MANAGING THE IMPACT OF IRRIGATION ON THE TOSCA-MOLOPO GROUNDWATER RESOURCE

by

GABRIËL STEPHANUS DU TOIT VAN DYK

Thesis submitted in the fulfillment of the requirements for the degree of

MASTER OF SCIENCE

In the Faculty of Natural and Agricultural Sciences,
Department of Geo-hydrology
University of the Free State
Bloemfontein, South Africa

May 2005

Supervisor: Prof. G.J. van Tonder

ACKNOWLEDGEMENTS

The contributions and support of the following persons and institutions towards this investigation and report are gratefully appreciated and acknowledged:

- All water users from the Tosca Molopo aquifer for their concerns regarding sustainability of the resource and access to their property for observations. Also the agricultural institutions that addressed the water issues through their structures.

- The Tosca Molopo water user association pilot committee in particular the chairman and vice-chairman Mr. Gert Stoltz and Lennox Louw, through whom most communication took place.

- Me. Erika de Villiers in her capacity as social consultant for her efforts in drafting the Constitution of the Tosca Molopo Water Users Association.

- All Department Water Affairs and Forestry internal members of the Pilot Tosca Molopo groundwater committee where strategies where formulated as possible solutions in the Tosca Molopo area. Also the staff from divisions responsible for implementation of these strategies.

- Mr. Johan Wentzel and Me. Linda Godfrey from the RDM office for completion of the reserve for this area.

- The staff from the DWAF Northern Cape region Geohydrology section for the bi-annual water level and abstraction monitoring.

- The DWAF Pretoria Geophysical team for the Geophysical investigations and borehole siting and use of their data.

- The DWAF WARMS office for assistance in verifying and communicating water rights with users.

- Me. Liezel Ferris from DWAF GIS section for GIS analysis and maps.

- DWAF Geomatics for surveying of irrigation areas.

- Professor Gerrit van Tonder and Dr. Ingrid Dennis from IGS UFS for guidance and evaluation of work and documentation of results for this thesis.

- Mr Siep Talma from CSIR Environmentek Quaternary Dating Research Unit for Groundwater Isotope results and recommendations towards use of data.

SUMMARY

From 1990 to 2000 rapid development of irrigation from groundwater resources in dolomite aquifers took place in the Tosca Molopo area. This abstraction lead to water levels declining 10 to 20m regionally and up to 60m proximate to intensive irrigation. The purpose of this study was to investigate the impact of irrigation on the resource and initiate actions to manage the resource. This thesis reports on the qualification and quantification of the impact, determination of water use and regulating use to ensure sustainable future use.

The Tosca Molopo area is located in South Africa proximate to the Botswana border. The area of interest is characterized by a flat topography. From the watershed in the west at 1210 m the elevation gradually decline to 1070 m in the east over a distance of 60 km. A number of non-perennial rivers drain the area, and although insignificant as surface water resources they play a major role in groundwater recharge.

A low annual rainfall, varying from 399 mm in the east to 385 mm in the west, characterizes the study area. Evaporation in the area is high at between 2050 – 2250 mm/a (WRC, 1994) with only a small percentage of rainwater available to recharge groundwater.

Two distinctive aquifers namely a primary aquifer formed by fine-grained sediments of the Kalahari Group and fractured/ carstified dolomites of the Ghaap Plato formation contribute to the system. The general flow is from the SW to the NE with the Molopo River the base of drainage. From the observed water level reaction the sediments contribute largely towards the storage of the aquifer system with the fractures of the dolomite contributing to high yielding flow.

The MODFLOW PMWIN 5.1.7 (Chiang 2000) software was used to construct a 2-layer finite difference flow model. The model covering 80 km east west and 50 km north south or 4000 km^2 was divided into cells of 0.5 X 0.5 km generating 100 rows and 160 columns. Based on the conceptual model provision was made for 2 layers namely the unconsolidated primary aquifer and the underlying fractured dolomite with its aquifer characteristics.

The first layer ranges from an elevation of 1160 mamsl at a depth of 10 m in the southwest. To the northeast it range from an elevation of 1080 mamsl to a depth 960 mamsl or a thickness exceeding 120 m. The base of the sediments is the top of the fractured dolomite aquifer with its base at 900 mamsl.

Of the number of dolerite dykes intruded into the dolomite the Grassbank and Quarreefontein dykes (both 15 m thick) are the most influential on the groundwater flow. Both these dykes act as no-flow boundaries of the Neumann (impervious) type impeding

flow from the south and west of the area. Towards the east the Quarreefontein dyke does not seem to be a no-flow boundary as the water level information indicate connection with the dolomite to the south. The surface and groundwater shed formed by the Banded Iron Formation of the Waterberge forms the boundary to the west. The combination of both a geological contact and watershed is a leaking boundary. The Molopo River forms the eastern boundary.

Recharge to the aquifer was determined with the chloride mass balance method with groundwater sample analysis and the Cl_{rain} content 0.8mg/l. Recharge zones as determined from this chloride analysis were used for the model. Recharge in each zone was based on seasonal recharge for the winter (ranging from 0.5% or 0.4 mm to 3% or 1.5 mm) and summer (ranging from 0.5% or 1.6 mm to 3% or 8.3 mm) depending on the precipitation.

Groundwater is the sole source of water for both agricultural and domestic requirements. As irrigation use is responsible for 99.5 % of the total use no domestic and stock watering abstraction was considered. Irrigation abstraction was calculated from the registration areas, field observations and reports from users. The volume was then averaged over a six-month period (182.5 days) according to crop cultivated to obtain the daily abstraction from the aquifer.

The calibrated model was used to test the following 10-year future scenarios of abstraction and recharge in order to assist in decisions regarding management of abstraction from the aquifer system.

Scenario 1 was with average precipitation and recharge at the current high abstraction rate of 16.1 Mm^3/a. This scenario was not acceptable due to the regional water level declines of 20 to 30m and 60 to 110 m water level declines proximate to irrigation.

Scenario 2 was with was with average precipitation and recharge at the restricted abstraction at 11.1 Mm^3/a. This scenario would result in regional water level declines of 10 to 20m and 30 to 60m proximate to irrigation. With strong abstraction control this scenario with controllable water level declines was acceptable.

Scenario 3 was similar to scenario 2, but with 20 % less than normal precipitation. The water level declines that will result with this scenario were similar to scenario 1, but it was expected that below normal precipitation would be the exception.

The 4th scenario tested was if normal precipitation prevailed and all irrigation abstraction was stopped. The regional water level would recover fully after 10 years with only 10 m still to recover proximate to heavily irrigated areas.

The model demonstrated that rates as specified by scenario 2 can be sustainable abstracted from the system at average recharge and that these abstractions would still be sustainable at 20 % less than average recharge as in scenario 3. Management of abstraction of the aquifer was consequently structured to ensure that abstraction would not exceed the sustainable yield of 11.1 M m^3/a.

Based on the evaluation and modeling of the resource the regulating and management of abstraction was addressed within the legal framework provided by the National Water Act (NWA) to obtain sustainable, equitable and fare dispensation of water use.

Only water use exercised before Oct 1998 is recognized as existing water use. Potentially unauthorized users were identified with the use of satellite images. These water users were given the opportunity to proof that they are authorized users through a communication process and to submit supporting evidence. Users who could not submit satisfactory evidence were directed to scale their use down to authorized use by a specific time (summer 2003). These water users appealed to the water tribunal against the ruling of the water use authority, but the tribunal ruled in favor of the water use authority.

In line with equitable access, application from new users were still processed with only 60 m^3/ha of property owned authorized in accordance with General Authorization as prescribed by regulations of the NWA.

With these actions the resource was still over allocated with water use still not within the accepted sustainable abstraction. Therefore it was decided that regulations would be implemented to enforce users to restrict their water use to 60 % of authorized water rights.

The NWA makes provision for local management structures to be established to manage their local water use. Such a Water User Association (WUA) was established in the Tosca area and would on the long term enhance the capabilities for water use management.

The resource is currently over allocated. It is recommended that the irrigation water use be restricted with 40% of authorized water rights.

The water rights are not fairly allocated. Although the above actions are aimed at normalizing the critical damage to the resource and eminent conflict in the area compulsory licensing would be the long-term solution in this area. Compulsory licensing is aimed at sustainable and equitable allocation of water rights.

The WUA should ensure that all users comply to abstraction control measures and water level monitoring the boreholes in the monitoring network would indicate if the resource would stabilize and recover to within sustainable use.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF PLATES

1. INTRODUCTION

During the later half of the decade 1990 rapid development of irrigation from groundwater resources in dolomite aquifers took place in the Tosca Molopo area. Abstractions from these resources lead to significant decline in water levels. The purpose of this study was to investigate the impact of irrigation on the resource and managing the resource. This thesis is to report on the resource status in terms of use, impact and sustainable potential. The strategies and activities aimed at qualification, quantification of the impact, determination and regulating of the water use and assurance of sustainable future use are discussed. The activities included:

- Physiograpical description of the aquifer and associated structures.
- Determination of the extent of irrigation and estimation of volumes irrigated.
- Analysis of spatial and temporal variation in groundwater levels and qualities.
- Determine mechanism and estimate recharge to the aquifer.
- Numerical groundwater flow modeling aimed at testing of abstraction scenarios and management options for the resource.
- Creation of management structures and capacitating of the users of the resource.
- Regulation of the resource by implementation of the NWA.

Table 1. Action and reactions following the problems experienced at Tosca:

Date	Event	Comment
1990	Exploration and assessment of the resource by CSIR contracted by DWAF	Classify the resource as high yielding with limited potential due to low recharge
1993	First concerns voiced by individuals in the community (Letter to Minister)	Explanation of local nature of abstraction
1994	Information session with community regarding the implications of the NWA	Divided community and with no legal mechanism due to private ownership of groundwater
1996	First estimation of extend of irrigation in the area (surface irrigated, volume abstracted)	No investigation regarding the status of the resource
2000	Registration of water use	At meeting interest to establish Water User association
2001 Jan	Establish pilot steering committee for WUA establishment	Was an initiative of the Local Farmers union
2001	Unified voice of concerns by individuals and groupings in the community (Letters to Minister)	Commitment from DWAF to address the problem in cooperation with the users.
2001 April	First monitoring of groundwater levels to establish status of resource	Measure approximately 10 to 20 m regional water level decline and 60 m local
2001 Aug	Discuss depleted status of resource with water users	Status of resource alarming with regional de-watering evident
2001	Larger community expressing concern regarding the resource	Commitment from DWAF to address the

Sept	unified (Number of letters of concern)	problem in cooperation with the users.
2002 Jan to June	Number of meetings to establish the WUA	Wide interest and cries for progress to manage the resource
2002 Jun	Completed report on the potential of the resource by CSIR	Estimated that the resource is over allocated by more than 100 %
2002 Aug	Land GPS survey of irrigated areas by Geomatics	When checked with office GIS it was found to correlate 90 to 100 % with GPS survey.
2002 Aug	Complete verification process of users by Satellite images	15 Potentially unauthorized users identified
2002 Oct	Commence with Section 35 process	15 Potentially unauthorized users requested to motivate their legality. 8 produce info to indicate that they should be authorized
2002 Aug	Geophysical investigation to confirm aquifer boundaries	Boundaries confirmed with slight spatial corrections to be made
2002 Dec	Submit draft WUA constitution for approval to head office	Numerous requests followed and proposed required needs for approval to be met
2003 Jan	Directives issued against 7 illegal users	To stop or reduce irrigation activities by March 2003
2003 Mar	Field inspections and communication confirm limited co-operation.	Will have to enforce directives
2003 Mar	Discuss and get user cooperation to implement a 40 % restrictions on legal water use	Mixed reactions to intended restrictions
2003 Sep	Commence with implementation of restrictions on voluntary basis	Authorized users reluctant to comply
2003 Sep	Commence with exploration drilling to confirm boundaries and extend monitoring network	Boundaries confirmed
2003 Sep	Confirm cooperation of unauthorized 7 users, only 3 users contravening directives issues against them	Commence with civil prosecution of these 3 users
2003 Oct	Three users charges with using water unauthorized from the Tosca Molopo aquifer	Charged through SAPD. SAPD does not seem interested to prosecute
2004 Feb	Meeting with water users to discuss alterations to the WUA draft constitution, CMA establishment and discuss projections from the groundwater model. All new water use applications tabled and their authorization discussed.	Users in agreement with model. Users questioning how new use was authorized
2004 Mar	Publication of revised General Authorizations whereby no GA applicable to catchments of the Tosca Molopo aquifer	In father all irrigation use to be licensed
2004 Jun	Approval of the WUA by the minister	Publication of establishment in the Government Gazette
2004 Sep	Approval for water restrictions	To be published in Government Gazette
2004 Oct	Publication of 40% water restrictions in Government Gazette	
2004 Dec	Establishment meeting and election of WUA management committee	Committee expressing need for DWAF assistance irt directives, crop planning, financial, capacity
2004 Dec	On request from WUA DWAF issue 6 directives for unauthorised use	
2005 Mar	6 monthly water level and use monitoring. Inspections reveal that 2 users complied satisfactory to directives by reducing use.	Region and HO plan to enforce conditions of directives by: Gain access to property, Remove pump installations from boreholes, seal boreholes
2005 Apr	Letters to gain access to property week of 16 May 2005 issued	Resistance from non complying water users
2005 May	Enforce water use compliance	Compliance successfully enforced

2. PHYSIOGRAPHICAL DESCRIPTION

2.1. *Location*

The Tosca Molopo area is located on in the border between South Africa and Botswana 150 km north of Vryburg (Figure 1). A tarred road connects Tosca to Vryburg while a network of secondary to tertiary roads serves the local communities transportation needs.

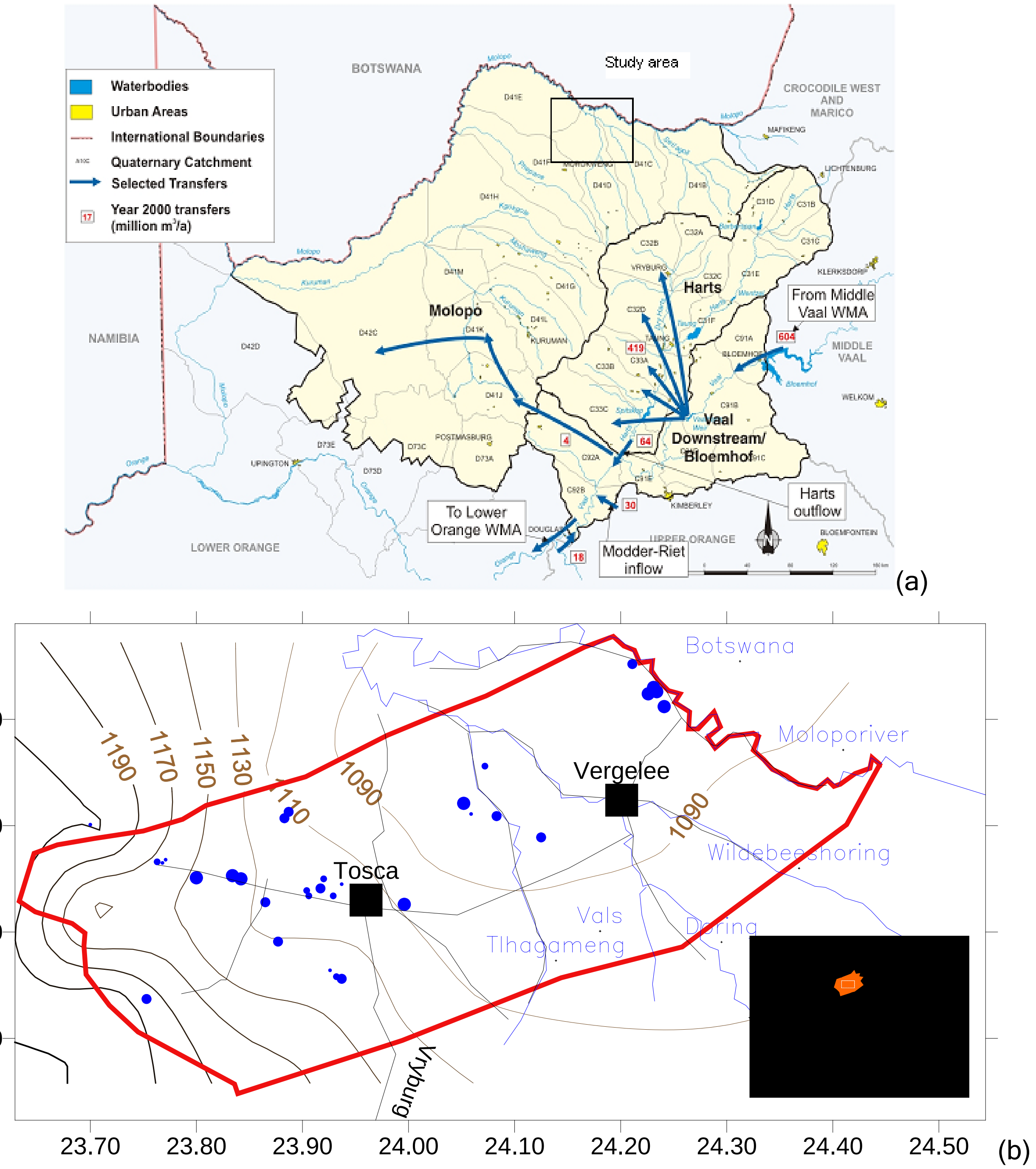


Figure 1. Location of the study area; (a) as located in the Lower Vaal Water management area and (b) showing major centers, roads, dry river beds, irrigation areas and surface elevation contours (mamsl).

2.2. Topography and drainage

The area of interest is characterized by a flat topography. The surface elevation contours are indicated in Figure 1. From the watershed in the east at 1210 m the elevation gradually decline to 1070 m in the west over a distance of 60 km. The only topographical features being the Waterberge rising 50 m above the plain to the north and a number of non-perennial riverbeds. These rivers are the Thlagameng, Vals, Doring, Wildebeesthoring and Molopo. Although insignificant as surface water resources they play a major role in groundwater recharge.

Plate 1. The Molopo River as seen from the farm Blackheath after precipitation in November 2001 and the same river after drought in November 2004.

The Molopo River is an ephemeral river that used to flow after heavy rainfall events, however the building of dams (Disaneng and recently the Setumo) upstream has impeded river flow. Although no official gauging station exists on the river, it is reported that before 1980 runoff only occurred every 2-3 years. Since 1980 flow in this section of the Molopo River only occurred 5 times, after severe heavy precipitation in 1988, '91, '96, 2000 and 2001. Plate 1 indicate lush grass growth in the river bed after precipitation and little plant cover after dry periodes.

2.3. Climate and precipitation

The study area is characterised by a low annual rainfall, varying between 107 – 928 mm/a. The calculated average rainfall is 385 mm/a (average of Pomfret [station 0504050X] and Vergelegen [station 0505347 6] records). Precipitation is erratic with the standard deviation from the mean 153 mm/a. Approximately 85% of the rain occurs during the summer months of October to March.

Evaporation in the area is high, between 2050 – 2250 mm/a (WRC, 1994). As such only a small percentage of rainwater is available to recharge groundwater.

Historical records of annual rainfall are shown in Figure 2. The precipitation since '99/00 season was measured as above average at the Pomfret station. Over the same period the precipitation at Vergelegen was measured below the average. It is noted that precipitation measurements at Pomfret was automated during 1991 while hand measurements are still taken at Vergelegen.

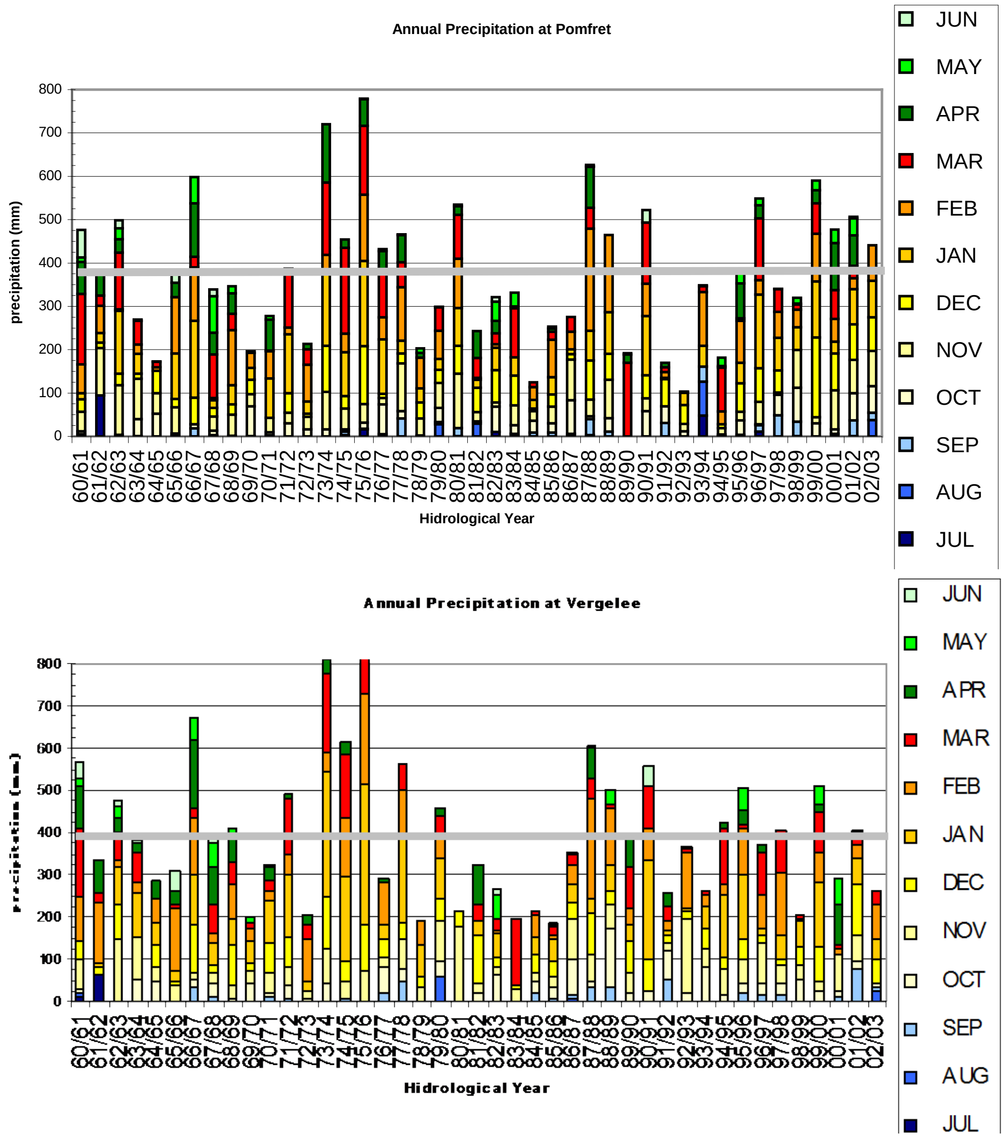


Figure 2. Precipitation as measured at rainfall stations Pomfret and Vergelegen.

2.4. *Soil and vegetation*

White calcium enriched soils are predominant in the east while red-brown iron enriched soils occur toward the west.

The low rainfall in the Molopo district results in semi-arid conditions, characterized by tropical bush and savanna types (Bushveld) vegetation. Acacia species are predominant with the distinctive tree species the Camel thorn (*Acacia Erioloba*). A number of grass species cover the areas between bush and tree.

2.5. Land use

The main economic activity within the area is agriculturally based. The Tosca Vergelegen area was historically a stock farming area with cattle farming and more recently game farming. The grazing capacity of the area is reported at 10 ha per large stock unit. At 400 000 ha the stock capacity of the area of interest is 40 000 large stock units.

Since 1990 rapid development of irrigation transformed the socio-economic and environmental prospects in the area. By 2002 it was estimated from registration of irrigation, satellite images, surveys and reports from farmers that approximately 2000 ha were irrigated consuming 18.9 million m^3 of water. The crops irrigated as illustrated in Figure 3 are corn (41%), paprika (19%), peanuts and wheat (30%) and potatoes and alfalfa (10%).

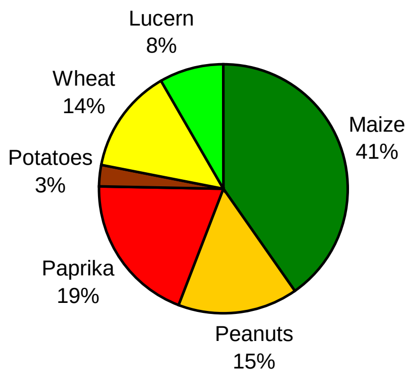


Figure 3. Graphical illustration of crops irrigated.

2.6. Water use

Groundwater is the sole source of water for both agricultural and domestic requirements. The water use of stock, domestic and other activities is negligible if compared to irrigation. The other uses are only 0.5 % of the total use with irrigation use responsible for 99.5 % of the total use. As such irrigation farming has placed a considerable strain on the dolomite aquifer.

A combination of factors led to the development of the resource for irrigation purposes. During 1990 the CSIR explored the resource and the resource was characterized as high yielding. Quality and Isotope samples taken from the water at the time did however flag the sustainability of the resources characterizing some of the water as fossil water. Reacting on half the recommendation farmers started developing irrigation with high yields and increased income in mind.

Table 2 indicates the rapid rate at which irrigation development took place.

Table 2. Increase in irrigation areas and volumes.

Year	1990	1996	2000	2001	2002
Irrigation systems	2	22	32	40	45
Irrigation area (ha)	100	600	1182	1495	2000
Volume Irrigated (Mm^3/a)	0.77	4.6	9.1	11.1	18.9[#]
Stock watering (Mm^3/a)	0.5	0.5	0.5	0.5	0.5
Human consumption (Mm^3/a)	0.5	0.5	0.5	0.5	0.5
Total (Mm^3/a)	1.8	5.6	10.1	12.1	19

All volumes estimated at $7500 m^3$/ha/annum.
[#]Estimated after crop factors for the different crops used.

Other factors contributing to the development of irrigation was the completion of the tarred road by 1994, the availability of electricity by 1995, the availability of high yielding pump and irrigation systems, unfavorable climatic and economic conditions for dry land cultivation, favorable prices and profit generated by crops and the knowledge to apply the technology.

3. GEOLOGY

3.1. Regional Geology

The stratigraphic succession of the area is given in Table 3 (SACS, 1980). The sub-outcrop geology is shown in Figure 4. Although almost the total area is covered by the Kalahari Group it is mapped only where its thickness exceed 15 m.

Table 3. Stratigraphy and litho logical explanation.

Sequence	Group	Formation	Description
	Kalahari	Gordonia Eden Budin Wessels	Red brown aeolian sand Calcareous sandstone and clay Red clay Sandstone and gravels
Post Karoo			Dolerite dykes and sills
Griqualand West		Makganyene	Diamictite
	Griquatown	Asbestos Hills	Banded ironstone, including jaspilite and chert
	Campbell	Ghaap Plateau Schmidtsdrift	Dolomite chert limestone Dolomite and shale
		Vryburg	Quartzite
Archaean			Granite

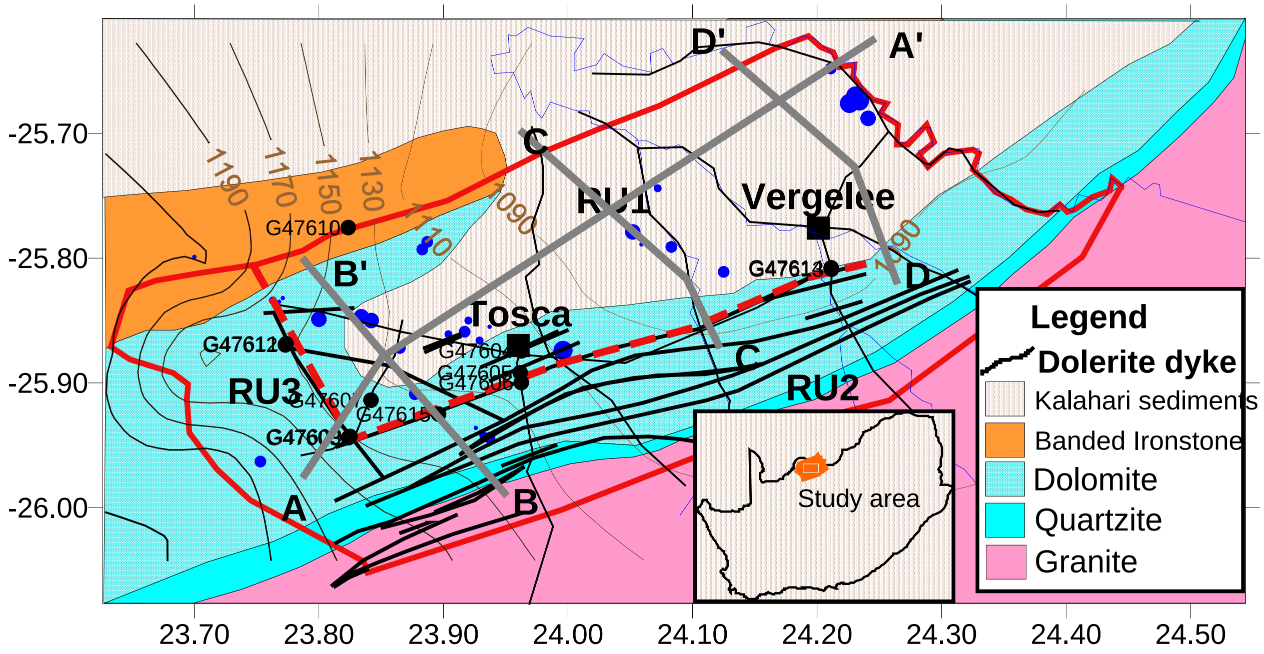


Figure 4. Geology of the Tosca area with the major economical centers, roads, dry riverbeds, irrigation areas (blue circles) and surface elevation contours (mamsl). The resource units RU1, RU2, RU3 is divided by the red dot line.

