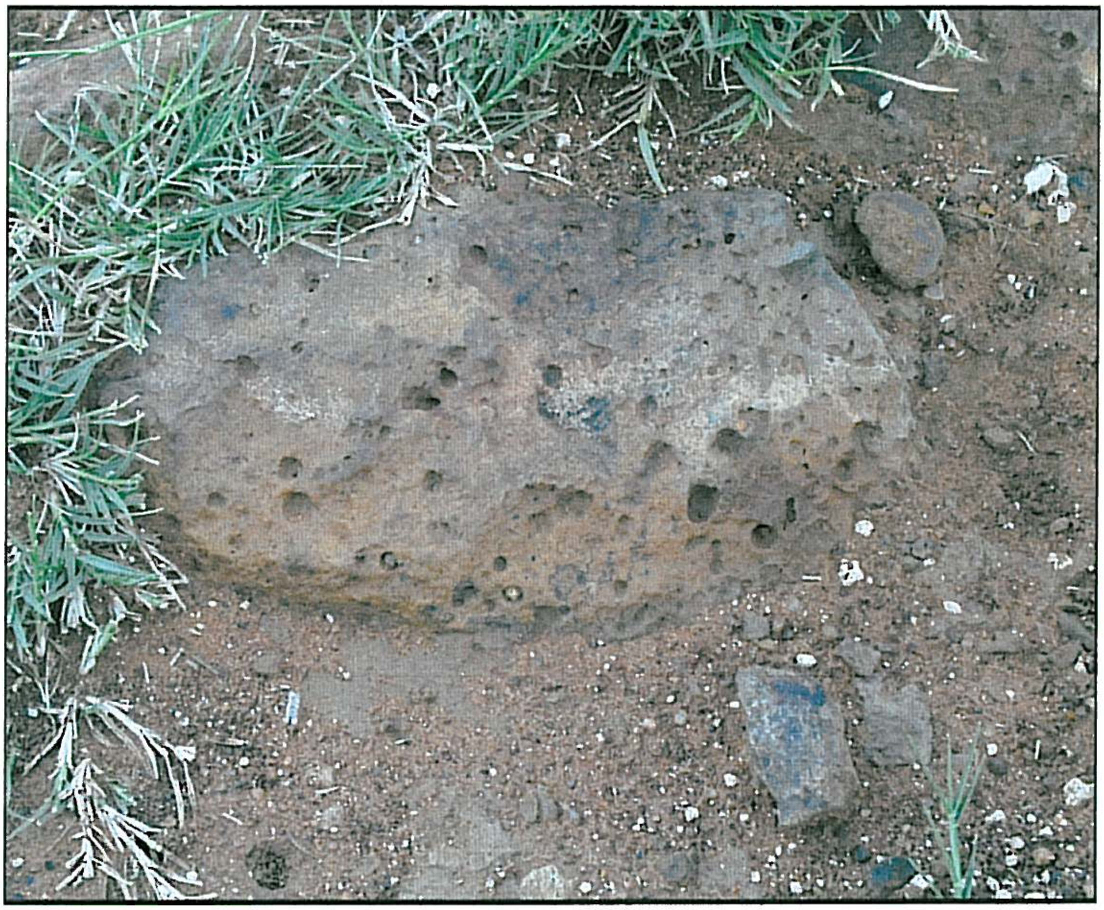


Plate 3.4 Allanridge lava with the amygdales weathered out.

3.2.5 Intrusive Dykes

The dolorite dykes are mostly covered with sand, but can be traced on aerial photographs because of the vegetation they support. The dolorite is dark in colour and ranges from fine to coarse in texture. The dolorite dykes associated with the Ventersdorp lavas are often weathered to clays on contact with the host rock.

3.2.6 Lineaments

Not very much is known of the lineament shown in Figure 3.1. However, a geophysical survey and drilling have indicated that the lineament may be a fault zone that is open in places.

3.2.7 Calcrete

The calcrete present in the area occurs mainly along dry riverbeds and in the pans. This suggests that the drainage system transported considerable quantities of carbonate in the past. However, wind also seems to have played a role in the deposition of calcrete in the pans, since the calcrete always occurs along the south-eastern edges of pans in line with the prevailing north-western winds. This situation may probably be ascribed to the fact that the pans are very shallow, with the result that the wind tends to drive the accumulated water towards the south-eastern side of the pan where it evaporates and deposits calcrete.

3.2.8 Gordonia Formation

The Gordonia Formation is comprised of red and yellow fine-grained sand. Although the formation is an aeolian deposit no dunes are present in the area, which suggests that the sand was reworked after its deposition.

3.2.9 Salt

Salt occurs in nearly all the pans on the Vryburg map area, but only two pans are in production at the moment, namely Koppiespan near Delareyville and Soutpan at Stella. The latter pan also yields gypsum as a by-product.

The pans in the Vryburg area are underlain by Ventersdorp lava, except for a few that are underlain by Dwyka tillite or Archaen granite-gneiss.

3.3 GEOPHYSICAL BOREHOLE LOGS

Although it is essential to have a good knowledge of the geology and geohydrology when investigating an area with a view to developing its groundwater resources, this information, usually gained from surface observations, is often not sufficient (Driscoll, 1986). It is therefore usually necessary to supplement the surface investigations with more detailed depth-dependent investigations. This applies in particular to characteristics such as the aquifer thickness and geological succession that play very important roles in the evaluation of the sustainable yields and effective management of aquifers.

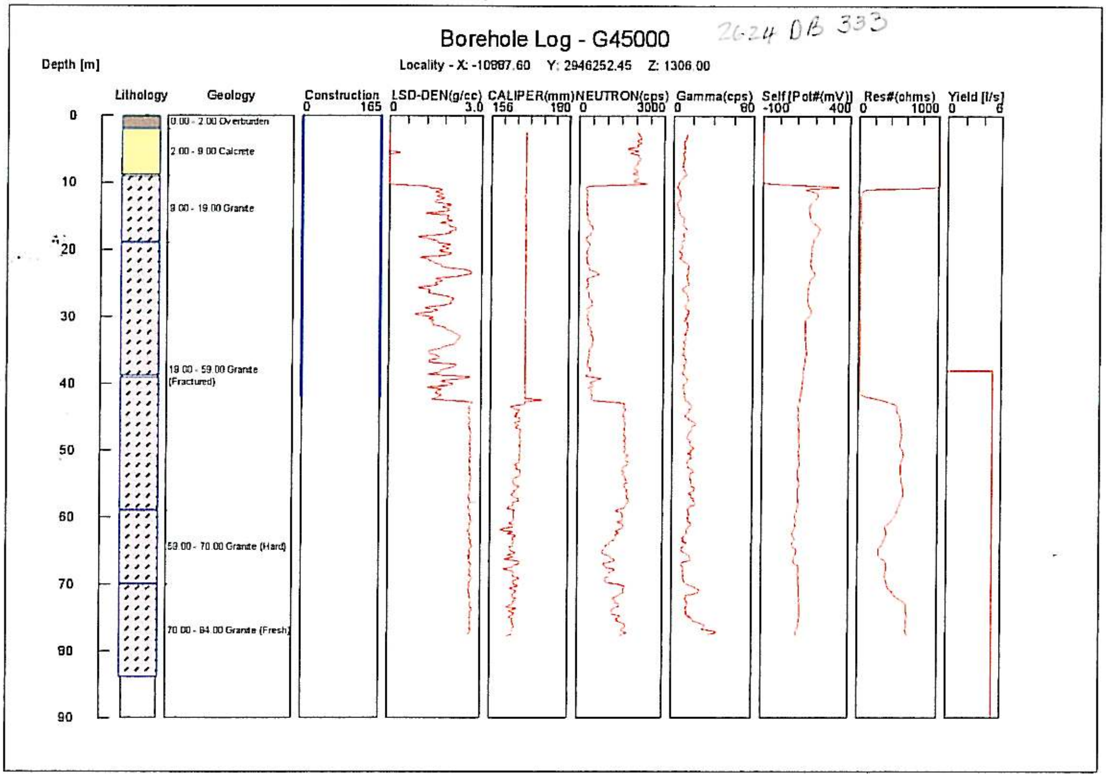
One method that is particularly useful for depth-dependent investigations is the geophysical logging or sounding of boreholes. There are several quantitative items that can be measured in such a logging or sounding exercise, such as electrical resistivity, spontaneous potential (SP), radioactivity (natural), flow velocities, borehole diameter and the water temperature distribution (Driscoll, 1986; Scott Keys, 1972).

Figure 3.2 and Figure 3.3 are examples of the geophysical borehole logs together with the lithology of boreholes G45000 and G44998 respectively. A total of 20 boreholes distributed across the aquifer were geophysicaly logged and interpreted. Table 3.1 shows a summary of the derived aquifer thickness using different geophysical log types together with an indication of the type of characteristic measured by the different probes.

Table 3.1 Derived aquifer thickness using different types of geophysical borehole logs and the characteristics measured by the different probes.

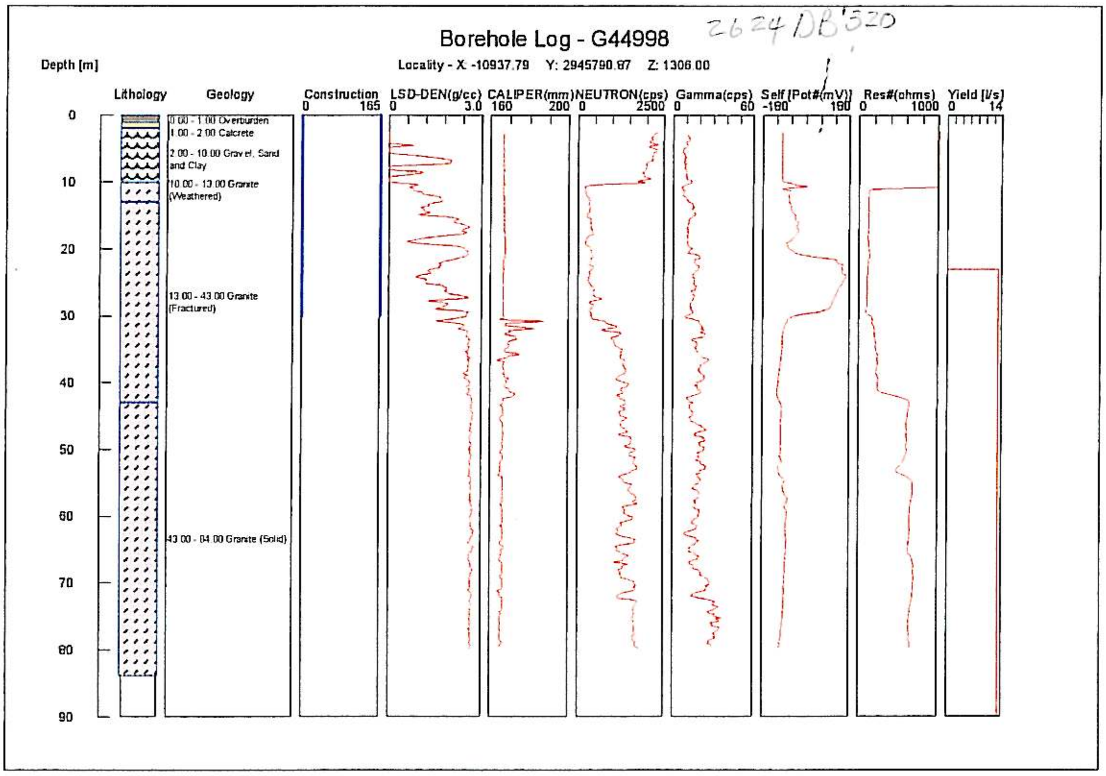
Log Type	Indication	Derived thickness of Aquifer (m)
Long Space Density	Density	40 to 45
Calliper	Blow outs	40 to 45
Neutron	H-atom content indicating Porosity	42 to 55
Gamma	Leached potassium minerals indicating weathering	40 to 75
Resistance	Fractured zone	40 to 45

From Table 3.1 it is clear that the Middel Kop aquifer is at least 40 m thick, based on geophysical borehole logs. Camera logging was used in some of the boreholes to characterise the geology. One particular advantage of the method is that it also enables the interpreter to view the geometry of the aquifer matrix and observe the physical characteristics of the borehole.



2624 DB 333

Figure 3.3 Geophysical borehole log of borehole G45000.



2624 DB 320

Figure 3.4 Geophysical borehole log of borehole G44998. 2624 DB 320

CHAPTER 4

GEOHYDROLOGY

4.1 INTRODUCTION

The success in evaluating the potential of an aquifer depends entirely on the quality and quantity of the available geohydrological data for the aquifer. This applies in particular to the following characteristics of the aquifer:

(a) Influence of geology on the geohydrology of the aquifer

(b) Borehole yields

(c) Groundwater quality

(d) Water levels.

A good spatial distribution as well as time series data is often useful in the conceptualisation and evaluation of the potential of the aquifer. These different sets of geohydrological data are used to delineate and conceptualise the main aquifer unit referred to as the Middel Kop granitic aquifer.

4.2 INFLUENCE OF GEOLOGY ON GEOHYDROLOGICAL PROPERTIES

4.2.1 Granite and Gneisses

The granite/gneiss formations in the Middel Kop area are very quartz rich and almost entirely dependent on secondary porosity for their water bearing properties. The hydrocensus data and interviews with the farmers indicated that there exists a series of near-horizontal fracture zones that are responsible for the high yields of boreholes (up to 25 L s^{-1}) drilled into these rocks. The geophysical logs of a number of boreholes support this view and indicate that the fractures mainly occur at depths of 20 to 45 m.

The small surface pans on the formation will not only collect water but also chemicals left behind by the evaporated water. One can therefore expect that groundwater recharge and chemical loading will be enhanced in and near the pans (Derby, 1995).

4.2.2 The Gold Ridge Formation

The banded ironstone and quartz rocks of the Gold Ridge Formation are only slightly weathered in general. This observation as well as an analysis of the outcrops of the Gold Ridge Formation on the farms Spitskop and Manjana indicates that the formation has only secondary porosity. However, the hydrocensus data indicates that there are high yielding boreholes (15 L s^{-1}) in the formation. It is also interesting to note that the larger scrubs and trees are restricted to areas underlain by this formation. This suggests that the formation may contain more near-surface vertical or sub-vertical fractures than indicated by the observable weathering and outcrops. The formation may therefore not only contain a viable aquifer, but also recharge the underlying granite and gneiss aquifer.

4.2.3 The Rietgat and Allanridge Formations

Very little data are available to evaluate the hydrogeological properties of the members of this supergroup of formations that are present in the area. However, a significant number of low yielding boreholes (1 L s^{-1} – 2 L s^{-1}) have been drilled by farmers in this formation. These boreholes are mainly equipped with windmills and are very old, with the result that no geohydrological information is available for them. The water quality of the boreholes is generally poor with an exceptionally high concentration of nitrates, although this may be because the boreholes mainly serve as stock watering points, some of them for at least 100 years.

4.2.4 Intrusive Dolorite Dykes

Boreholes with yields of approximately 2 L s^{-1} were drilled in the contact zones during the geophysical exploration of the dolorite dyke structures in the Spitskop area. Dolorite was however never intercepted in any of the exploration holes and was the existence of dolorite questioned in these structures. The continuity of these so called dykes is not known, but all indications are that they do not have a significant influence on the movement of groundwater in the area.

4.2.5 Calcrete

Limited calcrete is found next to drainage channels in the area as well as near Soutpan. However, the calcretes are not very thick and therefore do not seem to be of any particular geohydrological significance. None of the existing boreholes in this area seem to utilise water from the calcretes, although the existing information is limited.

4.2.6 Lineament

Boreholes with yields between 5 L s^{-1} and 10 L s^{-1} were drilled during an exploratory investigation of this structure, but some private boreholes within 100 m from the structure have yields of 20 L s^{-1}. However, hydraulic tests showed that these boreholes tend to recover slowly or incompletely, an indication that the lineament has a limited groundwater potential. Moreover, the high concentration of nitrates in the water makes it unsuitable for domestic consumption.

4.2.7 Salt

Although high concentrations of especially potassium and sodium are present in the water of Soutpan, the salt concentrations in water from boreholes, as close as 1 km from the pan, are so low that the untreated water is used as drinking water.

4.3 BOREHOLE YIELD

In secondary aquifers, the yield of the borehole is almost entirely dependent on the saturated fractures that are intercepted by the borehole. The fracturing and weathering characteristics of a specific formation will thus determine the occurrence and yields that can be expected for boreholes in the specific formation.

As shown by the contour map of blow yields in Figure 4.1, there are three areas in the Stella area where boreholes have relatively high blow yields.

The first and most extensive of these is Area 1 associated with the granites in the Middel Kop area. Area 2 contains at the moment only two closely spaced high yielding boreholes, associated with the lineament, while Area 3 contains three high yielding boreholes drilled into the Gold Ridge Formation. Although it would in principle be possible to drill more high yielding boreholes along the lineament and in the Gold Ridge Formation, Figure 3.1 shows that both these features are not very extensive. It would therefore be unwise to drill a large number of production boreholes in the latter two areas. This means that the aquifer in Area 1 must be considered as the major aquifer in the area.

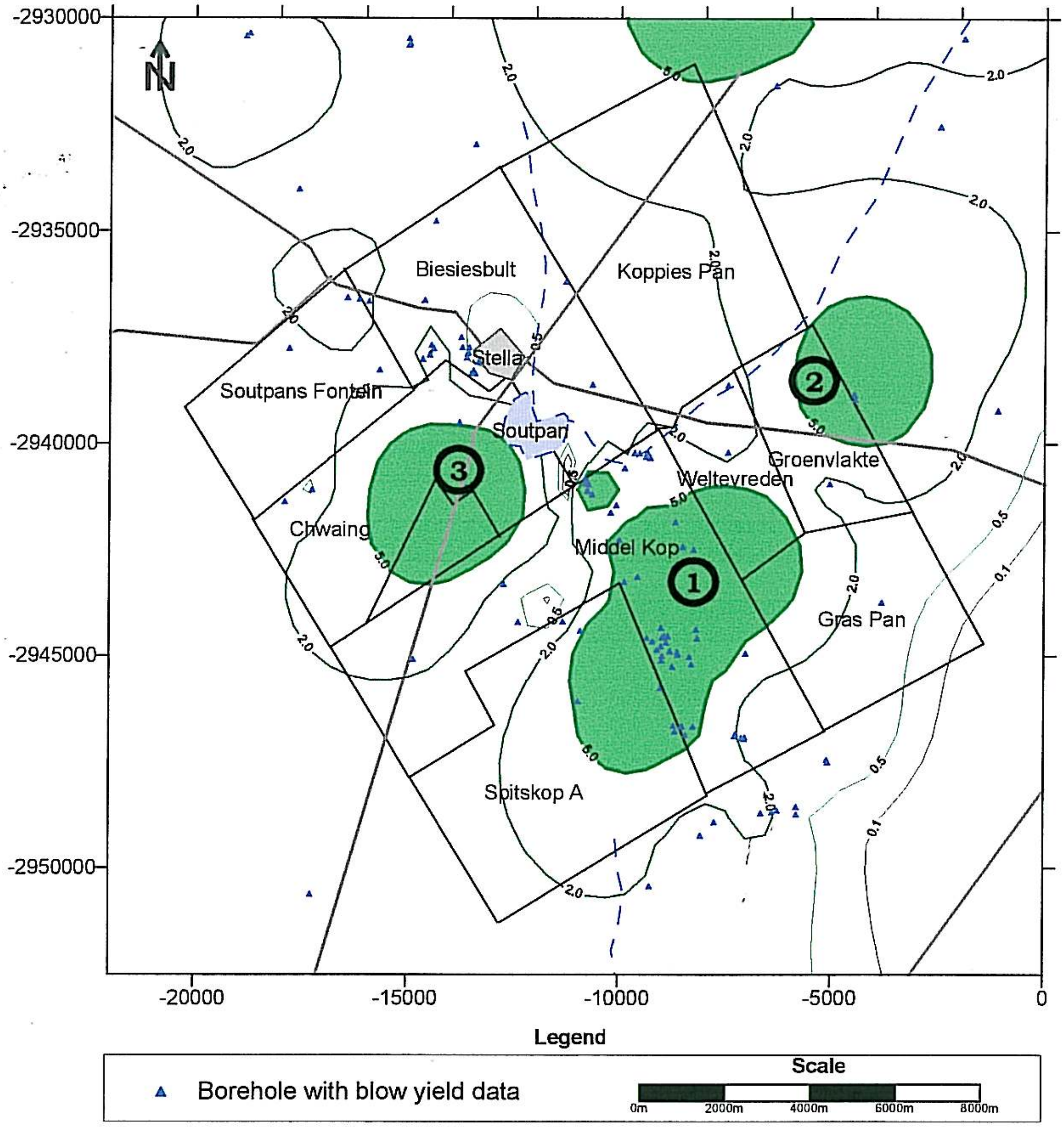


Figure 4.1 Contours of blow yields observed in various boreholes in the Stella district.