3.2. Local Geology

The full geological succession given in Table 3 is represented within the study area. The Archaean granites form the basement of the area, outcropping to the south of the study area. The granites are overlain by quartzites of the Vryburg formation, which reach thickness of only tens of meters. The dolomites of the Campbell Group reach thickness of 900-1650 m and are a significant water bearing formation. The dolomites are overlain in the north of the study area, by banded ironstone of the Asbestos Hills formation. Intruded into these rocks are dolerite sills and dykes. This package of rocks dips at approximately 10° into a northwesterly direction. Large north-south trending faults are present within the area.

An era of intense weathering and erosion followed the deposition of these formations, carving a northeast trending U-shaped valley into the dolomite. The thickness of the valley increases towards the Molopo River where a depth in excess of 150 meters is reached. This valley is filled with sediments of the Kalahari Group. At the base of the valley gravels and sandstones of the Wessels formation were deposited. These gravels are poorly sorted and range in size from less than 1 mm to 25 mm. On top of the gravels red-brown clay of the Budin formation were deposited, followed by fine-grained sandstone of the Eden formation. The sequence is covered by red-brown Aeolian sand, which covers most of the area. The thickness of Kalahari Group varies across the area from less than 15 m near the dolomite and granites outcrops in the west, to up to 150 m of thickness to the northeast of Vergeleë, in proximity to the Molopo river (Figure 4).

Along the Molopo River and tributaries, very recent river deposits are present. The channel of the Molopo River meandered within a 4 km wide band from the present channel to build up a riverbed deposit up to 30 m in depth. These deposits consist of gravels of 1 to 10 mm, sandbars and fine-grained sand and to a lesser extend silt.

3.3. Structural Geology

The most prominent structural controlling event is the presence of the now generally accepted Morokweng Impact Structure to the south. (See Figure 5). This impact structure formed when a meteorite penetrated this earth’s atmosphere and crashed into the earths crust. As a result of this Impact structure lineament are developed radially around this structure. These lineaments are faults that can be intruded by dolerite material and are aligned NE SW in the Tosca area. The host rock is fractured and weathered along these faults and dolerites. Due to the nature of dolomite rock solution of rock material can lead to the formation of cavities.

Although the total hard rock package dip at 10° northwest large folds could change the dip of rocks locally.

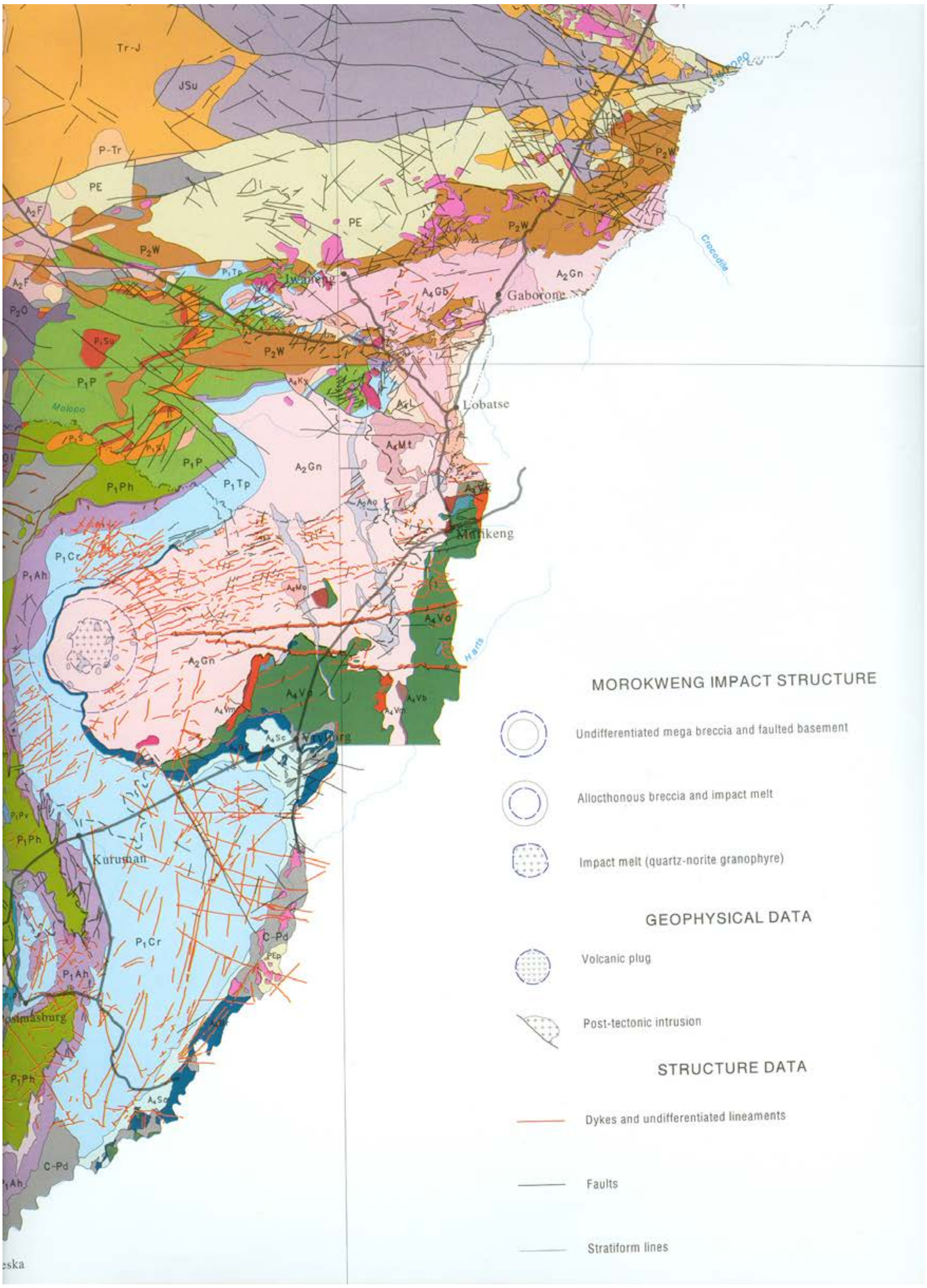


Figure 5. Regional geology of the Tosca area taken from SUB-KALAHARI GEOLOGICAL MAP by IG HADDON 2001.

4. HYDROGEOLOGY

4.1. Aquifer yield

The dolomite aquifer present in the Tosca area was characterized during the DWAF 1:500000 mapping program. This characterization was based on data captured till 1990 when water use in the area was limited to stock watering. From this information it is evident that more than 13% of successful boreholes yielded more that 5 l/s which would theoretically be needed for irrigation. (Figure 6)

Since high yielding boreholes to irrigate from became the objective a number of boreholes were sited and drilled. Advanced geophysical technology to locate fractures in depth and advanced drilling technology to drill holes through carstic formations to depth was used. The percentage of high yielding boreholes drilled therefore increased dramatically.

In contrast most boreholes in the Kalahari sediments yield less than 2 l/s.

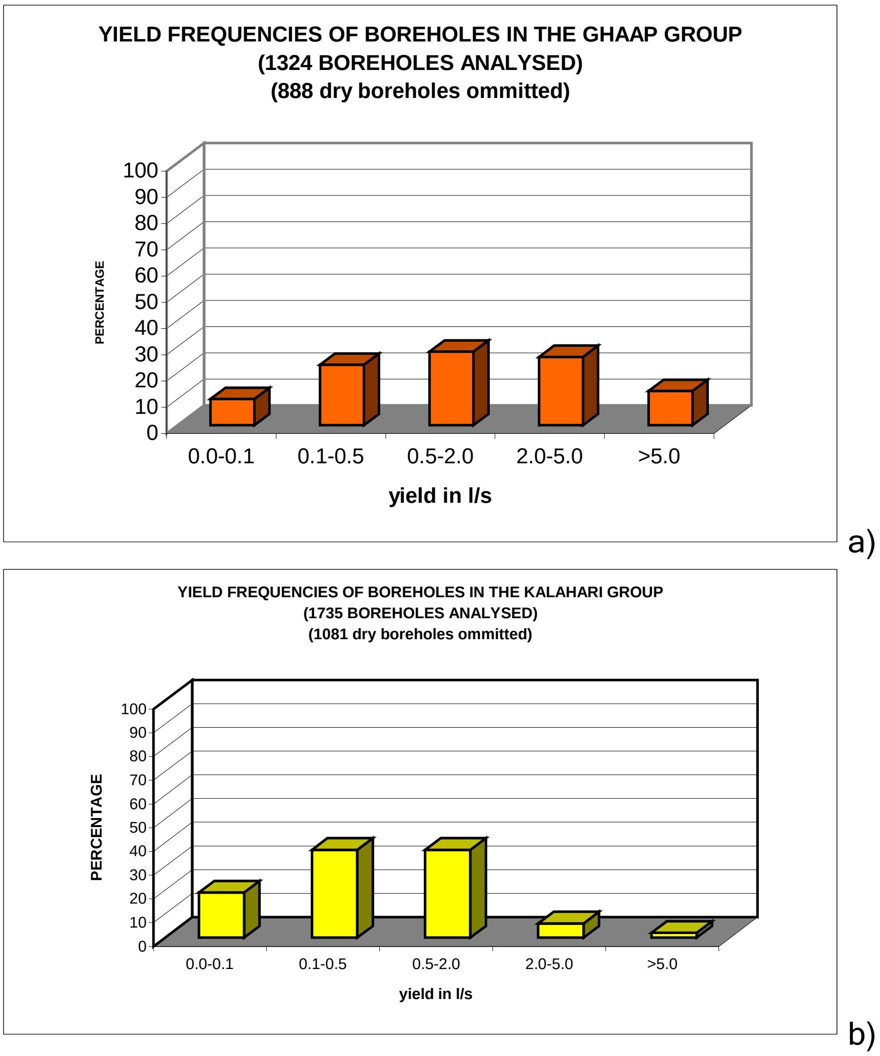


Figure 6. Yield frequency of boreholes in the a) Ghaap dolomite and b) Kalahari sediments groups.

Origin of groundwater in the Tosca Molopo Dolomite Aquifer.
There is the perception that water in this aquifer originates from the Okavango Delta, the Kuruman spring or the Molopo spring. To date no scientific evidence could support these theories and the following facts are listed to indicate why these water bodies cannot be connected to the Tosca Molopo aquifer:

- *The Tosca Molopo Dolomite Aquifer is located at an elevation of between 1150 and 1000 mamsl. The Okatanga Delta is located at elevation 950 mamsl, the Kuruman spring at 1410 mamsl and the Molopo spring at 1430 mamsl.*
- *Water from the other water bodies drain away from the Tosca Molopo aquifer with the Kuruman spring draining northwest, the Okavango southwest and the Molopo spring west.*
- *The Distance between this area and these water bodies is 700, 200 and 200 km respectively.*
- *Numerous Geological boundaries like different rock units, faults, dykes, impermeable layers (a number visible in Figure 6) transect the areas between these water bodies.*
- *The water quality is different in nature with the Tosca Molopo electrical conductivity at 50 to 200 mS/m, the deeper Okavango delta aquifers generally exceeding 300 mS/m, and the Kuruman and Molopo springs fresh at less than 50 mS/m.*
- *The Isotope character of the water is different.*

4.2. Resource units

Three Resource Units (RUs) are defined within the Tosca Molopo dolomite aquifer, identified from the observed aquifer characteristics, from drilling logs, water level response, aquifer tests and the presence of regional dolerite dykes, which divide the area into 3 major compartments (Godfrey 2002) (Figure 4). These include:

RU 1 – Tosca dolomite aquifer

RU 2 – Dolomite aquifer, area of post Karoo dolerite intrusive (dyke swarms)

RU 3 – Pomfret dolomite aquifer

These resource units are overlain by, low yielding, Kalahari sand aquifer. It is only used extensively close to the Molopo River due to the good quality water available above the Budin clay formation. Away from the river very little groundwater is available in this formation.

Within the three identified Resource Units (RU1-3), smaller geohydrological response units exist. They are typically formed by the intrusion of dolerite into the dolomite aquifer forming small compartments, which may act as isolated units. Where possible, reference is made to these response units.

4.3. Groundwater levels

Regional water level records for 2 periods (1977 and 1990) were available to assess the reference conditions of the groundwater resource within the eastern part of the Molopo dolomite aquifer (RU1 and RU2). During the 2 years prior to the 1974 hydro census, investigations in the area provided a data set of water levels (mamsl) (Figure 7(a)).

During 1990 a similar hydro census was conducted where 351 boreholes were located (Duvenhage & Meyer, 1991). Water level measurements were possible at 198 boreholes. The water levels in the northwest vary from 5 to 10m below surface, gradually deepening to 50 and 60 m to the northeast at the Molopo River (Figure 7(b)).

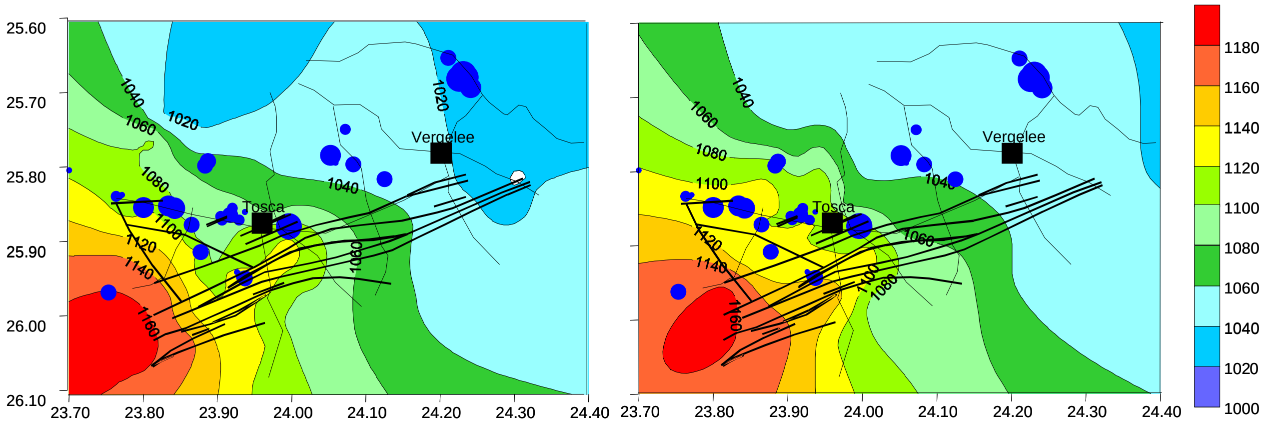


Figure 7. Groundwater level elevation contours (mamsl) (1977 (a) left and 1990 (b) right).

To assess how representative the water levels for 1977 and 1990 are as reference conditions, the precipitation for those years was compared with the average. It is evident that the pre-1974 water levels were measured in a period of average to below average rainfall (Figure 2) while the 1990 water levels were measured following high rainfalls in 1988.

Only minor changes in groundwater levels are evident between 1977 and 1990. The most striking being elevated water levels along the Molopo River and elevated water levels along the dyke swarms parallel to the Quarreefontein dyke. As such the groundwater levels in 1990 are still considered to be unimpacted, reference conditions. From both maps (Figure 7) the northeast gradient of groundwater levels towards the Molopo River is evident with the dyke swarms possibly impeding groundwater flow from the south and southwest. From the existing declined water levels it is possible to delineate the aquifer into at least 3 distinctive resource units. These are illustrated in Figure 4 and 11.

4.3.1. Resource Unit 1

This resource unit is the area north of the Quarreefontein dyke and east of the Grassbank dyke Figure (4 and 11). To date there is no evidence that this resource unit is sub divided in more compartments, as the water levels do not indicate that. In this area the thickness of the Kalahari sediments is generally more than the depth of the water level therefore effectively connecting the total area. Even with the declined water levels no separate compartments could be identified.

4.3.2. Resource Unit 2

This resource unit is separated from resource unit 1 by the Quarreefontein dyke to its north. Numerous dyke swarms intrude the dolomite of this area. The Kalahari sediments are thin at approximately less than 15 m with the water level below this depth. This effectively divides the area into numerous different compartments.

4.3.2. Resource Unit 3

Resource Unit 3 represents the Pomfret dolomite aquifer and overlying banded ironstone formation. Groundwater is encountered within the banded ironstones, the dolomite/shale contact and within fractures, brecciation zones and solution cavities within the dolomites.

The dolomite aquifer in the region of Pomfret is characterized by at least 13 compartments, bounded by dolerite dykes (van Dyk, 1993). Very little information on the reference conditions of water levels within these compartments is available. Different piezometric water levels are encountered in the three different aquifers in this RU. Water levels in the banded ironstone aquifer vary between 30-60m; water levels in the dolomite/shale transition zone vary between 40-70m while the water levels in the dolomite aquifer vary between 10-30m below surface.

As in the Tosca aquifer, the gradients of groundwater levels are towards the Molopo River, however the abstraction of groundwater from compartments 3 and 5 has resulted in a groundwater sink to the east of Pomfret. (van Dyk, 2003)

4.3.3. The primary sandy aquifer of Kalahari layers

This aquifer cannot be classified as a separate resource unit. It is the shallow, Kalahari aquifer, which overlies the Molopo dolomite aquifer. The thickness of the Kalahari sands varies from less than 5 m in the southwest of the study area to as much as 150 m in the northeast, adjacent to the Molopo river, as indicated in Figure 4. From the regional decline in the water level, abstractions from the underlying dolomites have resulted in water levels declining 10 to 20 m. Boreholes, which penetrate the Budin formation into the underlying, Wessels gravels (high yielding) are impacted upon by changes in water levels in the underlying dolomite aquifer.

The groundwater level in proximity to the Molopo River is approximately 50 mbgl. Away from the river water levels increase to between 70-90 mbgl. Since extensive abstraction commenced, the water levels in the shallow Kalahari boreholes, away from the river, decreased by between 10 and 20 meters.

The use of groundwater loggers logging water level data every hour at selected boreholes indicated a dynamic system with water levels reacting that to daily and seasonal influences. The graph in Figure 8 below from borehole G39793 proximate to the Molopo for 11 months indicate a seasonal variation of more than 10 meters in reaction to intensive abstraction for irrigation. The reaction when abstraction is stopped temporary during the time when levels are declining regionally is visible as temporary recovery of almost 2 m. Water level reactions of less than 10 cm is visible.

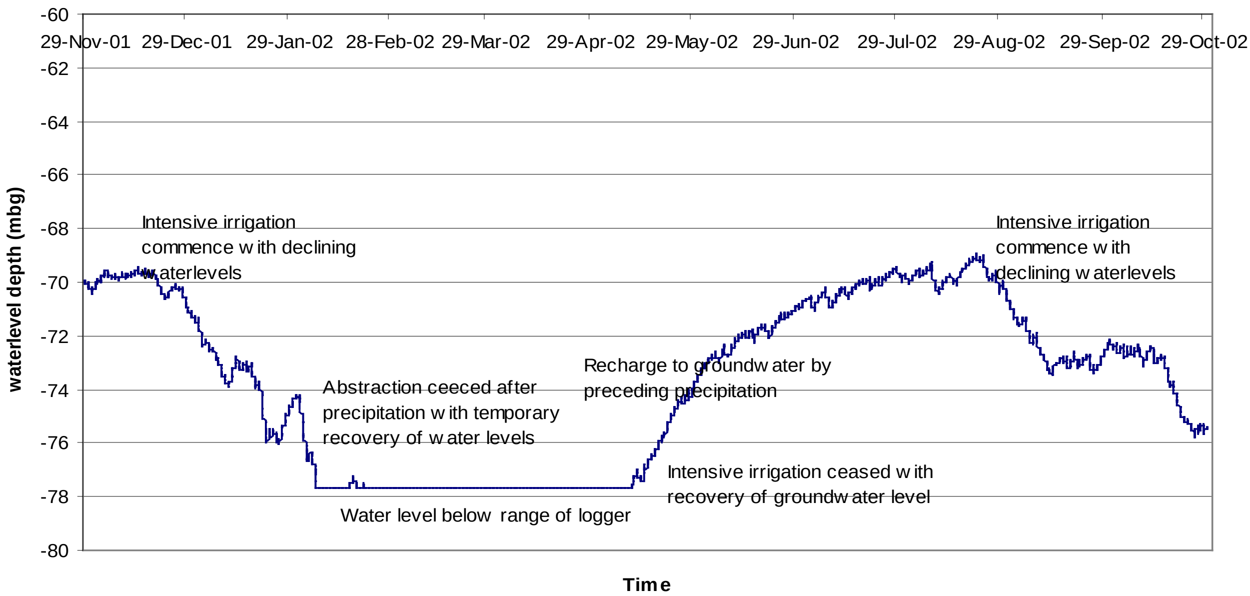


Figure 8. Groundwater level reaction in borehole G39793 in response to abstraction and recharge.

4.4. *Groundwater quality*

Groundwater quality data from the DWAF NGDB, for 316 samples is available for the study area. A summary of groundwater quality per Resource Unit is given in Table 4.

Table 4. Groundwater qualities for Resource Units 1-3. (Godfrey 2002)

Chemical Parameter		Resource Unit			(SABS 241:1999)		
		RU 1	RU 2	RU 3	Class 0	Class I	Class II
pH		7.3 - 7.8 - 8.3	7.3 - 7.7 - 8.4	7.2 - 7.7 - 8.4	6 - 9	5 - 9.5	4 - 10
Electrical Conductivity	mS/m	47 - 81 - 182	75 - 115 - 304	57 - 86 - 199	< 70	70 - 150	150 - 370
Calcium as Ca	mg/l	10 - 66 - 112	28 - 76 - 191	23 - 72 - 165	< 80	80-150	150-300
Magnesium as Mg	mg/l	28 - 57 - 87	37 - 71 - 179	26 - 55 - 131	< 30	30-70	70-100
Sodium as Na	mg/l	11 - 34 - 105	27 - 73 - 332	8 - 30 - 120	< 100	100-200	200-400
Total Alkalinity	mg/l	128 - 310 - 439	140 - 299 - 452	142 - 284 - 430	-	-	-
Chloride as Cl	mg/l	19 - 62 - 348	40 - 163 - 714	17 - 58 - 314	< 100	100-200	200-600
Sulphate as SO_4	mg/l	4 - 11 - 61	7 - 38 - 199	4 - 53 - 151	< 200	200-400	400-600
Nitrate as NO_x	mg/l	0.1 - 3.5 - 29	0.2 - 12 - 75	0.1 - 2.3 - 116			

* Values given as the 5th - median - 9th percentiles

It is evident from this summary that the groundwater of RU1 and RU3 are very similar in quality, generally low in total dissolved solids, while RU2 has an elevated salt content for all major cat ions and anions. More saline, higher TDS, groundwaters are therefore associated with the east-west dolerite dykes, as one would expect from the difference in ages of the groundwater (Section 5.1). The groundwater type varies considerably throughout the area from a Ca, Mg-HCO_3 type water to an Mg, Na-Cl type. The dominant cat ions are however Mg and Ca and dominant anions, HCO_3 and Cl. All groundwater quality samples have been plotted on the Piper Diagram (Figure 9), and show the spatial variation in groundwater quality within the study area, from low TDS waters typical of recharge areas, to high TDS groundwater.

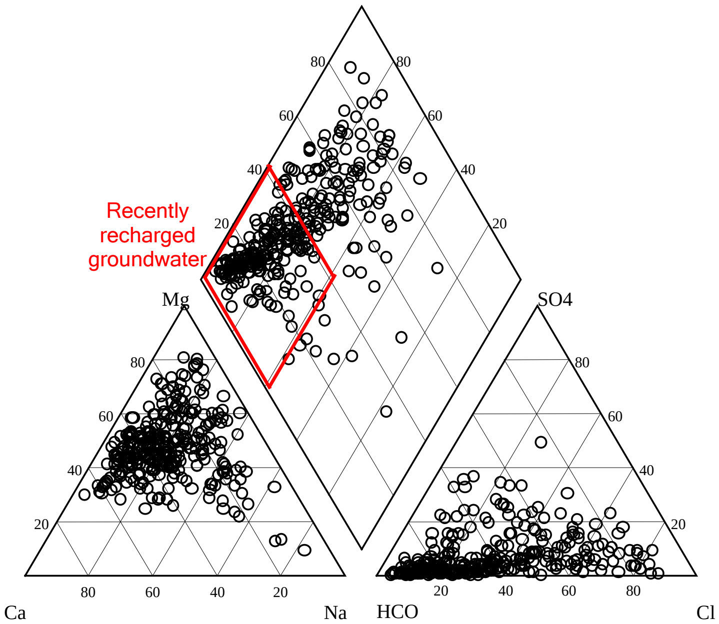


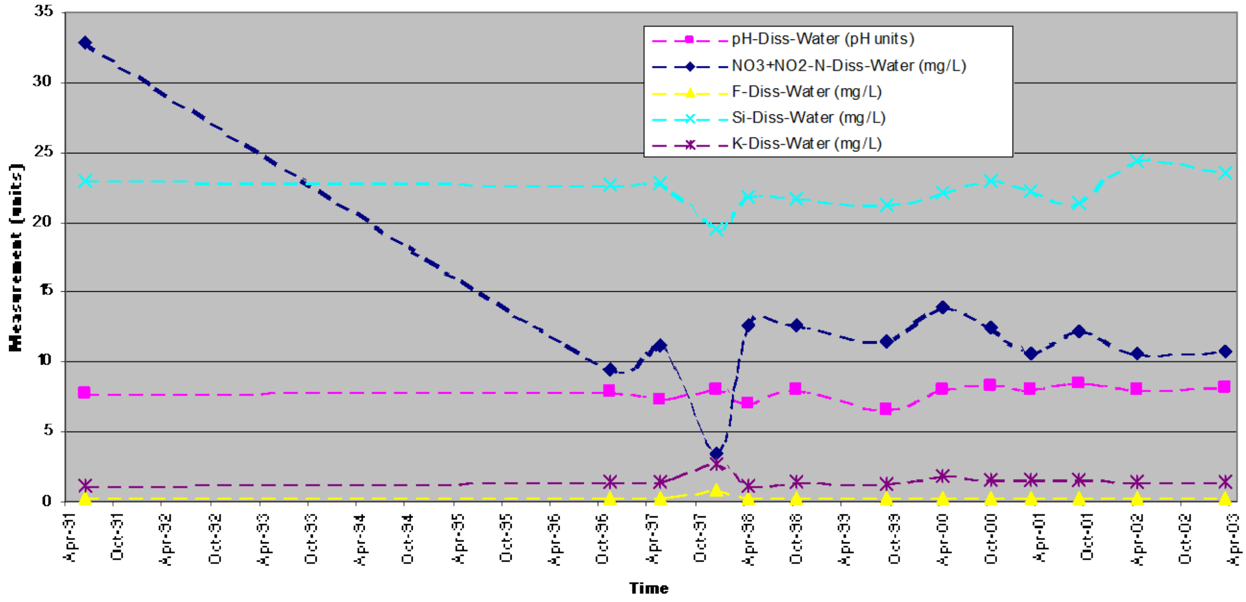
Figure 9. Piper diagram of groundwater quality of the Molopo dolomite aquifer.

Elevated concentrations of F and NO_3, often associated with pollution, are present in RU2 and RU3. The origin of the F could be from weathering of the dolerite intrusions or from the proximity to the granites. The elevated NO_3 in these units with their shallow water levels may be the result of local pollution from human and animal excreta and fertilizer application or naturally reduced denitrification processes. Tredoux et al. (2003) name a number of parameters that could influence the denitrification process. These include temperature, pH, organic carbon, carbon: nitrogen ratio, oxygen content and redox potential, microbal activity, water content of soil, permeability and porosity, anthropogenic activity (i.e. ploughing) and other nutrients. In this area specifically the absence of organic carbon and low soil water content combined with high soil permeability / porosity with high soil oxygen content could inhibit denitrification with rapid infiltration during recharge. Therefore it is postulated that recharging water rich in nitrogen reach the aquifer.

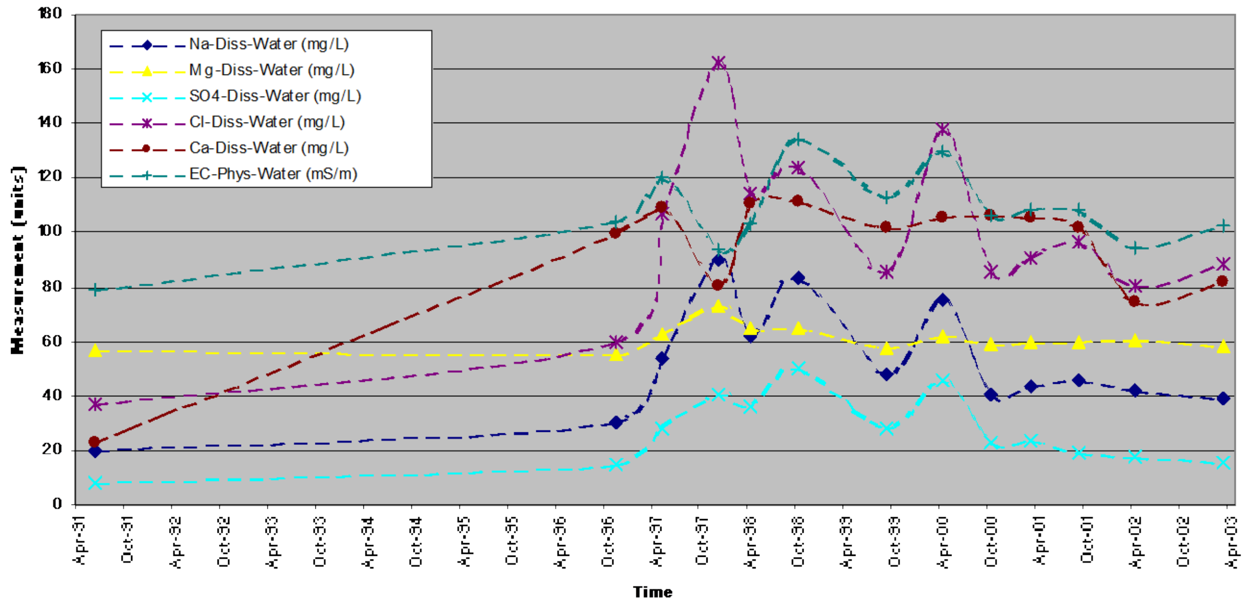
The borehole G39682 on the farm Grassbank has been sampled regularly as part of the National Groundwater Monitoring Program since 1996. The borehole was sampled 12 times during October and April aimed at before and after precipitation. During 1995 intensive irrigation proximate to the borehole commenced. The variation in selected chemical substances is compared with the initial concentrations when the borehole was completed in by 1991and graphically presented in Figure 10 a, b.

There was a significant increase in the anions SO_4 and Cl with a dramatic decrease in (NO_3+NO_2). The increase in SO_4 can be attributed to sulfate containing fertilizers. Although these fertilizers also contain nitrogen this nitrogen did not reach the groundwater. The enhancement of the denitrification process through ploughing the fields to release oxygen from the soil, higher soil water content due to irrigation, the increase of SO_4 through fertilization presence of organic carbon through cultivation enhanced microbal activity and therefore denitrification. Consequent recharge water to the aquifer is therefore with of lower nitrogen content.

The cationes Na and Ca also increased significantly. The Na, Ca and Cl increase can be attributed to evapotranspiration enrichment in the soil and infiltration of these substances during recharge to the aquifer. The other substances were stable compared to the initial concentrations and their variation seasonally.



a)



b)

Figure 10. G39682 Grassbank groundwater variation in selected chemical substances

5. WATER BALANCE

5.1. Groundwater recharge

5.1.1. Indirect deductions from maps and recharge tools

According to Vegter (WRC, 1995b), groundwater recharge within the catchment varies from 3 to 12 mm per annum. Recharge software developed by the Institute for Groundwater Studies (IGS) (van Tonder, 2000) was used to assess recharge for each of the resource units. The software makes use of three recharge methods, the Chloride method (Bredenkamp et al., 1995), Vegter's Recharge map (WRC, 1995b) and the Harvest Potential map (DWAF, 1996). The results of each of these methods are given in Table 5.

Table 5. Calculated recharge figures as a percentage of MAP from deductions and recharge tools.

Resource Unit	Recharge (1) [%/a of MAP] [mm/a of MAP]		
	Cl Method	Vegter	Harvest Potential
RU 1	0.13 – 9.2 6.4 - 45	0.75 – 3.0 3.7 – 14.7	6 – 53 29.5 - 260
RU 2	0.05 – 4.0 0.3 – 19.5	0.75 – 3.0 3.7 – 14.7	6 – 53 29.5 - 260
RU 3	0.20 – 7.2 9.8 – 35.3	0.81 – 3.2 4 – 15.7	6 – 57 29.5 - 279

(1) Rainfall figures for Vergelegen (399 mm/a) have been used for RU1 and RU2, while figures from Pomfret (371 mm/a) have been used for RU 3.

5.1.2. Chloride Mass Balance (CMB) as a chemical tracer method

The Chloride Mass Balance (CMB) method was identified as a suitable method more accurate recharge figures in South Africa (Bredenkamp et al., 1995) and its applicability to the study area was determined. As reported by van Tonder and Bean (2003) significant seasonal variation in the chloride content was measured for monthly composite rainfall samples.

A composite rainfall sample for the period Oct 2001 to February 2003 was taken on the farm Forres proximate to Tosca with an uPVC rainwater collector (CSIR, Weaver). When analyzed a Chloride content of 1.4 mg/l was reported. This content was regarded as unrealistic due to possible chloride content increased by PVC and silicon oil (Adams, 2004). The value of 0.8 mg/l that is more in line with proximate studies in Botswana (GRESS1,2 Beekman et. al. 1996) was used. A rainfall collector (DWAF van Wyk) was erected on the farm Quarreefontein and would collect future rainfall to determine local rainfall Cl content.

The recharge rates were calculated by using the Chloride Mass Balance (CMB) saturated zone ratio where the average chloride content in precipitation to that in groundwater is determined.

The total recharge is estimated by using he equation:

$$R_T = \frac{TD}{Cl_{gw}}$$

Where:
R_T = total recharge (mm/a)
TD =total deposition (mg/m^2/a)
Cl_{gw} =Cl content in groundwater (mg/l)

The fundamental basis of the CMB method is that the water mass flux crossing the plane of the water table can be calculated if most of the assumptions prescribed in Table 6 below are met (Wood, 1999 and Adams. 2004).

Table 6. Assumptions when using the CMB method in the Tosca Molopo dolomite aquifer.

Chloride in groundwater originates only from precipitation (no measurable chloride mass from overlying, underlying or adjacent aquifers and no measured surface water percolation)	No
Chloride is conservative in the system	Yes
The chloride mass flux has not changed over time	Unknown
There is no recycling or concentration of chloride within the aquifer	No
No evaporation of groundwater occurs up gradient from the groundwater sampling points	Yes in general
The adsorption of chloride in soils and the vegetation uptake is considered negligible	Yes

Although not all the assumptions are met with expected inaccuracies in results the CMB is still considered a suitable method for first approximation of recharge. The results of these calculations are included as Table 7.

Table 7. Recharge figures as calculated by different values of Cl in precipitation. The harmonic mean at Cl precipitation of 1.5% of MAP or 5.7 mm /a is representative.

	[Cl]gw	**[Cl]p = 0.9**	**[Cl]p = 0.9**	**[Cl]p= 0.8**	**[Cl]p= 0.8**	**[Cl]p=1.0**	**[Cl]p=1.0**	**Re = P*[Cl]p / [Cl]gw**
Farm name	**(mg/l)**	**Re(385 mm)**	**Re(400)**	**Re(385)**	**Re(400)**	**Re(385)**	**Re(400)**	P = precipitation (mm/a)
Albury	33	10.5	10.9	9.3	9.7	11.7	12.1	[Cl]p=concentration Cl in rainwater (mg/l)
Ascott	155	2.2	2.3	2.0	2.1	2.5	2.6	[Cl]p=concentration Cl in groundwater (mg/l)
Ascott	467	0.7	0.8	0.7	0.7	0.8	0.9	Re= recharge (mm/a)
Brentwood	44	7.9	8.2	7.0	7.3	8.8	9.1	
Buttermere	464	0.7	0.8	0.7	0.7	0.8	0.9	
Blackheath	28	12.4	12.9	11.0	11.4	13.8	14.3	
Birkdale	184	1.9	2.0	1.7	1.7	2.1	2.2	
Buxton	194	1.8	1.9	1.6	1.6	2.0	2.1	
Belvidere	46	7.5	7.8	6.7	7.0	8.4	8.7	
Belvidere	288	1.2	1.3	1.1	1.1	1.3	1.4	
Bees Wood	39	8.9	9.2	7.9	8.2	9.9	10.3	
Bees Wood	171	2.0	2.1	1.8	1.9	2.3	2.3	
Brenton	87	4.0	4.1	3.5	3.7	4.4	4.6	
Birnam Wood	39	8.9	9.2	7.9	8.2	9.9	10.3	
Bradbury	193	1.8	1.9	1.6	1.7	2.0	2.1	
Clearstream	35	9.9	10.3	8.8	9.1	11.0	11.4	

Clearstream	134	2.6	2.7	2.3	2.4	2.9	3.0
Exeter	57	6.1	6.3	5.4	5.6	6.8	7.0
Eden	118	2.9	3.1	2.6	2.7	3.3	3.4
Elchester	548	0.6	0.7	0.6	0.6	0.7	0.7
Elchester	1126	0.3	0.3	0.3	0.3	0.3	0.4
Forest hall	26	13.3	13.8	11.8	12.3	14.8	15.4
Forres 1	43	8.1	8.4	7.2	7.4	9.0	9.3
Forres 2	184	1.9	2.0	1.7	1.7	2.1	2.2
Geesdrif	131	2.6	2.7	2.4	2.4	2.9	3.1
Gannalaagte	45	7.7	8.0	6.8	7.1	8.6	8.9
Hou moed	26	13.3	13.8	11.8	12.3	14.8	15.4
Hurst Park	29	11.9	12.4	10.6	11.0	13.3	13.8
Harcourt	25	13.9	14.4	12.3	12.8	15.4	16.0
Harcourt	288	1.2	1.3	1.1	1.1	1.3	1.4
Knysna	84	4.1	4.3	3.7	3.8	4.6	4.8
Kokomeng	106	3.3	3.4	2.9	3.0	3.6	3.8
Kameeldoorns	93	3.7	3.9	3.3	3.4	4.1	4.3
Langedraai	11	31.5	32.7	28.0	29.1	35.0	36.4
Langedraai	532	0.7	0.7	0.6	0.6	0.7	0.8
Mositlane	139	2.5	2.6	2.2	2.3	2.8	2.9
Mositlane	774	0.4	0.5	0.4	0.4	0.5	0.5
Marstone	491	0.7	0.7	0.6	0.7	0.8	0.8
Marlborough	35	9.9	10.3	8.8	9.1	11.0	11.4
Weltevrede	251	1.4	1.4	1.2	1.3	1.5	1.6
Navarre	67	5.2	5.4	4.6	4.8	5.7	6.0
New Barnet	51	6.8	7.1	6.0	6.3	7.5	7.8
Knapdaar	76	4.6	4.7	4.1	4.2	5.1	5.3
Paddapan	1347	0.3	0.3	0.2	0.2	0.3	0.3
Paddapan	259	1.3	1.4	1.2	1.2	1.5	1.5
Platbosbult	77	4.5	4.7	4.0	4.2	5.0	5.2
Quareefontein	24	14.4	15.0	12.8	13.3	16.0	16.7
Ravensbourne	37	9.4	9.7	8.3	8.6	10.4	10.8
Redmonds hoek	70	5.0	5.1	4.4	4.6	5.5	5.7
Rhodes	299	1.2	1.2	1.0	1.1	1.3	1.3
Salamanca	167	2.1	2.2	1.8	1.9	2.3	2.4
Salamanca	338	1.0	1.1	0.9	0.9	1.1	1.2
Stretford	120	2.9	3.0	2.6	2.7	3.2	3.3
Sandilands	31	11.2	11.6	9.9	10.3	12.4	12.9
Thorntwaite	97	3.6	3.7	3.2	3.3	4.0	4.1
Thornwick	155	2.2	2.3	2.0	2.1	2.5	2.6
Thorncroft	19	18.2	18.9	16.2	16.8	20.3	21.1
Vogelvry	39	8.9	9.2	7.9	8.2	9.9	10.3
Vergelegen	62	5.6	5.8	5.0	5.2	6.2	6.5
Vergelegen	336	1.0	1.1	0.9	1.0	1.1	1.2
West End	202	1.7	1.8	1.5	1.6	1.9	2.0
Wakefield	133	2.6	2.7	2.3	2.4	2.9	3.0
Westward	27	12.8	13.3	11.4	11.9	14.3	14.8
Zandvloed	155	2.2	2.3	2.0	2.1	2.5	2.6
Sandvloed	132	2.6	2.7	2.3	2.4	2.9	3.0
Average	185.9	5.5	5.7	4.9	5.1	6.1	6.4
Harmonic mean	62.9	1.9	1.9	**1.7**	**1.7**	2.1	2.2

A spatial plot of these results highlighted areas of higher recharge, as shown in Figure 11. These areas coincide with existing structural features, such as lineaments, outcrop areas and alluvial channels, likely areas of recharge. The proposed recharge areas also coincide well with existing conceptual models and understanding of the dynamics of the dolomite aquifer. With this method recharge is calculated to be between 0.2 to 28 mm/a of MAP in the different areas of the aquifer. This harmonic mean for all groundwater analyzed is 1.7mm/a. This corresponds to 0.1 to 7.3% of MAP and a harmonic mean of 0.4%.To be more representative these figures were recalculated in resource unit context and the following recharge figures (Table 8) were obtained for each of the Resource Units.

Table 8. Calculated recharge figures using CMB in different resource units.

Resource Unit	Response Unit	% Recharge 5th - Median - 95th	Percentage of Boreholes < or > % Recharge				
			< 1%	> 1%	> 2%	> 5%	> 10%
RU 1	(i)	0.18 - 1.06 - 4.45	41.67	58.3	33.3	0.0	0.0
	(ii)	0.25 - 1.41 - 4.22	38.06	61.9	33.6	2.2	0.0
RU 2	-	0.12 - 0.51 - 2.05	81.11	17.8	5.6	0.0	0.0
RU 3	(i)	0.54 - 1.70 - 4.94	26.32	73.7	44.7	5.3	0.0
	(ii)	0.26 - 0.93 - 4.89	52.38	47.6	31.0	4.8	0.0
Average		1.12					

These recharge figures correspond well with those previously reported on by Smit (1977), who gave recharge figures in outcrop areas of 2.2 – 3.8%. According to Smit, no recharge to groundwater occurs in areas where the thickness of the Kalahari sand is greater than 15m, due to the high evaporation. In areas where the Kalahari is > 15m recharge to groundwater varies between 0.26 – 0.8%, with an average of 0.5% (Smit, 1977).

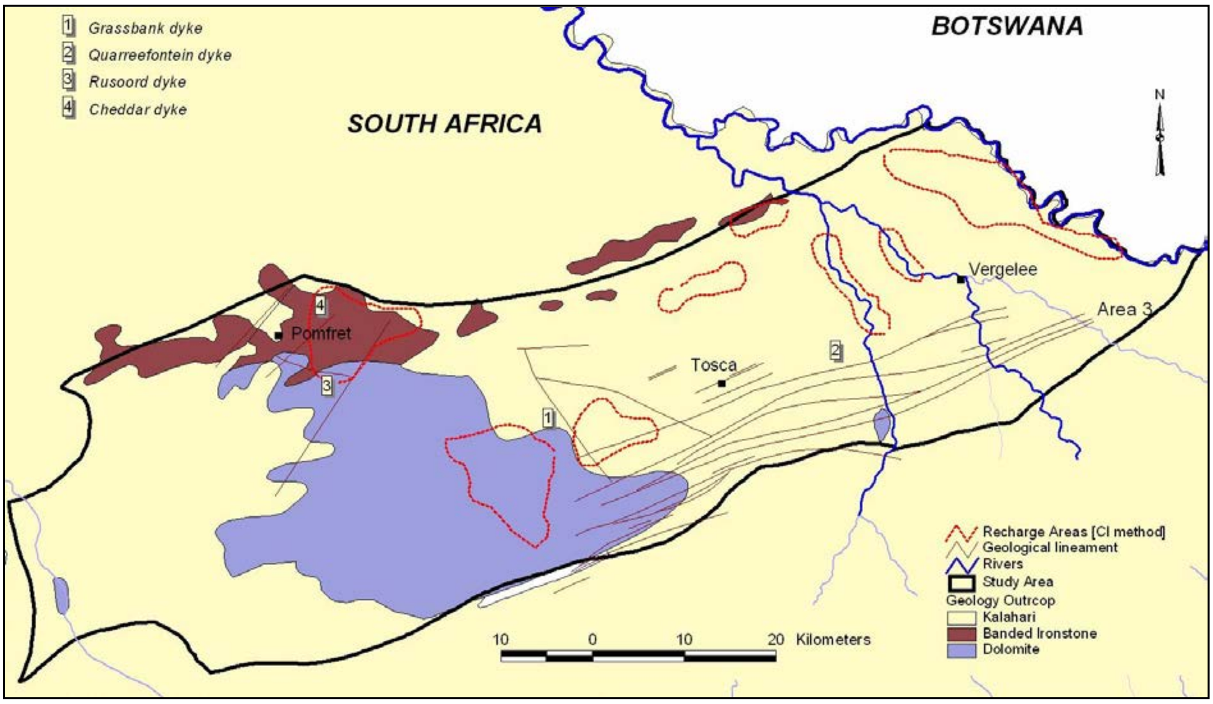


Figure 11. Areas of highest recharge, based on Cl values for existing boreholes. (Godfrey 2002)

Based on the results of the Chloride recharge method, the following areas of recharge to the dolomite aquifer are proposed (Figure 11):

- Recharge through geological lineaments (generally faults, and less dykes)
- Recharge through shallow outcrop and sub outcrop of dolomite (southwestern area)
- Recharge through banded ironstone formation (northern border of study area).
- Recharge through the alluvial channels of the Molopo River and tributaries.

Figure 11 indicate these areas (in red) of highest recharge values, based on groundwater quality of existing boreholes. As such the demarcation of these high recharge areas are based on the presence of existing boreholes and may actually extend further that indicated.

5.1.3. Stable and radioactive isotopes recharge determination methods

5.1.3.1. Carbon 14

Through groundwater age or mean residence times deductions can be made regarding recharge areas, recharge rates, groundwater flow as well as the identification of non renewable water resources (Beekman and Selaolo, 1997). These deductions must be made in combination with the existing geochemical conceptual model of the groundwater system. This method was utilized by Duvenhage and Meyer, (1991) in the Tosca Molopo area and the estimated ages in Table 9 were obtained.

Table 9. Results of age determination from selected boreholes as from Duvenhage and Meyer, (1991).

FARM	BOREHOLE	DATE sampled	LAT	LONG	C14	MRT	Description of sample point
TENNANT	PRIVATE	1991			89.3±0.8	<500	Water strike above Budin clay formation-recent water RU1
GRASSBANK	G39682	1991	25.85453	23.83918	80.5±0.5	490	N-S fault with high yield and good quality waterRU1
THORNTWAITE	G39692	1991	-25.878	24.01894	44.7±0.6	5290	Magma dyke contact with dolomite in RU2
KOKOMENG	G39686	1991	25.88783	23.99822	28.5±0.3	8880	Magma dyke contact with dolomite in RU2
LANGEDRAAI	G39693	1991	-25.6741	24.14435	41.1±0.6	5930	Water strike in deep primary aquifer at 150 m RU1

They concluded that significant recharge along faults and along the Molopo and other river beds could take place due to the age determinations of groundwater, which indicated young waters, i.e. more recent recharge (< 500 years) associated with faults, and older water (> 5000 years) associated with dykes (Duvenhage and Meyer, 1991). The conceptual model of significant recharge along faults, riverbeds and poor recharge along dykes and isolated compartments is supported by these age determinations.

The nuclear bomb testing during 1952/53 added additional radiocarbons into the atmosphere. Carbon dioxide (CO_2) from the air is trapped in rain and the water is tagged by atmospheric ^{14}C. This water infiltrates and is isolated from the atmosphere. The radioactive ^{14}C gradually decay. Carbon 14 ages refer to the period of time elapsed since the water moved deep enough into the groundwater zone to be isolated from the atmosphere.

Radioactive decay is expressed by:

$$A = A_0 e^{-1/\tau}$$

Where:

A	=	the specific activity of 14C
A_0	=	the initial activity per unit mass of sample
t	=	the decay age of the carbon isotopes (years)
τ	=	mean half life of ^{14}C (8270 years)

$$t = -8270 \ln (A/A_0)$$

Adams (2004) cited from Schwartz (1990) that the following processes could alter the ^{14}C activity of groundwater:

- Congruent dissolution of carbonate minerals, which add dead carbon or carbon without ^{14}C activity to the groundwater, effectively lowering the ^{14}C activity.
- Incongruent dissolution of carbonate or other Ca containing minerals accompanied by precipitation of calcite. This process will remove 14C as calcite precipitates and if dolomite is the mineral dissolving add dead carbon through this process. This process could occur in the zone of saturation following the rapid solution of calcite to equilibrium with subsequent precipitation as dolomite slowly dissolves.
- The addition of dead carbon from other sources such as the oxidation of old organic matter, sulphate reduction and methanogenesis can reduce the 14C activity.
- Isotopic exchange involving CO_3 and carbonate minerals could lower the 14C activity. This process is generally considered to have a negligible effect at normal groundwater temperatures.

The factors above need to be considered in radiocarbon dating and unrealistic high ages can be corrected geochemical models.

During 1998 the CSIR (Talma, 1998) took 4 samples in similar areas than 1991 and the results are tabled in Table 10.

Table 10. Analysis of boreholes sampled during 1998 by CSIR (Talma).

FARM	BOREHOLE	DATE sampled	LAT	LONG	C14	TRITUIM	C13	O18	Deut
GRASSBANK	G39682	19980206	25.85453	23.83918	78.2±0.6	1.5±0.2	-9.1	-4.86	-37.6
KOKOMENG	G39686	19980206	25.88783	23.99822	77.7±0.5	1.3±0.2	-9.7	-4.71	-34.5
THORNTHWAITE	G39665	19980206	25.87157	23.99882		1.0±0.2		-4.21	-28.5
THORNTHWAITE	NE4	19980206	25.87268	24.00167	70.8±0.4	0.7±0.2	-9.0	-5.07	-31.8

Calculation and re calculation of previous analysis with the discussed theory and formulas resulted in the ages as determined in Table 11.

Table 11. Recalculated Mean residence times (MRT) of groundwater.

FARM	BOREHOLE	DATE sampled	A	Q	MRT	Aquifer
TENNANT	PRIVATE	1991	89.3	0.85	<500	Water strike above Budin clay formation-recent water RU1
GRASSBANK	G39682	1991	80.5	0.85	450	N-S fault with high yield and good quality waterRU1 Water level at approx 25 m
THORNTWAITE	G39692	1991	44.7	0.85	5315	Magma dyke contact with dolomite in RU1
KOKOMENG	G39686	1991	28.5	0.85	9040	Magma dyke contact with dolomite in RU1
LANGEDRAAI	G39693	1991	41.1	0.85	6010	Water strike in deep primary aquifer at 150 m RU1
GRASSBANK	G39682	19980206	78.2	0.85	6900	N-S fault with high yield and good quality waterRU1. Water level at approx 60 m
KOKOMENG	G39686	19980206	77.7	0.85	740	Magma dyke contact with dolomite in RU2
THORNTHWAITE	NE4	19980206	70.8	0.85	1510	Magma dyke contact with dolomite in RU1

In the Grassbank area groundwater of older estimated age seem to have entered the fault fracture system and characteristics of the previously regarded younger water now reflect an older age. The water level also declined dramatically in the fracture system.

In the Kokomeng area previously older water now reflects a younger signature. This drastic difference can not be explained. The water level declined from 11 m to 15 m and precipitation during 1998 and previous years was above normal. The same happened in the Thorntwaite area.

In general contrast with very old and very modern water could have been averaged out by the more dynamic system and mixing due to abstraction. The system could have been activated by abstraction with modern recharged water from the recharge area mixing with the older water in the generally northeast draining water.

5.1.3.2. Stable isotopes -Oxygen 18 and Deuterium

The stable isotopes deuterium and oxygen 18 can be used to differentiate if groundwater in the saturated zone recharged directly (fast) or was added indirectly (delayed). Table 12 reflect the isotope composition of groundwater from selected boreholes and a bulk rainwater sample with a scatter plot of these values in Figure 12. The bulk rainwater sample was collected over the period Oct 01 to Feb 03. Like the Cl analysis from this precipitation sample the deuterium and oxygen 18 analyses also seem suspect.

Table 12. Isotope analysis from selected boreholes and precipitation in the study area.

FARM	BOREHOLE	TRITUIM	C13	δO18 (°/oo)	δDeut (°/oo)	Aquifer
GRASSBANK	G39682	1.5±0.2	-9.1	-4.86	-37.6	N-S fault with high yield and good quality waterRU1
KOKOMENG	G39686	1.3±0.2	-9.7	-4.71	-34.5	Magma dyke contact with dolomite in RU1
THORNTHWAITE	G39665	1.0±0.2		-4.21	-28.5	Magma dyke contact with dolomite in RU1
THORNTHWAITE	NE4	0.7±0.2	-9.0	-5.07	-31.8	Magma dyke contact with dolomite in RU1
FORRES	Precipitation			-1.88	-1.4	Bulk precipitation Oct 01 to Feb 03

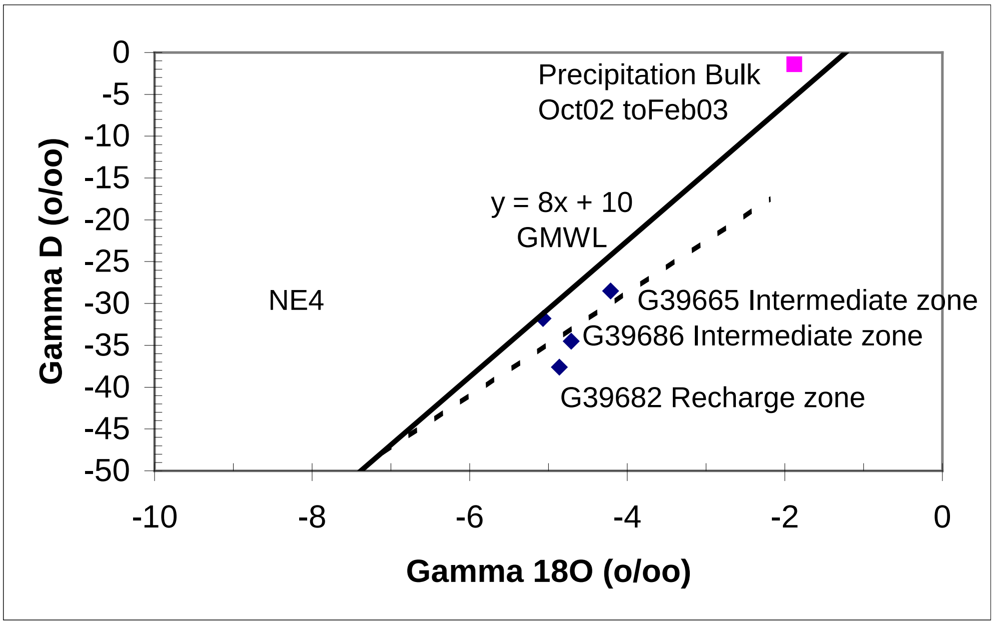


Figure 12. Scatter plot of δD (°/oo) vs δ^{18}O (°/oo) data.