4.4 GROUNDWATER LEVEL DATA

Groundwater levels are particularly important in the evaluation of the potential of any aquifer, because a change in water level is directly related to a change in volume of water, available in the aquifer. It is therefore unfortunate that historical data of water levels are available for only six boreholes in the area, shown in Figure 4.2, and are often discontinuous.

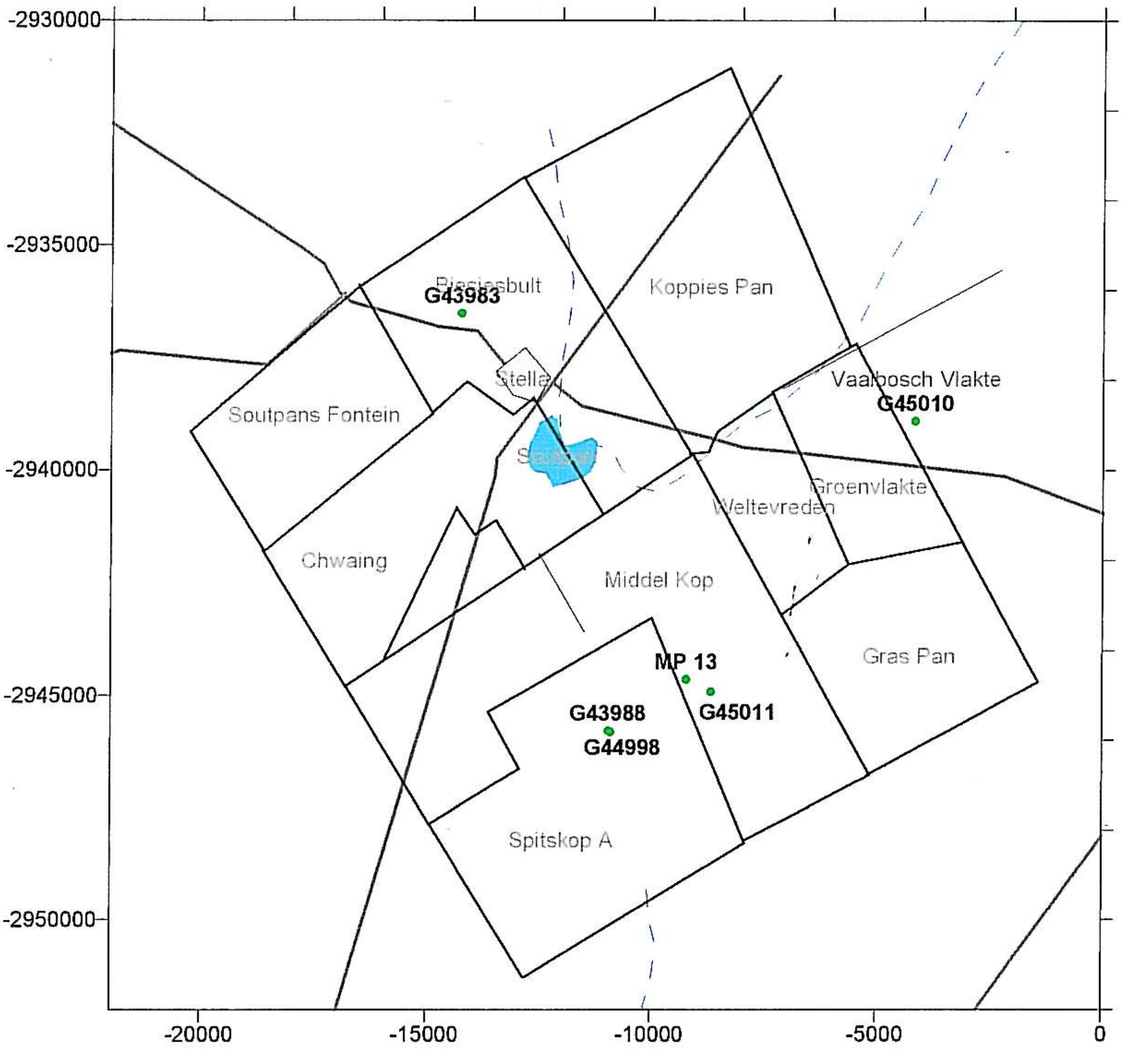


Figure 4.2 Positions of the boreholes in the study area for which historical water level data are available.

For example, water levels were first observed in Borehole MP 13 on the farm Middel Kop, but later in Borehole G45011. Nevertheless, it is clear from the graphs of the water levels as functions of time in Figure 4.3 that all water levels tend to decrease with time.

This is particularly noticeable in the case of the water levels of boreholes MP 13 and G45011 on the farm Middel Kop, which also display a significant seasonal trend. However, this behaviour is probably because the boreholes are situated close to boreholes used for the irrigation of 98 ha on the farm. This observation is supported by the fact that there has been a considerable increase in the magnitude of the seasonal trend since the addition of a second pivot in 1997. The water levels recover to some extent after each season, but not fully. The very steep downward trend of the water level in the Stella well-field (Figure 4.3) is without any doubt caused by over-pumping to supply the town with enough water. Indeed, it is known that the demand for water in the town often exceeds the supply (Van Voorn, Pers. Com.). The pumping of a large number of private boreholes, in the town further aggravates this situation. This large abstraction in Stella and the adjacent well-field do not affect the water balance of the Middel Kop aquifer and was the exact volumes abstracted by the private users not quantified.

The previous discussion clearly indicates that it will not be very useful to drill new production boreholes near the Stella well-field, nor on the farm Middel Kop. Any additional water taken from these well-fields will only increase the rate at which the water levels drop. No additional water should therefore be withdrawn from these well-fields. Indeed, all indications are that it may be necessary to reduce their discharge rates to ensure their future sustainability.

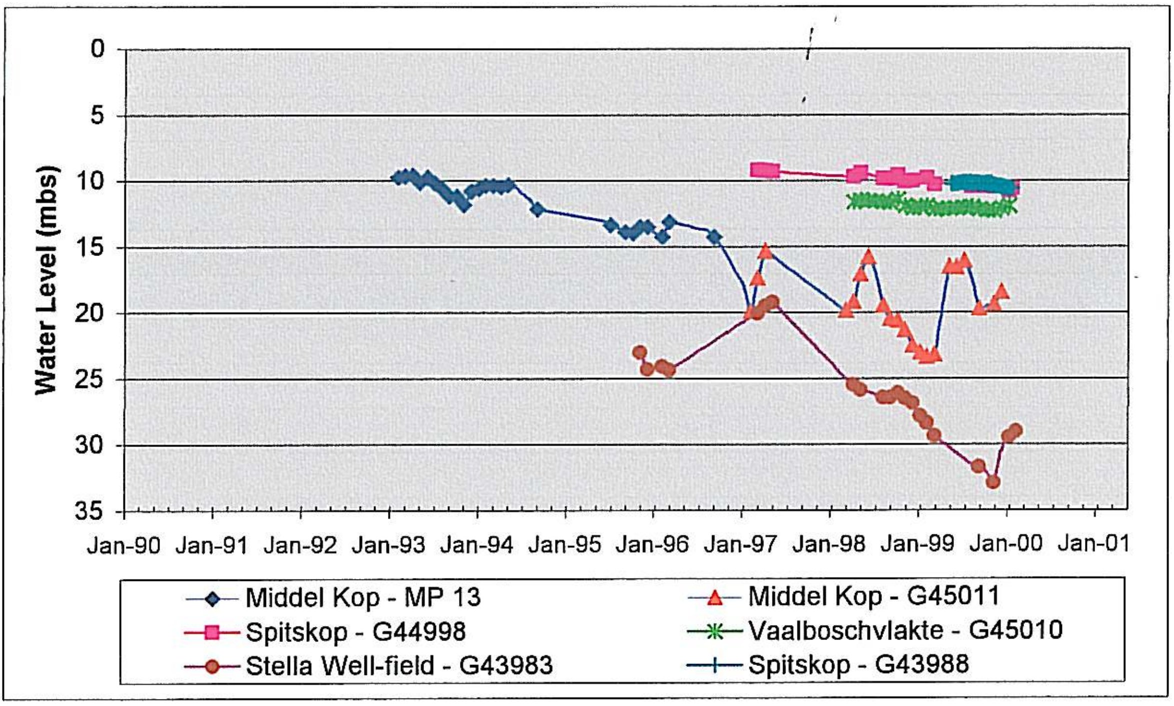


Figure 4.3 Graphs of the observed groundwater levels in the study area.

4.5 CURRENT APPLICATION OF THE GROUNDWATER RESOURCES

The potential of an existing groundwater resource to yield additional water depends essentially on its ability to yield additional water without affecting the current users now and in the future. It is therefore necessary to evaluate the current use of water from the aquifer and its sustainability under the present load before more water is pumped from the resource. This section and following discussion will evaluate the water uses by the different water use sectors on the Middel Kop aquifer.

4.5.1 Water Use for Animals

The majority of production boreholes on the farms in the Stella area are equipped with windmills. These generally low-yielding boreholes are mainly used to supply cattle with water. Since the cattle grazing capacity in this area is estimated at one large stock unit per ten hectares, the 10 000 ha underlain by the aquifer can support approximately 1 000 large stock units. This implies that 55 $m^3 d^{-1}$ of water have to be allocated to animals, assuming that each large stock unit needs approximately 55 L d^{-1}. The future development of the aquifer must incorporate this water use and the accompanying pollution potential at water drinking points.

4.5.2 Domestic Water Use

The owners of eight farms situated on the Middel Kop granitic aquifer, and their labourers presently use approximately 230 $m^3 d^{-1}$ of water from the aquifer. Although some of the water is used for gardening, the largest portion is used for what can be considered as basic human needs. This water is mainly supplied by submersible pumps installed in low-yielding boreholes (< 1 L s^{-1}) that often result in excessive drawdowns of the water levels in the aquifer.

4.5.3 Current Irrigation Needs

The hydrocensus of 1999 revealed that 183 ha farmland are irrigated in and around the Middel Kop study area (Table 4.1). Of these, a total of 171 ha are irrigated with groundwater pumped from a number of high-yielding boreholes in the granitic aquifer on the farm Middel Kop and near the Gold Ridge Formation as illustrated in Figure 4.4.

The crops irrigated include potatoes, maize, lucerne, paprika and winter fodder for the cattle. The water need for these crops in this area, excluding rainfall, is approximately 0.8 m per crop. Approximately 8 000 $m^3 ha^{-1}$ of water are therefore needed for one crop. This figure agrees with the 8 300 $m^3 ha^{-1}$, estimated from hour-meter readings taken from one of the pivots on the farm Middel Kop. However, some of the farmers are producing two crops a year, which means that the water used for irrigation purposes is probably closer to 16 000 m^3 ha^{-1}. The very long growing season of lucerne crops also requires 16 000 m^3 ha^{-1}.

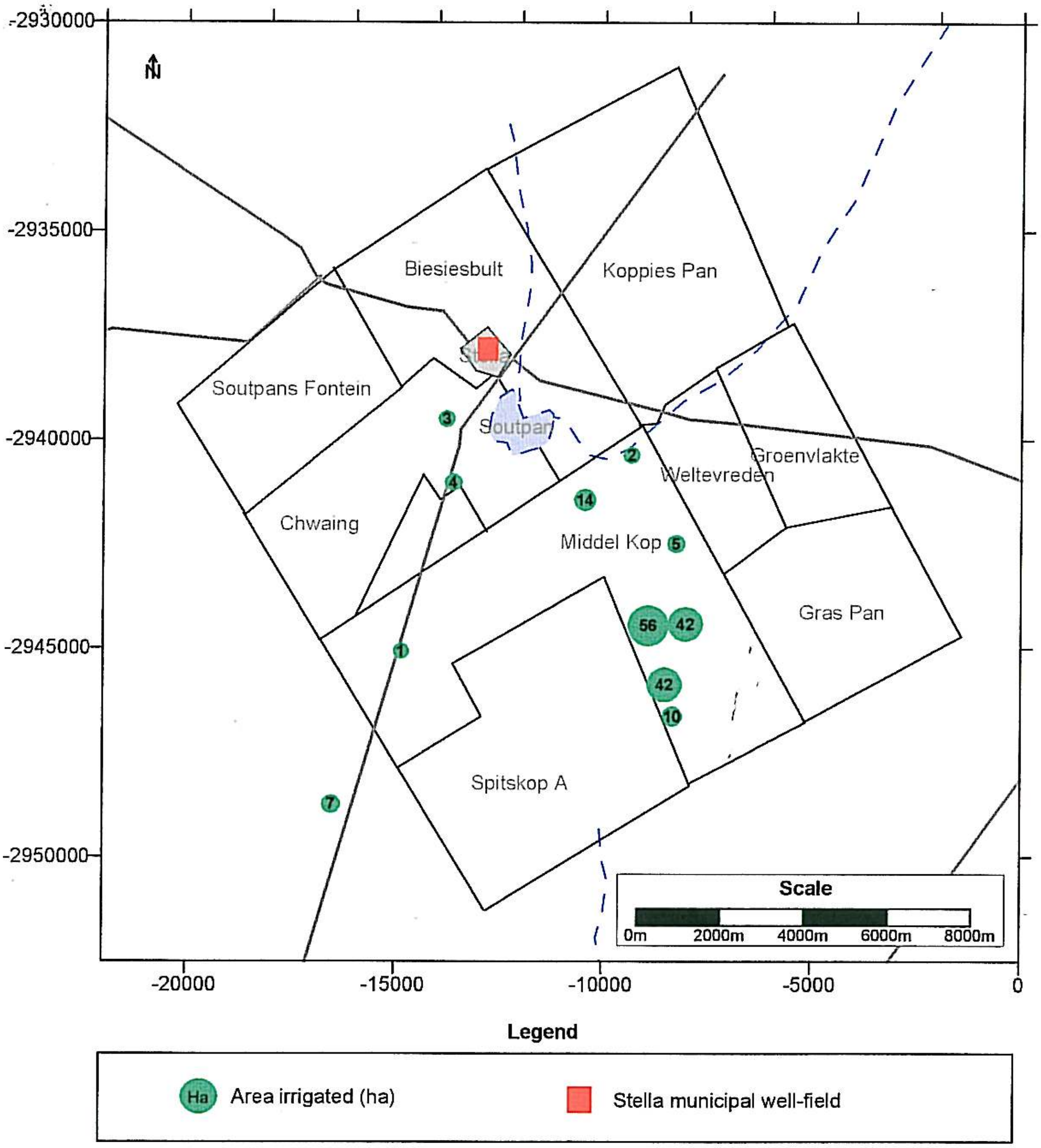


Figure 4.4 Distribution of irrigation areas and the Stella well-field

Table 4.1 Current irrigation areas in the Stella area

Farmer	Farm	Irrigation (Ha)	Year Started
Mr. Oosthuizen	Middel Kop	10	1990
		Increased to 56	1992
Mr. Oosthuizen	Middel Kop	42	1997
Mr. Coertze	Middel Kop - Lafrans	30	1992
		Increased to 42	1996
Mr. Swarts	Middel Kop - Draaispruit	10	1995
Mr. De Villiers	Middel Kop - Appelkoosboom	14	1995
Mr. Viljoen	Middel Kop - Bestehoop	7	1997
Mr. Kemp	SoutpansFontein	4	1992
Mr. Scheepers	Pan Plaats - Moscow	7	1992
Mr. Kleinhans	Spitskop Mexico	1	1990

4.5.4 Water Use by Stella Municipality

The town Stella is supplied with water from a well field north-west of the town, from which an average of 7 080 m^3 is pumped monthly according to the records available from July 1994 to June 1998 (Figure 4.5).

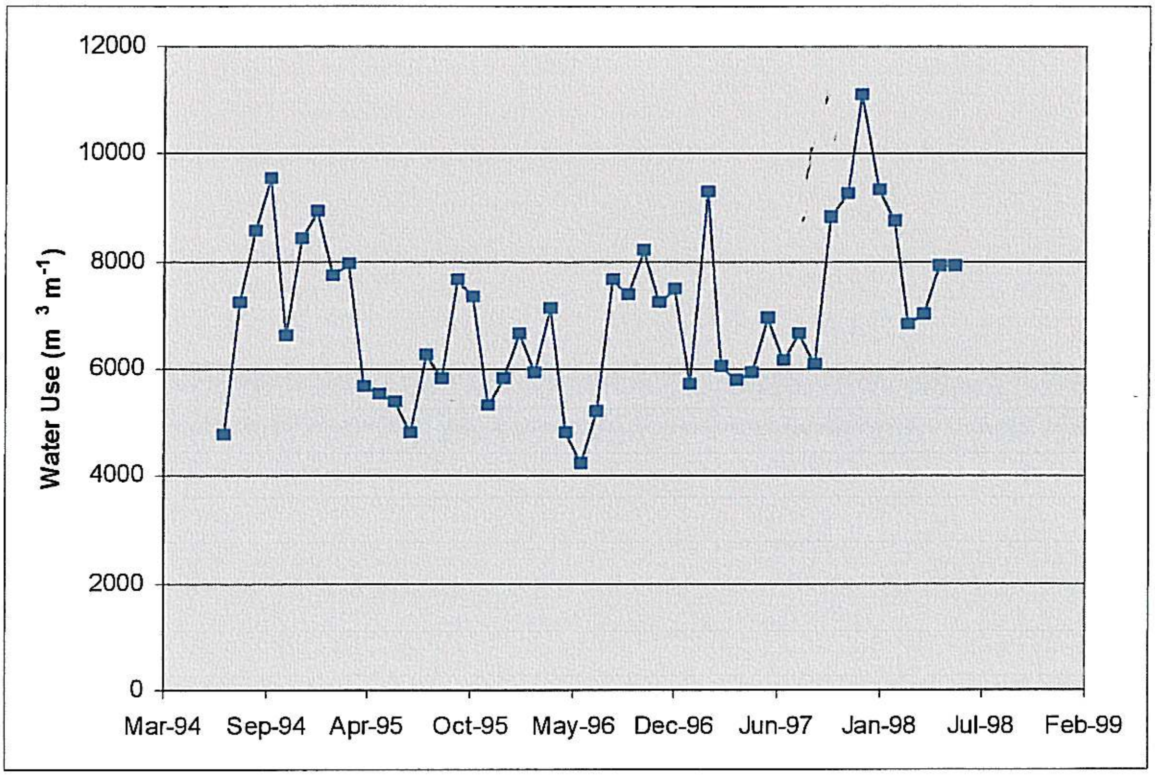


Figure 4.5 Volumes of water pumped from the Stella municipal well-field.

Approximately 1500 people are currently living in Stella town and therefore supplied by water from the Stella well-field. No notable industries are supplied with water from this well-field and it can be assumed that the average daily use of the 1 500 people is 236 $m^3 d^{-1}$. After resettlement about 3 500 people are expected in the town (Van Voorn, Pers. Com.). If the proposed new inhabitants of the town have the same water needs as the current inhabitants, about 550 $m^3 d^{-1}$ is needed immediately after resettlement.

Considering population growth estimates of 1.25% and 2.5% (Erasmus, Pers. Com.) the population of Stella is computed at 4 500 and 5 750 respectively with estimated water needs of 708 $m^3 d^{-1}$ and 905 $m^3 d^{-1}$ respectively. It should be noted that these estimates do not cater for any industrial needs and growth of the town.

4.6 GROUNDWATER QUALITY AND CHEMICAL CHARACTERISATION

All groundwater contains naturally variable quantities of dissolved solids. The type and concentration of these dissolved solids depend essentially on the geochemical environment, the velocity and source of the groundwater (Everett, 1983). Groundwater quality can therefore be very helpful in the evaluation of the potential and characterisation of a groundwater resource, with special reference to the following aspects:

(a) Characterisation of the resource

(b) Ability of the water to support the proposed use

(c) Protection of the resource.

Table 4.2 lists the groundwater quality data for a few boreholes in the study area with positions shown in Figure 4.6. The data are classified and colour coded, as proposed in the DWAF drinking water assessment guide of Kempster *et al.* (1998). What these data show is that there are not very large variations in the groundwater quality of the area, except for that of boreholes G43628 and G43629 on the farm Middel Kop. However, as shown in Table 4.2, both boreholes are considerably deeper than the rest. This suggests that the area is underlain by two aquifers, one with acceptable groundwater quality and one with poor quality groundwater. This conclusion is further supported by the graph of the electrical conductivities as a function of the borehole depths in Figure 4.7, which clearly indicates that there is a jump in the electrical conductivities between 120 m and 160 m. One must therefore be careful not to drill too deep boreholes in the area, at least not until the existence of the two aquifers has been confirmed by future investigations.

As can be seen from Table 4.2, the quality of the water in the upper aquifer is generally within the acceptable drinking water standards, except for the nitrate and fluoride values that are higher than the acceptable drinking water standards. The nitrate values can probably be related to cattle farming, a major agricultural activity in the area. However, it is difficult to explain the high concentrations of fluoride, except to note that the fluoride in groundwater is often associated with the weathering of the mica in granite and gneiss. This suggests that the chemical data may be quite useful in delineating the extent of the upper aquifer, which is not known at the moment. A few of the chemical species that may be particularly useful for this purpose are therefore discussed in more detail below.

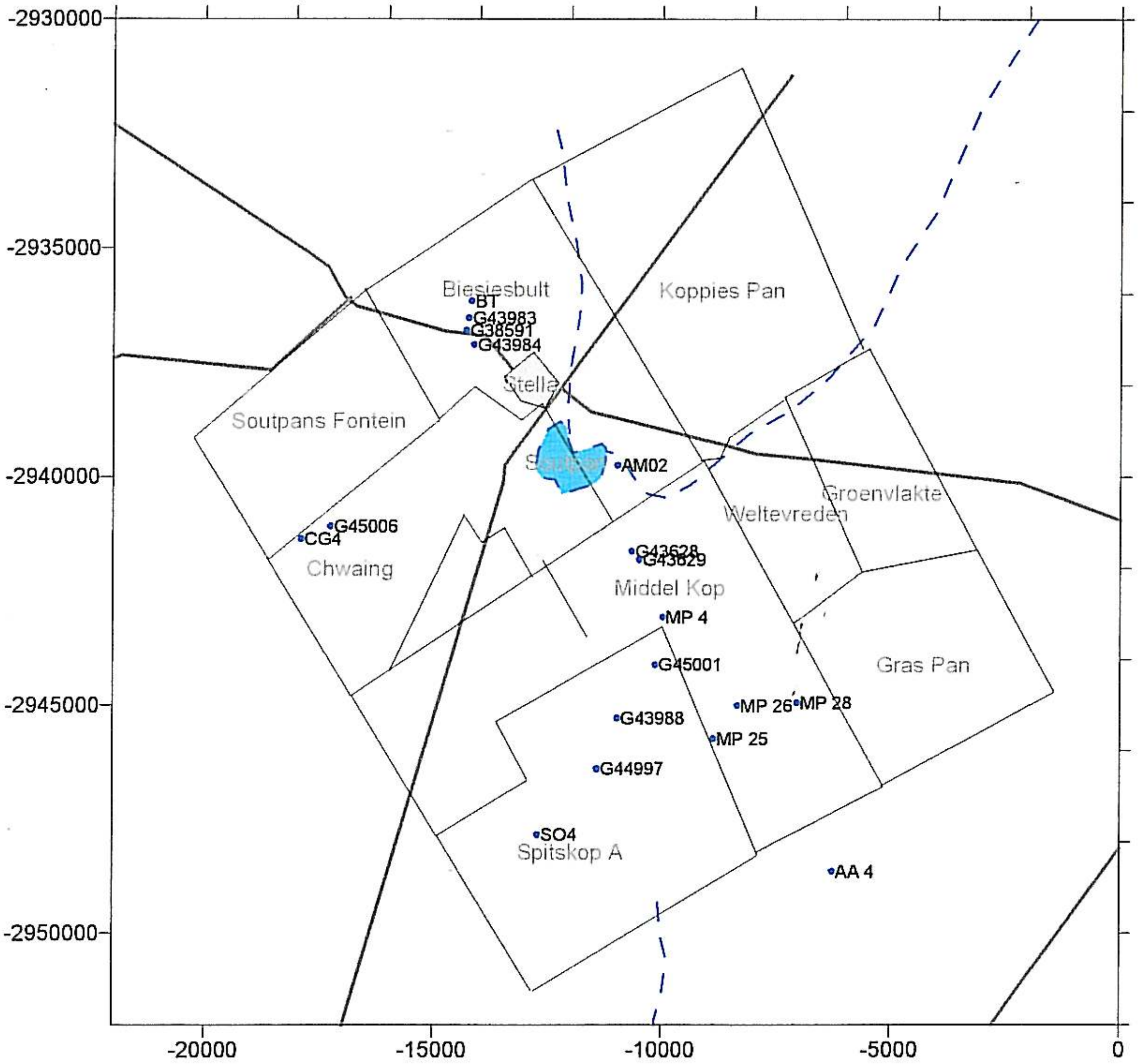
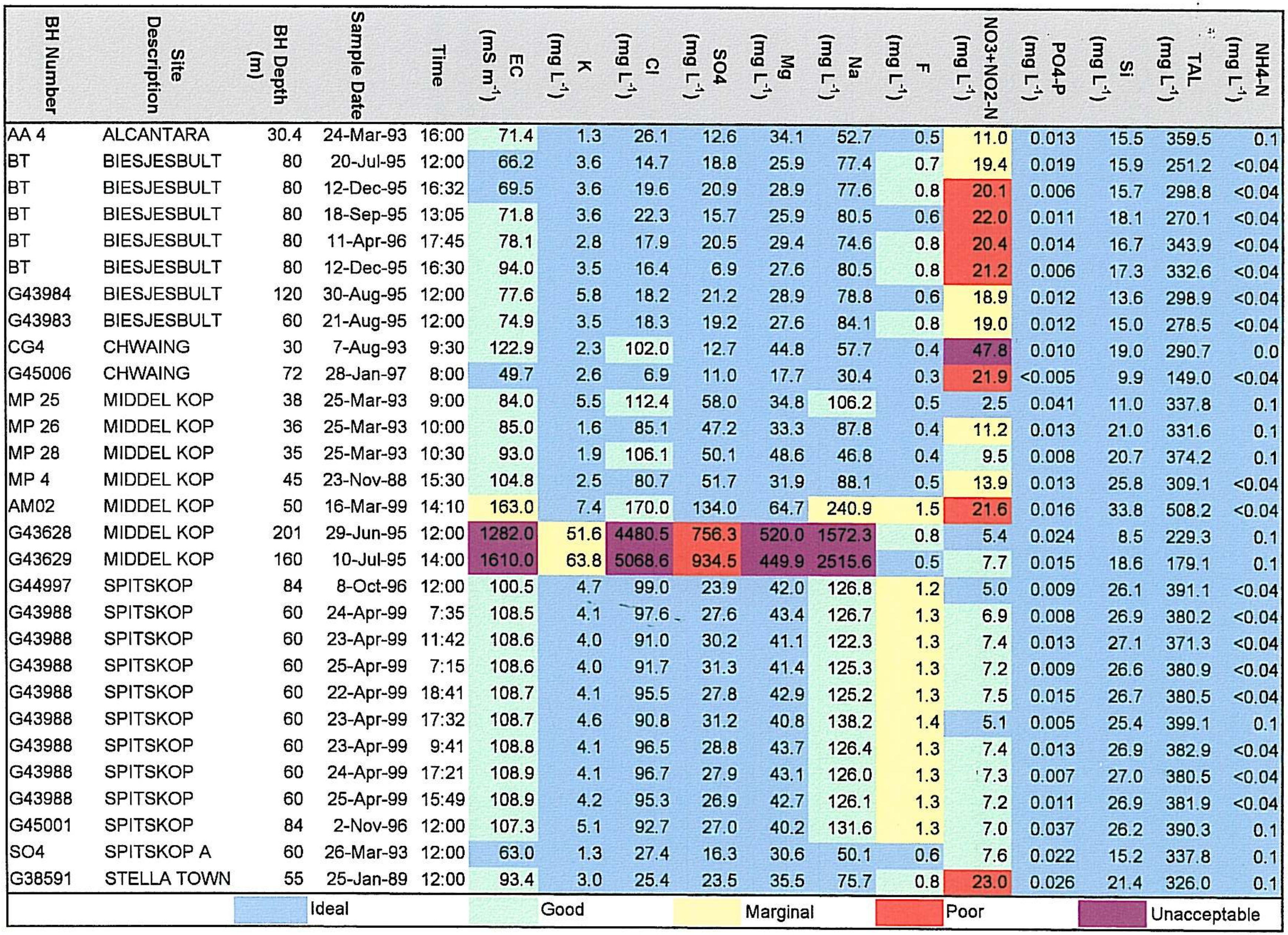


Figure 4.6 Positions of the boreholes used to characterise the aquifers in the study area.

Table 4.2 Selected groundwater quality data from the study area colour-coded and classified according to the Assessment Guide of Kempster *et al.* (1998).



BH Number	Site Description	BH Depth (m)	Sample Date	Time	EC (mS m^{-1})	K (mg L^{-1})	Cl (mg L^{-1})	SO4 (mg L^{-1})	Mg (mg L^{-1})	Na (mg L^{-1})	F (mg L^{-1})	NO3+NO2-N (mg L^{-1})	PO4-P (mg L^{-1})	Si (mg L^{-1})	TAL (mg L^{-1})	NH4-N (mg L^{-1})
AA 4	ALCANTARA	30.4	24-Mar-93	16:00	71.4	1.3	26.1	12.6	34.1	52.7	0.5	11.0	0.013	15.5	359.5	0.1
BT	BIESJESBULT	80	20-Jul-95	12:00	66.2	3.6	14.7	18.8	25.9	77.4	0.7	19.4	0.019	15.9	251.2	<0.04
BT	BIESJESBULT	80	12-Dec-95	16:32	69.5	3.6	19.6	20.9	28.9	77.6	0.8	20.1	0.006	15.7	298.8	<0.04
BT	BIESJESBULT	80	18-Sep-95	13:05	71.8	3.6	22.3	15.7	25.9	80.5	0.6	22.0	0.011	18.1	270.1	<0.04
BT	BIESJESBULT	80	11-Apr-96	17:45	78.1	2.8	17.9	20.5	29.4	74.6	0.8	20.4	0.014	16.7	343.9	<0.04
BT	BIESJESBULT	80	12-Dec-95	16:30	94.0	3.5	16.4	6.9	27.6	80.5	0.8	21.2	0.006	17.3	332.6	<0.04
G43984	BIESJESBULT	120	30-Aug-95	12:00	77.6	5.8	18.2	21.2	28.9	78.8	0.6	18.9	0.012	13.6	298.9	<0.04
G43983	BIESJESBULT	60	21-Aug-95	12:00	74.9	3.5	18.3	19.2	27.6	84.1	0.8	19.0	0.012	15.0	278.5	<0.04
CG4	CHWAING	30	7-Aug-93	9:30	122.9	2.3	102.0	12.7	44.8	57.7	0.4	47.8	0.010	19.0	290.7	0.0
G45006	CHWAING	72	28-Jan-97	8:00	49.7	2.6	6.9	11.0	17.7	30.4	0.3	21.9	<0.005	9.9	149.0	<0.04
MP 25	MIDDEL KOP	38	25-Mar-93	9:00	84.0	5.5	112.4	58.0	34.8	106.2	0.5	2.5	0.041	11.0	337.8	0.1
MP 26	MIDDEL KOP	36	25-Mar-93	10:00	85.0	1.6	85.1	47.2	33.3	87.8	0.4	11.2	0.013	21.0	331.6	0.1
MP 28	MIDDEL KOP	35	25-Mar-93	10:30	93.0	1.9	106.1	50.1	48.6	46.8	0.4	9.5	0.008	20.7	374.2	0.1
MP 4	MIDDEL KOP	45	23-Nov-88	15:30	104.8	2.5	80.7	51.7	31.9	88.1	0.5	13.9	0.013	25.8	309.1	<0.04
AM02	MIDDEL KOP	50	16-Mar-99	14:10	163.0	7.4	170.0	134.0	64.7	240.9	1.5	21.6	0.016	33.8	508.2	<0.04
G43628	MIDDEL KOP	201	29-Jun-95	12:00	1282.0	51.6	4480.5	756.3	520.0	1572.3	0.8	5.4	0.024	8.5	229.3	0.1
G43629	MIDDEL KOP	160	10-Jul-95	14:00	1610.0	63.8	5068.6	934.5	449.9	2515.6	0.5	7.7	0.015	18.6	179.1	0.1
G44997	SPITSKOP	84	8-Oct-96	12:00	100.5	4.7	99.0	23.9	42.0	126.8	1.2	5.0	0.009	26.1	391.1	<0.04
G43988	SPITSKOP	60	24-Apr-99	7:35	108.5	4.1	97.6	27.6	43.4	126.7	1.3	6.9	0.008	26.9	380.2	<0.04
G43988	SPITSKOP	60	23-Apr-99	11:42	108.6	4.0	91.0	30.2	41.1	122.3	1.3	7.4	0.013	27.1	371.3	<0.04
G43988	SPITSKOP	60	25-Apr-99	7:15	108.6	4.0	91.7	31.3	41.4	125.3	1.3	7.2	0.009	26.6	380.9	<0.04
G43988	SPITSKOP	60	22-Apr-99	18:41	108.7	4.1	95.5	27.8	42.9	125.2	1.3	7.5	0.015	26.7	380.5	<0.04
G43988	SPITSKOP	60	23-Apr-99	17:32	108.7	4.6	90.8	31.2	40.8	138.2	1.4	5.1	0.005	25.4	399.1	0.1
G43988	SPITSKOP	60	23-Apr-99	9:41	108.8	4.1	96.5	28.8	43.7	126.4	1.3	7.4	0.013	26.9	382.9	<0.04
G43988	SPITSKOP	60	24-Apr-99	17:21	108.9	4.1	96.7	27.9	43.1	126.0	1.3	7.3	0.007	27.0	380.5	<0.04
G43988	SPITSKOP	60	25-Apr-99	15:49	108.9	4.2	95.3	26.9	42.7	126.1	1.3	7.2	0.011	26.9	381.9	<0.04
G45001	SPITSKOP	84	2-Nov-96	12:00	107.3	5.1	92.7	27.0	40.2	131.6	1.3	7.0	0.037	26.2	390.3	0.1
SO4	SPITSKOP A	60	26-Mar-93	12:00	63.0	1.3	27.4	16.3	30.6	50.1	0.6	7.6	0.022	15.2	337.8	0.1
G38591	STELLA TOWN	55	25-Jan-89	12:00	93.4	3.0	25.4	23.5	35.5	75.7	0.8	23.0	0.026	21.4	326.0	0.1

Ideal Good Marginal Poor Unacceptable

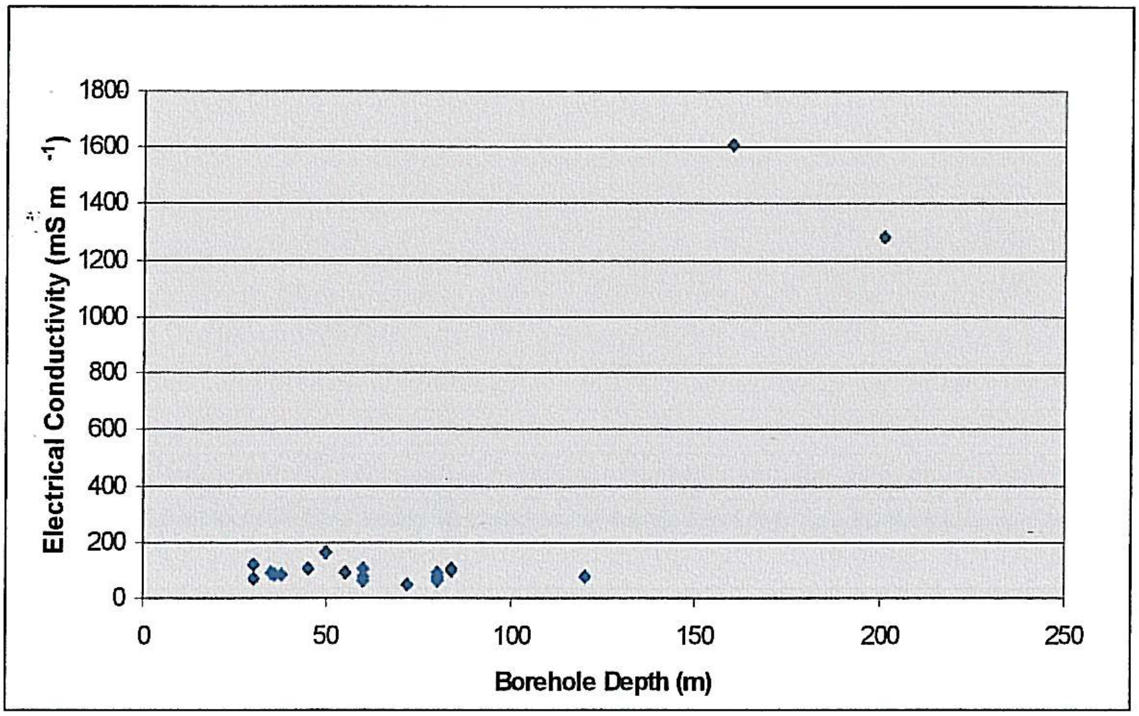


Figure 4.7 Graph of the electrical conductivity as a function of the depths of boreholes in which it was observed.

4.6.1 Potassium and Sodium

The major sources of potassium and sodium in the study area are the feldspars and some micas. It is therefore not strange that the higher concentrations of potassium (Figure 4.8) and sodium (Figure 4.9) correlate with the distribution of the granite/gneiss in the Middel Kop granitic aquifer. High concentrations of potassium and sodium in Soutpan are probably related to the high evaporation rates from the pan. Some high concentrations of potassium and sodium observed in boreholes near Stella may be due to the transportation of these salts from Soutpan.

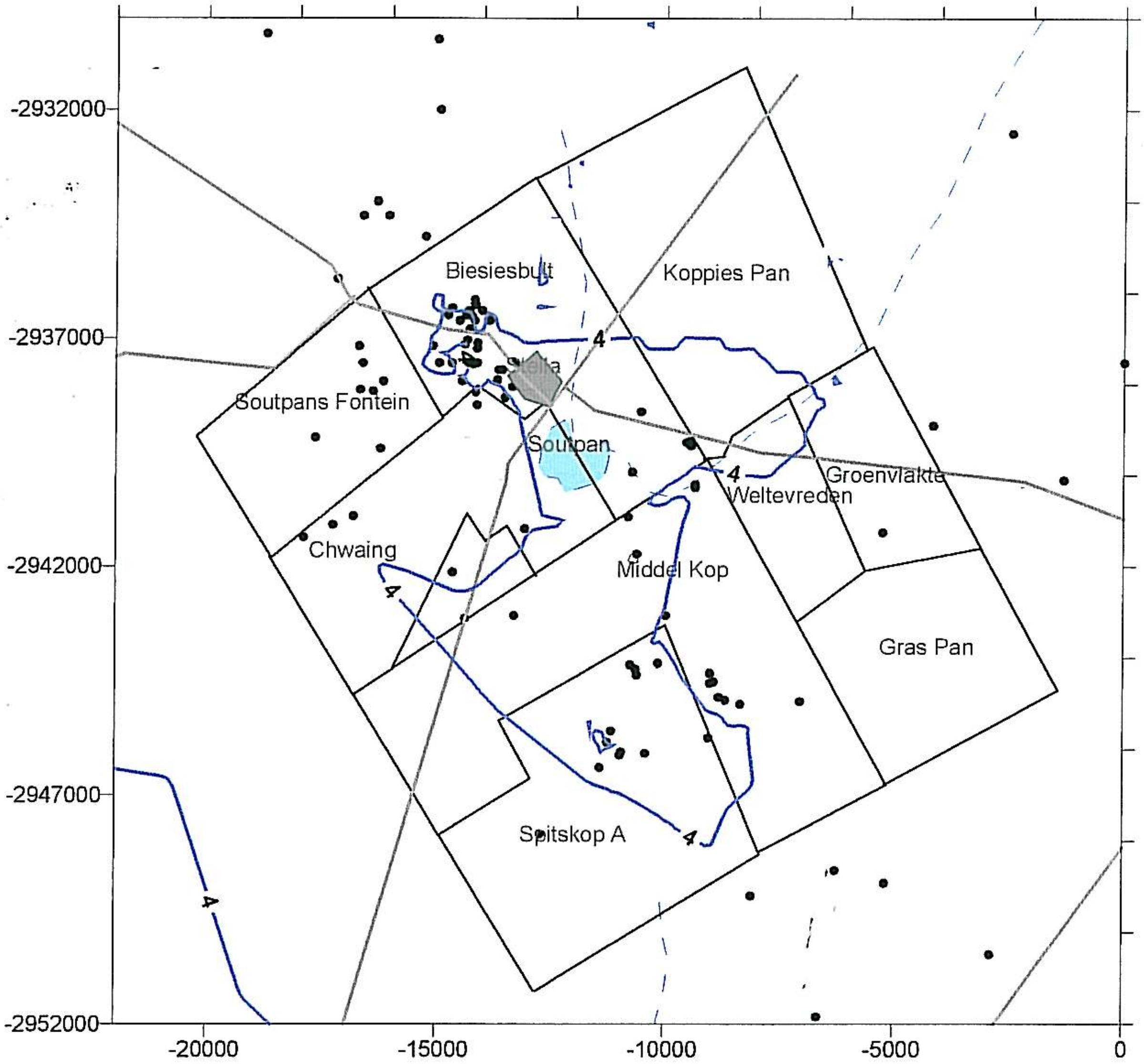


Figure 4.8 Distribution of potassium concentrations in the groundwater related to the presence of feldspar in the granite aquifer.