The global meteoric water line (GMWL) is the solid line. The bulk precipitation sample was collected during the period Oct 2001 to Feb 2003. With only one precipitation analysis no conclusions regarding the nature and variability of the isotope content of the precipitation can be made. No local meteoric water line (LMWL) can be determined.

The slope of the line through groundwater δD (°/oo) vs δ^{18}O (°/oo) scatter plot is > 6 and the negative values imply that a degree of the precipitation character took place before the water reached the saturated zone. Visually it is evident that infiltration in this area must be immediate as no surface water bodies, rivers or any other structure exist that can delay infiltration. The only exception is the Molopo River where water would be present for a few weeks after precipitation, which could enhance transpiration. The other mechanism that could delay recharge is evapotranspiration in the unsaturated zone. This process must be active and is supported by groundwater δD (°/oo) vs δ^{18}O (°/oo) character to conclude (Smit, 1977) that in areas where the Kalahari thickness exceeds 15m, recharge to groundwater must be low.

5.1.4. Cumulative rainfall departure (CRD).

The CRD method is based on the premises that water level fluctuations are caused by rainfall events. (Beekman et al. 2004, Bredenkamp 1995). Data requirements for this method are monthly rainfall records, matching water level records for the rainfall, borehole abstractions and aquifer properties (storativity) and size of recharge area. The CRD method is represented by the following equation:

$$ {}_{av}{}^{1}CRD_i = R_i - kR_{av} + {}_{av}{}^{1}CRD_{i-1} $$

Where:
CRD_i = accumulated rainfall departure from mean at time i
R_i = rainfall at time i
K = 1 indicate natural conditions and k>1 indicate that the aquifer is being exploited
R_{av} = average rainfall

The absence of long enough monthly water level records over the appropriate period made it difficult to apply this method to determine the recharge and it is rather recommended that monthly water level data be gathered in efforts to refine the determined recharge estimates calculated from other methods.

5.1.5. Saturated Volume Fluctuation (SVF).

The SVF method is an inventory of input to the aquifer over a specific time period with output from the aquifer. The water balance is reflected in the water level reaction. This method is suitable for most hydro geological analysis and aquifer management applications (Bredenkamp et al., 1995). The formula of this saturated water balance is:

$$ I - Q + Re - Q = S\,\frac{V}{t} $$

Where:
S = storativity/ specific yield
V = saturated volume of aquifer
I = lateral inflow
O = lateral outflow
Re = recharge
Q = net discharge
t = time

The absence of long enough monthly water level records over the appropriate period made it difficult to apply this method to determine the recharge and it is rather recommended that monthly water level data be gathered in efforts to refine the determined recharge estimates calculated from other methods.

5.1.5. Recharge summarized

With the available data only the CMB could be applied with confidence. With this method recharge is calculated to be between 0.2 to 28 mm/a of MAP in the different areas of the aquifer. This harmonic mean for all groundwater analyzed is 1.7mm/a. This corresponds to 0.1 to 7.3% of MAP and a harmonic mean of 0.4%.

The stable isotopes deuterium and oxygen 18 indicate immediate and delayed recharge to the aquifer in different areas of the aquifer and carbon 14 confirm that preferred recharge in areas of the aquifer and probably along preferred pathways.

The CRD and SVF methods could not be applied with certainty due to the lack of sufficient water level data.

5.2. Reserve determination

In response to pressure on the groundwater resource a preliminary intermediate reserve determination was done for the Pomfret Vergelegen dolomite aquifer, which includes the Tosca Molopo dolomite aquifer. (Godfrey 2002). The results of this reserve are included as Table 13 and the area of investigation as figure 13.

The findings of this reserve determination were that the total resource unit 1 was over utilized and portions of resource unit 3 were over utilized. Their present category status was classified as F, which is very poor and modified and it is desired that with intervention this could be improved to C (good or moderately modified) as in Table 14.

Table 13. Determination of the groundwater component of the Reserve.

BOUNDARIES AND TYPING			RECHARGE					Groundwater component of baseflow (Mm^3/a)	RESERVE			Allocatable (Mm^3/a)
Resource Unit		Aquifer Type	Total Area (km^2)	% Recharge	MAP (mm/a)	Recharge (Mm^3/a)	Total Recharge (Mm^3/a)		Baseflow Required by IFR (Mm^3/a)	BHN Reserve (Mm^3/a)	Reserve as % of Recharge	
1	(i)	BIF/Dolo	138	1.58	399	0.87	6.90	0	0	0.037	0.54	6.86
	(ii)	Dolomite	863	1.75		6.02						
2	-	Dolomite	624	0.69	399	1.72	1.72	0	0	0.005	0.29	1.72
3	(i)	BIF/Dolomite	254	2.08	371	1.96	10.95	0	0	0.091	0.83	10.86
	(ii)	Dolomite	1478	1.64		8.99						
TOTAL							*19.57*	*0*	*0*	*0.133*	*0.68*	*19.44*

Table 14. Present Status Category and Desired Management Class

Resource Unit	Present Status Category	Desired Management Class
RU 1	F	C
RU 2	B	B
RU 3	F	c

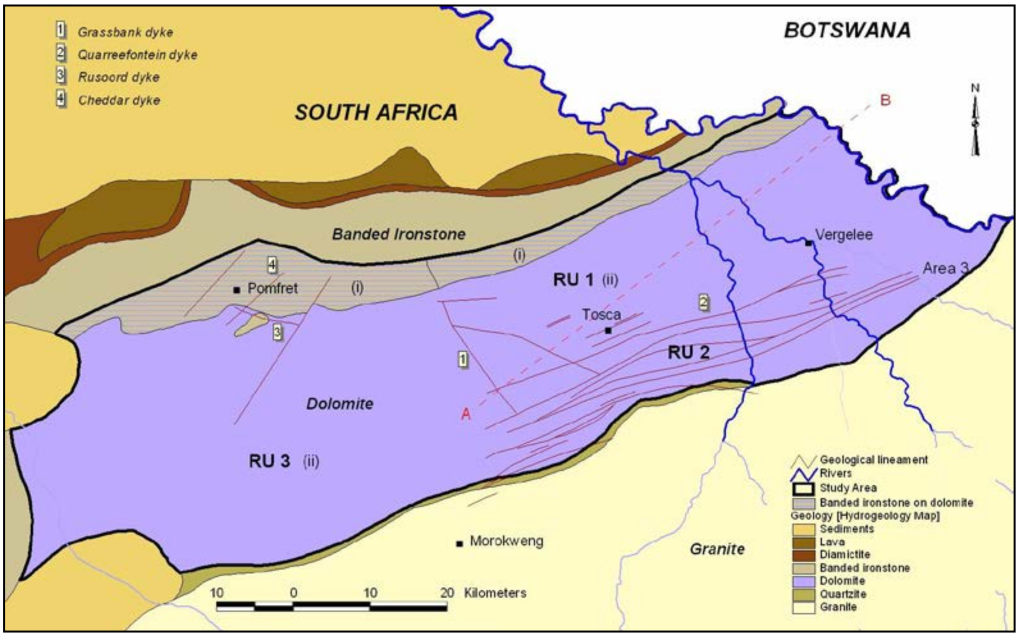
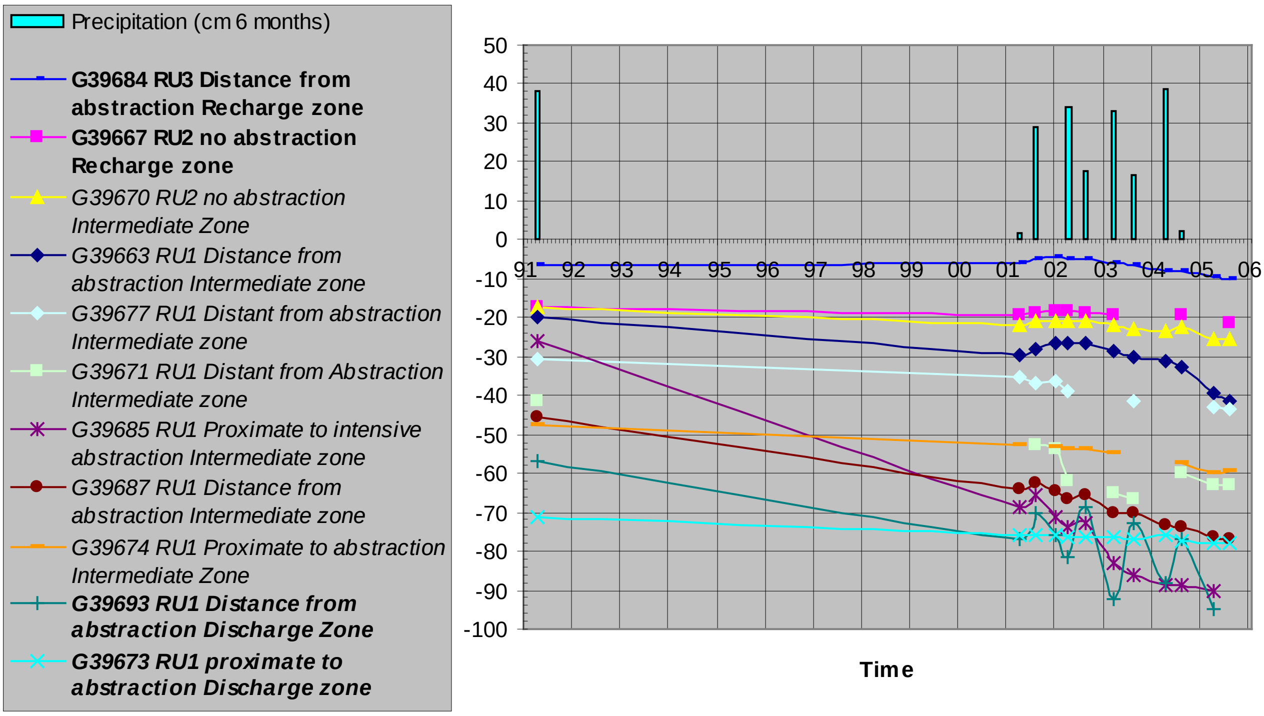


Figure 13. Molopo dolomite aquifer area.

The following recommendations from this reserve determination are listed and were pursued:

- The current over utilization of the aquifer must be stopped immediately, so as to ensure the long-term sustainability of the aquifer. This may be done by:
  - Removing all unauthorized groundwater users in the area (post 1998);
  - Reducing the current volumes of groundwater abstracted by authorized groundwater users through compulsory licensing; and
  - Removing unauthorized groundwater users as well as reducing volumes abstracted by authorized water users.
- The actual volumes of groundwater abstracted from the aquifer for use, on a monthly basis must be quantified. This may involve the installation of flow meters on all abstraction boreholes.
- Continuous water level monitoring within the dolomite aquifer is essential, to assess the response of the aquifer to the reduction of pumping. There are currently two boreholes installed, equipped with continuous water level loggers (since Oct/Nov 2001). The boreholes carefully selected in areas as described in table 15 with graphical presentation give a representative indication of water level movement.

Table 15. Representative boreholes across the aquifer to indicate water level movement.



- Due to the conservative approach adopted in estimating the available groundwater, recharge values must be refined to improve upon the level of confidence for future evaluations. A rainfall collector is apparently in place to obtain more accurate Cl values for rainfall, the results of which should be available in November 2002.
- A quantitative 2D model for the Molopo aquifer must be created, to use as a decision support tool, to manage the aquifer, and assess the response of the aquifer to the reduced abstraction volumes.
- Continuation of the groundwater quality-monitoring programme for the Molopo dolomite aquifer at strategic boreholes within the area.

6. GROUNDWATER FLOW MODELLING (GM)

A model is defined as a tool designed to represent a simplified version of reality (Wang and Anderson, 1982). From the hydro census, geophysical investigations, drilling records, geology, aquifer test, water level dynamics, groundwater chemistry, groundwater isotope character, recharge investigations and any other relevant observations the conceptual model was constructed. The aquifer boundaries and parameters are the numerical components of this conceptual model.

The aim of modeling groundwater flow is to predict the aquifer piezometry under various groundwater stress situations. The rapid and drastic piezometric level variations made GM a suitable tool to explain observed variations. Prediction of future variations would be extremely valuable.

6.1. Conceptual model

The area to be modeled is approximately 80 km by 50 km as depicted in Figure 15. The 2D dimensional features from this geological map were extended into the 3 rd dimension through the sections depicted by Figure 14 (positions of these sections are visible in Figure 4).

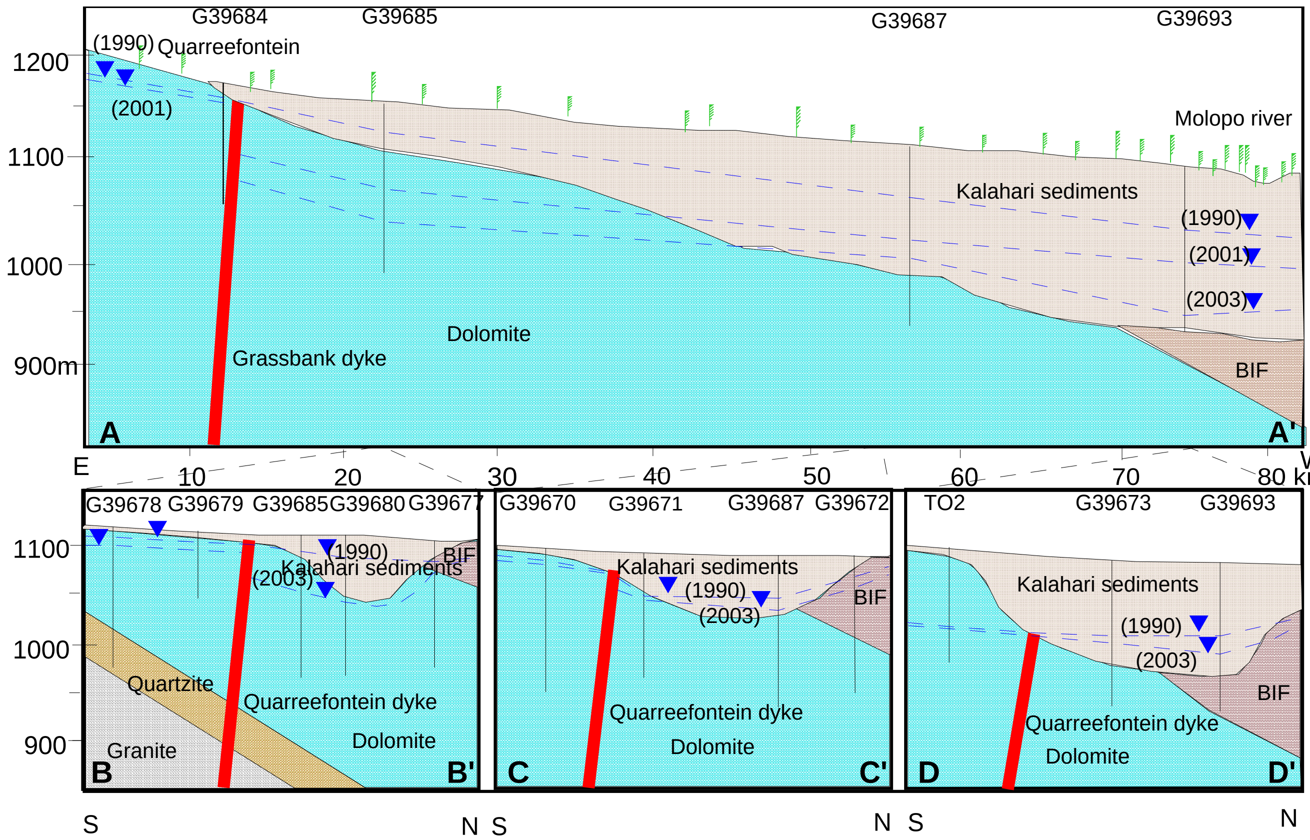


Figure 14. Conceptual model of the Tosca Molopo aquifer indicating the major boundaries, aquifer units and historic water levels.

The aquifer consists of the sediments of the Kalahari Group and dolomites of the Ghaap Plato formation. The spatial dimensions are approximated in the conceptual model. The basin of sediment deposition deepens and is also broader closer to the Molopo River. The general flow is from the SW to the NE at the Molopo River. From the observed water level reaction the sediments contribute largely towards the storage of the aquifer system with the fractures of the dolomite contributing to high yielding flow.

6.2. Model design and discretisation

The MODFLOW PMWIN (Chiang 2000) software was used to construct a flow model. A large-scale model covering 80 km east west and 50 km north south or 4000 km^2 was constructed. The area was divided into cells of 0.5 X 0.5 km generating 100 rows and 160 columns. Based on the conceptual model provision was made for 2 layers namely the unconsolidated primary aquifer and the underlying fractured dolomite with its aquifer characteristics.

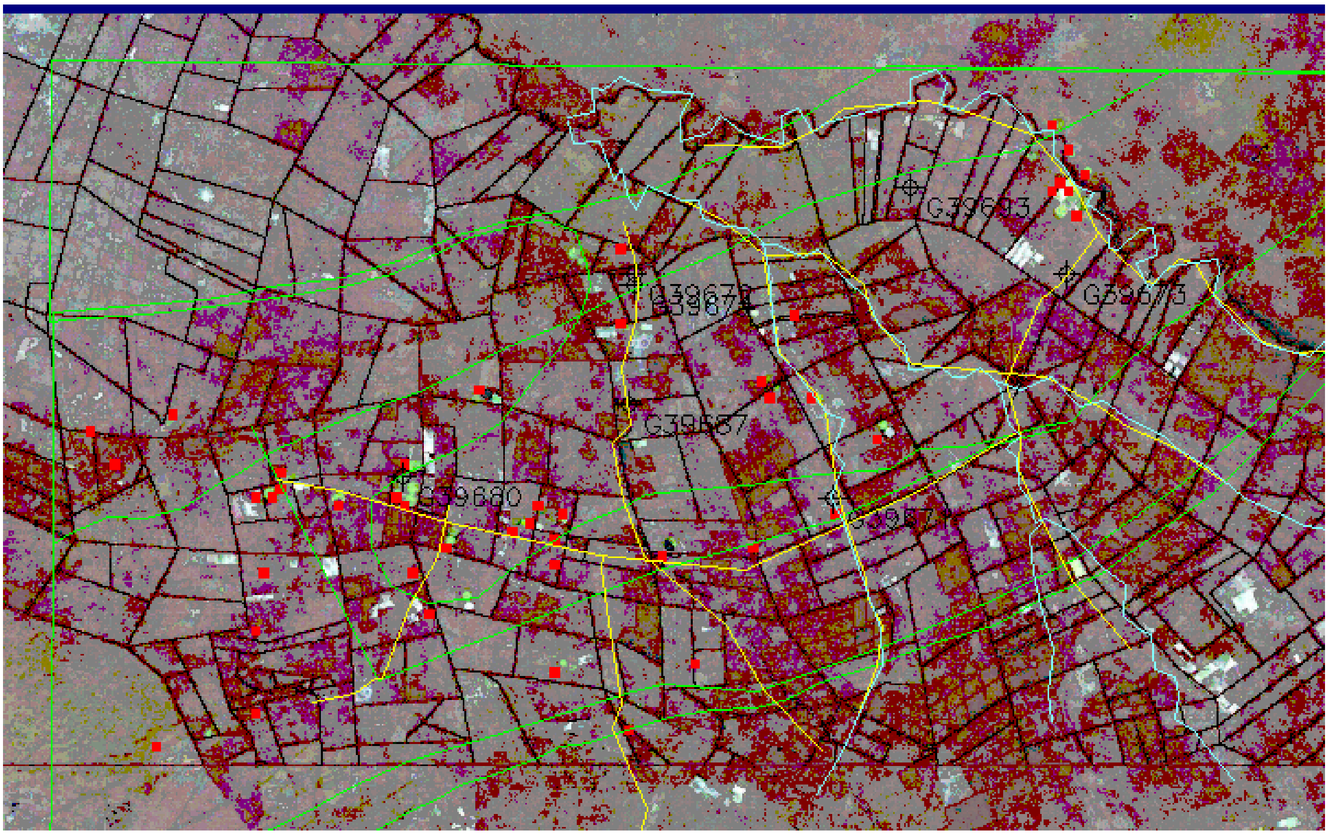


Figure 15. Arial extend of the Tosca Molopo groundwater model with abstraction cells (red) (50X80 km)

Borehole information from approximately 40 boreholes and the Kalahari formation isopagh map as produced by P Smit on the 1:250 000 geological map Bray was used to determine layer thickness. The first layer (primary aquifer of sediments) start at an elevation of 1160 mamsl. This layer is between 1 and 10 m thick in the southwest. It thickens to the northeast where the thickness exceeds 120 m from an elevation of 1080 mamsl to an elevation of 960 mamsl. The 2 nd layer (dolomite layer) lies directly beneath the first layer from an elevation of approximately 1159 to 900 mamsl in the southwest. To the northeast this layer wedge out to be present at an elevation of 1080 to 900 mamsl.

6.3. Aquifer boundaries

Of the number of dolerite dykes intruded into the dolomite the Grassbank and Quarriefontein dykes are the most influential on the groundwater flow. Plate 2 indicate and explain the boundary.

The Grassbank dyke form a boundary in the west. The Grassbank dyke was interpreted to dip slightly to the west with a thickness of 15 m. This dykes act as no-flow boundary of the Neumann (impervious) type impeding flow from the west of the area.

The Quarreefontein dyke form a boundary in the south. The Quarriefontein dyke is also interpreted as 15 m thick with a slight dip to the south. This dykes act as no-flow boundary of the Neumann (impervious) type impeding flow from the south of the area. Towards the east (Figure 10 Section D-D') the Quarreefontein dyke does not seem to be a no-flow boundary as the water level information indicate connection with the dolomite to the south (see section 6.4).

The surface and groundwater shed formed by the Banded Iron Formation of the Waterberge forms the boundary to the west. The combination of both a geological contact and watershed is a leaking boundary.

The Molopo River forms the eastern boundary. This boundary collect water from this Tosca Molopo aquifer as well as water from the aquifers east in Botswana.

The total area of the model extent well beyond these boundaries. The cells on the western, northern and eastern rim of the model was set as fixed head cells in which initial heads will be kept constant. All other cells were set as specific flux cells where the hydrolic head would be calculated at Neumann conditions.

Plate 2. A spring on the farm Nokani where groundwater well out in reaction to the barrier created by the Quarreefontein dyke. On the other side groundwater levels are deeper than 10 m below surface and further north they decline to 85 m below surface.

6.4. Geophysical investigation to confirm dolerite dykes

The positions of the dolerite dykes and their presence were deducted from aerial photos and the 1:250 000 geological map. To confirm the positions of these dykes the magnetic and electromagnetic geophysical method was used at investigate and select positions over the dykes on the farms Millbank, Quarrefontein, Ascot and Buxton. The magnetic profiles from line 2 (Millbank), line 3 and 4 (Quarreefontein), line 5 (Ascot) and line 6 (Buxton) are included in Appendix 3. As these lines indicate prominent magnetic anomalies is dyke material could be present. The similar anomalies over the strike of these dykes can be expected and it can be concluded that both dykes are present. The position of these dykes varied negligibly from their interpreted positions from the maps.

6.5. Drilling of boreholes to confirm water level elevation difference.

To confirm that these dykes form compartment/resource boundaries the boreholes listed in Table 16 and mapped on figure 4 were drilled to observe water level differences over these dykes. The boreholes were sited on the geophysical investigations reported in section 6.4.

Table 16. Borehole information of drilled boreholes (Oct 2003 to March 2004) to confirm aquifer boundaries.

Bore hole	Farm	Lat	Long	Elevation (mamsl)	Depth (m)	Water interception (m)	Yield (l/s)	Ec (mS/m)	Water level (m)	Hydrolic Head (mamsl)	Casing (m)	Comment
G47604	Ascot	-25.8743	23.9625	1115	102	54	2.65	336	50.70	1064	6	In town, water provision, No geophysical siting
G47605	Ascot	-25.8918	23.9616	1120	102	43, 76	0.2, 0.3	160	34.72	1085	6	North of Dyke 5 m difference over dyke, Line 5
G47606	Ascot	-25.8997	23.9625	1120	150	81	1.48	102	29.26	1091	7	South of Dyke 5 m difference over dyke, Line 5
G47607	Quarrefontein	-25.9138	23.8418	1133	150	123	0.10	61	8.37	1125	30	Farm water provision, No Geophysical siting
G47608	Quarrefontein	-25.9438	23.8238	1150	50	7	0.88	110	3.99	1146	6	West of Dyke, Line 3
G47609	Quarrefontein	-25.9429	23.8249	1145	102	7	0.10	92	8.86	1136	7	East of Dyke, line 3
G47610	Marlborough	-25.8140	23.7900	1140	150	121, 131	1.6, 2.6	64		1140	37	Water provision
G47611	Millbank	-25.8686	23.7737	1145	102	0	dry		41.37	1104	6	West of Dyke, Line 2
G47612	Millbank	-25.8695	23.7730	1145	150	47	0.10	60	55.45	1090	6	East of Dyke, line 2
G47613	Buxton	-25.8089	24.2116	1082	150	67	0.10	81	54.31	1028	18	South of Dyke, Line 6
G47614	Buxton	-25.8077	24.2113	1079	150	53, 72	0.50	79	52.50	1027	15	North of Dyke, Line 6
G47615	Forres	-25.9250	23.8961	1135	132	102, 121, 128	0.2, 2.5, 2.8		77.38	1058	3	Water provision, no geophysical siting
Totals					**1490**						**147**	

On the farm Ascot between G47606 South and G47605 North there is a 6 m water level elevation difference (drop) over the Quarreefontein dyke. On the farm Buxton between G47613 South and G47614 North there is less than 1 m groundwater elevation difference (drop) over the Quarreefontein dyke. In this area impeded water movement over the boundary seem to take place. There is a 10 m groundwater elevation difference (drop) over the Grassbank dyke between G47608 west and G47609 east on the farm Quarreefontein. Between G47611 and G47612 over the Grassbank dyke there is a 14 m groundwater level elevation difference (drop).

The groundwater elevation differences over these boundaries are significant and compartments as interpreted valid. With major water level declines (up to 60 m) within these resource units/ compartments even larger differences were expected. It can therefore not be excluded that there is still minor movement over these boundaries.

6.6. Aquifer parameters

To determine the aquifer parameters aquifer tests were conducted on 4 selected boreholes during October 2001. These boreholes were drilled during 1991. (Duvenhage, 1992). Two additional aquifer test were done by an irrigator and this information was also used.

Aquifer tests provide information regarding the flow within the aquifer. The aquifer test analyses are included as Appendix 2. The results of these analyses are tabled in table 17. The location of these boreholes is visible in Appendix 12.

The aquifer test data was analyzed with the Flow Characteristic (FC) (van Tonder and Xu, 1999) software programme. The FC method use derivatives of the Cooper Jacob equation with respect to log (t) to estimate values for the transmissivity (T), and storativity (S) of an aquifer.

Table 17. Calculated transmissivity, storativity and yield values from controlled aquifer tests.

Bore hole	**Lat**	**Long**	**T-late [m²/d]**	**Est. S-late**	**Q (l/s/ 24h)**	**Water strike (m)**	**Remark**
G36669	25.882	24.113	6.30	0.002	**1.02**	36,45,55,57	Carstic dolomite Layer 2
G39684	25.949	23.826	109.59	0.002	**16.70**	34-40	Carstic dolomite Layer 2
G39691	25.877	24.019	41.02	0.002	4.00	110	Carstic dolomite Layer 2
G39693	25.674	24.144	37.92	0.005	13.00	96, 157	Primary aquifer Layer 1
TO1	25.954	23.754	1000	0.002	22.00		Carstic dolomite Layer 2
TO3	25.949	23.756	790	0.002	28.00		Carstic dolomite Layer 2

The following parameter values estimated from the aquifer tests were used as initial parameters for the calibration of the groundwater flow model:

- Transmissivity: As input for the primary Kalahari aquifer (layer 1) an initial value of 50 m^2/d was used as this aquifer is renowned for its low yields.
  As input for the flow model a 200 m^2/d was used as an initial value for the dolomite (layer 2) since a number of high yielding boreholes exist in the area.
- Storativity: The calculated value of 0.005 from borehole G39693 is used as initial storativity value for the primary Kalahari aquifer (layer 1).
- The calculated value of 0.002 for the fractured dolomite is in agreement with values calculated and used in other similar dolomite areas for layer 2 (Pering Mine, Moseki, 2001)
- Aquifer thickness: The 1st layer is 1 to 10 m thick in the west and it thickens to over 150 m in the east proximate to the Molopo river. The thickness was observed at a number of boreholes from where the thickness was interpolated. The thickness of the 2nd layer

(carstic and fractured aquifer) was observed in boreholes to be from shallow in the west to 150 m. Its thickness was set at an elevation of 900 mamls.