It has been known for some years that sodium may increase hypertension, while potassium tends to reduce it. However, recent research suggests that the ratio of sodium to potassium in the diet may be more important than the specific amounts of sodium and potassium. The American Heart Association therefore does not any longer recommend a specific intake of sodium for hypertension patients, but rather a sodium-to-potassium ratio of one-to-one (Anderson and Endo, 1992). This suggests that groundwater with a relatively high concentration of sodium may still be used for domestic purposes, provided that the ratio of sodium to potassium concentrations is of the order of one-to-one.

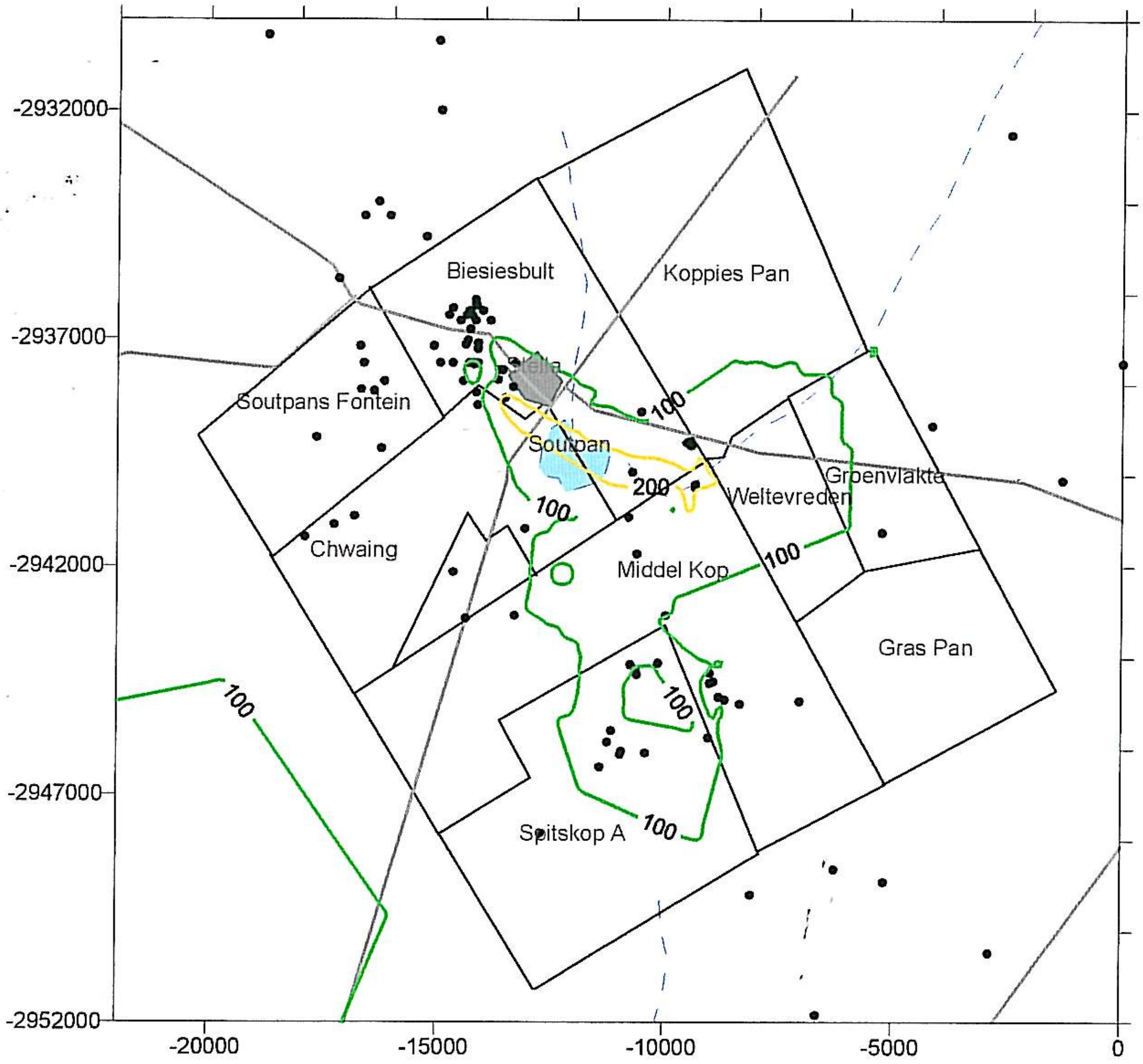


Figure 4.9 Distribution of sodium concentrations in the groundwater related to the presence of feldspar and mica in the granite aquifer.

4.6.2 Nitrate

The main sources of nitrate in the study area are animal excrement at the watering points and nitrogenous fertilisers applied on the irrigated areas.

Lower nitrate values can be seen in the Spitskop area (Figure 4.10). This farm is also used for cattle grazing, but the watering points for the animals are distributed away from the windmills. Possible contamination points of nitrate are separated from the boreholes in this way.

It is known that high concentrations of nitrate in drinking water (>10 mg L^{-1}), may cause some health risks of which the sometimes-fatal condition called methemoglobinemia, or "blue baby syndrome" (Frankenberger, 2000) is probably the best known. Some studies also found evidence that women who drink nitrate contaminated water during pregnancy are more likely to have babies with birth defects. Nitrate ingested by the mother may also lower the amount of oxygen available to the foetus (Wisconsin, Dept. of Natural Resources, 1998). It is also known that certain inherited enzyme defects or cancer may be more sensitive to the toxic effects of nitrate in people who have heart and lung diseases. In addition, some experts believe that the long-term ingestion of water with high nitrate concentrations may increase the risk of certain types of cancer (Wisconsin, Dept. of Natural Resources, 1998).

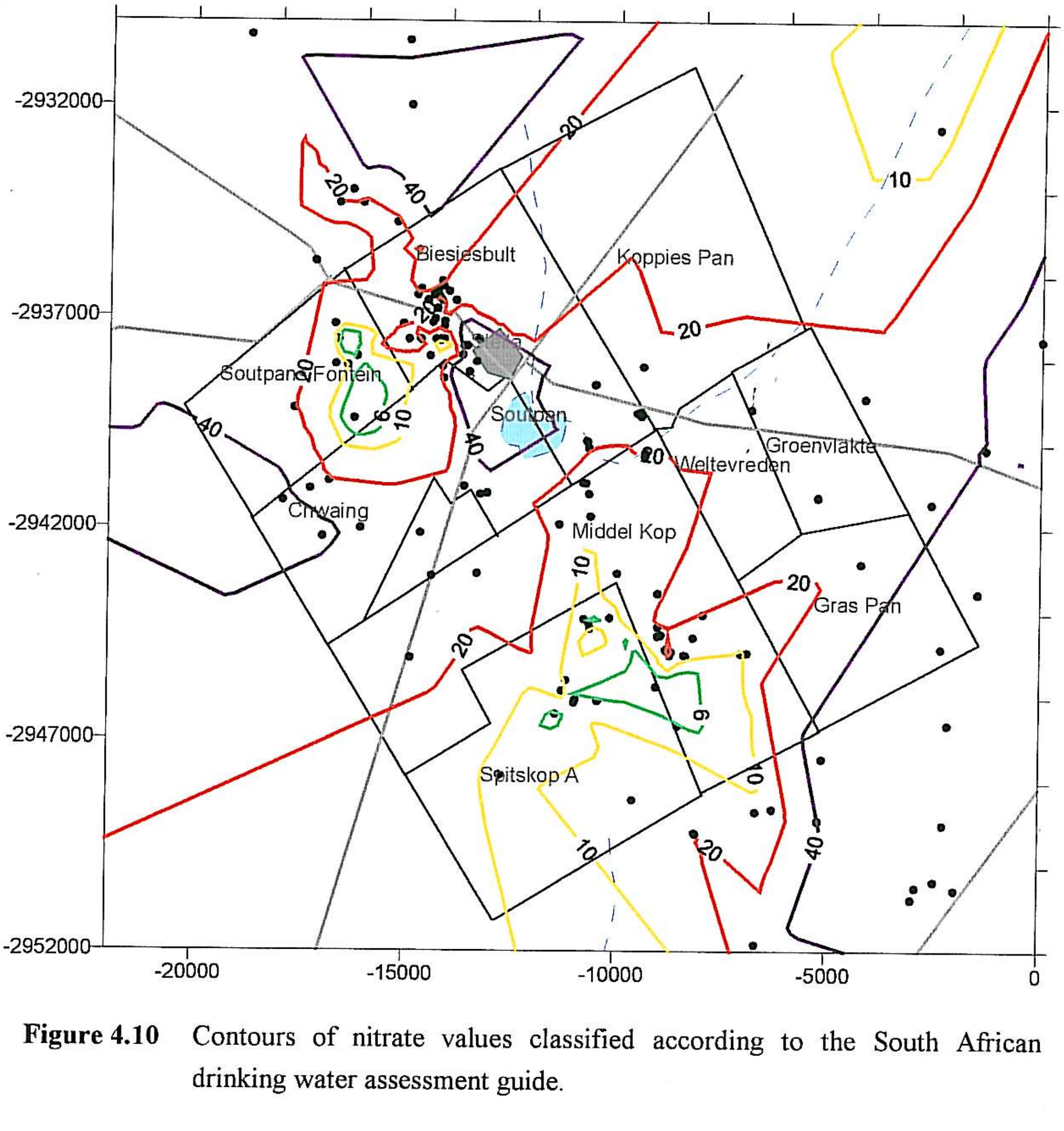


Figure 4.10 Contours of nitrate values classified according to the South African drinking water assessment guide.

4.6.3 Fluoride

Fluoride is a weathering product of mica, which is found in granites and gneisses. The relatively high fluoride concentrations observed in the Spitskop and Middel Kop areas (Figure 4.11) may therefore be regarded as an indication of the extent of the granitic aquifer.

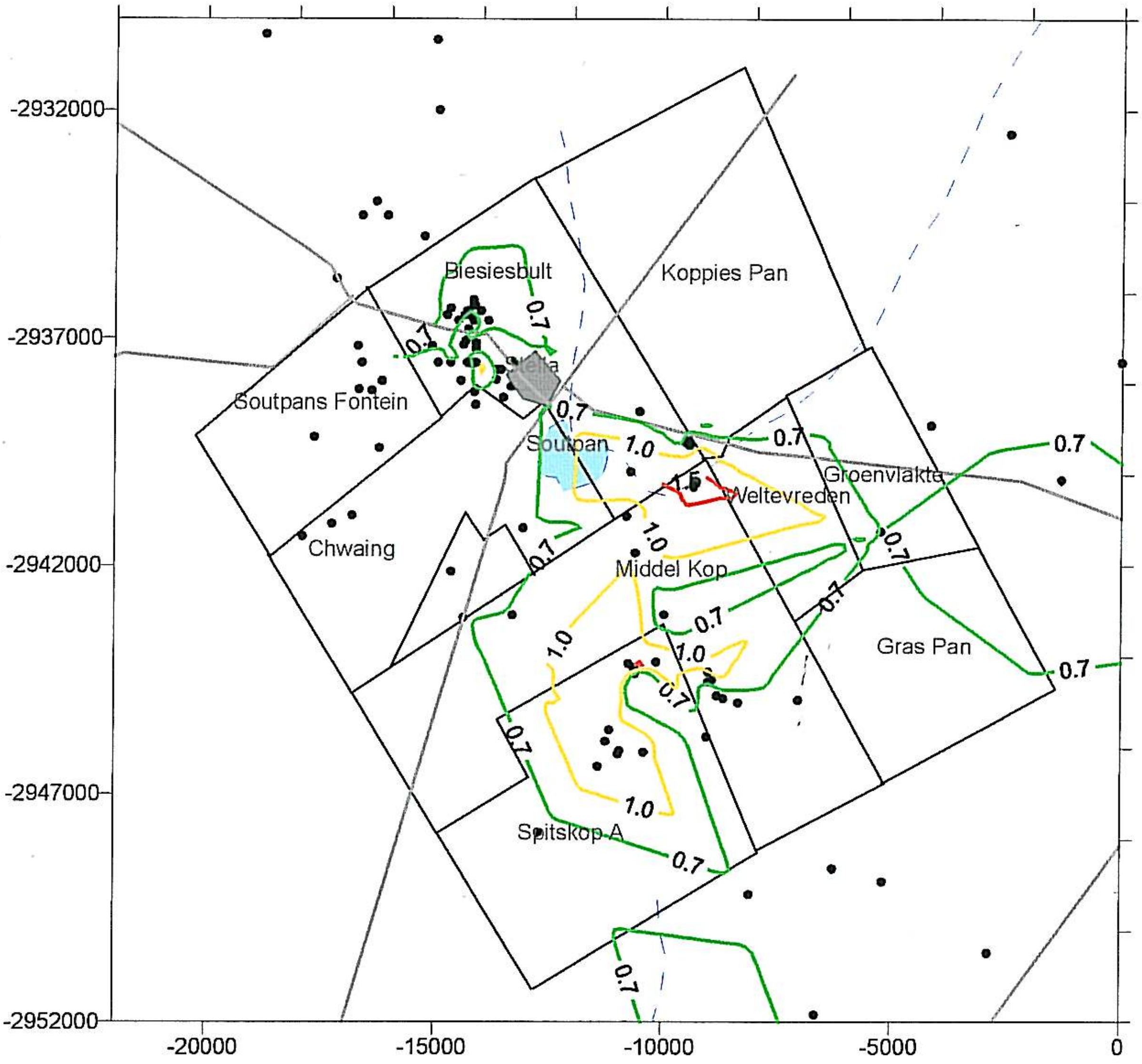


Figure 4.11 Distribution of fluoride concentrations in the groundwater of the study area.

Fluoride concentrations above 1.5 mg L^{-1} in drinking water can contribute significantly to abnormalities in humans like dental fluorosis, Downs syndrome, irritable bowel syndrome, osteoporosis and depressed thyroid function. Groundwater resources with high concentrations of fluoride should therefore be avoided as a permanent domestic source, or the water should be mixed with water with lower concentrations of fluoride.

4.7 DELINEATION OF THE AQUIFER

The delineation of an aquifer is essential in the evaluation of the potential of the aquifer. This applies in particular to aspects such as the recharge of the aquifer, its storage capacity and the area that needs to be protected from pollution.

Three indicators were used in an attempt to delineate the boundaries of the Middel Kop granitic aquifer. The first was the area covered with small pans visible on the aerial photograph in Figure 2.3. The existence of these pans is probably related to differences in the weathering characteristics of the various rocks that crop out in the area, and may consequently enhance recharge to the upper aquifer. It is also interesting to note that the concentration of nitrates (Figure 4.10) near the pans is generally less than in the surrounding areas. This suggests that the pans may also act as receptacles for run-off in the area.

As mentioned above, the relatively high fluoride concentrations on the farms Middel Kop and Spitskop in (Figure 4.11) can therefore serve as an indicator of the extent of the granitic aquifer. Although the same may be true of the sodium and potassium concentrations, these compounds are often influenced by plant absorption and evaporation from the Soutpan. They were therefore not considered in the delineation.

The area enclosed by the 5 L s^{-1} contour of the blow yields, denoted as Zone 1 in Figure 4.1, was the last indicator used in the delineation. This area is characterised by high yielding boreholes and large areas irrigated from these boreholes.

The total extent of the area, delineated by the three indicators and illustrated in Figure 4.12, is approximately 100 km^2.

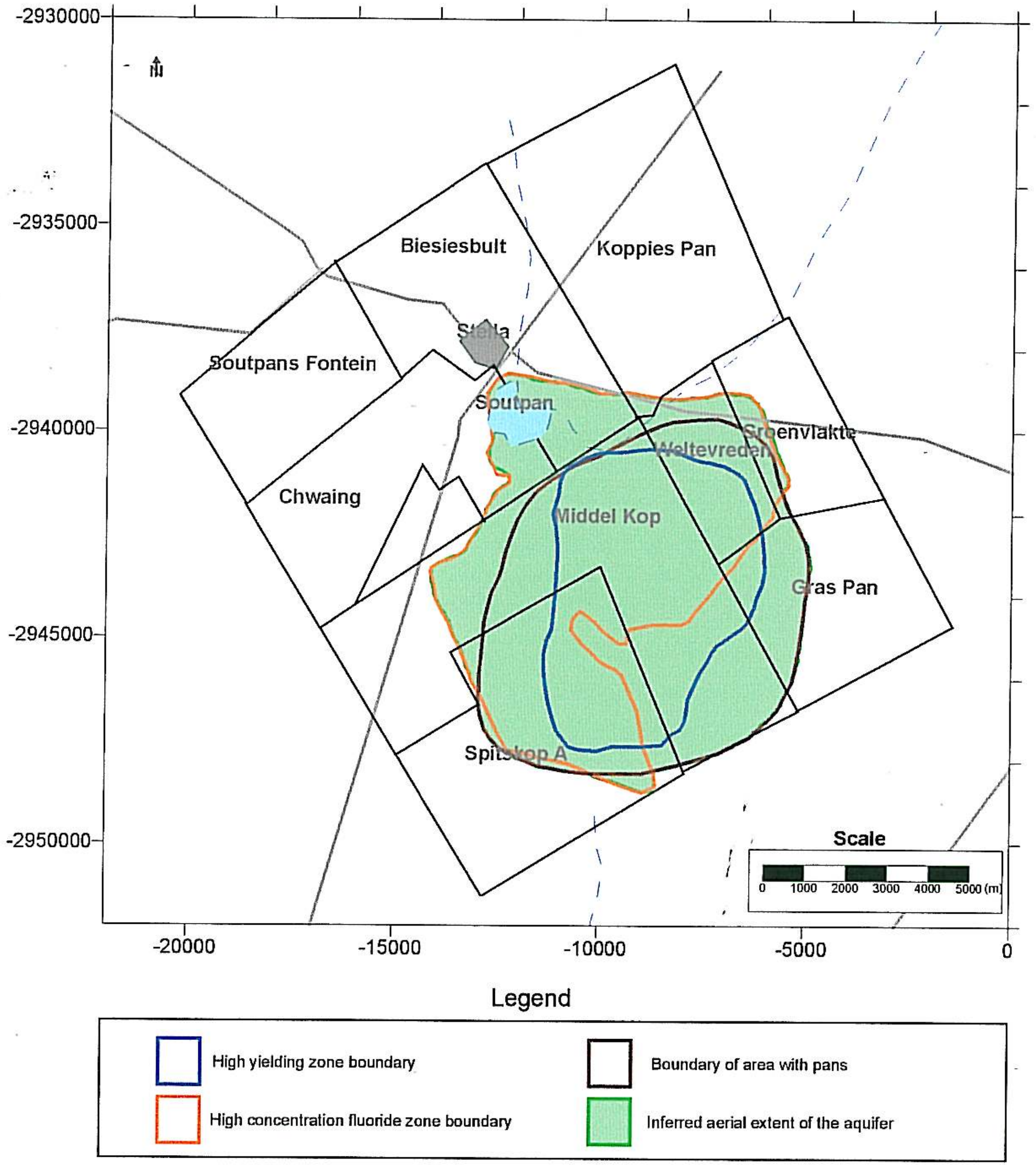


Figure 4.12 Delineation of the Middel Kop granitic aquifer.