- The average porosity of the dolomite is assumed to be 0.03.

6.7. Model calibration-steady state

The model was run in its steady state and most of the assumptions proved valid with the exception of the transmissivity of the dolomite aquifer. The aquifer was subdivided in different zones based on the conceptual model and observations (isotope, recharge, hydrochemistry) and the calibration that followed produced a better fit for the scatter plot of calculated hydrolic heads against observed hydrolic heads (Figure 16).

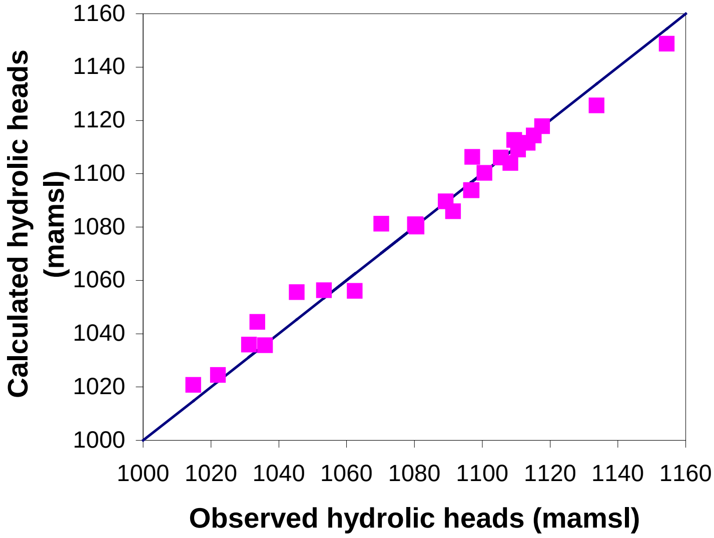


Figure 16. Observed versus simulated hydrolic data

The parameters are tabled in table 18 for the different zones of the aquifers in layer 1. These zones are spatially represented in Figure 17.

Table 18. Transmissivity and storativity in zones of layer 1.

Layer 1 Zone	**Identification color**	**Transmissivity (m^2/d)**	**Storativity [ ]**
Unconsolidated sediments	Yellow	17	0.005
Thick calcrete with minor sand cover	Dark Green	20	0.005
Clay and calcrete with minor gravel	Red	9	0.005
Calcrete along riverbeds	Light green	27	
Basal gravel	Brown	37	0.005
Zone associated with weathered dolerite	Light Brown	9	0.005

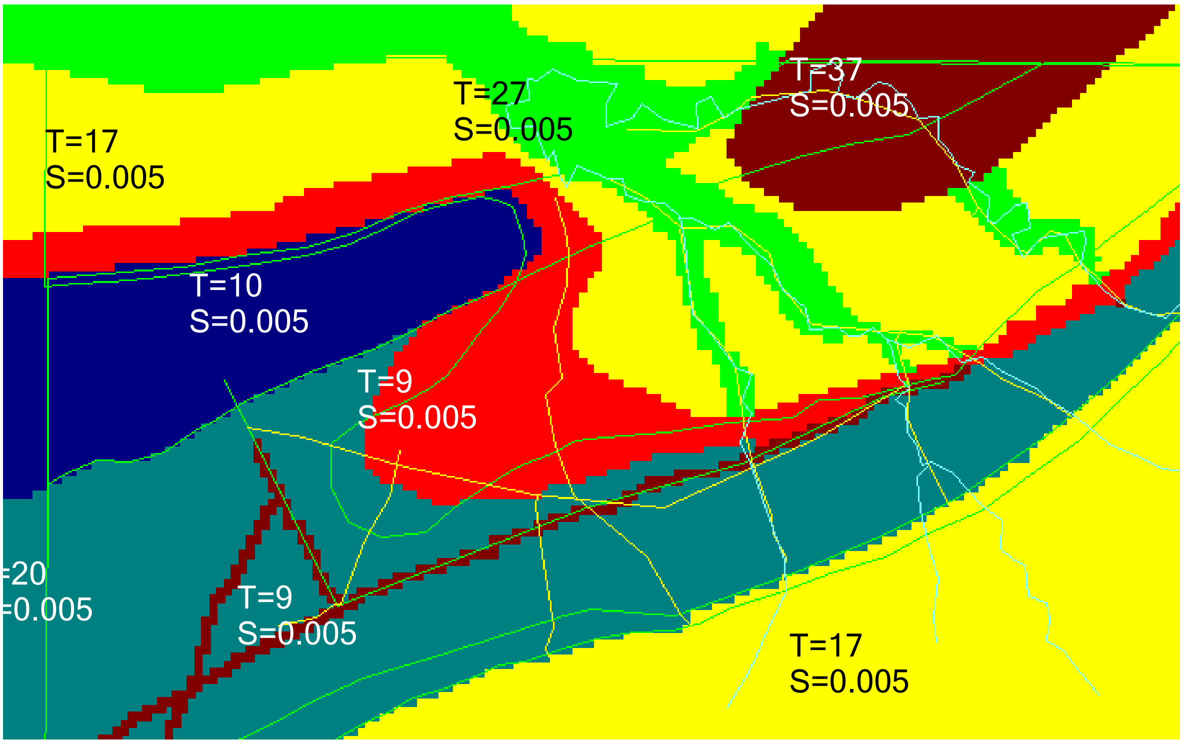


Figure 17. Spatial extend of transmissivity and storativity zones in layer 1.

The calibrated transmissivities of between 9 and 37 m^2/day are lower than the assumed value of 50 m^2/day. This is consistent with the conceptual understanding of the primary sandy layers. This layer is heterogeneous with fine sand and clay material that can reduce the tranmissivity.

The calibrated parameters are tabled for the different zones of the dolomite aquifers of layer 2 in table 19. The different zones are spatially represented in Figure 18.

Table 19. Transmissivity and storativity in zones of layer 2.

Layer 2 Zone	Identification color	Transmissivity (m^2/d)	Storativity [ ]
BIF	Green/ Brown	5	0.002
Dolomite with dolerite	Blue	25	0.002
Dolomite with chert	Light Green	30	0.002
Dolomite with chert, shale and fractured BIF	Grey	40	0.002
Dolomite with chert, shale and fractured BIF high yielding	Light Grey	60	0.002
Lava and diamictite	Purple	10	0.002
Dolerite	Brown	2	0.002

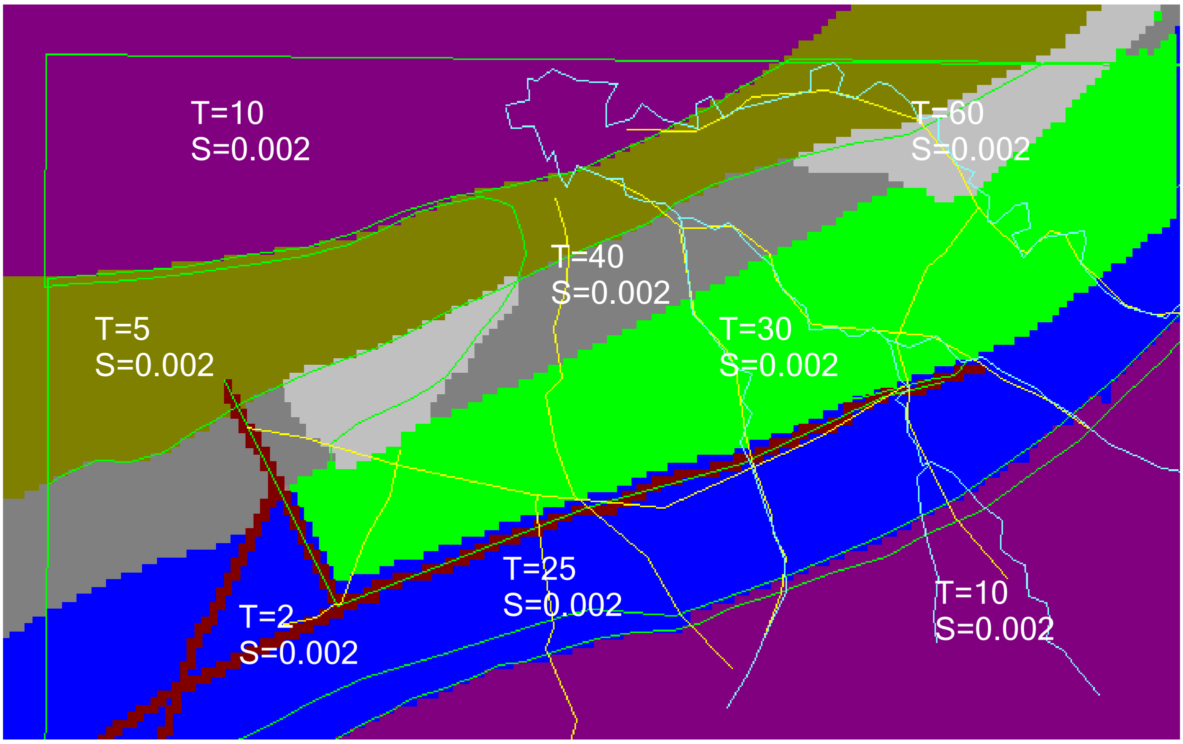


Figure 18. Spatial extend of tranmissivity and storativity in layer 2.

The zones in this dolomite layer are consistent with the sedimentary layers. The calibrated transmissivity values are significantly less than the assumed values deducted from the aquifer test results in table 17. In general the assumption is made that the extremely high transmissivity associated with production boreholes is the exception and that the total aquifer is less transmissive.

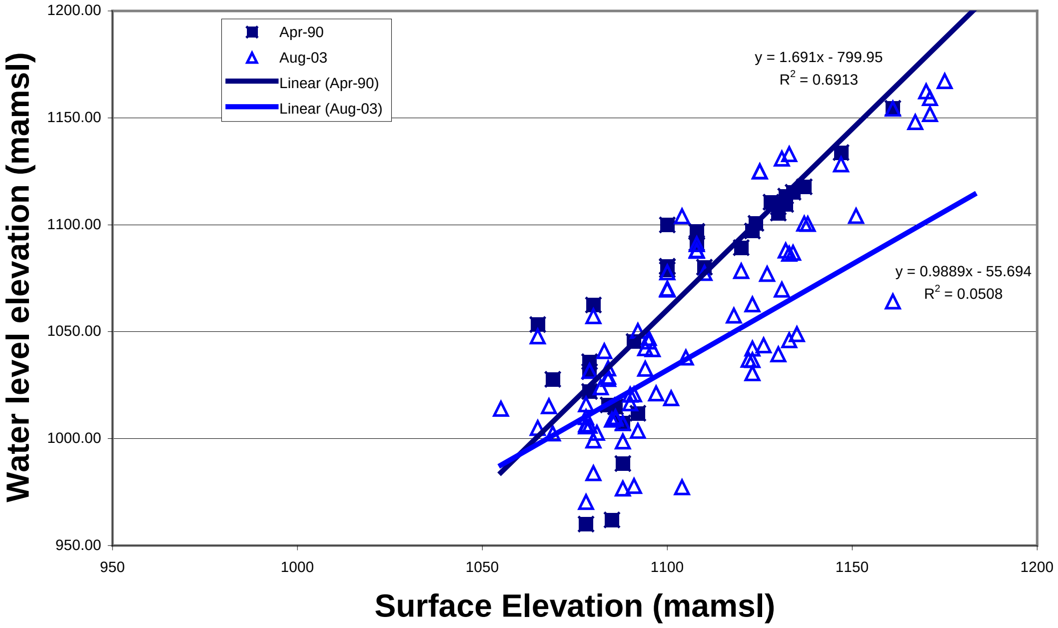
6.8. Hydrolic head interpolation

Two sets of water level data were available for the area. Smith (1977) collected water levels over a number of years, but the quality of the water levels is questioned by Duvenhage and Meyer (1991).

A hydro census reported by Duvenhage and Meyer (1991) was done in 1990 with 351 boreholes located. At 198 points water levels were measured and a further 28 borehole were drilled where water levels were available. At the time irrigation took place on the farms Thorntwaite and Blackheath. Although Duvenhage and Meyer reported water level declines on these properties the 1990 and pre 1977 water level elevation maps are similar in character (See figure 7). The 1990 water level data is therefore accepted as representing initial water levels. From this information the water levels were interpolated over the total area. Water levels collected by Appelcryn (1992 to 1993) were also used in the south and north.

The correlation between measured water levels from 1991 and the topography at R^2 =0.69 is poor due to water levels in the unconsolidated sediments. As abstraction over time increased there is no correlation with R^2=0.05 by Aug 2003. See Figure 19.

Figure 19. Groundwater versus surface elevation.



6.9. *Aquifer recharge*

The aquifer recharge as calculated by the chloride method was used for modeling purpose. Recharge zones as determined from this chloride analysis were used for the model. The recharge ranged from 0.25 mm (0.5%) average in winter and 6.6 mm (3%) average for summer, but different values were used depending on the precipitation at the time and the area.

The spatial distribution of these zones is indicated in Figure 20 with the corresponding volume of recharge per day to that zone calculated in table 20. Eventually the average recharge used was 1,75 % of MAP or 9.7 mm/a of MAP. With the deep water table and observed water level reaction a delay period of 6 months was estimated. Therefore the summer precipitation reaches the aquifer that winter and the winter precipitation the aquifer the next summer.

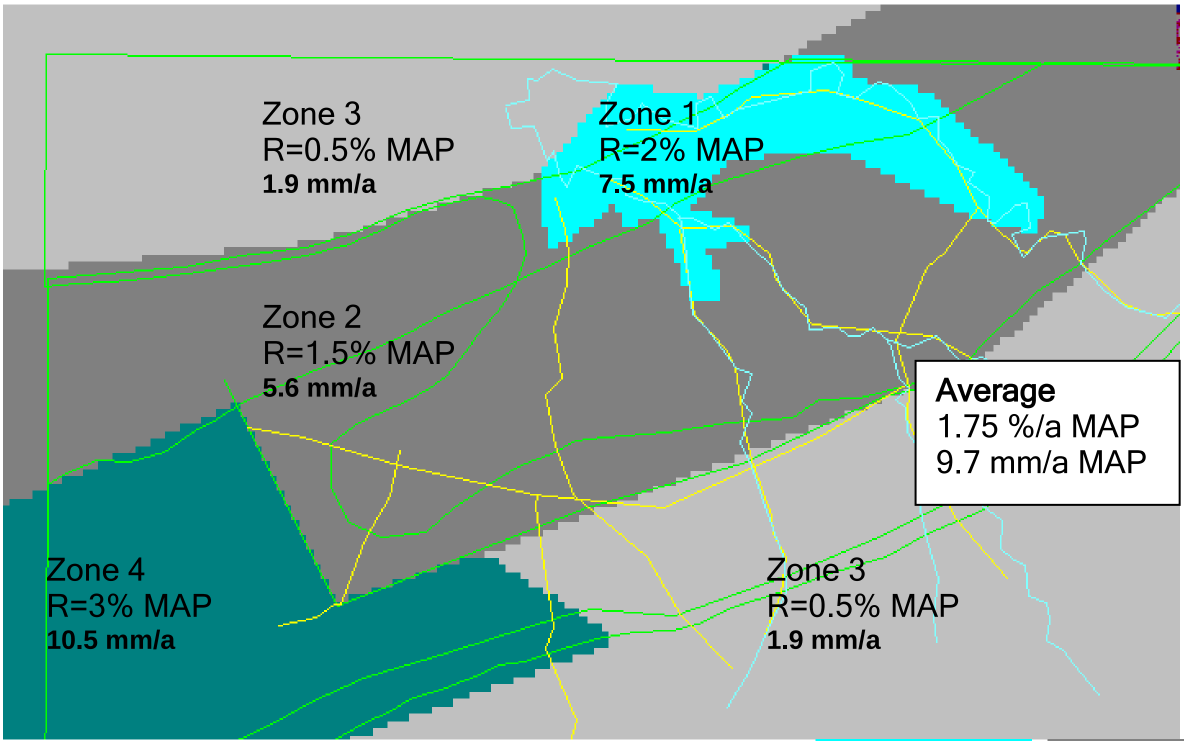


Figure 20. Recharge zones in the Tosca Molopo aquifer with Zone 1 light blue, Zone 2 dark grey, Zone 3 light grey and Zone 4 dark green.

Table 20. Recharge to the different zones as calculated from the summer and winter precipitation (182 days) in m³/day.

Year	Stress period	Precipitation @ Vergelegen for 6 months (mm)	Precipitation @ Pomfret for 6 months (mm)	Recharge Zone 1 @ 2% of Vergelegen (7.5 mm/a) (m^3/d)	Recharge Zone 2 @ 1.5% of Vergelegen (5.6 mm/a) (m^3/d)	Recharge Zone 3 @ 0.5% of Vergelegen (1.9 mm/a) (m^3/d)	Recharge Zone 4 @ 3% of Pomfret (10.5 mm/a) (m^3/d)	Average 1.75% of MAP 9.7 mm/a (m^3/d)
93/94 S	1	260.0	185.6	0.00003	0.00002	0.00001	0.00003	**0.00002**
94 W	2	1.0	3.4	0.00000	0.00000	0.00000	0.00000	**0.00000**
94/95 S	3	410.0	102.9	0.00004	0.00003	0.00001	0.00002	**0.00003**
95 W	4	14.0	27.0	0.00000	0.00000	0.00000	0.00000	**0.00000**
95/96 S	5	400.0	185.6	0.00004	0.00003	0.00001	0.00003	**0.00003**
96 W	6	104.0	136.4	0.00001	0.00001	0.00000	0.00002	**0.00001**
96/97 S	7	336.1	157.6	0.00004	0.00003	0.00001	0.00003	**0.00002**
97 W	8	34.5	94.2	0.00000	0.00000	0.00000	0.00002	**0.00001**
97/98 S	9	388.0	269.2	0.00004	0.00003	0.00001	0.00004	**0.00003**
98 W	10	16.0	34.2	0.00000	0.00000	0.00000	0.00001	**0.00000**
98/99 S	11	204.5	477.8	0.00002	0.00002	0.00001	0.00008	**0.00003**
99 W	12	0.0	15.6	0.00000	0.00000	0.00000	0.00000	**0.00000**
99/00 S	13	447.2	291.4	0.00005	0.00004	0.00001	0.00005	**0.00004**
00 W	14	61.5	59.0	0.00001	0.00001	0.00000	0.00001	**0.00001**
00/01 S	15	122.9	270.6	0.00001	0.00001	0.00000	0.00004	**0.00002**
01 W	16	166.0	177.0	0.00002	0.00001	0.00000	0.00003	**0.00002**
01/02 S	17	326.0	331.4	0.00004	0.00003	0.00001	0.00005	**0.00003**
02 W	18	86.0	167.6	0.00001	0.00001	0.00000	0.00003	**0.00001**
02/03 S	19	227.0	386.2	0.00002	0.00002	0.00001	0.00006	**0.00003**
03 W	20	21.5	21.5	0.00000	0.00000	0.00000	0.00000	**0.00000**
03/04 S	21	300.0	280.0	0.00003	0.00002	0.00001	0.00005	**0.00003**
Average		**373.9**	**349.9**	**0.00002**	**0.00002**	**0.00001**	**0.00003**	**0.00002**
Av W		**50.5**	**73.6**	**0.000006**	**0.000004**	**0.000001**	**0.000012**	**0.000006**
Av S		**316.2**	**275.3**	**0.000035**	**0.000026**	**0.000009**	**0.000045**	**0.000029**
20% W		40.36	58.872	0.000004	0.000003	0.000001	0.000010	0.000005
20% S		252.936	220.216	0.000028	0.000021	0.000007	0.000036	0.000023

6.10. *Abstraction from the aquifer*

No domestic and stock watering abstraction was considered. Irrigation abstraction was calculated from the registration areas, field observations and reports from users. Table 21 indicate the volumes abstracted by different users while figure 15 indicate the position of this abstraction positions as in summer 2003 when abstraction reached a peak. Through the registration of water use, which gave water users the opportunity to comply with the NWA water use volumes were obtained. These volumes were verified in the Tosca Molopo area and found that registered volumes were only reflecting 60 % of the actual volume abstracted. This was done through the field observations, water use verification and crop factor analysis.

Abstraction was divided into summer and winter abstraction for the different crops. The surface area and crop type combined with the crop use factor was used to calculate total need to cultivate that crop. This volume needed was then averaged over a six-month abstraction period (182.5 days) to obtain the daily abstraction from the aquifer. Abstraction was assumed to be from the total cell of 500X500m.

The growth period for different crops could not be accommodated. Paprika is wetted for up to 8 months; maize 4 to 5 month and potatoes could be as short as 3 months. All calculations were averaged over six months.

The accurate measuring of abstraction volumes for irrigation purposes in South Africa from groundwater resources is still a challenge to be met. In this area the estimations based on the above principles was the best option and the estimate abstraction volumes believed to be a accurate reflection.

Table 21. (Next page) Estimated water abstraction from the aquifer for each half-year m^3/day.

Name	Total use	60%	03_04	2003	03_02	2002	02_01	2001	01_00	2000	00_99	1999	99_98	1998	98_97	1997	97_96	1996	96_95	1995	91_90	1990
	m^3/a	m^3/a	sum	win	sum	win	sum	win	sum	win	sum	win	sum	win	sum	win	sum	win	sum	win	sum	win
J.C.C. Grobbelaar	69954	69954	383	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A.V.H. Maree	153870	122322	670	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Avon Trust	74112	74112	406	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Eben Du Toit	74112	74112	406	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Thornwick Boerdery	81954	79172	434	0	450	0	450	0	450	0	450	0	0	0	0	0	0	0	0	0	0	0
Tosca Trust	35382	35382	194	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H.M. Joubert	51900	51900	284	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
M. Theron	25710	25710	1315	0	1644	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fanie Griesel	65760	65760	360	0	1096	0	1096	0	110	0	110	0	0	0	0	0	0	0	0	0	0	0
C.E. le Roux	0	0	0	0	2466	0	2466	0	2466	0	2466	0	0	0	0	0	0	0	0	0	0	0
J.J. Hayward	95458	87275	478	0	2464	0	2464	0	2464	0	2464	0	0	0	0	0	0	0	0	0	0	0
J.H. Fourie	64543	64543	354	0	493	0	493	0	493	0	0	0	0	0	0	0	0	0	0	0	0	0
G I Rossouw	39902	39902	219	0	822	0	822	0	822	0	0	0	0	0	0	0	0	0	0	0	0	0
P J Haasbroek	45876	45876	1027	0	4110	0	4110	0	2055	0	0	0	0	0	0	0	0	0	0	0	0	0
W H Simmons	55063	55063	302	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
G H Stolz	66076	66076	362	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Emtron Bdy	367500	250500	1096	0	2014	0	2014	0	2014	0	2014	0	288	0	0	0	0	0	0	0	0	0
P.W. Beyer	240000	174000	2795	1233	4192	0	4192	0	4192	0	4192	0	0	0	0	0	0	0	0	0	0	0
Leniesdeel Trust	822500	523500	2532	0	4567	0	4507	0	4507	0	4507	0	3685	0	3685	0	3685	0	1096	0	0	0
J.H. Fourie	290000	204000	953	0	1589	0	1589	0	1589	0	1589	0	1589	0	1589	0	1589	0	794	0	0	0
D.B. Grobbelaar	482000	319200	1585	0	2642	0	2642	0	2642	0	2642	0	2642	0	2642	0	2642	0	2642	0	2642	0
Rosstol Trust	585000	381000	1973	1233	1973	1233	1973	1233	1973	1233	1973	1233	1973	1233	1973	0	1602	0	1602	0	0	0
Rosstol Trust	1725000	1065000	1726	4110	8219	1726	8219	1726	8219	1726	8219	1726	4576	1726	4576	1726	4726	0	4726	0	0	0
C.J. Caroll	2395000	1467000	7874	0	13123	0	13123	0	13123	0	13123	0	8767	0	8767	0	4762	0	4762	0	2853	0
W.C. Kriel	335950	231570	1104	0	1841	0	1841	0	1841	0	1841	0	1228	0	1228	0	920	0	920	0	0	0
Clearstream Trust	585000	381000	1923	0	3205	0	3205	0	3205	0	3205	0	3205	0	3205	0	1600	0	1600	0	0	0
Avon Trust	120000	102000	66	0	658	0	658	0	658	0	658	0	0	0	0	0	0	0	0	0	0	0
J.H. Nieuwoudt	145000	117000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F. Barnard	144000	116400	638	0	789	0	789	0	789	0	789	0	789	0	789	0	789	0	789	0	0	0
F.V.Z. Engelbrecht	440000	294000	1311	0	2411	0	2411	0	2411	0	2411	0	1311	0	1311	0	1311	0	1311	0	0	0
J.P. van den Berg	1035000	651000	3567	740	4932	740	4932	740	4932	740	4932	740	3781	0	3781	0	284	0	284	0	0	0
F. Barnard	487500	322500	1767	0	2671	0	2671	0	2671	0	2671	0	1254	0	1254	0	1254	0	1254	0	0	0
S.G. Griesel	18000	18000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Zenith Ranch (Pty. Ltd)	258300	184980	1014	0	0	0	0	0	0	0	0	0	0	0	4932	0	4932	0	4932	0	0	0
A.C.J. Du Plessis	79800	77880	427	0	427	0	427	0	427	0	427	0	427	0	427	0	0	0	0	0	0	0
A.M. Steyn	114000	98400	539	0	539	0	539	0	539	0	539	0	539	0	539	0	0	0	0	0	0	0
Pretorius	77097	76258	422	0	422	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
I de Beer	66150	66150	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
I de Beer	72386	72386	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
K. van der Heever	110121	96073	526	411	603	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hulp Alleen Familie	130500	108300	593	0	593	0	593	0	593	0	274	0	274	0	274	0	274	0	274	0	0	0
M. Hamman	35000	35000	192	0	192	0	192	0	192	0	192	0	192	0	0	0	0	0	0	0	0	0
W.H.A. Hamman	42500	42500	233	0	233	0	233	0	233	0	233	0	233	0	0	0	0	0	0	0	0	0
P.A. Theunissen	225000	165000	904	0	1233	0	1233	0	1233	0	0	0	0	0	0	0	0	0	0	0	0	0
F.J. Hamman	231700	169020	926	0	1270	0	1270	0	1270	0	926	0	926	0	926	0	926	0	926	0	0	0
Centwise BK	74406	74406	408	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
E.C. Grobbelaar	682200	439320	2012	0	3738	0	3738	0	3738	0	3738	0	2407	0	2407	0	1096	0	1096	0	0	0
P.E. Kriel	124250	104550	573	0	681	0	681	0	681	0	681	0	681	0	0	0	0	0	0	0	0	0
Sandtrap Boerdery	525000	345000	2877	0	2877	0	2877	0	2877	0	2877	0	2877	0	0	0	0	0	0	0	0	0
Botswana1	375000	255000	2055	0	2055	0	2055	0	2055	0	2055	0	2055	0	0	0	0	0	0	0	0	0
Botswana2	90000	84000	493	0	493	0	493	0	493	0	493	0	493	0	0	0	0	0	0	0	0	0
Botswana3	225000	165000	1233	0	1233	0	1233	0	1233	0	1233	0	1233	0	0	0	0	0	0	0	0	0
Total m3/day for season	14755532	8883319	53531	7726	84958	3699	82228	3699	79187	3699	73922	3699	47424	2959	44305	1726	32391	0	29007	0	5495	0
Total million m3 for year			11.18	16.91	16.18	15.68	15.68	15.13	15.13	14.17	14.17	9.33	9.19	8.63	8.40	6.23	5.91	5.29	5.29	1.00	1.00	

6.11. Initial Hydraulic heads

As discussed in data interpolation a representative dataset is available for 1990. Although the precipitation data reflect that from 1990 to 1994 below average precipitation prevailed and therefore recharge was limited, abstraction from the aquifer was also limited. These 1990 initial hydraulic heads are therefore assumed to be representative for 1994.

6.12. Stress periods and time steps

The model parameters (transmissivity, storitivity), recharge and abstraction were used as input for the model. The length of each time step is 6 months (182.5 days) and each time step is a stress period. The period from 1993/94 summer to winter 2003 is therefore represented by 20 stress periods of 6 months each. Stress periods 2,4,...,20 (even) represent winter (April to Sept) with stress periods 1,3,...,19 (uneven) representing summer (Oct to March).

6.13. Model calibration-transient state

The model was run and water levels were generated at the 28 observation boreholes. The observed water levels were compared with the generated values. Figure 21 indicate the correlation between selected observed and modeled water level values.