CHAPTER 5

GROUNDWATER POTENTIAL

5.1 INTRODUCTION

The groundwater potential of an aquifer is mainly determined by the following two principles (Vegter, 1995a):

(a) The ability of the aquifer to support a supply rate equal to the long-term mean recharge rate of the aquifer for a sufficient period (preferably as long as or longer than the longest period between recharge events).

(b) Adequate storage space should be available at all times to accommodate water from future recharge events.

The water balance of an aquifer can be conveniently expressed through the equation

$$S\Delta V = [(I - O) + RE - Q]\Delta t \tag{5.1}$$

Where:

S = Storativity of the aquifer [1]

V = the saturated aquifer volume [L^3]

ΔV = change in the saturated volume of the aquifer [L^3]

Rf = rainfall intensity [$L\ T^{-1}$]

RE = $f(Rf)$ = recharge over a given period [$L^3\ T^{-1}$]

I = rate at which subsurface water flows into the aquifer [$L^3\ T^{-1}$]

O = rate at which subsurface water flows out of the aquifer [$L^3\ T^{-1}$]

Q = rate at which water is withdrawn from the aquifer [$L^3\ T^{-1}$]

Δt = the period for which the water balance must be computed.

As shown by Equation (5.1), the change in saturated volume of an aquifer depends on both the recharge and its storativity. Although these quantities are independent of each other, the common practice to estimate them from changes in observed water levels in the aquifer forces them to become circular dependent. Every effort should therefore be made to try and get independent estimates of these parameters.

A particularly attractive application of Equation (5.1) in groundwater investigations is to compute the rate at which an aquifer is recharged, which, as discussed above, plays a prominent role in the potential of an aquifer. However, this can only be done provided that I, O, S, Q, ΔV and Δt are known. The measurement of Q and Δt does not present any practical difficulties, while values of S can in principle be derived from hydraulic tests described in Section 5.2. The real problem arises with the estimation of I, O, and ΔV. One approach often used for this is the so-called equal volume approach described in Section 5.3.1.

5.2 HYDRAULIC TESTS

It is quite common to begin the evaluation of the potential of an aquifer with one or more hydraulic tests. One advantage of these tests is that they can provide some information on the type of flow within the aquifer. For example, if the observed drawdowns in a constant rate test display a linear variation with log(t), the flow is generally horizontal and radial. A linear dependence on $\sqrt{t}$ on the other hand would indicate vertical flow towards a fracture (Van Tonder *et al.*, 1998). Unfortunately, none of the drawdowns observed during constant rate tests performed on a number of boreholes in the study area display a definite trend, as illustrated by the graphs of the drawdowns for Borehole G43988 in Figure 5.1.

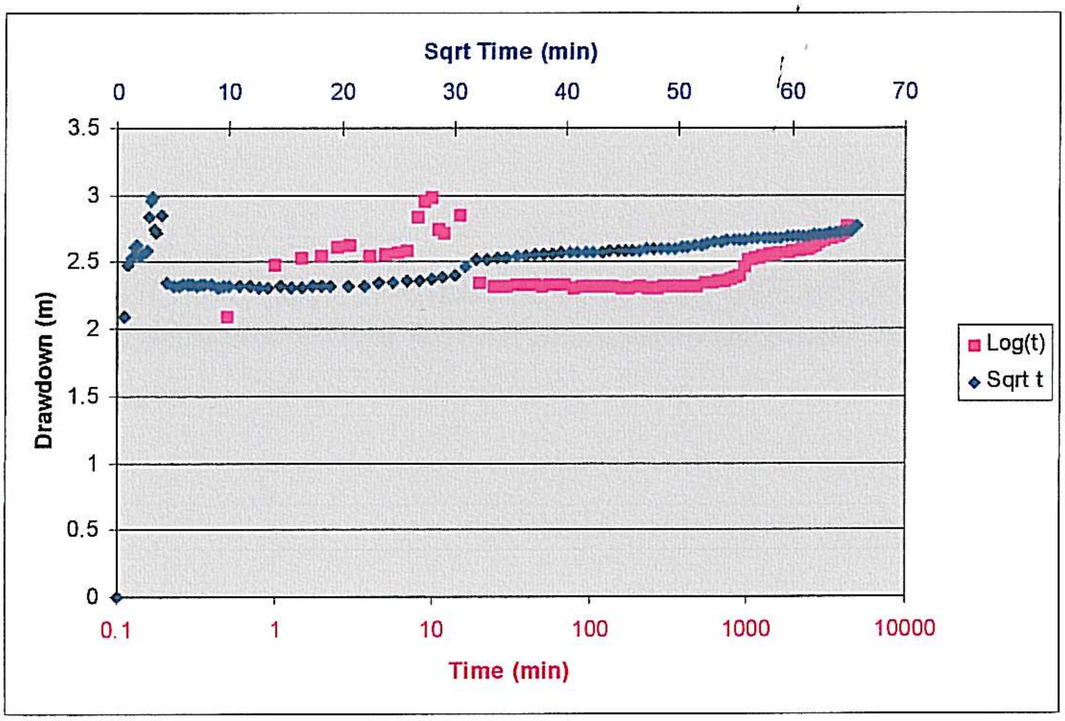


Figure 5.1 Graph of the drawdowns observed in Borehole G43988 during a constant rate test, (a) as a function of $\sqrt{t}$ and (b) as a function of log(t).

A number of methods were therefore used to analyse the results of constant rate tests performed in the study area. These include:

(a) The Theis and related Cooper-Jacob Methods (Kruseman & De Ridder, 1992). These methods can be applied in situations where the flow in the aquifer is essentially horizontal and radial, the latter at late times (Figure 5.2).

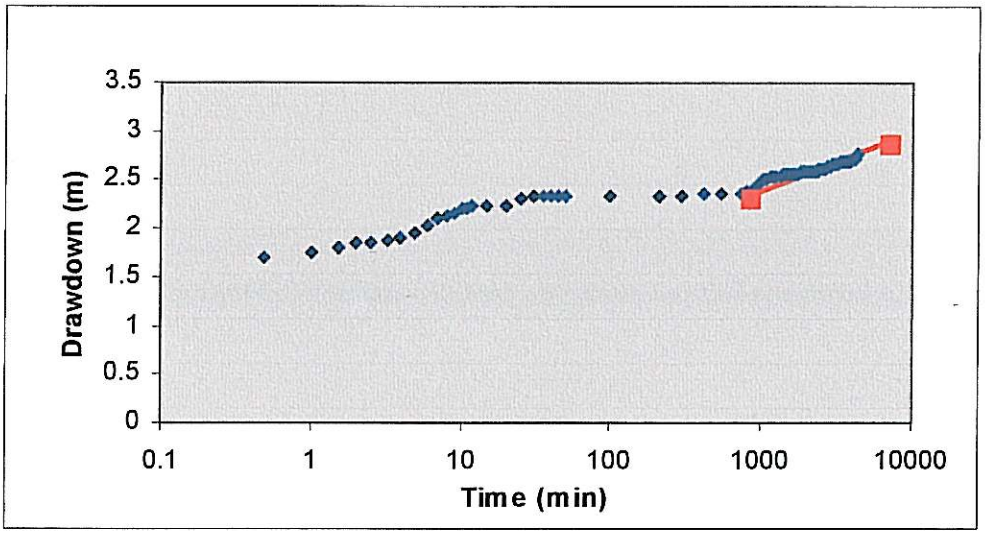


Figure 5.2 Graph showing the drawdown data of borehole G43988 at late time used for the interpretation of the Theis and Cooper-Jacob methods.

(b) The Flow Characteristic (FC) Method. This method uses the derivative of the Cooper-Jacob equation with respect to log(t) to estimate values for the transmissivity, T, (Figure 5.3) and storativity, S, (Figure 5.4) of an aquifer (Van Tonder *et al.*, 1998).

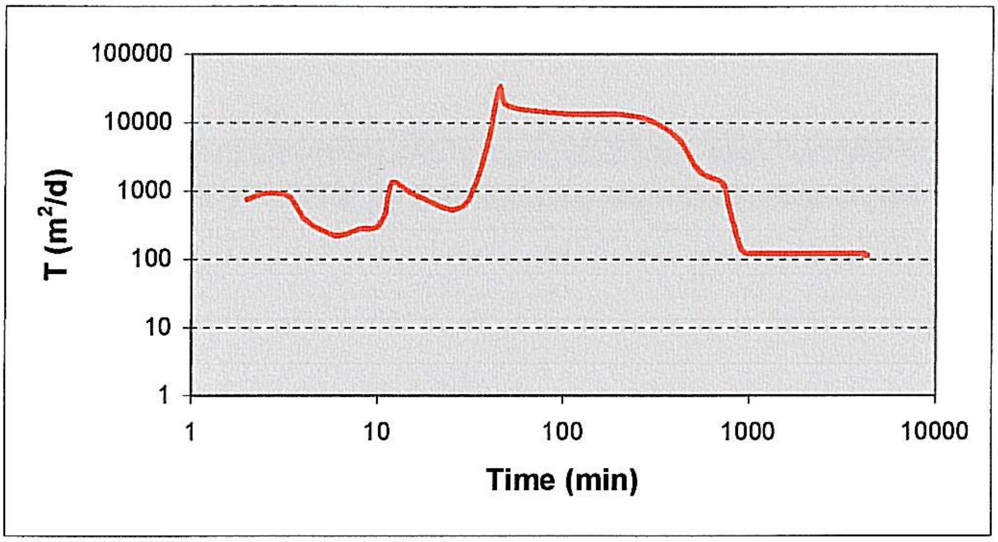


Figure 5.3 Transmissivity values with time obtained from borehole G43988 using the Flow Characteristic (FC) Method.

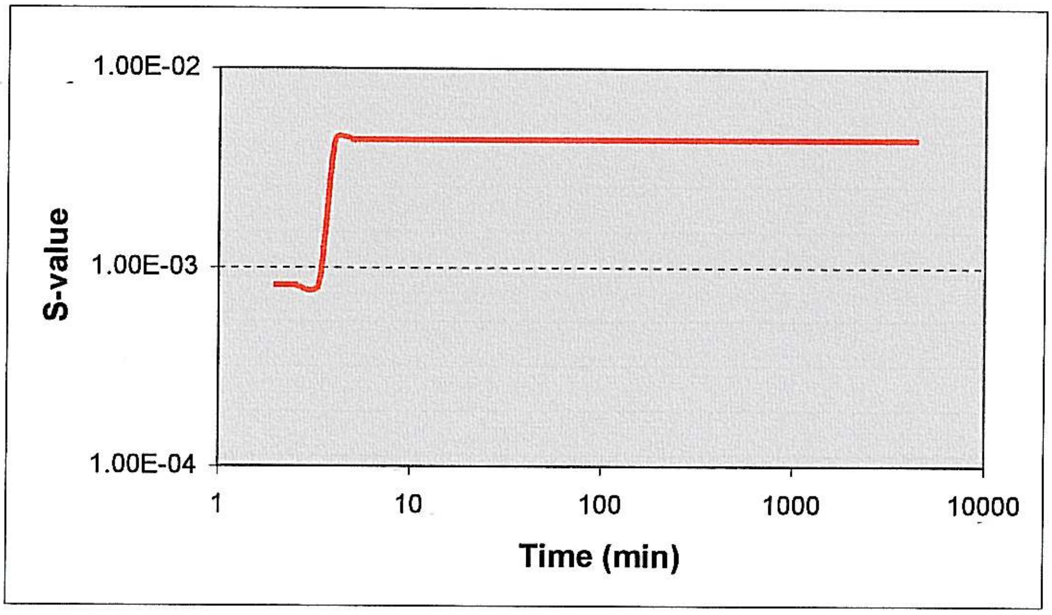


Figure 5.4 S-value with time obtained from borehole G43988 using the Flow Characteristic (FC) Method.

(c) RPTsolv Method. This method was devised to analyse the results of constant rate tests in Karoo aquifers, where the dominant flow direction is from the rock matrix to a horizontal fracture. The method is able to estimate the transmissivity and storativity of both the fracture and the matrix (Figure 5.5) (Verwey *et al.*, 1995).

The above mentioned methods really only apply in the case where the water levels are observed in an observation borehole some distance from the borehole pumped during a constant rate test. However, Van Tonder *et al.* (1998) has found that they can also be used to analyse data from the pumped borehole, provided one uses the so-called *'effective radius'* of the borehole in the analysis.

The results for the constant rate tests performed during this investigation are summarised in Table 5.1 and Table 5.2. The geometric mean of the storativities, 0.0049, is in good agreement with the storativities of fractured aquifers quoted by Bredenkamp *et al.* (1995) and Kirchner *et al.* (1991).

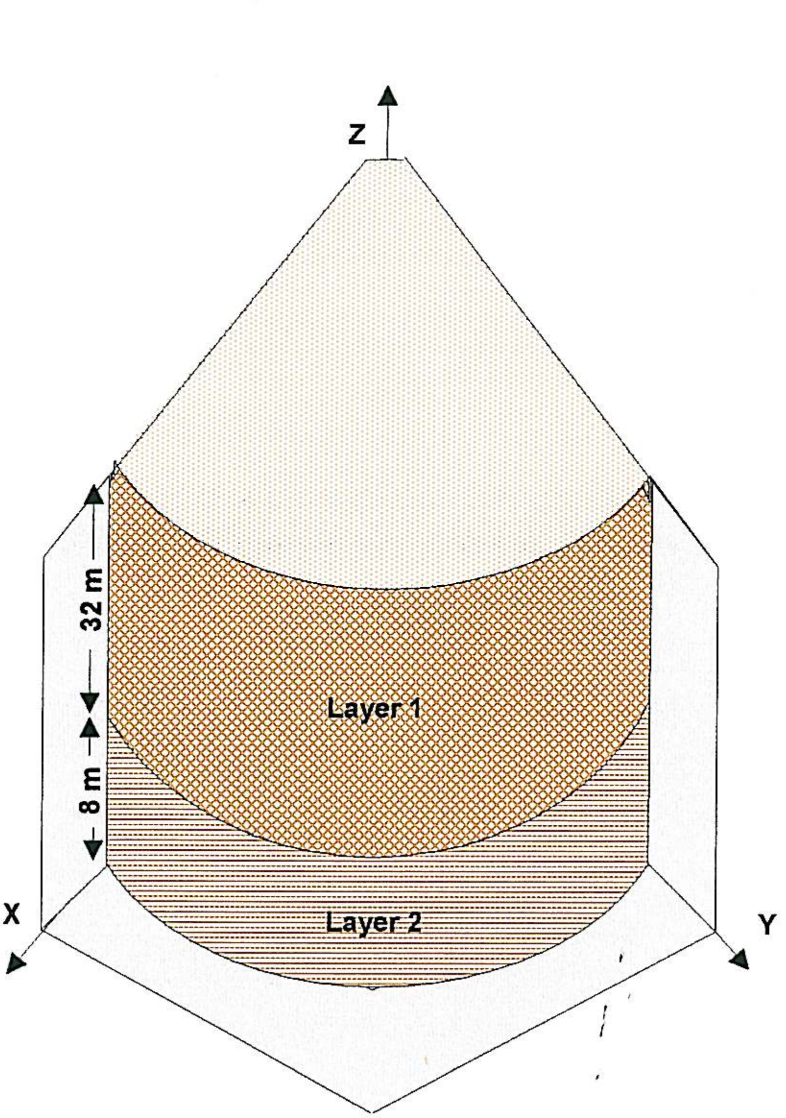


Figure 5.5 The two-layered aquifer used to represent the aquifer in the Spitskop area during the interpretation of the hydraulic test data of borehole G43988 using the RPTsolv method.

Table 5.1 Summary of a few estimated transmissivities (in $m^2 d^{-1}$) for the Stella aquifer obtained from a constant rate test performed on Borehole G43988 with a few methods of analysis.

Borehole Number	Borehole Description	Effective Borehole Radius	Theis	Cooper-Jacob	FC	RPTSolv (Fracture)	RPTSolv (Matrix)	Geometric Mean
G43988	Production	3.5	315	310	140	302	2.4	100
G45005	Observation	48.8	332	335	210	2245	3.5	179
G45004	Observation	68.6	736	812	392	2563	1.2	235
G44999	Observation	48.4	731	688	362	2148	3.0	259
G45000	Observation	110.9	456	452	240	1580	3.0	188
All								**183**

Table 5.2 Summary of the estimated storativities of the Stella aquifer obtained from the same constant rate test and methods of analysis used in estimating the transmissivities of the aquifer in Table 5.1.

Borehole Number	Borehole Description	Effective Borehole Radius	Theis	Cooper-Jacob	FC	RPTSolv (Matrix)	Geometric Mean
G43988	Production	3.5	0.0036	0.0035	0.0040	0.0070	0.0043
G45005	Observation	48.8	0.0775	0.0680	0.0002	0.0050	0.0084
G45004	Observation	68.6	0.0520	0.0430	0.0002	0.0050	0.0067
G44999	Observation	48.4	0.0740	0.0760	0.0004	0.0052	0.0102
G45000	Observation	110.9	0.0040	0.0042	0.0000	0.0042	0.0012
All							**0.0049**

5.3 ESTIMATION OF RECHARGE IN THE MIDDEL KOP AQUIFER

Recharge, direct from precipitation and the infiltration of surface water, involves the vertical downward movement of groundwater under the influence of vertical head differentials (Walton, 1970). It is important to note here that lateral inflow due to piezometric head differences is not included in this definition. The reason for this is that other users of the same aquifer can influence lateral gain.

According to Equation (5.1) both inflow and outflow from the aquifer will change its saturated volume over time. It is therefore important to evaluate the inflow and outflow of groundwater at the boundaries of the aquifer when recharge estimations are made based on water lever interpretations.

The inflow (I) and outflow (O) into an aquifer can be estimated from Darcy's equation:

$$I = T L_j i \tag{5.2}$$

where L_j is the width of the inflow boundary (dimensions L), i the groundwater gradient (dimensions 1) and T the transmissivity at the boundary of the formation losing the water. The water level contour map (Figure 5.6) of the hydrocensus data shows that such inflow boundaries exist east, north and west of the Middel Kop aquifer, while the aquifer is losing water along the southern boundary.

The inflow of groundwater to the Middel Kop aquifer is limited considerably by the low transmissivities of the surrounding formations, as indicated by the fact that the borehole yields in the surrounding areas are approximately 10 times smaller than the average yield computed for the Middel Kop aquifer. Since no T-values were available for these aquifers, a value of 18 m^2 d^{-1}, equal to 10% of the estimated T-value for the Middel Kop aquifer, was used in the computation described below.

Inflow into the Middel Kop aquifer was computed from the groundwater gradients that exist at the boundary of the granitic formation in the groundwater level contour map of the hydrocensus data (). The length of the flow boundaries with the specific gradient was also estimated from this figure. The loss from the aquifer was likewise computed from the water level gradients and boundary length on the southern boundary of the Middel Kop aquifer. This yielded an estimated net inflow of 857 m^3 d^{-1} for the Middel Kop Aquifer from the surrounding areas (Table 5.3).

Table 5.3 Computation of inflow volumes at the boundary of the Middel Kop aquifer.