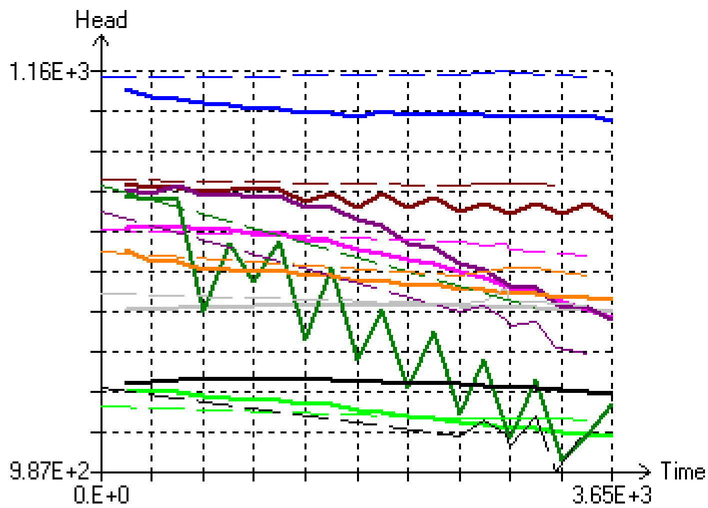
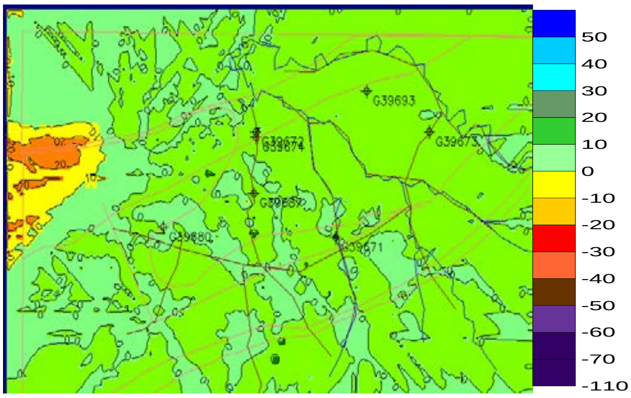


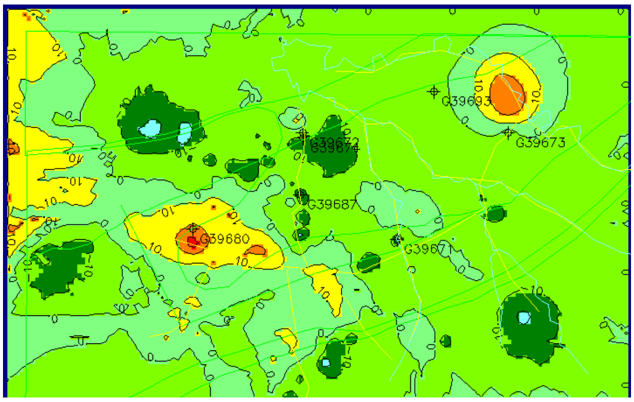
Figure 21. Correlation between observed (dotted line) and modeled water levels (solid lines) for the 20 stress periods representing winter 1994 (year 0-10) to winter 2004 (year 0). Water level elevation on vertical scale with the days on the horizontal scale.

G36667 redbrown, G36670 light grey, G36673 light green, G36677 pink, G36682 dark green, G36684 blue, G36693 black and G36694 orange.

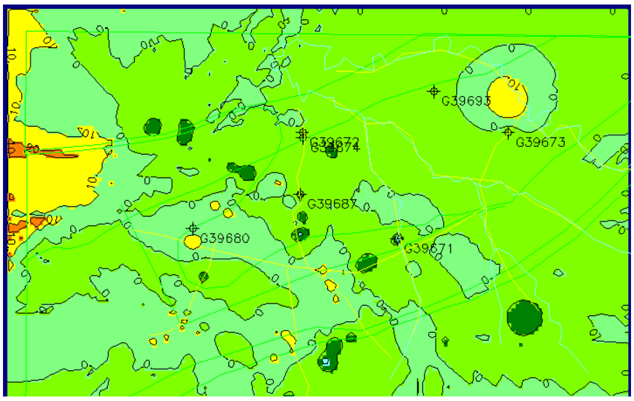
The model is under estimating water levels in the recharge zone by approximately 10 m. In the intermediate zone water level estimation is accurate within 1 to 5 m. In the discharge zone water levels are overestimated by approximately 10 m.



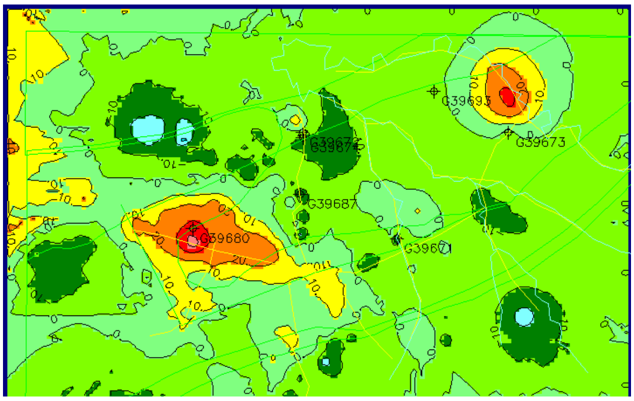
1. Stress periode 1 -93/94 summer (year 0-9.5)



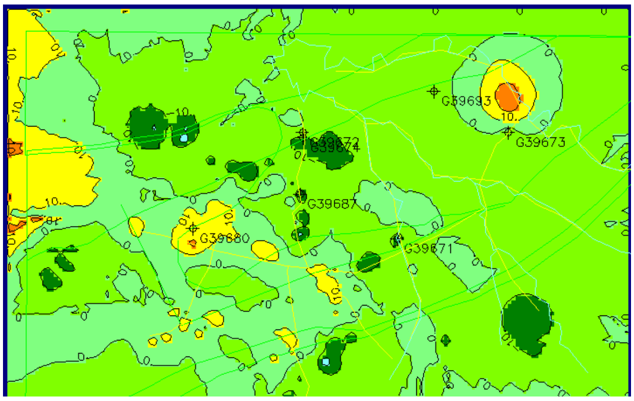
4. Stress periode 13 -99/00 summer (year 0-3.5)



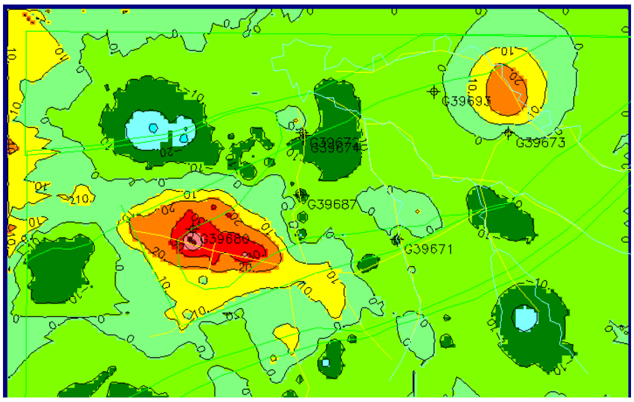
2. Stress periode 5 -95/96 summer (year 0-7.5)



5. Stress periode 17 -01/02 summer (year 0-1.5)



3. Stress periode 9 -97/98 summer (year 0-5.5)



6. Stress periode 19 -03/04 summer (year 0-0)

Figure 22. Selected draw down maps (meter below initial heads) results from transient state calibration of the model. The six 2 year periods pre-ceding the winter of 2004 were used.

The water level draw down maps from Figure 22 compare favorably with the observed water level draws down maps in Appendix 6. These maps were prepared with from observed measurements with Surfer contouring software package. The data extrapolation by the package distorts contours at the edges of these maps. The slight under estimation of draw down is also visible.

6.14. *Scenario predictions*

With the satisfactory calibrated model scenario predictions can be made to assist in making decisions towards the sustainable managing of the water resource. The following scenarios were tested:

6.14.1. Scenario 1 (High abstraction with average precipitation)

- Water abstraction was estimated to be as in Table 21 (column 4- 02/03) and the equivalent surface area irrigated is graphically represented in Figure 23.

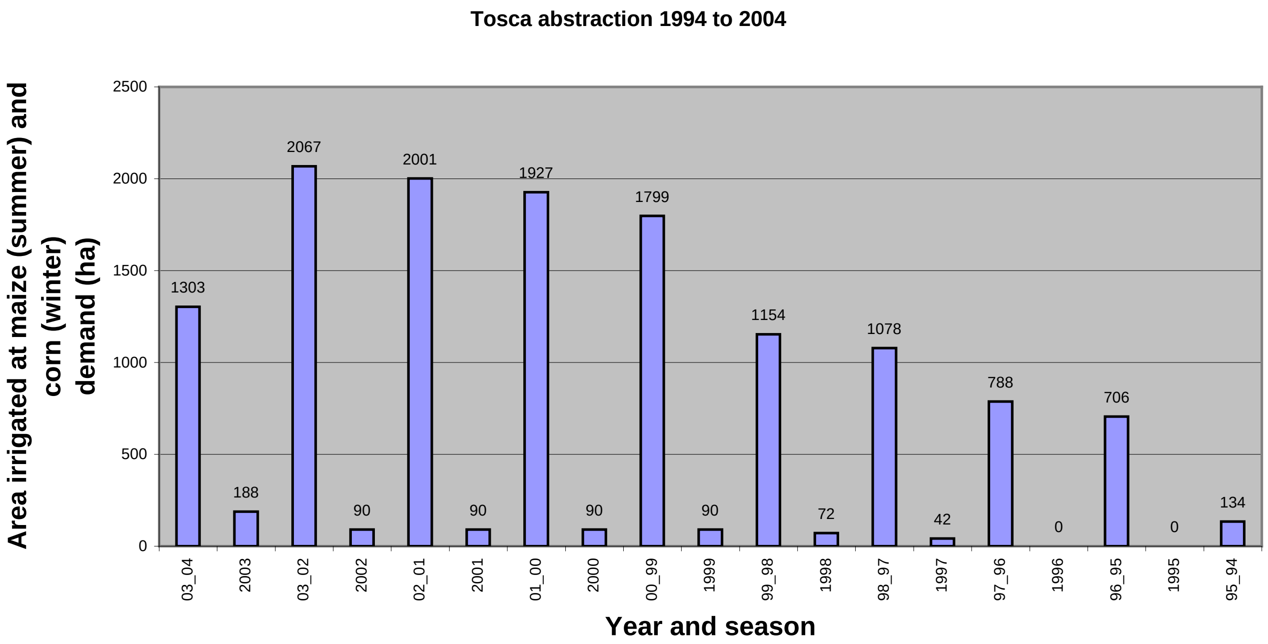


Figure 23. Estimated surface area irrigated for each half year in the Tosca Molopo aquifer.

- Abstraction from 2004 to 2014 is assumed to at 2002 winter en 2002_ 2003 summer volumes by each user bringing the total abstraction to ***16.1 M m^{3} annum*** water (highest volume ever to be abstracted)
- Precipitation is assumed to be the average as calculated from the rainfall measurements at 50.5 mm and 73.6 mm in winter and 316.2 and 275.3 mm in summer at Vergelegen and Pomfret respectively. The recharge was then calculated as assigned to the different zones ranging from 0.25 mm (lowest) to 8.3 mm (highest) as in table 20. The precipitation was then allocated to the different zones (figure 20) with a 6 months time lag as follow.

Year	Stress period	Precipitation @ Vergelegen for 6 months (mm)	Precipitation @ Pomfret for 6 months (mm)	Recharge Zone 1 @ 2% of Vergelegen (m/d)	Recharge Zone 2 @ 1.5% of Vergelegen (m/d)	Recharge Zone 3 @ 0.5% of Vergelegen (m/d)	Recharge Zone 4 @ 3% of Pomfret (m/d)	Average
Av W		**50.5**	**73.6**	**0.000006**	**0.000004**	**0.000001**	**0.000012**	**0.000006**
Av S		**316.2**	**275.3**	**0.000035**	**0.000026**	**0.000009**	**0.000045**	**0.000029**

This scenario was modeled and the piezometric heads from selected boreholes are graphically represented by figure 24 and the contoured water levels for selected stress periodes in figure 25.

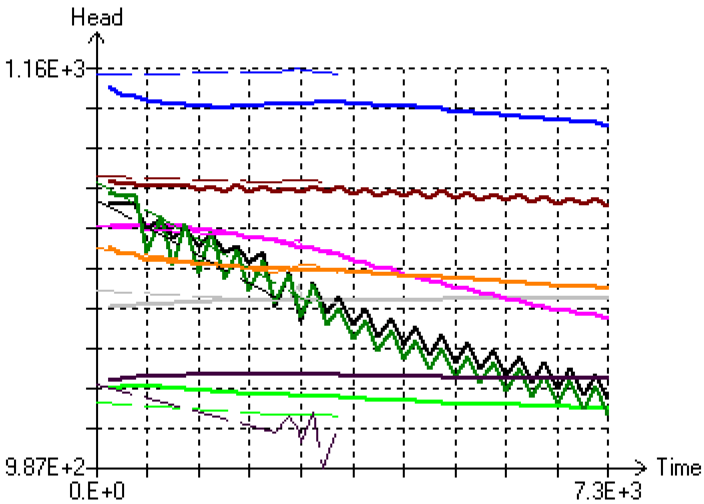


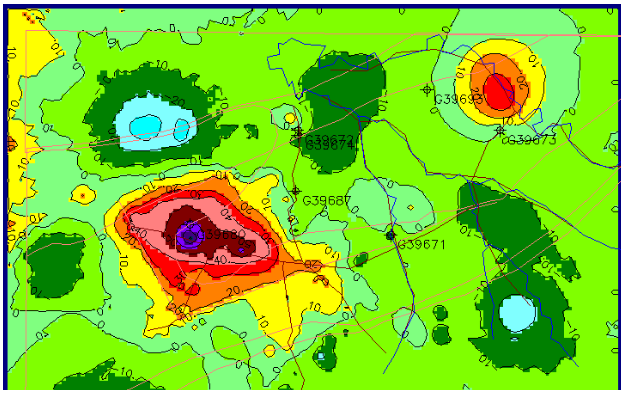
Figure 24. Correlation between observed (dotted line) and modeled water levels (solid lines) for the 40 stress periods representing 1994 to 2014 for Scenario 1 conditions. Water level elevation on vertical scale with the days on the horizontal scale.

Note: G36667 redbrown, G36670 light grey, G36673 light green, G36677 pink, G36682 dark green, G36684 blue, G36693 black and G36694 orange.

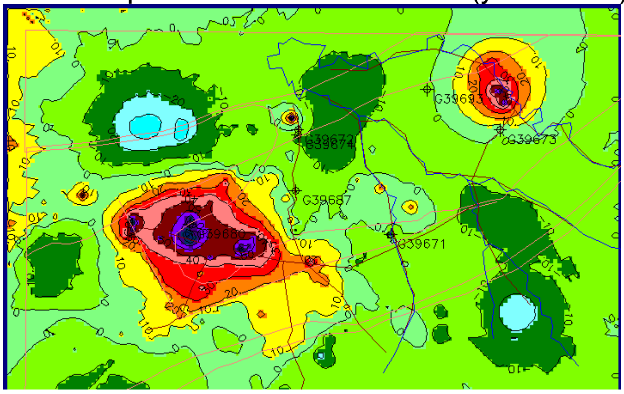
With this high abstraction average precipitation scenario water levels would proceed to decline.

Results: (Figures 24 and 25).

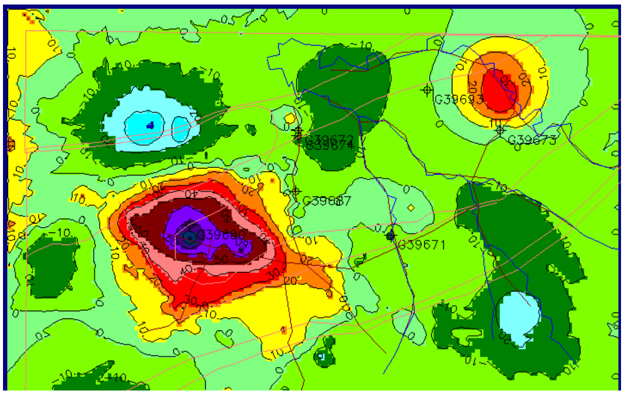
- Water levels in resource unit 1 would decline regionally with 20 to 30 m (i.r.t. 1990 water levels). The sink formed by this decline would spread over an area of 20 X 5 km and boreholes in this area are at risk to be de-watered.
- At Grassbank water levels would decline to 110m (i.r.t. 1990 water levels) and 60 m at Blackheath.



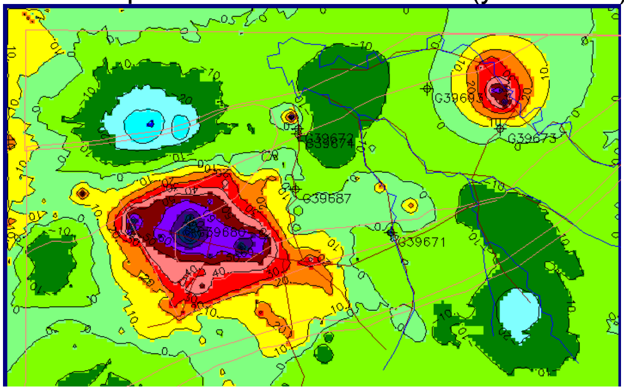
1. Stress periode 31 -08/09summer (year 0+5.5)



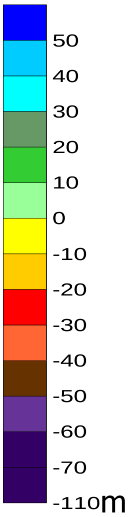
2. Stress periode 32 -2009 winter (year 0+6)



3. Stress periode 39 -12/13summer (year 0+9.5)



4. Stress periode 40 -2013winter (year 0+10)



Legend

Positive water level fluctuation indicating an increase in water levels i.r.t. initial (1991) water levels.

Zero water level fluctuation indicating an increase in water levels i.r.t. initial (1991) water levels.

Negative water level fluctuation indicating an increase in water levels i.r.t. initial (1991) water levels

Figure 25. Selected stress periode draw down (meter below initial heads) results from Scenario 3 of the model.

- In resource unit 2 water levels would decline by approximately 20 m (i.r.t. 1990 water levels) in the Forres area and stay constant through the rest of the area.
- In resource unit 3 water levels would decline by 10 to 20 m (i.r.t. 1990 water levels) proximate to the Grassbank dyke and would remain constant or decline less than 1 m over the rest of the area.

6.14.2. Scenario 2 (Restricted abstraction [–40%] with average precipitation)

- Water abstraction for the periode 93 to 2003 is as estimated in Table 21.
- Abstraction from 2004 to 2014 is assumed to be restricted with ***40%*** by each user (column 3- 60%) with the total abstraction at summed at ***11.1 M m^3/annum***.
- Precipitation is assumed to be the average as calculated from the rainfall measurements at 50.5 mm and 73.6 mm in winter and 316.2 and 275.3 mm in summer at Vergelegen and Pomfret respectively. The recharge was then calculated as assigned to the different zones ranging from 0.25 mm (lowest) to 8.3 mm (highest) as in table 20. The precipitation was then allocated to the different zones (figure 20) with a 6 months time lag as follow.

Year	Stress period	Precipitation @ Vergelegen for 6 months (mm)	Precipitation @ Pomfret for 6 months (mm)	Recharge Zone 1 @ 2% of Vergelegen (m/d)	Recharge Zone 2 @ 1.5% of Vergelegen (m/d)	Recharge Zone 3 @ 0.5% of Vergelegen (m/d)	Recharge Zone 4 @ 3% of Pomfret (m/d)	Average
Av W		**50.5**	**73.6**	**0.000006**	**0.000004**	**0.000001**	**0.000012**	**0.000006**
Av S		**316.2**	**275.3**	**0.000035**	**0.000026**	**0.000009**	**0.000045**	**0.000029**

This scenario was modeled and the piezometric heads from selected boreholes are graphically represented by figure 26 and the contoured water levels for selected stress periodes in figure 27. With this lower abstraction average precipitation scenario water levels would stabilize.

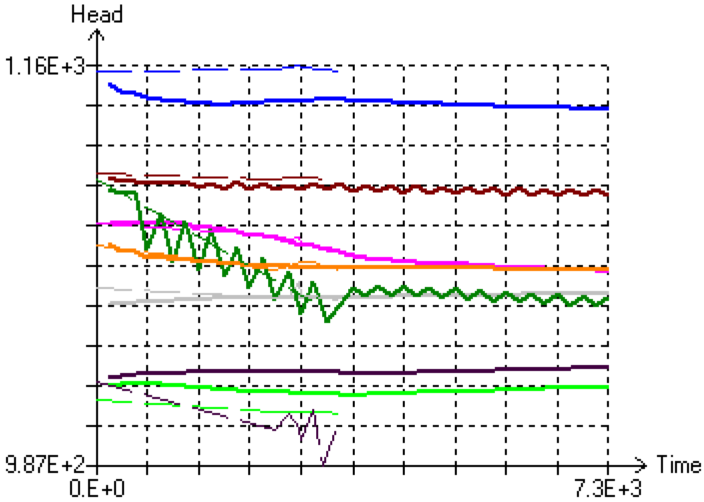
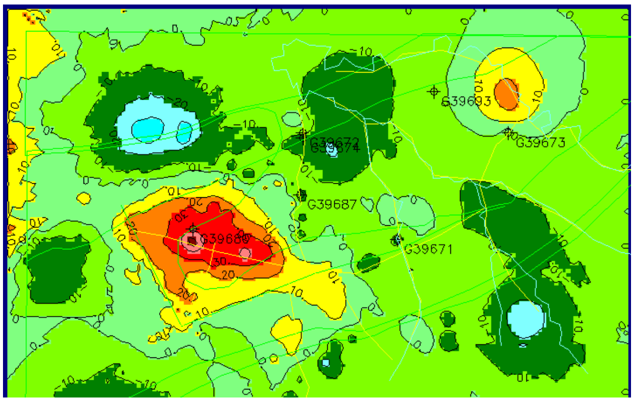
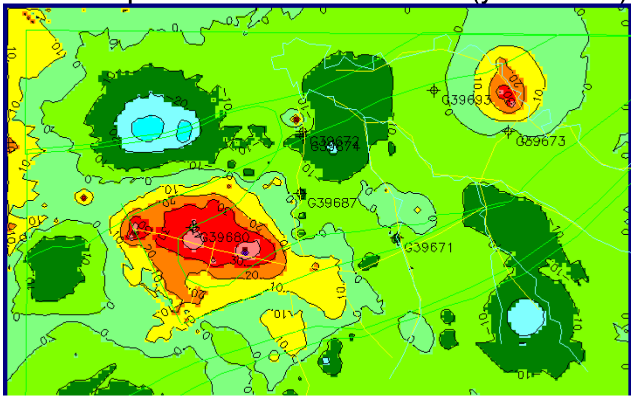


Figure 26. Correlation between observed (dotted line) and modeled water levels (solid lines) for the 40 stress periods representing 1994 to 2014 for Scenario 2 conditions. Water level elevation on vertical scale with the days on the horizontal scale.

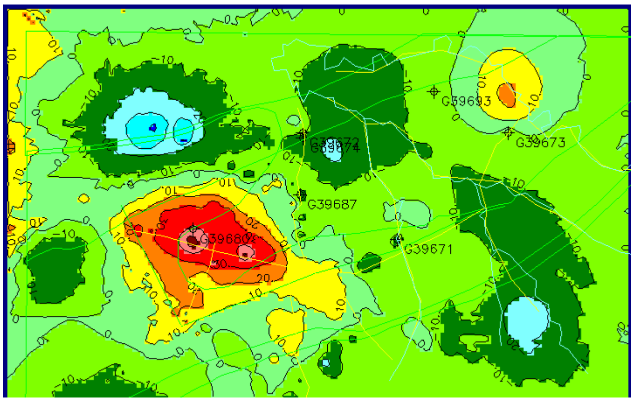
Note: G36667 redbrown, G36670 light grey, G36673 light green, G36677 pink, G36682 dark green, G36684 blue, G36693 black and G36694 orange.



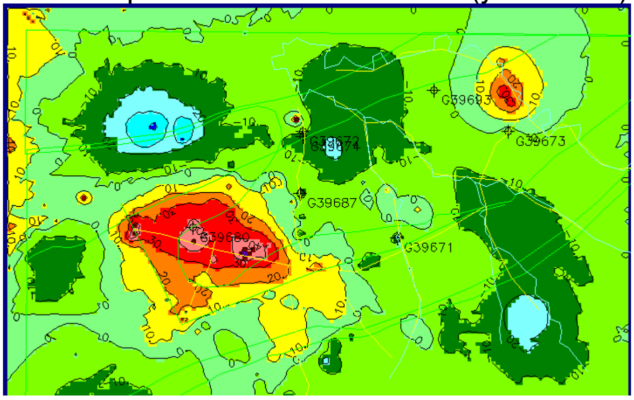
1. Stress periode 31 -08/09summer (year 0+5.5)



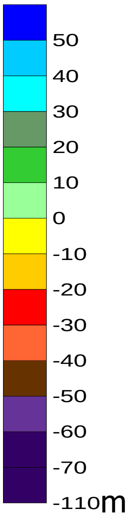
2. Stress periode 32 -2009 winter (year 0+6)



3. Stress periode 39 -12/13summer (year 0+9.5)



4. Stress periode 40 -2013winter (year 0+10)



Legend

Positive water level fluctuation indicating an increase in water levels i.r.t. initial (1991) water levels.

Zero water level fluctuation indicating an increase in water levels i.r.t. initial (1991) water levels.

Negative water level fluctuation indicating an increase in water levels i.r.t. initial (1991) water levels

Figure 27. Selected stress periode draw down (meter below initial heads) results from Scenario 2 of the model.

Results: (Figures 26 and 27).

- Water levels in resource unit 1 would decline regionally with 20 to 30 m (i.r.t. 1990 water levels).
- At Grassbank water levels would decline 60m (i.r.t. 1990 water levels) and 30 m at Blackheath.
- There would be a 10 m water level recovery compared to the water levels of 2004.
- There would be a 10 m water level recovery compared to the water levels of 2004.
- In resource unit 2 water levels would remain constant (i.r.t. 1990 water levels).
- In resource unit 3 water levels would remain constant (i.r.t. 1990 water levels).

6.14.3. Scenario 3 (Restricted abstraction [–40%] with below average [–20%] precipitation)

- Water abstraction for the periode 93 to 2003 is as estimated in Table 21.
- Abstraction from 2004 to 2014 is assumed to be restricted with ***40%*** by each user (column 3- 60%) with the total abstraction at summed at ***11.1 M m³/annum***.
- Precipitation is assumed to be the at ***20 % less*** than the average as calculated from the rainfall measurements at 50.5 mm and 73.6 mm in winter and 316.2 and 275.3 mm in summer at Vergelegen and Pomfret respectively as in Table 20. The recharge was then calculated as assigned to the different zones ranging from 0.2 mm (lowest) to 6.6 mm (highest) as in table 20. The precipitation was then allocated to the different zones (figure 20) with a 6 months time lag as follow.The precipitation was then allocated to the different zones with a 6 months time lag as follow.

Year	**Stress period**	**Precipitation @ Vergelegen for 6 months (mm)**	**Precipitation @ Pomfret for 6 months (mm)**	**Recharge Zone 1 @ 2% of Vergelegen (m/d)**	**Recharge Zone 2 @ 1.5% of Vergelegen (m/d)**	**Recharge Zone 3 @ 0.5% of Vergelegen (m/d)**	**Recharge Zone 4 @ 3% of Pomfret (m/d)**	**Average**
20% W		40.36	58.872	0.000004	0.000003	0.000001	0.000010	0.000005
20% S		252.936	220.216	0.000028	0.000021	0.000007	0.000036	0.000023

This scenario was modeled and the piezometric heads from selected boreholes are graphically represented by figure 28 and the contoured water levels for selected stress periodes in figure 29.

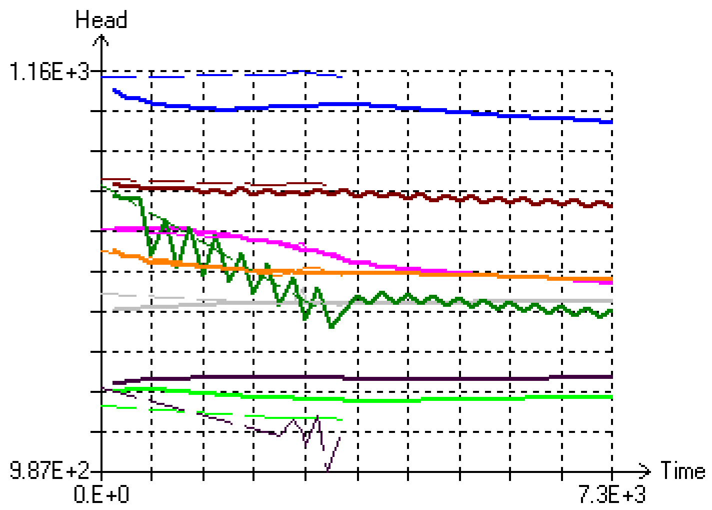
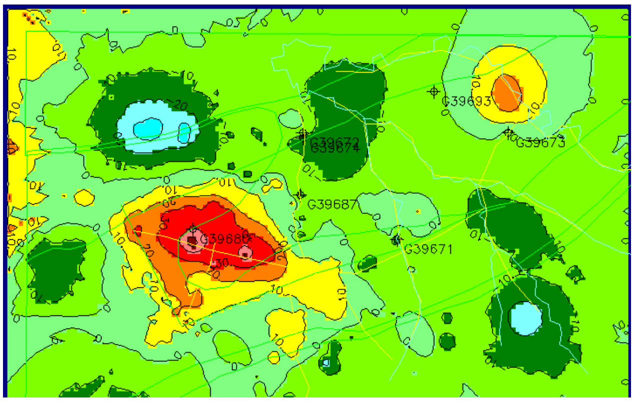
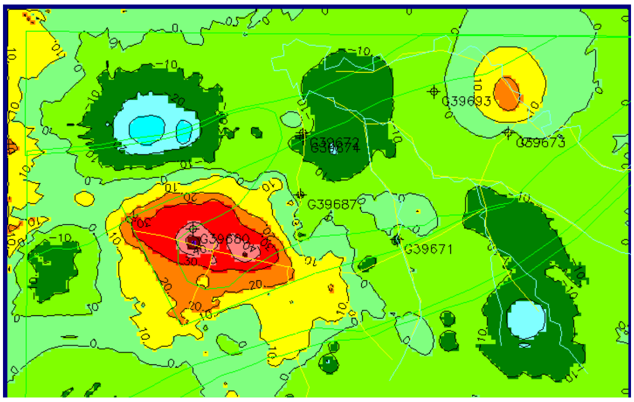


Figure 28. Correlation between observed (dotted line) and modeled water levels (solid lines) for the 40 stress periods representing 1994 to 2014 for Scenario 3 conditions. Water level elevation on vertical scale with the days on the horizontal scale.

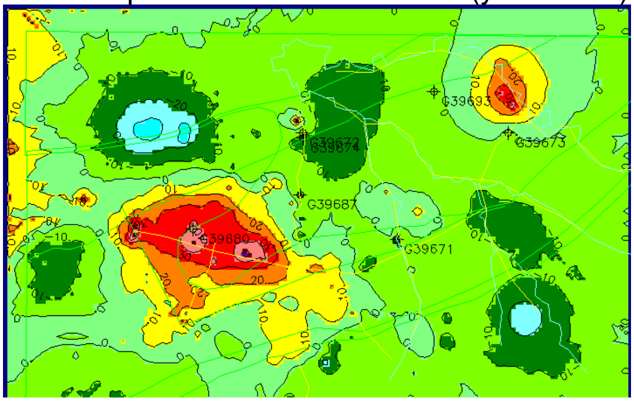
Note: G36667 redbrown, G36670 light grey, G36673 light green, G36677 pink, G36682 dark green, G36684 blue, G36693 black and G36694 orange.



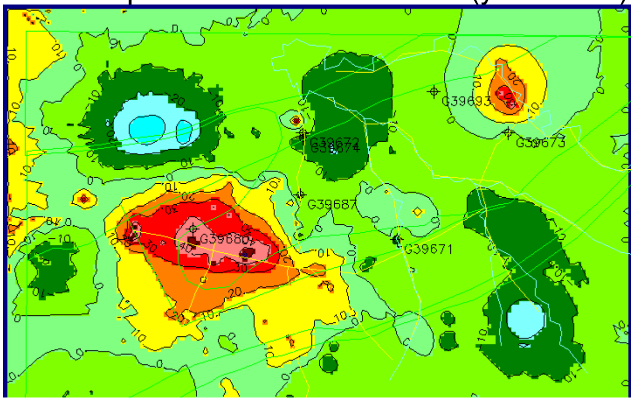
1. Stress periode 31 -08/09summer (year 0+5.5)



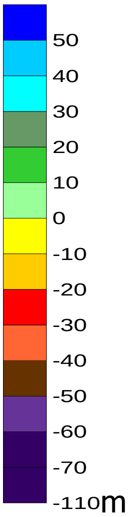
3. Stress periode 39 -12/13summer (year 0+9.5)



2. Stress periode 32 -2009 winter (year 0+6)



4. Stress periode 40 -2013winter (year 0+10)



Legend

Positive water level fluctuation indicating an increase in water levels i.r.t. initial (1991) water levels.

Zero water level fluctuation indicating an increase in water levels i.r.t. initial (1991) water levels.

Negative water level fluctuation indicating an increase in water levels i.r.t. initial (1991) water levels

Figure 29. Selected stress periode draw down (meter below initial heads) results from Scenario 3 of the model.

Results: (Figures 28 and 29)

- Water levels in resource unit 1 would decline regionally with 10 to 20 m (i.r.t. 1990 water levels).
- At Grassbank water levels would decline 40 to 50m (i.r.t. 1990 water levels) and 30 m at Blackheath.
- There would be a 10 m water level recovery compared to the water levels of 2004.
- In resource unit 2 water levels would remain constant (i.r.t. 1990 water levels).

In resource unit 3 water levels would remain constant (i.r.t. 1990 water levels).

6.14.4. Scenario 4 (No abstraction with average precipitation)

- Water abstraction for the periode 93 to 2003 is as estimated in Table 21.
- Abstraction from 2004 to 2014 is assumed to have stopped or ***0 M m^3/annum***.
- Precipitation is assumed to be the average as calculated from the rainfall measurements at 50.5 mm and 73.6 mm in winter and 316.2 and 275.3 mm in summer at Vergelegen and Pomfret respectively. The recharge was then calculated as assigned to the different zones ranging from 0.25 mm (lowest) to 8.3 mm (highest) as in table 20. The precipitation was then allocated to the different zones (figure 20) with a 6 months time lag as follow.

Year	Stress period	Precipitation @ Vergelegen for 6 months (mm)	Precipitation @ Pomfret for 6 months (mm)	Recharge Zone 1 @ 2% of Vergelegen (m/d)	Recharge Zone 2 @ 1.5% of Vergelegen (m/d)	Recharge Zone 3 @ 0.5% of Vergelegen (m/d)	Recharge Zone 4 @ 3% of Pomfret (m/d)	Average
Av W		**50.5**	**73.6**	**0.000006**	**0.000004**	**0.000001**	**0.000012**	**0.000006**
Av S		**316.2**	**275.3**	**0.000035**	**0.000026**	**0.000009**	**0.000045**	**0.000029**

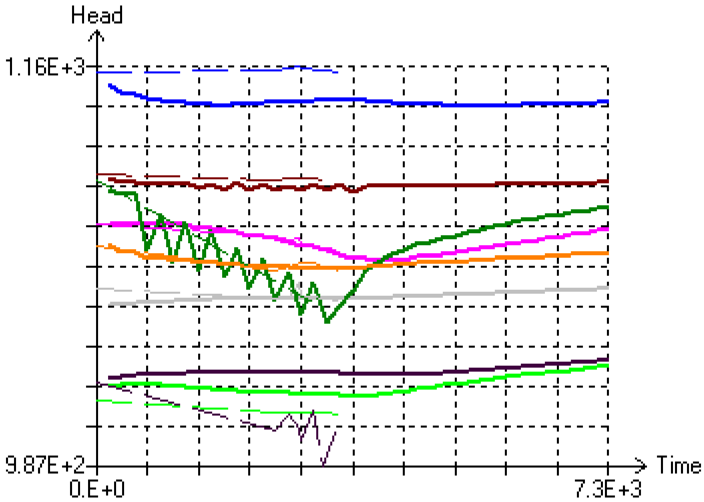
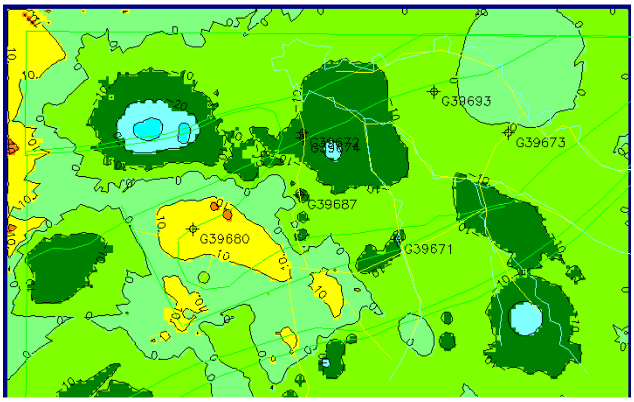


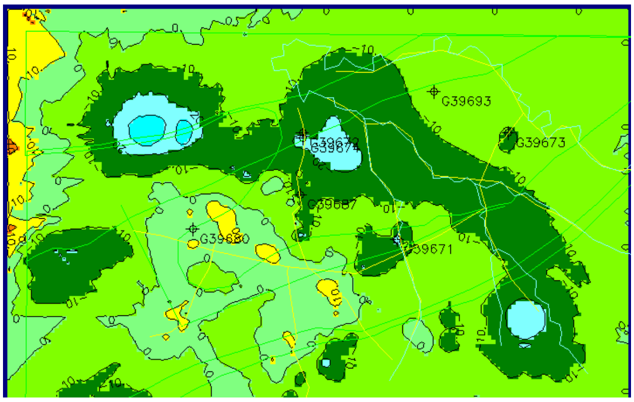
Figure 30. Correlation between observed (dotted line) and modeled water levels (solid lines) for the 40 stress periods representing 1994 to 2014 for Scenario 4 conditions. Water level elevation on vertical scale with the days on the horizontal scale.

Note: G36667 redbrown, G36670 light grey, G36673 light green, G36677 pink, G36682 dark green, G36684 blue, G36693 black and G36694 orange.

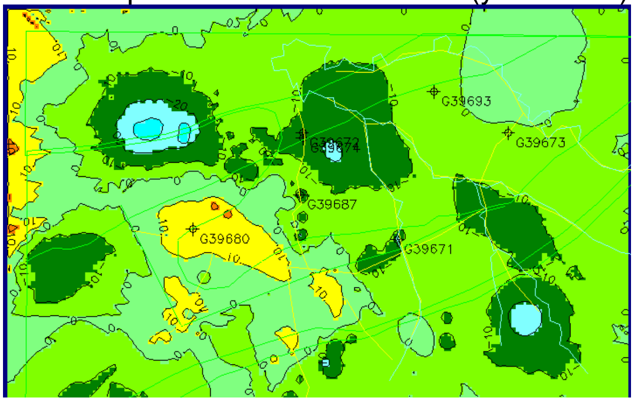
With this no abstraction and average precipitation scenario water levels would recover to their original levels (1990).



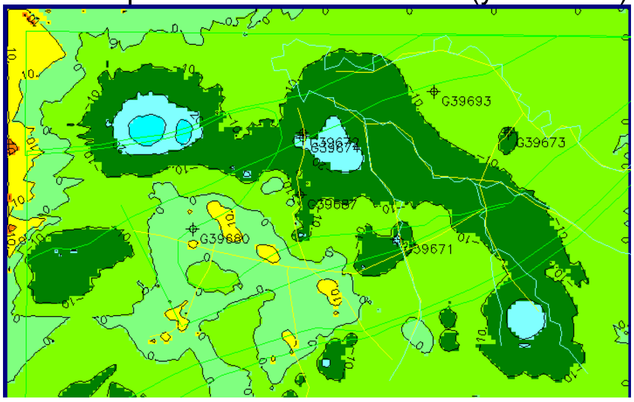
1. Stress periode 31 -08/09summer (year 0+5.5)



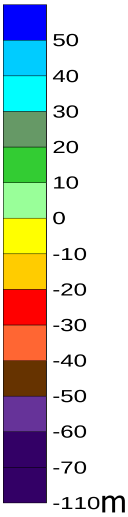
3. Stress periode 39 -12/13summer (year 0+9.5)



2. Stress periode 32 -2009 winter (year 0+6)



4. Stress periode 40 -2013winter (year 0+10)



Legend

Positive water level fluctuation indicating an increase in water levels i.r.t. initial (1991) water levels.

Zero water level fluctuation indicating an increase in water levels i.r.t. initial (1991) water levels.

Negative water level fluctuation indicating an increase in water levels i.r.t. initial (1991) water levels

Figure 31. Selected stress periode draw down (meter below initial heads) results from Scenario 4 of the model.

Results: (Figures 30 and 31)

- By 2010 water levels would have recovered substantially (i.r.t. 1990 water levels) in all areas and by 2014 regional water levels would have recovered fully to the levels prior to intensive abstraction (1990 levels)
- Only in areas proximate to intensive abstraction Grassbank and Blackheath water levels would still be 10 m lower (i.r.t. 1990 water levels).

6.15. *Scenario predictions summarized*

The calibrated model was used to test the following 10-year future scenarios of abstraction and recharge in order to assist in decisions regarding management of abstraction from the aquifer system.

Table 22. Scenario predictions and management decision from the groundwater model.

	Recharge (mm/a)	Abstraction Mm^3/a	Water level reaction by 2014 (irt 1990 levels)	Management Decision
Scenario 1	0.4 - 1.5 winter 1.5 - 8.3 summer	16.1	Decline regionally 20 to 30 m Proximate to irrigation 60 to 110m declined	Not acceptable
Scenario 2	0.4 - 1.5 winter 1.5 - 8.3 summer	11.1	Decline regionally 10 to 20 m Proximate to irrigation 30 to 60m declined	Acceptable with strong abstraction control.
Scenario 3	0.2-1.2 winter 1.2-6.7 summer	11.1	Decline regionally 20 to 30 m Proximate to irrigation 60 to 110m declined	Acceptable with strong abstraction control.
Scenario 4	0.4 - 1.5 winter 1.5 - 8.3 summer	0	Full regional water level recovery Proximate to irrigation 10 m declined	Acceptable unconditionally

The model demonstrated that rates as specified by scenario 2 can be sustainable abstracted from the system at average recharge and that these abstractions would still be sustainable at 20 % less than average recharge as in scenario 3. Management of abstraction of the aquifer was consequently structured to ensure that abstraction would not exceed the sustainable yield of 11.1 M m^3/a.

6.16. *Limitations of the model*

- Water level increase is modeled in the area north of the BIF, which could be as a result of declines prior to the initial heads assumed for that area.
- In the area proximate to the Molopo River modeled water levels are lower than observed water levels. However these water levels recover substantially after periods of abstraction.
- In the Belvedere area elevated water levels are modeled to increase contrary to observed declines.

7. REGULATION OF WATER USE

7.1. Water use conflict and its economic implications.

The competition for the groundwater resource and its rapid deterioration resulted in conflict between users. At first the environment had unlimited access to the water resource with only natural events like droughts impeding availability. Drilling technology evolved to make the resource accessible to domestic, stock watering, small scale gardening and ultimately irrigation. The mentioned number of factors lead to irrigation in the area impeding on both environmental; domestic, stock watering, small gardening and lately also basic human needs for municipal use.

Plate 3. Abstraction points on 2 farms from the same fracture complex separated only by the farm boundaries.

The Nash equilibrium (John Nash) popularised by the film “A beautiful mind” 2001 entails the best possible action for all players to arrive at the dominant strategy. The dominant strategy for all other users would be to pressurise and ensure that the irrigators consume less water.

The irrigation water use developed unregulated and with large capital investment. The estimated capital investment by water users in terms of boreholes, pipes, electricity, pipes, dams, irrigation equipment was R52 million by 2002 (Estimated by Mr G. Stoltz Letter 2002). The estimated potential income from irrigation crops is tabled in Table 23 and compared to stock farming. With big capital investment and high potential income the dominant strategy for irrigators would therefore be to irrigate as big possible areas to generate profit and ensure income on capital investment.

Table 23. Estimated potential income form irrigation of the crops in the Tosca area compared to stock.

Crop	Surface (ha)	Potential yield (T/ha)	Price (R/T)	Income (R/ha)	Income (R)	Input Cost per ha (R)	Cultivation Input Cost (R)	Water use (m3/ha)	Water cost (@R0.36 /ha) ®	Profit/ Loss with water cost (R)	Profit/ Loss (R per ha)
1	2	3	4	(3*4) 5	(2*5) 6	7	(2*7) 8	9	(2*10) 11	(6-8-11) 12	13
Maize	775	12.00	800	9,600	7,440,000	7,200	5,580,000	7,500	2,092,500	-232,500	-300
Peanuts	197	3.50	3,903	13,661	2,691,119	7,000	1,379,000	7,000	496,440	815,679	4,141
Paprika	306	2.00	10,000	20,000	6,110,000	1,500	458,250	12,000	1,319,760	4,331,990	14,180
Potatoe	68	30.00	2,000	60,000	4,050,000	57,000	3,847,500	7,000	170,100	32,400	480
Wheat	235	6.50	1,100	7,150	1,680,250	6,000	1,410,000	7,500	634,500	-364,250	-1,550
Lusern	93	19.00	650	12,350	1,142,375	5,600	518,000	11,400	379,620	244,755	2,646
Totals/ Average cultivation	1,673	12.17	3,076	37,419	23,113,744	14,050	13,192,750	8,733	*5,092,920*	4,828,074	2,887
cattle	400,000	0.015	10000	150	60,000,000	35	14,000,000	2.19	315,360	45,684,640	114

Bekker A., (2003). Kostegids vir besproeiing in die Griekwaland Wes Kooperasie gebied. GWK Douglas.

Comparing cattle production in the area of interest at 4000 km^2 or 400 000ha one unit large stock can be sustained at average on 10 ha (Department Agriculture North West). Therefore 40000 stock of which approximately 24 000 can be sold annually at R1900 per unit the potential income is R45.6 million from stock farming. This is profit at a low rate of R114 per ha. The total potential income of R23.1 million on the 1673 ha is high, but the high cultivation and water pumping cost reduce the net profit to only R4.8 million at an average of R2887 per ha. The question would be if this irrigation income utilizing 99% of the water, justifies the risk water loss risk (boreholes drying up) it poses to the stock industry with the potential income of R45.6 million annually.

Decisions regarding water rights and authorization must therefore take into consideration all factors. The potential irrigation income to be generated by both all sectors of water use and the capital investment made by these water users to ensure their livelihood. All efforts should be made to ensure that the authorized use is managed appropriately not to impact negatively on the sectors where profits cannot justify drilling replacement holes exc.

Plate 4. Carting of water and re-drilling of a dried up borehole on the farm Quarreefontein after the water level declined an estimated 60 m due to proximate irrigation abstraction.

7.2. Water use authorization

The registered water use from WARMS and observed irrigation development indicate a surface area of 2076 ha requiring 12.2 million m^3 of water. As reported the volume registered on WARMS seem unrealistic considering crop demand. Recalculation of the use considering crop demand sum to 18.1 million m^3/annum.

The reserve determination (Godfrey 2002) delineates the area into 3 resource units at different status of impact. It was decided that in the short term the resource rather be managed in as a unit, to ensure consistent actions against all users in the community regardless of the specific status in the resource unit. This would imply that the sustainable abstraction from the resource is estimated at 11.1 million m^3 per annum. The aim of actions would therefore be to reach this volume in the short term.

7.2.1. Termination of reserved water use rights.

A number of users registered use not developed yet in order to reserve water rights for future use. The volumes registered by these users was cut back to general authorization applicable in this area. This effectively reduced the potential development of registered use of 2.6 million m^3 (or 247 ha) to 0.6 million m^3 of water under general authorization.

7.2.2. Termination of unauthorized water use.

The section 35 processes (NWA) verification of existing lawful use was used to verify registered and actual water use in the area. After potential unauthorized irrigation use was identified from February 1999 and March 2002 satellite images (See appendix 7) the prescribed letters were dispatched to these users requiring them to respond by applying for verification of the legality of their water use.

Their response was evaluated by the Regional Water Use Authorization Committee on the 9 the December 2002. Table 24 is a summery of the recommendations from this committee. The legality of use of 15 users was questioned. Six users could supply evidence that their use should be considered authorized. The remaining 9 users (red) were directed to reduce their use with effective dates during March 2003. Following these directives 2 users supplied information and directives issued against them were cancelled.

The result of this action would be a total reduction of approximately 251 ha in surface irrigated or 3 .7 million m^3 in volume abstracted from the resource.

Table 24. Suggested actions against users following section 35 verification.

Name user	REG NR	VOLUME REG	Date bought	Farm	Farm Area	General Auth	Total Irri	Correct volume crop factor	New permitted use	RU	Sat Image Jan 1999	Sat Image Mar 2002 (Ha)	Remove ha	Suggested actions
M. Theron	25001514	277900	1997	Millbank	428.5	25710	50	404000	25710	**1**	No	50	45	Cut back to GA. Directive issued 5 Ha
Fanie Griesel Trust	10082527	200000	2000	Belvidere	1096	65760	40	456000	65760	**1**	No	25	13	Cut back to GA. Directive issued 12 Ha
Emtron Bdy	10081216	335650	1999	Grassbank	785.8057	47148	55	520500	520500	**1**	7	50	0	Total use transferred from Forres. May continue
C.E. le Roux	25007117	152100	2000	Westward Ho	1892.43	0	60	666000	0	**1**	No	60	60	No GA in D41C, Cut back to 0. Directive issued.
P Haasbroek	License application	0	2001	Marlborough	713.6	42816	50	375000	42816	**1**	No	50	45	Cut back to GA. Terminate current arrangement. Enforce directive 04/2002. New Directive issued 5 ha
J.J. Hayward	25008679	282900	1997	Forres	1590.975	95458	30	441000	95458	**1**	No	30	14	Cut back to GA. Directive issued. 16 Ha
J.H. Fourie	10081323	255400	1988	Hurstpark	2494.751	149685	60	440000	60240	**1**	40	60	0	The use registered as GA on Blanco farm. No action
Mr. P.W. Beyer	10081234	798200	2003	Harcourt	1241.4	74484	140	1174000	439000	**1**	30	60	30	Remove 30 ha, rest legal. Directive issued.
Leniesdeel Trust (Jan Fourie)	10081350	655100	1995	Harcourt	620.7	37242	120	935000	777500	**1**	106	146	40	Remove 40 ha, rest legal. Directive issued
Hulp Alleen Familie Trust	25006010	95850	2000	Genade	471	28260	18	130500	130500	**3**	No	18	0	Cut back to GA. Considered information. Declared as existing legal use
P.A. Theunissen	10081243	182400	1998	Nokani	293.4542	17607	30	225000	225000	**3**	No	30	0	Cut back to GA. Considered information. Declared as existing legal use
E.C. Grobbelaar	10081369	484060	1992	Robyn	2254.6	135276	66	682200	682200	**3**	52	52	0	All legal no action
Mr. F.J. Hamman	10081314	66570	1994	Sentac		0	24	231700	231700	**3**	19.8	28.3	4	Remove 4 ha, rest legal
Mr. P.E. Kriel	10081261	89180	1999/10/01	Millbank	856.5315	51392	17.5	124250	124250	**3**	6	15	0	Motivations justify planned to irrigate area, quotations supplied, no action
Mr. F. Barnard	10081289	383750		Woodborough	1551.1	93066	50	555000	444000	**NA**	40	50	0	Moved irrigation, Remove registered use from Elchester
		4259060	Volume	Reduced		3495516		7360150	3864634	Total	192	2726.3	251	Ha reduced
			Volume	Reduced	RU1	3384516		5411500	2026984	1	183	441	247	Ha reduced RU1
			Volume	Reduced	RU3	little		1393650	1393650	3	118	193	4	Ha reduced RU3

7.2.3. Consideration and authorization of new water use.

Considering the depleted state of the resource new water use applications were considered with caution. To ensure equitable access to the resource and the depleted state of the resource it was decided that restricted authorization be permitted. All new water use applications were restricted to the general authorization applicable to each catchment. Table 25 summarize the volumes water users applied for and the volumes allocated.

Table 25. General authorization on license applications and its effect.

Name	Farm	Catch	Date	*Farm Area*	*General Auth*	*Volume applied*	*Suggested auth*	*Area for maize (ha)*	*RU*	Effect of allocation from RU
G I Rossouw	Harcourt	D41D	10/12/2001	620.7	37242	30500	**37242**	**5**	**1**	
P J Haasbroek	Marlborough	D41D	13/01/2002	713.62	42817	750000	**42817**	**6**	**1**	
W H Simmons	La Rochelle	D41D	02/08/2002	856.53	51392	181200	**51392**	**7**	**1**	
G H Stolz	Willarie	D41D	10/06/2002	1027.85	61671	147000	**61671**	**8**	**1**	
D.J. Marais	Rouwkoop	D41C	10/3/2003	1426.8	0	85608	**0**	**0**	**1**	
A. van Zyl	Clearstream	D41D					**0**	**0**	**1**	
JAS Simmons	Tennant	D41D	3/10/2003	994	59640	45600	**45600**	**6**	**1**	201480
SG Griesel	Monti Piano	D41D	26/11/2002	300	18000	225000	**18000**	**2**	**2**	
Zenith Ranch	Forres	D41D	10/12/2004	4305	258300	640000	**258300**	**34**	**2**	
Rose	Kokomeng	D41D	10/12/2005	1135	68100	600000	**68100**	**9**	**2**	344400
Pretorius	Quareefonein	D41D	14/09/2001	1284.95	77097	375000	**77097**	**10**	**3**	
P E Kriel	Millbank	D41D	16/07/2002	428.15	25689	110250	**0**	**0**	**3**	
I de Beer	Nokani	D41D	05/09/2002	1029	61740	180000	**61740**	**8**	**3**	
I de Beer	Koedoeskop	D41D	05/09/2003	1126	67560	180000	**67560**	**9**	**3**	
K. van der Heever	Deelfontein	D41D	10/12/2002	1713	102780	146700	**102780**	**14**	**3**	
Centwise	Nokani	D41D	3/10/2003	1240	74406	375000	**74406**	**10**	**3**	383583
				17580	969192	4041358	**929463**	**124**		

By applying this principal the these new license applications would result in authorization of only 977223 m^3 in total or 180 ha in surface area to be irrigated.

7.3. Effect of NWA water use authorization on water use.

The net result of these water use regulation actions can be summarized as follow:

Description	Irrigation area (Ha)	Volume (million m^3/a)
Registered irrigation surface and volume	2076	18.2
Termination of reserved use	-260	-2
Termination of unauthorized use	-451	-2.0
New water use authorization	124	0.93
Total irrigation areas after NWA reduction processes	1489	15.13

The resource is still over allocated by 4 million m^3 of water annually.

7.4. Implementation restriction on authorized water use.

The registration of use from the area was verified and use by 15 users was requested to motivate that they should be considered as authorized through the section 35 processes. Of these 15 users the use of 7 was reduced or stopped. The net result is termination of unauthorised use of 251 ha of irrigation or abstraction of 4 M m^3/a.

Application for new water use was from considered and use up to General Authorization was recommended. The net result is authorization of an additional 124 ha or 0.93 M m^3/a. Therefore the total future use is between 15 and 16 Mm^3/a.

A model of the resource was constructed with abstraction, recharge and water levels the last 10 years (1994 to 2004) as input. Prediction from this model indicate that the water levels would continue to decline at this abstraction rate of 15 to 16 Mm^3/a. The resource is still over allocated by 40%. A restriction of 40% on authorized use is needed to reduce the abstraction from the resource to 11 M m^3/a. The current estimated sustainable volume available from the resource is 11 M m^3/annum.

The above scenarios were discussed with the water users and they agreed that water restrictions could relieve stress on the aquifer. They requested that economic viability of irrigation units be ensured by effecting 40% restrictions on use exceeding 10 ha or the volume of 75 000 m^3/a.

The schedule of registered use in Table 26 indicating the volume to which each user would be restricted. The 40% restrictions would effectively reduce use to approximately 10 Mm^3/a.

For these restrictions to be effective and to measure the response by the aquifer these restrictions would have to be imposed for 5 years (to be effective as from water year April 2004 to April 2009). These measures could be reconsidered when compulsory licensing is implemented.

The restrictions would be implemented in line with Schedule 3 Section 6 of the National Water Act.