Boundary	Transmissivity m^2 d^{-1}	Gradient m m^{-1}	Boundary Length m	Flow m^3 d^{-1}
North	18	0.00364	4539	298
NE	18	0.00382	2829	195
East	18	0.00502	4259	385
SE	18	0.00508	4679	428
South	180	-0.00156	4067	-1144
SW	18	0.00490	2512	222
West	18	0.00121	4340	95
NW	18	0.00612	3442	379
Total				**857**

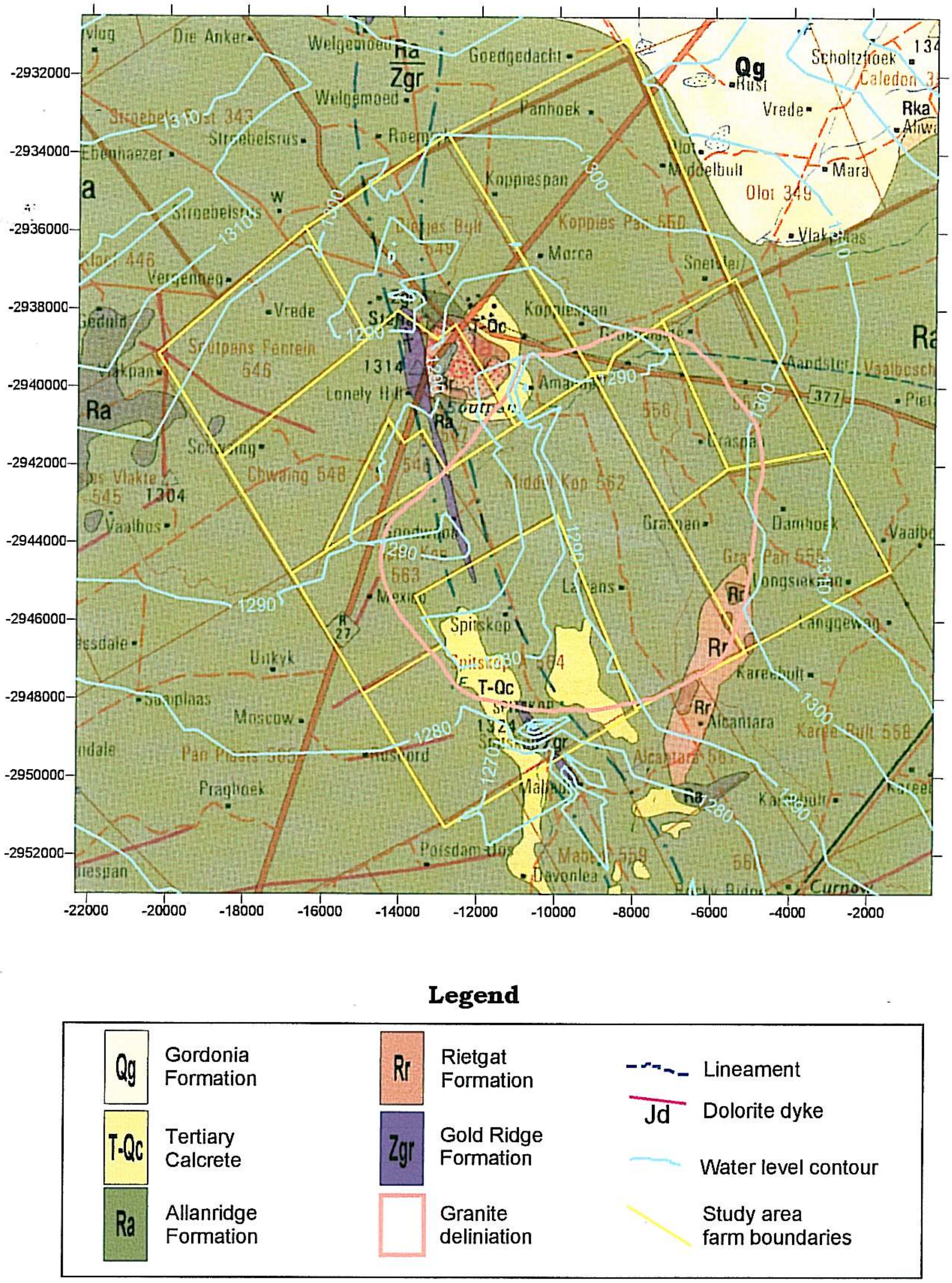


Figure 5.6 Water level contour map used in the evaluation of the inflow and outflow components of the Middel Kop aquifer.

5.3.1 Depression Focussed Recharge

Topographic depressions are low-lying areas in the landscape. Generally, surface runoff from higher elevations will collect in these depressions and increase the seepage potential at these locations. Also of great significance is the presence of chemicals, which would also be concentrated in these low-lying areas. Hence groundwater recharge as well as chemical loading is enhanced at the site of depression (Derby, 1995).

Small pans are found all over the granitic aquifer in the study area with water collecting in these pans during large precipitation events. From Plate 5.1 a clay layer can be seen just beneath the surface near one of the small pans on the farm Spitskop. Below this clay layer seems to be a coarse sand layer.

Depending on the continuity of the clay layer, these pans might contribute significantly to recharge. No salts are found at the surface of these small pans, indicating that water does not evaporate significantly, but probably recharges the aquifer.

Plate 5.1 Soil near a small pan indicating a thin clay layer before going through into a coarse sand layer beneath the pan surface.

5.3.2 Equal Volume Method

If there is no change in groundwater storage over a selected period, ($\Delta V = 0$), the term containing the storativity of the aquifer vanishes and Equation (5.1) reduces to

$$RE = Q - (I - O) \tag{5.3}$$

Since such periods often occur in historical sets of water levels, as illustrated in Figure 5.7, the possibility exists that one can compute a number of recharge rates from a given set of historical water levels, provided I, O and Q are known.

The exact volumes of water withdrawn (Q) for the periods where equal volume conditions exist are not known. The long term average monthly rate, discussed in Section 4.5.3, was consequently used to compute the volume of water abstracted during the various periods in Figure 5.7 where equal volume conditions existed. This estimate and the estimated inflow into the aquifer derived above ($857\ m^3\ d^{-1} = 0.283\ 10^6\ m^3$) yielded a recharge volume (*RE*) of $1.49\ 10^6\ m^3$ for the period August 1993 to June 1994. This is equivalent to 3 % recharge of the 503 mm precipitation over the 100 km^2 Middel Kop aquifer.

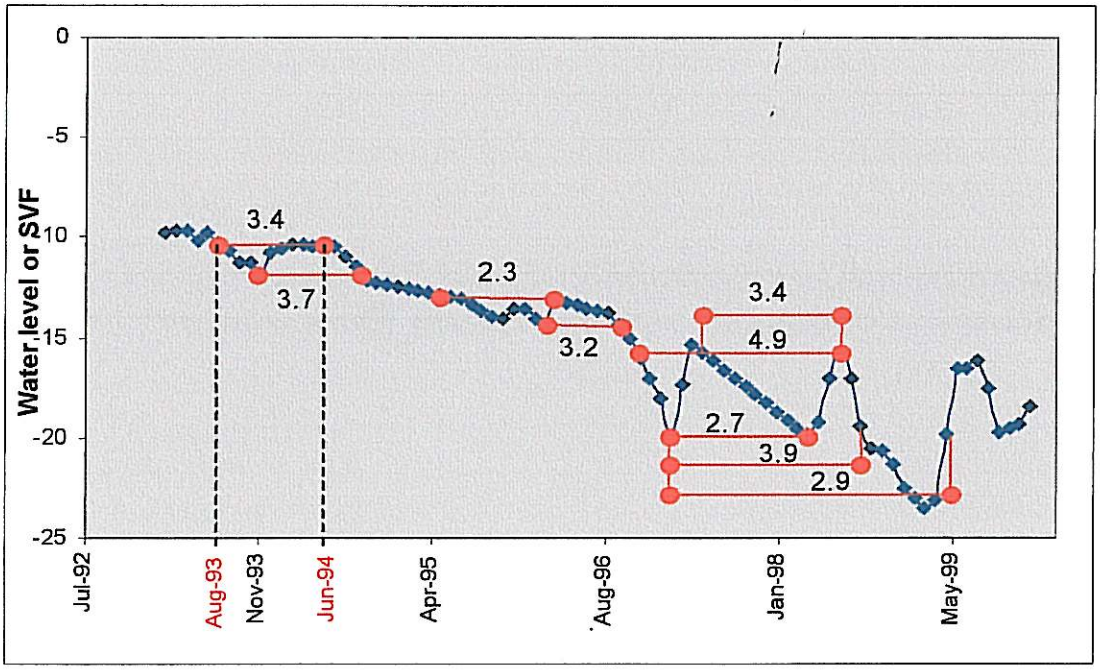


Figure 5.7 Graph showing periods of equal volume in the aquifer where the Equal Volume Method was used to estimate the recharge.

5.3.3 Saturated Volume Fluctuation Method (SVF Method)

In this investigation Equation (5.1) was used to estimate the long term recharge for the aquifer by estimating and comparing the computed water level change (ΔV) with actual observed water levels. By changing the recharge component in the equation, the simulated water level change can be computed for every month where *Rf*, *Q* and *(I-O)* data or estimations are available (Figure 5.8). The computed drop in water level is however comparable to the general observed drop in water levels. A recharge estimation of 2.4% is obtained using the SVF Method (Figure 5.8). From Equation (5.1) and the above discussion it is clear that recharge can only be estimated if the storage coefficient of the aquifer is known.

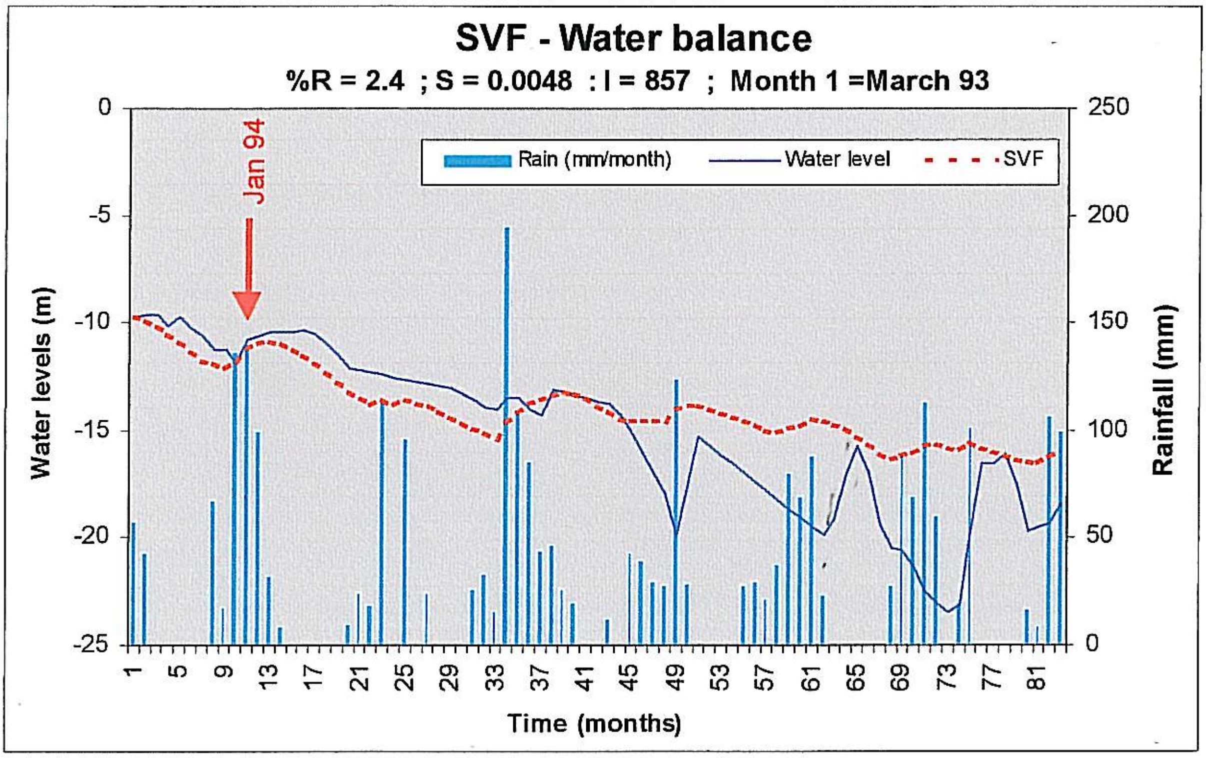


Figure 5.8 Recharge estimation by comparing the results of the Saturated Volume Fluctuation water balance model with observed water levels.

For example the estimates Q = 118 283 m^3 and $(I - O)$ = 25 710 m^3 (857 m^3 d^{-1}) for January 1994 (month 11) together with a estimated long term *RE* of 2.4 % of the 140 mm precipitation, which equals a recharge of 336 10^3 m^3 over the aquifer area of 100 km^2 for the month, was used to estimate the change in volume for the aquifer. This estimate and the average S-value (0.004 8) derived from the hydraulic tests, indicated that the water level in the aquifer should have risen by 0.51 m. However, the measured rise in water level was only 0.2 m. The most probable cause for this discrepancy is that the long term estimated monthly abstraction is not a true representation of the actual abstraction during that month. This estimation of change in water level is applied for all the months where data is available. The general trend of the measured water levels is then compared to the estimated change in water levels with time.

5.3.4 Cumulative Rainfall Distribution Model (CRD Model)

The CRD reflects the natural balance of groundwater under the combined effects of recharge to and the losses from a system (Bredenkamp *et al.*, 1995). The CRD in terms of head, can be represented by the following equation:

$$h_i = h_{i-1} + \left[RE + \sum_j \frac{I_i}{A_j^I} - \sum_k \frac{O_i}{A_k^O} - \frac{Q_i}{A} \right] \frac{(t_i - t_{i-1})}{S} \qquad (5.4)$$

where:

h_i = head in month i [L]

h_{i-1} = head in month i–1 [L]

RE' = recharge per unit area = (RE/A) [L T^{-1}]

P_i = precipitation in month i [L T^{-1}]

A = area of the aquifer [L^2]

A_j^I = area influenced by the j-th inflow boundary [L^2]

A_k^O = area influenced by the k-th outflow boundary [L^2]

The water levels in the aquifer are simulated by solving Equation (5.4) in one-month time steps by estimating the recharge and comparing the computed water levels with the observed water levels. The recharge estimate that yields an acceptable correlation between the computed and observed water levels is then taken as recharge to the aquifer. By changing the recharge component in the equation, the simulated water level reaction can be matched with the measured water levels (Figure 5.9). By comparing and matching the heads computed from the CRD model with the measured water levels the effective recharge is estimated. A recharge value of 2.4 % of MAP was obtained using the CRD method (Figure 5.9).

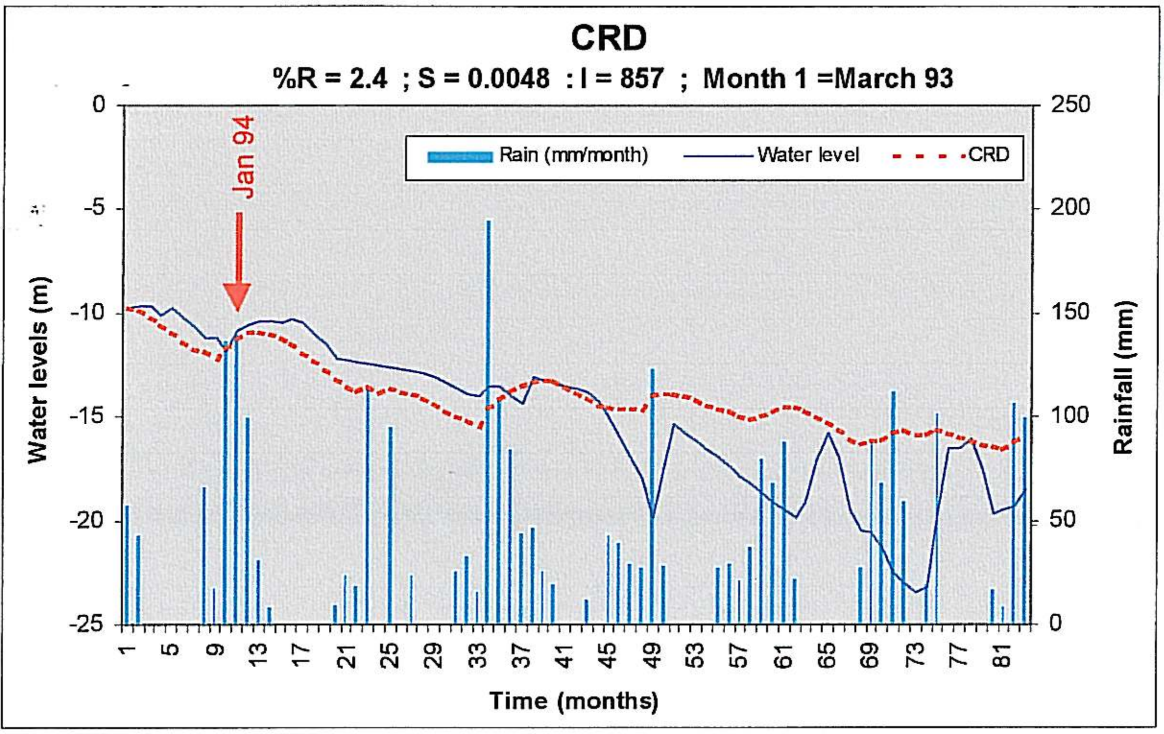


Figure 5.9 Comparison between measured water levels and calculated heads obtained estimating recharge with the Cumulative Rainfall Departure (CRD) method.

As example January 1994 (month 11) is again used and using the values as described in Section 5.3.2, assuming that the inflow and outflow volumes influence the water levels across the whole aquifer, $A^{I\text{-}O} = A = 100 \text{ km}^2$, this yields a computed rise of 0.51 m for the month, whereas the measured rise was only 0.2 m.

5.3.5 Chloride Mass-Balance Method

The chloride mass-balance method compares total chloride deposition at the surface with chloride concentrations in groundwater as measured in samples from boreholes. Assuming chloride to be a conservative ion and rainwater to be the only source of chloride (Cl), conservation of mass leads to the following relation between precipitation and recharge

$$RE = \frac{Cl_p Rf}{Cl_{gw}} \tag{5.5}$$

where Cl_p and Cl_{gw} represents the chloride concentration in precipitation [M L^{-3}] and groundwater [M L^{-3}] respectively and the other symbols have the meanings defined above

(Bredenkamp *et al.*, 1995; Ting *et al.*, 1998). For this example, assume that the chloride concentration in precipitation of 0.8 mg L^{-1} observed by (Bredenkamp *et al.*, 1995) at Coetzersdam, approximately 50 km from Stella, is also representative of Stella. The concentration of 97.6 mg L^{-1} observed in the groundwater sample taken from borehole G43988 during a 72-hour aquifer test in Table 4.2 and the average rainfall estimated value of 408 mm at Stella yields an *RE* value of 3.34 mm, which is equivalent to 0.8 % of the rainfall. This procedure and the harmonic mean of the chloride concentrations observed in groundwater samples from the different geological formations at Stella were used to estimate values of the recharge in the formations. The results are summarised in Table 5.4.

Table 5.4 Recharge rates for a number of geological formations in the study area, estimated with the chlorine mass-balance method. (MAP = mean annual precipitation)

Geology	**Number of Samples**	**Harmonic Mean (Mg L^{-1})**	**Recharge (mm a^{-1})**	**Recharge (% of MAP)**
Granite	28	64.1	5.1	1.2
Granite & Gold Ridge	13	16.6	19.7	4.8
Gold Ridge & Ventersdorp	57	35.3	9.3	2.3
Ventersdorp	35	36.9	8.9	2.2

The relatively low recharge rate (1.2 % of the mean annual precipitation) for the granitic formation is probably influenced to some extent by the increased evaporation from the irrigated farm lands, which is mainly restricted to this formation. This and the associated higher transpiration rates of the plants will cause a higher chloride concentration in the top soil and therefore the mass of chlorine dissolved in the infiltrating water. Since the areas surrounding the granite and Gold Ridge formations are not affected by irrigation, the recharge estimate for these formations may be more representative of the Middel Kop aquifer.

5.4 RESULTS

The recharge rates estimated above are compared with the independent estimates of Vegter (1995) and the Harvest Potential map of Seymor (1996) in Table 5.5. The assignment of confidence levels is an attempt to make provision for uncertainties in the estimation procedures.

Using the Equal Volume, SVF and CRD methods of *RE* estimation, average long term estimations of Q are sufficient, provided that a long enough time series of water level data is available. Monthly abstraction data would however have increased the confidence of the recharge estimations, in order to simulate seasonal water level drawdowns and recoveries more accurately.

The effects of irrigation on the concentration of salts influenced the confidence levels of the chloride method, while the Vegter and Harvest Potential estimates were assigned low confidence levels, because of the scale used in the compilation of the maps. If the recharge estimates discussed above are weighted with these confidence levels, the weighted average recharge to the Middel Kop aquifer is 15.4 mm a^{-1} or (4 227 m^3 d^{-1}).

Table 5.5 Summary of recharge estimates and methods used for the Middel Kop aquifer.

Method	**mm/a**	**% of rainfall**	**Confidence Level (High=5; Low=1)**
Cl	19.7	4.8	3
SVF: Equal Volume	13.4	3.3	4
SVF: Water Balance	9.8	2.4	4
CRD	9.8	2.4	4
Independent Estimates			
Vegter	20.0	4.9	2
Harvest Potential	12.0	2.9	2
Average recharge	**15.4**	**3.8**	
Area (Km^2) =	100	Km^2	
Annual Rainfall (mm) =	408	mm	
Recharge =	**4227**	m^3 d^{-1}	

CHAPTER 6

PROTECTION OF THE MIDDEL KOP AQUIFER AND THE ALLOCATION OF WATER

6.1 INTRODUCTION

The National Water Act of South Africa (Act 36 of 1998) emphasises that all water resources must be protected to ensure sustainable yields now and in the future. This means that sufficient measures must be in place to ensure the comprehensive protection of water resources before water is allocated from a specific source. The Department of Water Affairs and Forestry consequently has introduced the so-called Resource Directed Measures (RDM) (MacKay, 1999) to allocate water from a specific resource. These measures include:

(a) Classification of the resource

(b) Reserve allocations

(c) The resource quality objectives (RQOs)

(d) Monitoring.

Since there are no significant surface water resources in the Stella area, it stands to reason that every effort should be made to protect the available groundwater resources from depletion and pollution. Otherwise, one will have to import water from other sources at great cost. It is therefore extremely important to protect the available groundwater resources with the RDM.

6.2 AQUIFER CLASSIFICATION

6.2.1 General

A national protection-based classification system has recently been proposed by Braune *et al.* (2000). In this scheme the groundwater resources are grouped into categories depending on

(a) the extent that the resource has been modified and damaged

(b) risks of causing irreversible damage to the resource as a source of water

(c) level of protection needed to safeguard the future use of the resource.

The categories are summarised in Table 6.1 and take into account the changes in the resources and the implications of a damaged resource.

Table 6.1 Summary of the classification system for water resources proposed by Braune *et al.* (2000).

Category	Definition
A	Unmodified or approximates natural conditions
B	Largely natural conditions with only a few localised modifications; no negative effects apparent
C	Moderately modified; moderate changes are apparent
D	Largely modified; a widespread loss of natural functioning
E	Seriously modified; the losses of natural functioning are extensive
F	Critically modified; modifications have reached a critical level and the unit has been modified completely with almost complete loss of natural functioning

6.2.2 Current Status

The current status of the aquifer in the classification scheme of Braune *et al.* (2000) is essentially based on the degree of modification and the risk of irreversible damage, but also takes the water quantity, water quality and environmental aspects (aquifer structure and ecology) into account. The determination of reference conditions, is a necessary step to ascertain the "unimpacted" conditions, in order to evaluate the degree of modification.

Reference conditions need to be determined for water quality, water quantity, aquifer structure and for ecological aspects. Time series data, historical data and anecdotal information are most important in the determination of reference conditions for the resource. The determination of reference conditions is then followed by the classification of the resource according to current status.

Figure 6.1 shows the current status classification of the resources in the Stella area considering aspects of quality, quantity and environmental change due to the use of the water. Water level drawdowns due to abstraction in the Middel Kop aquifer and Stella well-field negatively influenced the current status classification for these areas and were C-classes awarded to these well-fields. The rest of the study area had no known negative effects regarding abstractions. Water quality data and the possible impact of abstraction on the environment were also considered in the evaluation of the current status classification for the study area. The current classification outcome was however not dramatically influenced by the groundwater quality and impacts on the environment.

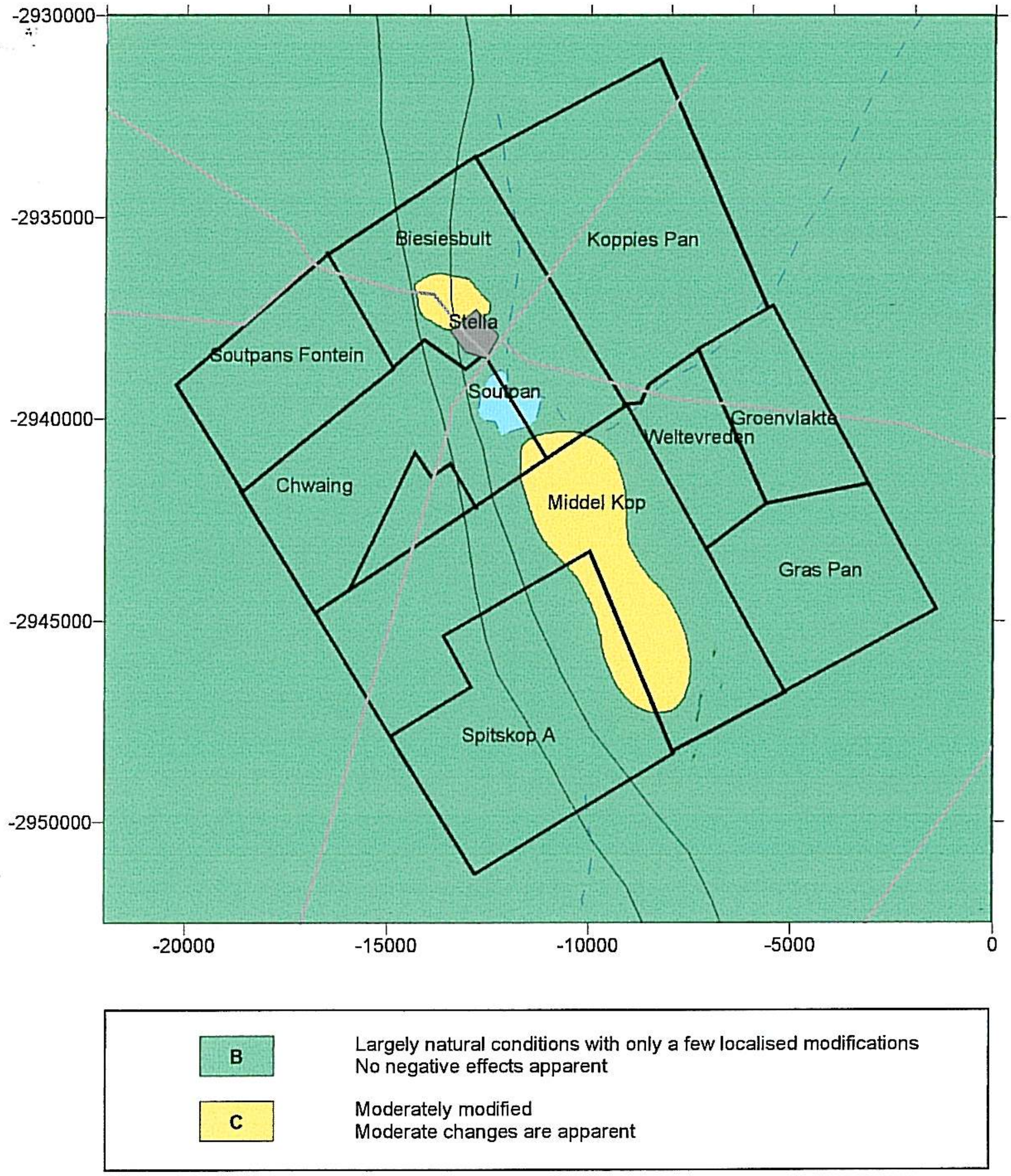


Figure 6.1 Current status classification of the groundwater resources in the Stella area considering aspects of quality, quantity and environmental change due to the use of the water.

6.2.3 Future Management Class

The final step in the classification process is to determine a suitable management class for the protection and minimisation of irreversible damage to the aquifer in the future. The main aim behind the managing of a aquifer usually entails one of more of the following objectives (Freeze, 1990):

(a) ensure that the water quality and quantity of the aquifer does not deteriorate with time,

(b) to clean up a contaminated aquifer or restore a damaged aquifer

(c) ensure that a highly contaminated aquifer does not pollute other water resources in its vicinity.

This is supported by the proposed management classes by Braune *et al.* (2000), where management classes could equate to the current status categories, or could be set higher if improvement of the resource is required.

There are only 4 management classes (A through D), as E and F is not acceptable as future management classes. Aquifer classifications E and F represent a degree of modification, which have already resulted in or carry an unacceptably high risk of irreversible degradation. These classifications would not allow sustainable utilisation of an aquifer and should these aquifers be managed towards higher classes in order to ensure the sustained utilisation of these aquifers. The relationship between current status categories and management classes is given in Table 6.2 below.

Table 6.2 Description of the management classes introduced by Braune *et al.* (2000) with the symbols defined as in Table 6.1.

Present Status Category	Management Class
A	A
B	B
C	C
D	C
E or F	D

Bad management practices have often damaged (even destroyed) aquifers more than would have been the case if the aquifer were not managed at all in the past. Fortunately, the efficiency of management procedures has now reached such a state that they can be applied with confidence, provided the system is monitored simultaneously and the person in charge has a detailed knowledge of groundwater models and related management practices. The world-wide view today is that water supply schemes, whether they are based on surface or subsurface sources, should be managed efficiently. However, there are a number of approaches that can be followed to manage a water resource, as a review of the literature on the management of water resources will show. For example, one may have to assign more resources to the management of a sole source aquifer (as defined above) than a large surface reservoir in an unpolluted river. The situation can of course also arise where a sole source aquifer has sufficient high quality water to supply the long term needs of its users, but the pollution in a nearby poor quality aquifer is spreading towards the sole source aquifer. In such a case, it would obviously be appropriate to pay more attention to the poor quality aquifer than the sole source aquifer.

One approach that is gaining momentum today is to use *hydrogeological decision analysis*, originally introduced by Freeze (1990) for the management of water resources. The basic idea behind this approach is to maximise the benefit of a resource for the users, and at the same time minimise the costs involved with the management of the resource and the risks the resource may pose to users. One can therefore expect that the management procedures will vary considerably from one resource to the next. Nevertheless, it may be worthwhile to introduce various classes of management schemes, such as the one introduced by Braune *et al.* (2000) and summarised in Table 6.2.

The advantage of this approach is that it allows a regulatory authority to set a management standard when issuing an authorisation permit to use an aquifer as a source of water. However, such a decision should be based in consultation with and active participation of the applicant for the permit. It is however recommended that the quantity classification of the Middel Kop area and Stella well-field be improved. A reduction in abstractions from both these aquifers is recommended in order to reduce the total drawdowns in these aquifers.

6.3 RESERVE

The ultimate aim of the National Water Act (Act No. 36 of 1998) is to achieve the sustainable use of water for the benefit of all users. The act tries to achieve this objective by introducing the term *Reserve* defined as the quantity and quality of water required to:

(a) Satisfy *basic human needs* by securing a basic water supply (as prescribed under the Water Services Act of 1997) for people who are or who will in the reasonably near future be relying upon, taking from, or being supplied from the relevant water resource.

(b) Protect aquatic ecosystems in order to secure ecologically sustainable development and use of water resources.

The Water Services Act (Act 108 of 1997) currently allocates 25 L d^{-1} as the basic human need, described as *the minimum volume of water needed by an individual to sustain a minimum living standard*. This includes water for essential purposes, such as drinking, food preparation and personal hygiene. The near future population of the study area is estimated at 3 500 people (Van Jaarsveld, Pers. Com.). At least 87.5 $m^3 d^{-1}$ of water will therefore be needed to supply the basic human needs of the area. The majority of these people will be living in the town Stella and therefore not be able to take water directly from the resource. This means that provision must be made to allocate some of the water from the Middel Kop aquifer to the town council for water supply.

The protection of both aquatic and terrestrial ecosystems is increasingly being recognised as essential to the protection of public health and the environment. Only through the conservation of ecological processes will it be possible to maintain native ecosystems and environmental gradients between the ecosystems.

There are no indications that the rate at which water is currently withdrawn has a negative effect on the terrestrial ecosystem above the Middel Kop aquifer. The native trees in the area are also well adapted to the large fluctuations in water levels commonly observed in semi-arid conditions, although this situation may change if the water table is lowered considerably more in the future. One can therefore not rule out the possibility that a too deep water table may affect the natural vegetation adversely in the future, particularly if one keeps in mind that the influence the withdrawal of groundwater has on terrestrial ecosystems is not well understood and difficult to quantify. Nevertheless, it is felt that no water needs to be allocated from the aquifer for ecological purposes, since there are no aquatic ecosystems, riparian zones or springs in or near the Middel Kop aquifer.

6.4 RESOURCE QUALITY OBJECTIVES AND DRAWDOWN LIMITATIONS

In determining resource quality objectives, a balance must be sought between the need to protect and sustain water resources on the one hand, and the need to develop and use them on the other (National Water Act , Act No. 36 of 1998). The following Resource Quality Objectives and Drawdown Limitations therefore seems reasonable for the Middel Kop aquifer and surrounding areas.

(a) The groundwater quality of the Middel Kop aquifer should not degrade in the long term. It is therefore essential that the influx of contaminated water from the surrounding areas be monitored on a regular basis, and that spills of nitrogenous fertilisers be prevented. A reasonable limit for the nitrate concentration in drinking water at this time is 20 mg L^{-1}.

(b) The influence of Soutpan on water quality in the Middel Kop aquifer is not well understood at this stage. Water level measurements in boreholes close to Soutpan indicate that the unsaturated zone beneath the pan is approximately 3 m thick. Since large volumes of water enter Soutpan during the rainy season the possibility exists that some of the salts will find their way to the groundwater below Soutpan and the Middel Kop aquifer. It is therefore important that the water level gradient towards Soutpan should always be maximised as far as possible.

6.5 PROPOSED MANAGEMENT SCHEME FOR THE MIDDEL KOP AQUIFER

6.5.1 Resource Directed Measures

There is not sufficient information available now to determine what volume of water can be withdrawn from the Middel Kop aquifer, without contravening the objectives of the RDM. However, the discussion in the preceding section indicates that the aquifer may already be exploited. It is therefore essential that a long-term monitoring program be implemented in the area as soon as possible, but not later than the implementation of the envisaged water supply scheme. One of the main aims of such a program should be to study the dynamic nature of groundwater systems as affected by both natural phenomena and man-induced changes (Everett, 1983). Special attention should therefore be given to areas where large impacts are expected or where impacts should be prevented in the monitoring scheme.

The implementation of a long-term monitoring program has the additional advantage that it will enable one to develop a suitable management plan for the aquifer that will:

(a) ensure the sustainable use as well as protection of the aquifer,

(b) allow one to re-evaluate the potential of the aquifer regularly, and

(c) ensure that the resource quality objectives are met.

6.5.2 Monitoring Groundwater Levels Discharge Rates and Rainfall

A preliminary groundwater model was used to determine the areas where the envisaged well-field will have the largest impact on the water resources in the area and where water levels should be monitored. This model is essentially based on the currently known well-fields, discharge rates, and the precipitation data of the past 18 years. It was also assumed that the Gold Ridge Formation and the pans on the granitic aquifer are the main recharge areas. The results are summarised graphically in Figure 6.2.

The main aim of the proposed continuously and monthly monitored boreholes in Figure 6.2 is to gather sufficient data to refine the existing model to evaluate of future water levels and the influence that external activities may have on the Middel Kop aquifer. However, to achieve this it will be necessary to also measure the rates at which water is withdrawn from the aquifer. This applies in particular to water not covered by the permissible use as defined under Schedule 1 in the National Water Act. These measurements should be conducted at least on a monthly basis or more frequently where possible and supplemented with the simultaneous recording of precipitation data. A permanent weather station on the farm Middel Kop that records climatological parameters such as soil and air temperatures and rainfall continuously will be particular useful in this connection.

6.5.3 Water Quality Monitoring

The movement of people from rural to urban areas puts severe stresses on towns and cities, as is evident in the plight of homeless street-dwellers, polluted air, lack of safe drinking water and sanitation, factors that can cause premature deaths and ill health (Green Paper on the Environment, 1996). Leachate arising from domestic waste landfills that contain high concentrations of hazardous chemical and biological substances is particularly important in this regard, as it can pollute both surface and groundwater. Moreover, there is ample evidence to believe that the quality of groundwater near municipal landfills deteriorates continuously with time (Paling, 1991).

The vulnerability to pollution of an aquifer can be determined using the DRASTIC method. The DRASTIC methodology has been developed by the USGS (Aller *et al.*, 1987) to provide a systematic and consistent evaluation of the potential for groundwater contamination on a national basis. The methodology depends on seven hydrogeological parameters summarised in the name. These are:

(a) **D**epth to the water-table
(b) the rate at which the aquifer is **R**echarged
(c) the **A**quifer formations
(d) **S**oil types
(e) **T**opography of the area
(f) **I**mpact on the vadose (unsaturated) zone
(g) the hydraulic **C**onductivities of both the vadose and saturated zones.

The DRASTIC methodology is based on two numerical indices: weight and rating, assigned to every one of the hydrogeological parameters. The weights that range from 5 (most significant) to 1 (least significant), shown in Table 6.3, are used to designate the significance the specific parameter. This means that the DRASTIC methodology considers the depth to the water table and the impact of the unsaturated zone as the most important parameters in the pollution of groundwater resources. Each one of the DRASTIC parameters is divided into several classes through a rating indicator, which is based on a scale of 1 (least contamination potential) to 10 (highest contamination potential).

The DRASTIC methodology basically consists of two steps. The first is the division of the area under investigation in a number of cells and the second the assignment of a suitable weight and rating, given in Table 6.3, being assigned to each of the cells and a DRASTIC index computed from the equation

$$DI = D_R D_W + R_R R_W + A_R A_W + S_R S_W + T_R T_W + I_R I_W + C_R C_W \qquad (6.1)$$

where the subscripts W and R denote the weight and rating of the parameter. The higher the DRASTIC index, the greater the potential of the aquifer to become contaminated.

The study area was therefore divided into cells of 1 km × 1 km and the seven basic parameters assigned to each cell. The DRASTIC indices computed for the cells are displayed in the form of a vulnerability map in Figure 6.2.

Table 6.3 The assigned weights and ratings in the DRASTIC methodology for the assessment of an aquifer's vulnerability to groundwater pollution. (After Aller *et al.*, 1987.)

Factor	Weight	Range of rating values
Depth to water	5	1-10
Recharge	4	1, 2, 4 and 5
Aquifer media	3	3-9
Soil media	2	4-10
Topography	1	1-5
Impact on vadose zone	5	1-5
Hydraulic Conductivity	3	4-8

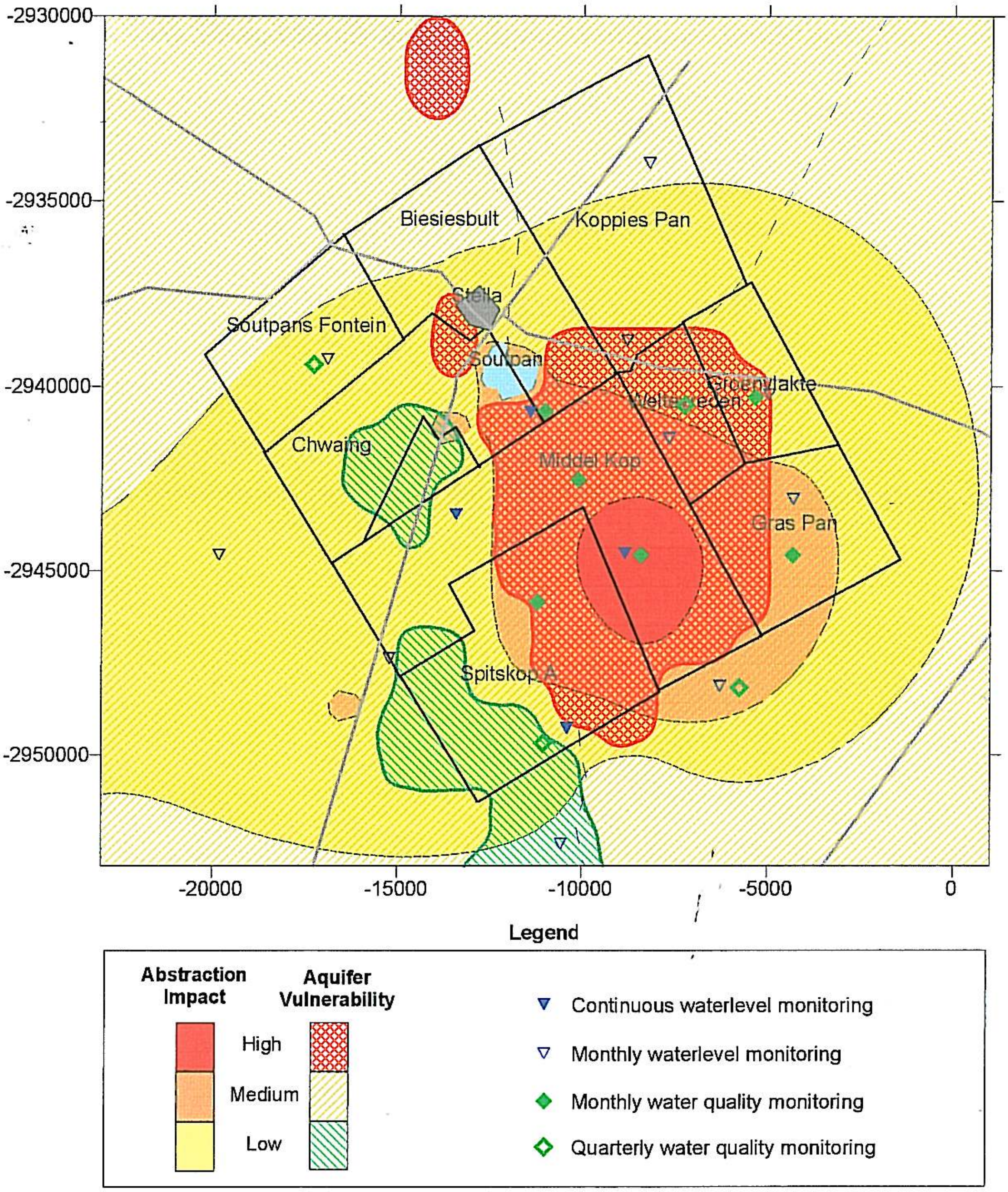


Figure 6.2 Simulated impacts of the existing well-fields on the groundwater levels and aquifer vulnerability of the Middel Kop aquifer together with the recommended positions of monitoring boreholes.

As mentioned in Section 6.5.1, the most logical approach to ensure that the Resource Directed Measures, and by implication Resource Quality Objectives, are met, is to monitor the water levels as well as the water quality. The DRASTIC indexes were therefore combined with the results of the preliminary numerical model to establish a complete aquifer monitoring network (Figure 6.2).

It is recommended that water quality samples be taken at monthly intervals, but more frequent measurements may be needed in areas with a very high vulnerability. The proposed monitoring points in the areas surrounding the Middel Kop aquifer need only be sampled quarterly, unless there is a drastic change in the water quality of these aquifers or the Middel Kop aquifer in which case more frequent measurements will be needed.

6.6 ALLOCATION OF WATER FROM THE MIDDEL KOP AQUIFER

6.6.1 General

There are at least three aspects that need to be taken into account when considering the allocation of water from a specific resource. These are:

(a) the sustainable yield of the resource

(b) the Permissible Use (as defined in Schedule 1 of the National Water Act)

(c) measures to protect the resource.

6.6.2 Sustainable Yield

All aquifers have finite physical dimensions and therefore do not have an unlimited supply of water. The best way to ensure that an aquifer will be able to comply with the National Water Act is therefore not to exceed its so-called *sustainable yield*. This quantity is defined by (Walton, 1970) as *the rate at which water can be withdrawn continuously from the aquifer, without exceeding its recharge, lowering its piezometric head below a critical depth, or causing undesirable changes in water quality*. One approach to fulfil the letter of the act will therefore be to simulate the behaviour of the system into the future. However, this can be a formidable task, especially if one keeps in mind that such a simulation has to include conditions that are currently unknown (Van Blerk, 2000). The common practice in geohydrology is therefore to try and limit the rate at which water is withdrawn from an aquifer to its average annual recharge. This approach may not be ideal, but it is the only practical approach available today, unless one is willing to follow the approach proposed by Van Blerk (2000) for the disposal of radioactive waste.

According to the discussion in Section 5.8 the average annual recharge of the Middel Kop aquifer is approximately 4 227 $m^3\ d^{-1}$. However, this estimate, which is based on current weather conditions and existing data, may change in the future.

6.6.3 Permissible Use (Schedule 1)

The Permissible Use is described in Schedule 1 of the National Water Act (Act No. 36 of 1998) as water that a person with lawful access to a water resource may take directly from the source for the following purposes:

(a) reasonable domestic use in the person's household,

(b) small, non-commercial gardening, and

(c) watering of animals within the grazing capacity of the land.

The water required from the Middel Kop aquifer for domestic and gardening purposes amounts to approximately 230 m^3 d^{-1}, according to the discussion in Section 4.5, while the water needs of animals on the 10 000 ha were estimated as 55 m^3 d^{-1}. The total Permissible Use for the Middel Kop aquifer is therefore approximately 285 m^3 d^{-1}.

6.6.4 Protection of the Middel Kop Aquifer

It is vital to protect all resources of potable groundwater from over-exploitation and pollution. Steps need therefore to be taken from the outset to ensure that it is not forgotten in the medium to long term (Hobbs *et al.*, 1997).

The first approach to achieve the previous objective is to limit the volumes of water that can be withdrawn from the aquifer and the dumping of waste in or near the aquifer. Since there are no industrial developments currently near the Middel Kop aquifer and it is unlikely that the area will attract large scale industries in the future, the present discussion will be restricted to the volume of water that can be withdrawn from the aquifer.

As mentioned above, the National Water Act allows people with legal rights to withdraw a volume of water equal to the Permissible Use (Schedule 1) from the aquifer, which in the case of the Middel Kop aquifer amounts to 285 m^3 d^{-1}. This leaves one with a total of approximately 3 942 m^3 d^{-1} which can be used for other purposes. This is slightly more than the 3 748 m^3 d^{-1} that farmers need to irrigate the existing 171 ha of lands for one crop per year. The town of Stella uses approximately 233 m^3 d^{-1} from the Stella aquifer. Since this volume is probably slightly larger than the basic human needs of the Stella population, all needs can be satisfied by using the Stella and Middel Kop aquifers conjunctively.

However, this neglects the 1.25% to 2.5% growth in population, predicted by Erasmus (Pers. Com.) over the next 20 years. It is thus unlikely that both aquifers will be able to supply the demand envisaged for the next 20 years, unless other measures are also taken. As mentioned in Section 4.5.3, some of the farmers are actually producing two crops a year. This may explain the continuous drawdown displayed by the groundwater levels in Figure 4.3, which is a clear indication that the Middel Kop aquifer is over-exploited. The only viable option to supply the future demand of Stella and the farmers is therefore to reduce the total abstraction for irrigation. This can be done by reducing the irrigation area to 73% of the current area and to restrict the farmers' rights for irrigation water to one crop a year, instead of two, as is currently a major practice. Such a restriction may seem harsh, but it is the only procedure that can sustain the yield of the aquifer, even if no water has to be supplied to the Stella Municipality, as can be seen more clearly from the summary of the calculations in Table 6.4.

Table 6.4 Summary of the volumes of groundwater available in the Middel Kop aquifer and required by Stella.

Middel Kop Aquifer			
Description	**($L\ s^{-1}$)**	**($m^3\ a^{-1}$)**	**($m^3\ d^{-1}$)**
Estimated annual recharge of the aquifer	48.92	1542855	4227
Legal Permissible Use (Schedule 1)	3.30	104025	285
Volume available for allocation	45.63	1438830	3942
Volume needed to irrigate one crop on 171 ha of the irrigated land	43.38	1368000	3748
Stella Municipality			
Basic Human Needs after resettlement	1.02	32120	88
Current use by Stella municipality	2.73	86140	236
Water use after resettlement	6.37	200750	550
20 year estimated use (1.25 % Growth)	8.19	258420	708
20 year estimated use (2.5 % Growth)	10.44	329230	902

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

7.1 GENERAL

Groundwater is the sole source of water to the town of Stella. Large drawdowns are currently experienced in the well-field used by the town and the demand is often not met. Money has become available for the resettlement of about 2000 people to Stella. A suitable water resource must therefore be identified for the supply of water to these people before the people can be resettled. A long term water resource of adequate potential and quality is needed for the supply of water to the town.

The potential of the Middel Kop granitic aquifer was evaluated in this study for the possible supply of water to the town. The total current use of groundwater from the Middel Kop aquifer proved to be more than the estimated sustainable potential of the aquifer. A reduction of irrigation abstractions will be needed to ensure that enough water is available to meet the estimated water use of Stella after the proposed resettlement.

Data shortages and gaps in the data gave rise to only medium confidence levels on the evaluations that were done on the sustainability of the aquifer. Especially water level data and measured abstraction volumes by the different users proved to be problems in the assessment of the potential of the aquifer.

Monitoring is regarded as the most important need in an attempt for sustainable management of the Middel Kop aquifer for the use of future generations.

7.2 CONCLUSIONS

The most important conclusion derived from the present study is that the Middel Kop aquifer can sustain the current needs of the irrigation farmers, as well as current needs of Stella. The needs of Stella after the resettlement of the estimated 2000 people can however only be met with some form of reduction in irrigation abstraction. Monitoring of the effects of abstraction however is critical in the protection of the aquifer and ensuring its use for future generations.

The total extent of the Middel Kop aquifer is approximately 100 km^2. This delineation is essential to aspects such as recharge to the aquifer, storage capacity and the area that needs to be protected from pollution. Three indicators were used in an attempt to delineate the boundaries of the aquifer. The first was the extent of the area covered with small pans indicating the weathering characteristics. Second were the relatively high fluoride concentrations that were identified as an indicator of the extent of the granitic aquifer. The last indicator used in the delineation was the area characterised by high yielding boreholes and large areas irrigated from these boreholes.

The average recharge estimation for the Middel Kop aquifer is 3.8% of the mean annual rainfall and is equivalent to 4 068 m^3 d^{-1}. Independent estimates of recharge estimation from the work done by Vegter as well as the Harvest Potential Map were used, together with the Saturated Volume Fluctuation (SVF) method, Cumulative Rainfall Departure (CRD) method, Equal Volume method and the Chloride method to obtain an average representative estimation. Different weights of confidence were assigned to the estimation methods depending on the confidence and accuracy of data used in the specific methods.

The allocatable volume of water from the Middel Kop aquifer was estimated at 3 942 m^3 d^{-1}. This volume of water is sufficient to supply Schedule 1 use, current needs of Stella, together with irrigation water to cultivate one crop a year, limited to 8 000 m^3 a^{-1} ha^{-1}. The water need of Stella after resettlement can however only be met by reducing the irrigation to 73% of the current irrigation.

Relatively high fluoride concentrations were observed in the Spitskop and Middel Kop areas due to the weathering of mica, which is found in granites and gneisses. Groundwater resources with high concentrations of fluoride should be avoided as a permanent domestic source, or the water should be mixed with water with lower concentrations of fluoride.

The National Water Act of South Africa (Act 36 of 1998), emphasises that all water resources must be protected to ensure sustainable yields now and in the future. This means that sufficient measures must be in place to ensure the comprehensive protection of water resources before water is allocated from a specific source.

The resource sensitivity classification of the Middel Kop aquifer was classified as a Class C, which is generally defined as: "*Moderate modified with moderate changes apparent.*" Management activities should however aim to improve the class of a resource where possible (Braune *et al.*, 2000), but the economical value and the social importance (primary and agriculture) of the water in the Middel Kop aquifer will however make it very difficult to better the status of the resource. It is therefore recommended that the resource classification be maintained as a Class C.

There are no aquatic ecosystems, riparian zones or springs in or near the Middel Kop study area and therefore no water allocated for Ecological Reserve purposes. There are also no indications that the rate at which water is withdrawn at the moment has a negative effect on the terrestrial ecosystem above the aquifer.

Basic Human Needs for the near future population of the study area (3 500 people) is estimated at 87.5 m^3 d^{-1}. The majority of these people will be living in the town Stella and therefore not be able to take water directly from the resource. This means that provision must be made to allocate this water from the Middel Kop aquifer to the town council for Basic Human Needs water supply.

In determining resource quality objectives a balance must be sought between the need to protect and sustain water resources on the one hand, and the need to develop and use them on the other according to the National Water Act (Act No. 36 of 1998). Resource quality objectives were set in an attempt to protect the aquifer from contamination. The main concern here is the risk of contamination associated with the salts in Soutpan. This management of salts entering the aquifer will be dependent on water level gradients between Soutpan and the Middel Kop aquifer.

A water level monitoring network was recommended to refine the existing model to evaluate future water levels as well as the influence of external activities on the Middel Kop aquifer. Rates at which water is withdrawn from the aquifer, as well as precipitation data will also be needed in order to protect the aquifer from over-utilisation.

The high risk of polluting the aquifer however also plays a major role in the management of this area and prevention measures should be implemented for the protection of this resource. A water quality monitoring network based on the risk of contamination is proposed for the protection of the aquifer.

7.3 RECOMMENDATIONS

The National Water Act (Act No. 36 of 1998) recognises that the ultimate aim of water resource management is to achieve the sustainable use of water for the benefit of all users.

The protection of groundwater resources from over-exploitation and pollution threats is vital to the sustainable utilisation of these sources of potable water. This consideration must be recognised from the outset and steps taken to ensure that it is not forgotten in the medium to long term (Hobbs *et al.*, 1997).

The implementation of a long-term monitoring program is recommended, which has the advantage that it will enable one to develop a suitable management plan for the aquifer that will:

(a) Ensure the sustainable use as well as protection of the aquifer

(b) Allow one to re-evaluate the potential of the aquifer regularly

(c) Ensure that the RQOs are met.

Areas where water level monitoring should be done were evaluated using a groundwater model. Monitoring positions are based on the assessment of the impact of abstraction on the groundwater resources. Areas where large impacts are expected should be equipped with continuous water level logging devices, while areas serving as background water level data can be monitored on a less frequent (monthly) basis.

The aquifer vulnerability map based on the DRASTIC methodology was used to propose a water quality monitoring network for the study area. Water quality samples should be taken at a monthly interval in areas with high vulnerability to pollution for at least the first two years. This data will aid in the understanding of the natural fluctuations in water quality as well as sources of recharge, affecting the quality of the system. Activities related to high impacts on groundwater quality should be discouraged and managed properly in order to prevent permanent damage to the resource.

Groundwater abstraction data is essential for the successful management of the limited groundwater resources in the Stella area. Evaluation of the potential of the resource depends on accurate abstraction data and this was found to be a major concern in the confidence levels of the assessment methods based on groundwater abstraction data. It is recommended that all abstractions other than the permissible use defined under Schedule 1 use in the National Water Act be measured.

Continuous rainfall recording should be installed on the farm Middel Kop in order to assess the local rainfall influence on water levels and water quality.

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SUMMARY

The importance of groundwater is strongly reflected in the new South African water policy and legislation. All water resources, including groundwater, are now seen as an indivisible asset, with the National Government as its custodian to ensure that the resources are protected, developed and managed properly.

Groundwater is the sole source of potable water for the town of Stella in the Lower Vaal Water Management Area of the Northwest Province, but the existing well-field is barely able to supply the present demand. Previous attempts to supply the town with water from groundwater resources have failed, because of the low potential of the aquifers and the poor quality of the groundwater. The proposed resettlement of 2 000 people therefore has to be postponed until sufficient additional water resources can be found for the town.

One possible source, not included in previous groundwater explorations of the area, is the granitic aquifer on the farm Middel Kop situated approximately 5 km south-east of Stella. Farmers have used this aquifer extensively since 1990 to irrigate 171 ha of agricultural land. It was consequently decided to investigate this aquifer as a possible additional source of water for Stella. However, farmers have already noticed a continuous decline in the water levels over the years. This meant that the focus of the investigation had to be changed from merely an exploration exercise to an evaluation of the aquifer and the development of a suitable management scheme for the aquifer, as described in this thesis.

There are not enough data available to perform a detailed assessment of the aquifer at the moment, a deficiency that should be addressed in future investigations and management of the aquifer. The existing data, however, indicate that the aquifer may be able to sustain a yield of approximately 4 227 $m^3 d^{-1}$ in the near future. This volume of water will be able to supply in the needs of the present population and the additional 2 000 resettled people, while allowing 73% of the current irrigated area approximately 8 000 $m^3 ha^{-1}$ annually for irrigation. The latter figure can only be achieved if the farmers are allowed to produce one crop per year instead of the two, which is in some cases the practice. This reduction in the water allocated for irrigation may seem harsh, but the decline in the water levels over the last couple of years clearly indicate that the farmers cannot continue with the present practices for much longer.

The groundwater quality of the Middel Kop aquifer can be rated as marginal for human consumption. This applies in particular to the relatively high concentrations of fluoride and nitrate in the water, which could affect the health of the population adversely if used untreated for long periods.

The conclusion reached in the thesis is that the Middel Kop aquifer can only be used as a source of water for Stella on condition that a detailed monitoring scheme is introduced from the beginning and used to develop a suitable management scheme for the aquifer. This approach will ensure that any impacts on the resource can be properly evaluated and that the quality and quantity of the water can be preserved for future generations.

OPSOMMING

Die belangrikheid van grondwater word sterk beklemtoon in die nuwe Suid Afrikaanse water beleid en wetgewing. Alle waterbronne, insluitende grondwater, word nou as 'n onverdeelbare bate beskou, met die Nasionale Regering as bewaarder, ten einde te verseker dat die bronne beskerm en oordeelkundig benut en bestuur word.

Grondwater is tans die enigste bron van drinkbare water vir die dorp Stella in die Laer Vaal Waterbestuursgebied van die Noordwes Provinsie. Die bestaande bron is egter skaars in staat om in die behoeftes van die inwoners te voorsien. Vorige pogings om nuwe bronne vir die dorp te vind het egter almal gefaal, weens die lae potensiaal en swak kwaliteit water in die omliggende bronne. Die voorgestelde hervestiging van ongeveer 2 000 mense in Stella moes dus uitgestel word totdat 'n nuwe bron van water vir die dorp gevind kon word.

Een bron wat nie vantevore ondersoek is nie, is die granitiese akwifeer op die plaas Middel Kop, wat ongeveer 5 km suidoos van Stella geleë is en reeds sedert 1990 deur boere gebruik word om 171 ha landbougrond te besproei. Gevolglik is daar besluit om op hierdie bron te konsentreer. Boere het egter gevind dat die watervlakke in die bron met die jare kontinue gedaal het. Die fokus van die ondersoek van die bron moes dus verskuif word van 'n blote eksplorasie na die evaluering en bestuur van die bron, wat in hierdie verhandeling bespreek word.

Daar is nie voldoende data om die bron op hierdie stadium volledig te evalueer nie, 'n tekortkoming waarmee rekening gehou moet word in toekomstige ondersoeke en bestuur van die bron. Die bestaande data dui egter aan dat die bron in staat behoort te wees om 4 000 m^3 d^{-1} in die onmiddellike toekoms te lewer. Hierdie volume water behoort in die behoeftes van die huidige en die 2 000 hervestigde inwoners van Stella te voorsien en ook boere toe te laat om op 73% van die huidige besproeiing oppervlak, 8 000 m^3 ha^{-1} jaarliks vir besproeiing te gebruik. Laasgenoemde syfer beteken egter dat boere slegs een gewas per jaar sal kan produseer, in plaas van die twee soos wat in sommige gevalle gebeur. Die afname in die water wat aan boere vir besproeiing toegeken word, kan moontlik as kras gesien word. Die afname in die watervlakke van die akwifeer oor die afgelope paar jaar, dui egter aan dat boere moeilik hierdie gebruik in die onmiddellike toekoms sal kan volhou.

Die grondwater kwaliteit in die Middel Kop akwifeer kan as marginaal beskou word in terme van menslike gebruik. Dit is veral die floried en nitraat konsentrasies wat relatief

hoog is en gesondheidsrisikos vir die gebruikers kan skep indien dit onbehandeld vir lang periodes gebruik word.

Monitering van die bron behoort 'n hoë prioriteit te wees in 'n poging om die langtermyn volhoubaarheid van die bron in terme van kwaliteit en kwantiteit te verseker. Die gebruikers van die bron moet toesien dat enige impakte op die bron voldoende ge-evalueer word en dat voldoende bestuur en beskermingsmaatreëls in plek is om toe te sien dat die bron vir toekomstige geslagte beskikbaar is.

Die gevolgtrekking waartoe in die verhandeling gekom word, is dat die Middel Kop akwifeer slegs as waterbron vir Stella gebruik kan word indien die akwifeer van die begin af behoorlik gemoniteer word en die inligting gebruik word om 'n geskikte bestuursplan vir die akwifeer op te stel. Hierdie benadering sal verseker dat enige impakte op die bron behoorlik ge-evalueer kan word, sodat die kwaliteit en kwantiteit van die water vir toekomstige gebruikers behoue bly.

KEYWORDS

(a) Groundwater Potential
(b) Granite
(c) Aquifer delineation
(d) Recharge
(e) Allocation
(f) Protection
(g) Resource Directed Measures
(h) Reserve
(i) DRASTIC
(j) Monitoring