A flow meter combined with a volume recorder on each borehole is installed to record the volume abstracted/irrigated or a bulk meter is installed to measure the total volume irrigated.

The user would log the measurement on a monthly basis and supply this measurement on a monthly basis to the responsible authority.

The responsible authority would inspect both the surface/ crop areas and the measuring device by August and April annually and enforce the above i.t.o. Schedule 3 section 6 items 4,5.

The responsible authority should have the right to terminate the use of users not complying with restrictions or its enforcement i.t.o. Schedule 3 section 6 items 4,5.

Table 26. Authorized user with registered volume and the volume restricted.

			Not developed at date=	625983	83	
Reg no:	**Name**	**Farm Description**	**Title deed number**	**Volume Registered (m3/a)**	**Use exceeding 75000 (m3/a)**	**Total restricted use (m3/a)**
25009473	F.V.Z. Engelbrecht	Albury farm no. 171 portion no. 2	T2601/1994	398000	323000	**268800**
10081001	Tosca Trust	Ascot farm no. 184 portion no. 0-remaining extent	T302/2000	187000	112000	**142200**
10082527	Fanie Griesel Trust	Belvidere Farm No. 157	T63/2000	65760	0	**65760**
25021949	W.H. Simmons	Belvidere farm no. 157 portion no 1	T3027/2002	51393	0	**51393**
10081225	Carroll Family Enterprises	Blackheath farm no. 90 portion no. 0-remaining extent	T1802/2001	1735000	1660000	**1071000**
25017213	J.H. Fourie	Blanco Farm no. 173 portion no. 1	T3321/1999	64543	0	**64543**
10081378	J.C.C. Grobbelaar	Brenton farm no. 180 portion no. 0-remaining extent	T1352/1979	69954	0	**69954**
25007821	Avon Trust	Brentwood Farm No 181 Portion 1	T4173/2000	74112	0	**74112**
10081252	Eben Du Toit	Brentwood farm no. 181 portion no. 0-remaining extent	T215/1996	74112	0	**74112**
10081412	J.P. van den Berg	Buttermere farm no. 1017 portion no. 0	T1913/1998	1035000	960000	**651000**
25007698	Clearstream Trust	Clearstream Farm No. 168 Portion No. 0	T493/2000	585000	510000	**381000**
25021976	K. van der Heever	Deelfontein Farm no. B215 remaining extent	T857/1986	102780	27780	**91668**
10081298	P.M. Fourie	Elchester farm no. 174 portion no. 1	T1283/2001	144000	69000	**116400**
25006831	Johan en Esta Theron Familie Trust	Forres	T489/2000	302400	227400	**211440**
10081190	W.C. Kriel	Forres farm no. 216 portion no. 2	T285/1989	335950	260950	**231570**
25008679	J.J. Hayward	Forres farm no. 216 portion no. 5	T1467/1997	95458	20458	**87275**
25021280	Zenith Ranch (Pty. Ltd)	Forres farm no. 216 portion no. 8	T1663/2000	258300	183300	**184980**
25000310	Leamy Family Trust	Forrest Hall farm no. 182 portion no. 0	T2109/2001	153870	78870	**122322**
10081181	H.M. Joubert	Gannalaagte farm no. 6 portion no. 0	T2667/1996	90250	15250	**84150**
25017972	Hulp Alleen Familie	Genade Farm 209 Portion 0 - Remaining extent		130500	55500	**108300**

25021412	Fransua Stolz Trust	Grassbank Farm No. 187 Portion No. 0-Remaining extent	T742/1995	1202500	1127500	**751500**
10081216	Emtron Bdy	Grassbank farm no. 187 portion no. 2	T1725/1999	367500	292500	**250500**
	K. van der Heever	Harcourt farm no. 185 portion no. 0-remaining extent	T603/1968	37242	0	**37242**
New Owner	Beyer Trust	Harcourt farm no. 185 portion no. 0-remaining extent	T1466/2003	360000	285000	**246000**
10081350	Leniesdeel Trust	Harcourt farm no. 185 portion no. 1	T2840/1995	655100	580100	**423060**
25003638	M. Hamman	Hastings farm no. 142 portion no. 0-remaining extent	T931/1988	35000	0	**35000**
10081323	J.H. Fourie	Hurstpark Farm No. 170	T212/1988	440000	365000	**294000**
25002675	S.G. Griesel	Kokomeng farm no. 178 portion no. 2	T148/2001	18000	0	**18000**
	Rose	Kokomeng		68100	0	**68100**
25021930	I de Beer	Koodooskop farm no. 206 portion no. 0-remaining extent	T1715/2001	67560	0	**67560**
25004753	A.C.J. Du Plessis	Libertas-Zand vloed farm no. 218 portion no. 1-remaining extent	T1589/1983	79800	4800	**77880**
25021921	P J Haasbroek	Marlborough farm no. 167 portion no. 0-remaining extent	T2010/2001	42818	0	**42818**
10081261	P.E. Kriel	Millbank farm no. 188 portion no. 1-remaining extent	T635/1994	124250	49250	**104550**
25001514	M. Theron	Millbank farm no. 188 portion no. 2	T2209/1999	25710	0	**25710**
10084865	Sandtrap Boerdery	Millbank farm no. 188 portion no. 3		525000	450000	**345000**
	I de Beer	Nokani		67560	0	**67560**
25018203	F.J. Hamman	Nokani Farm No. 208 Portion No. 2-Remaining extent	T2693/1997	15420	0	**15420**
10081243	P.A. Theunissen	Nokani farm no. 208 portion no. 3-remaining extent	T1015/1988	225000	150000	**165000**
25022573	Centwise BK	Nokani farm no. 208 remaining extent	T191/1988	85656	10656	**81394**
25018196	Pretorius	Quareefontein Farm No. 212 Portion No.1	T2665/2001	77097	2097	**76258**
25007028	J.H. Nieuwoudt	Quareefontein farm no. 212 portion no. 2	T4582/1998	145000	70000	**117000**
25021404	Fransua Stolz Trust	Rhodes Farm No. 186 Portion No. 0	T1421/2000	450000	375000	**300000**
10081314	F.J. Hamman	Senlac farm no. 143 portion no. 0-remaining extent	T350/1977	212800	137800	**157680**
25003503	W.H.A. Hamman	Stilton farm no. 189 portion no. 22	T2278/1996	127000	52000	**106200**
25020726	JAS Simmons	Tennant farm no. 152 portion no. 0-remaining extent	T648/1967	45600	0	**45600**
10081387	D.B. Grobbelaar	Thornthwaite farm no. 179 portion no. 0	T973/1978	482000	407000	**319200**
10081163	Kwagga Molopo Trust	Thornwick farm no. 175 portion no. 0-remaining extent	T2787/2002	121600	46600	**102960**
10081430	A.M. Steyn	Vaalboschoek Farm 227 Portion 1	T452/1995	114000	39000	**98400**
25021912	G H Stolz trust	Willarie 1019 portion no. 0		61671	0	**61671**
10081289	F. Barnard	Woodborough farm no. 159 portion no. 0	T374/1987	487500	412500	**322500**
25007732	Avon Trust	Woodborough farm no. 159 portion no. 1	T1115/2003	120000	45000	**102000**
10081369	E.C. Grobbelaar	Wynberg farm no. 165 portion no. 1	T1046/1977	612000	537000	**397200**
				13451866	**9942311**	**9474942**

During September 2004 the proposed restrictions were approved by the Director General and publication of the notice in the Government Gazette as attached in Appendix 13 would give the responsible authority powers to implement these restrictions.

7.5. Termination of general authorization.

The borders of the surface water drainage D41D and D41 C catchments transect the geological and aquifer borders of the Tosca Molopo dolomite aquifer. The general authorization of 60 m^3/ha/a applicable to D41D and not to D41C created problems in terms that potentially every landowner in the area can claim this right. It was therefore requested that this authorization be terminated. Termination of this General Authorization came into effect by the publication of **REVISION OF GENERAL AUTHORISATIONS IN TERMS OF SECTION 39 OF THE NATIONAL WATER ACT, 1998 (ACT NO. 36 OF 1998)** in the Government Gazette on 26 March 2004. This would ensure a uniform water use authorization.

8. ESTABLISHMENT OF A WATER USER ASSOCIATION

Sandoval (2004) concluded that water management requires not only a lot of “water wisdom”, but also “management wisdom”. Complex problems such as groundwater misuse will never be properly faced with participation processes that are merely a consultative effort (Sandoval 2004). Only a structure that is part of the problems can be committed to provide the solutions. The NWA (1998) provides for a suitable structure in the form of a Water Users Association.

Water users in the community initiated the establishment of a water user association. A pilot committee was established during January 2001 with Mr. Gert Stoltz as chairman and Mr. Lennox Louw as vice chairman. There was a prominent division within the committee between the irrigation water users and the stock watering users. The stock watering community requested that the pilot committee be re-elected on the grounds that it is biased and advancing irrigation interest. DWAF persisted with this committee on the grounds that it did not have any powers in water regulation and management. The role of the pilot committee is solely to compile a draft constitution for the WUA to the Minister (DWAF) to establish the WUA.

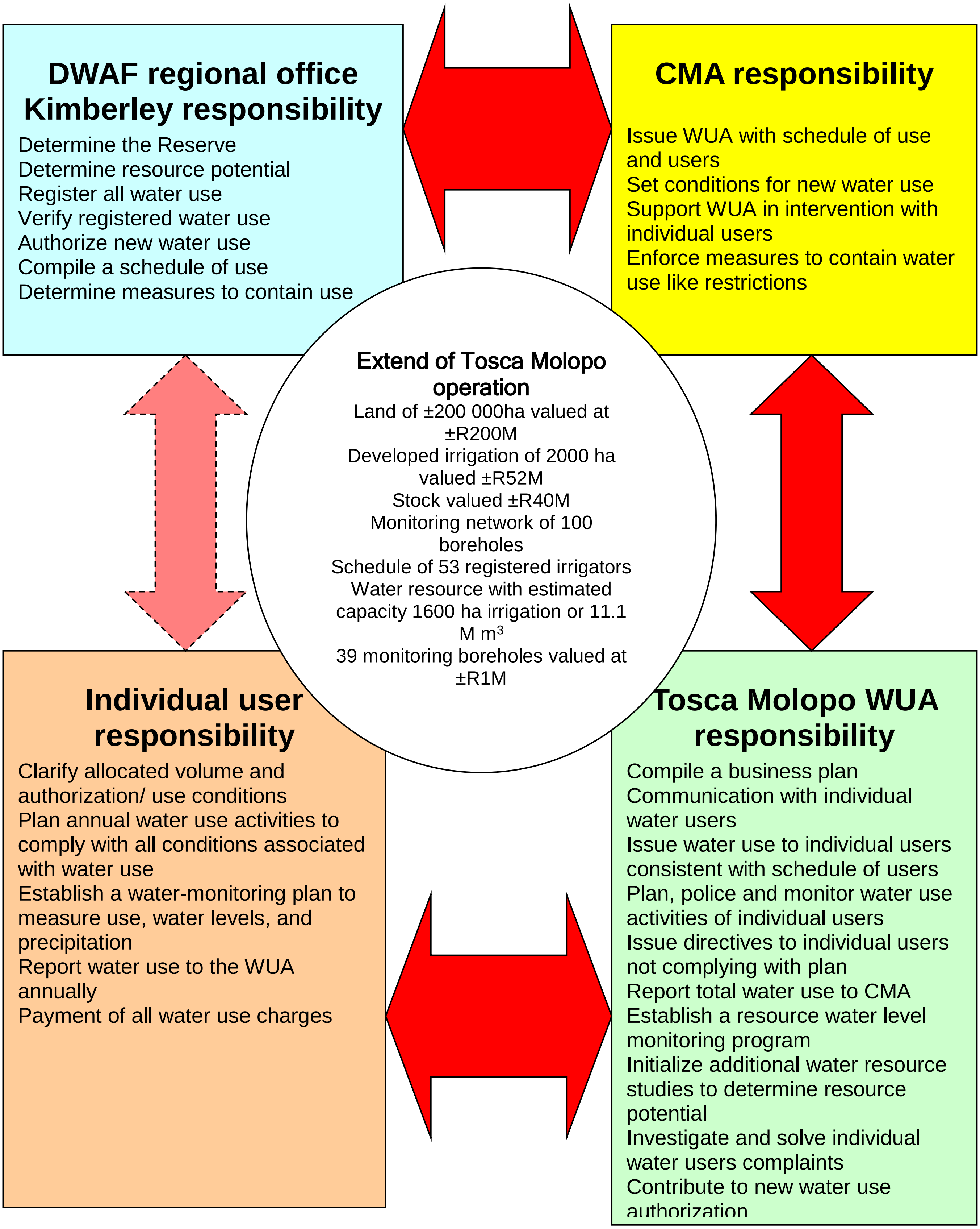
The chairman commenced with compiling this draft constitution, but with the above reservations DWAF decided to appoint a consultant to proceed. Me. Erika de Villiers was appointed and after a number of consultative meetings this draft constitution was submitted for approval by Oct 2002. A number of improvements to the constitution followed before approval of the constitution by May 2004.

After elections of a committee and submittance of a business plan the WUA will commence its activities. This WUA would enhance water use from the aquifer. The area of responsibility of the WUA is reflected in Appendix 1 and is estimated at 200 000 ha with 53 registered irrigation water users, a domestic bulk water supplier, approximately 200 stock water users.

The roles and responsibilities of the different water institutions are reflected in figure 31. The institutional capacity is greatly enhanced in relation to the current direct interaction between individual water user and a national government department. This would enhance water user and resource protection.

On the 16 July 2004 the Minister of Water Affairs approved the establishment of the WUA and Forestry with the publication of its establishment in the Government gazette as reflected in Appendix 14.

Figure 32. Roles and responsibilities of the different water institutions.



9. WATER USE ENFORCEMENT

At establishment the WUA indicated that cooperation of water users i.r.t. compliance would be problematic. This was recognized by DWAF as the past 4 years at Tosca indicated that most users did not believe that there would be actions to enforce compliance. By December 2004 6 water users were identified as users exceeding there entitled volume. New directives were issued directing these users to cut back those crops contributing to them exceeding their entitled volume by January 2005. Inspections regarding their compliance to these directives in March 2005 revealed the information tabled in table 27.

Table 27. Water users exceeding water entitlement during 04/05 season.

User	Property	Authorized use m^3	Estimated actual use (SAPWAT) m^3
Centwise	Nokani 203	85656	180000
C.E. le Roux	Westward Ho	0	375000
S.C. Bosch	Marlborough 167	42818	200000
P.W. Beyer Trust	Harcourt	360000	450000
M. Theron	Millbank	25710	240000
Fanie Griesel Trust	Belvidere	65760	200000
		579944	1645000

After careful consideration and discussions with the Legal Division it was decided that there was confusing evidence that transfers took place in the Millbank case and that there was compliance in the Harcourt case with late removal of crop. Enforcement actions were conducted against the remaining 4 users planned at mid May 2005 when crops were at the end of irrigation with the least loss in income to the users in mind.

The enforcement actions included:

- Removal of pumps from irrigation production boreholes,
- Sealing of irrigation production boreholes.
- Recovery of costs of the operations from the respective water users.

Water users entitlements were restored after payment of costs, signing and agreement with WUA regarding future compliance and acceptance of entitlement or agreement that existing legal avenues would be taken regarding entitlement.

Plate 5. Removal of pump equipment from borehole.

Plate 6. Sealed borehole to enforce compliance.

10. CONCLUSION

1. The Tosca Molopo aquifer is a combination of a silty primary aquifer with low yield and high storativity underlain with a fractured/ carstified dolomite aquifer with high yield and low storativity.
2. Within the primary aquifer coarse-grained sand and gravel layers form high yielding zones. Areas with carstified dolomite are limited to vertical to sub vertical fault lines and dolerite intrusions. Development of carst is also enhanced where there are chert and shale layers within the dolomite.
3. Recharge to the aquifer is low at an estimated 0.5% of the average annual precipitation. Along fault zones, river courses and in areas where the water level is elevated (less than 10 m) recharge is enhanced to an estimated 8% of average precipitation. The average recharge to the aquifer is estimated at 2% of annual precipitation or 7.8 mm per annum. For GM purposes the average of 1.75% of MAP or 9.7 mm/ of MAP was used.
4. Abstraction for irrigation purposes from the aquifer has increased over the last 10 years leading to declining water levels. This abstraction is unsustainable and is endangering primary water use (human, stock watering), the environment and the aquifer. Water levels have declined 10 to 20 m regionally and up to 60 m proximate to intensive irrigation.
5. It is estimated that the potential profit from stock farming is R114 /ha. Irrigation water users have invested more that R52 million towards boreholes, pumps, electricity, and irrigation equipment. The average calculated profit for irrigation in this area with the current crop profile is R2887 / ha. It is calculated that a loss can be expected from wheat and maize cultivation whilst up to R14 000/ ha profit can be expected from paprika.
6. The volumes of 15000 to 25000 $m^3/km^2/a$ or 150 to 250 m^3/ha as indicated on the Harvest Potential Map (Seymour and Seward 1996) cannot be harvested in this area. With the recharge of 7.8 mm/a the harvest Potential is rather 78 $m^3/ha/a$.
7. Irrigation water use is more than 99% of the water from this area. Human consumption and stock watering is less than 1% in this area.
8. The 2003 high of 2067 ha or 16.1 Mm^3 irrigation in this area is modeled as unsustainable. If this irrigation scenario is continued the water levels would decline 20 to 30 m and up to 110 m proximate to irrigation by 2014. This would not only lead to dry boreholes and water shortage, aquifer depletion but also land subsidence and ultimately sinkhole formation

9. If irrigation can be reduced by 40% to 1300 or 11.1 Mm^3 water levels would stabilize at the current declined levels 2003. Limited further decline would take place even if below average precipitation is experienced.
10. If irrigation use were stopped completely the water levels would recover fully by 2010 with only limited sinks of 10 to 20 m proximate to intensive irrigated areas.
11. Registration and verification of water use in this area was conducted resulting in the reduction of use with 250 ha or 4 M m^3/a. Registered water use in this area reflected only 66% of the real volume abstracted from the aquifer. Individual users under registered and gross misuse of water by the majority of water users were taking place.
12. Management of irrigation use can only be reached through a participative approach with a capacitated and informed structure like the WUA. Management of use and the aquifer should be by all users and based on the best available scientific information.

11. RECOMMENDATIONS

11.1. Local water management structure

The Water Users Association needs to be established to ensure local management of the resource and use. It is the responsibility of DWAF to establish and capacitate the WUA.

11.2. Abstraction control

The responsible authority (DWAF or CMA) would issue the WUA with the allocation schedule (table 16). Abstraction control is the function of the WUA and specifically to ensure that all water use in their area of responsibility is planned and used according to the schedule. It is also their function to manage the water resource.

The WUA need to compile its business plan with to reflect abstraction control, water resource management or other measures as prescribed.

Abstraction can be monitored by implementing a system of firstly consultation and planning with each authorized user on the volume available for the water year starting in May of each year. An agreement should be reached to the area and crop this volume can irrigate. The water user must then report use to the responsible authority on a monthly basis. An example is attached as Appendix 11.

The water use authorized in the area need to reduced. The water use for irrigation should be reduced to 40% of the authorized use for irrigation for the next 5 years from May 2004 to May 2009. This use can be reconsidered if new information justifies that.

11.3. Water resource monitoring network

The effect of the abstraction on the aquifer needs to be monitored. Precipitation, water level and water quality, need to be monitored.

Precipitation would be measured at the SAWS stations at Pomfret and Vergeleë. Additionally a rainfall collector, which would also measure the precipitation, was erected in the recharge area on the farm Quarrefontein. DWAF would be responsible for operation and maintenance of this collector.

The water level monitoring network consists of a number of carefully selected boreholes based of the conceptual model and modeling results. Initially as many as possible boreholes were measured resulting in disturbed pumping water levels proximate to irrigation. Water level loggers were installed on 4 boreholes along the gradients of the system on boreholes G47608, G39685, G39687 and G39693 to log water levels each hour. At the other 38 boreholes water level measurements would be taken every six months during April and August.

11.4. Recalibration of the model

The current groundwater model could be enhanced with new information collected. The information collected above would be used to recalibrate the groundwater model every 2 year with new recommendations regarding abstraction to be made only after 5 years.

11.5. New irrigation water use authorization

No new water use should be considered for the new 5 years. Only if the water level information and recalibrated model suggest that the water levels recovering should new authorizations be considered.

11.6. Risk of declining water levels

There could be time delay for measures to stabilize water levels and eventually recover water levels.

From the water level data it is possible to construct a map delineating areas at risk. Figure 32 delineates the area from low risk to exceptionally high-risk areas due to water levels declining. The associated risks of ground subsidence, sinkhole formation and aquifer reduction could occur over the total area. It is more likely that these disasters would be limited to the high and exceptionally high-risk areas

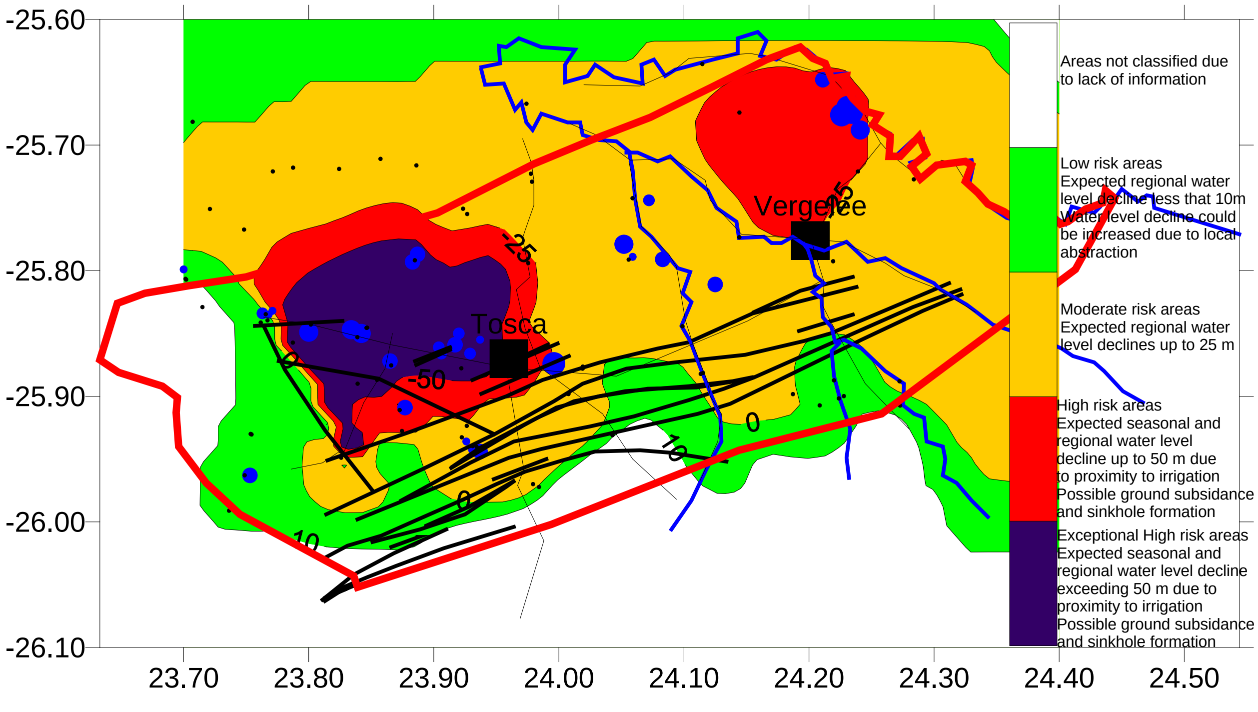


Figure 33. Risk areas based on water level declination data over the area.

Measures to protect basic human need and other water use in these areas should be negotiated and the WUA should be responsible for implementation of these measures.

12. REFERENCES

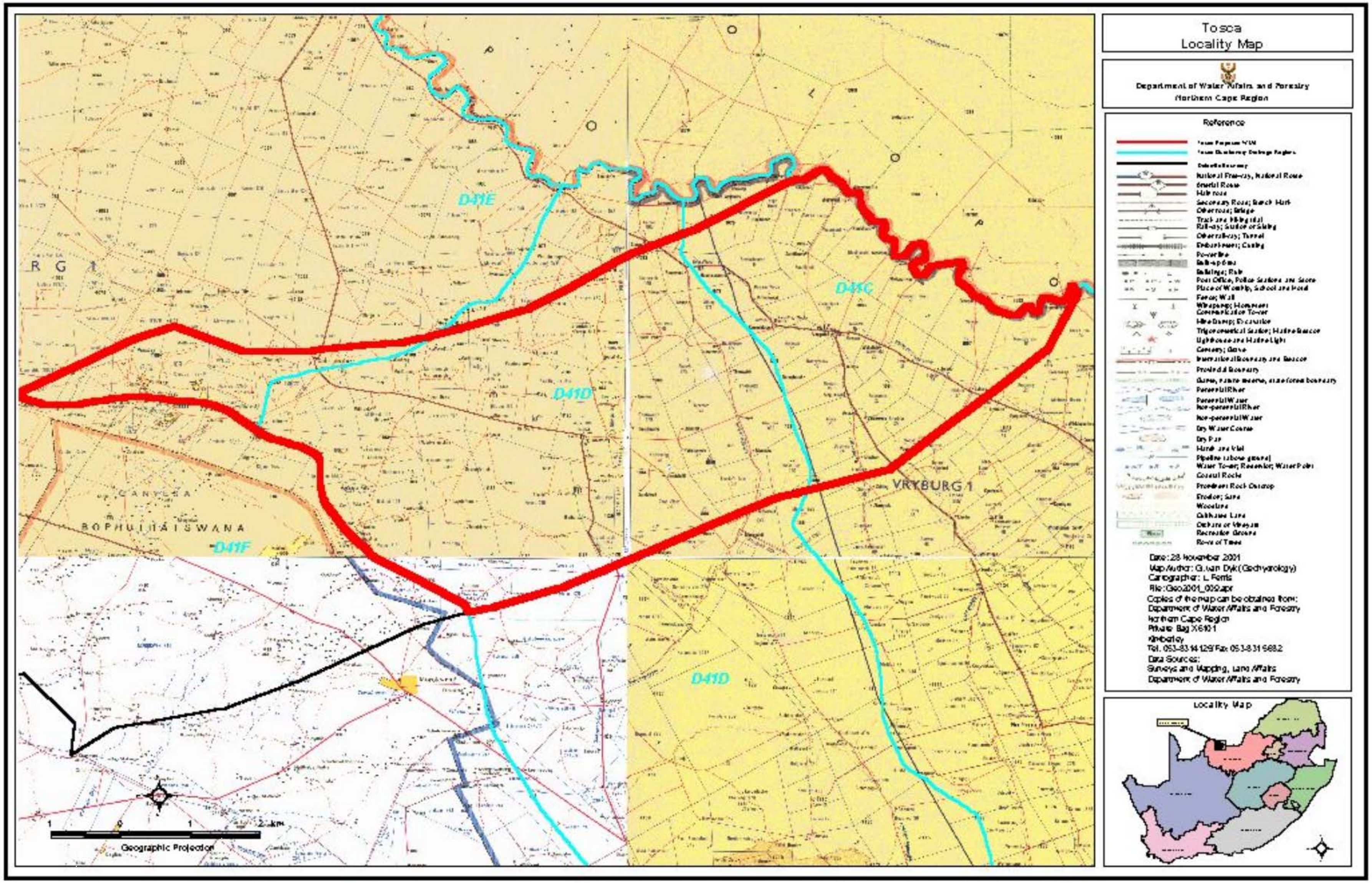
1. Adams S., (2004), Groundwater recharge assessment of the basement aquifers of the central Namaqualand, Water Research Commission Report in preparation, WRC.
2. Beekman H.E., Grieske A. Selaolo E.T. (1996). GRES: Groundwater Recharge studies in Botswana 1987- 1996. *Botswana journal of earth science Vol3, Dec 1996.*
3. Bekker A., (2003). Kostegids vir besproeiing in die Griekwaland Wes Kooperasie gebied. GWK Douglas.
4. Braune E., (2000). Towards comprehensive groundwater resource management in South Africa. *IAH 2000 Conference proceedings: Groundwater Past Achievements Future challenges* P7-17.
5. Bredenkamp D.B., Botha, L.J. van Tonder G.J, van Rensburg H.J, (1995). Manual on quantative estimation of groundwater recharge and aquifer storativity. WRC TT73/95.
6. de Villiers E., (2002), Tosca Molopo water gebruikers vereniging, Konsep grondwet. DWAF internal document.
7. Duvenhage A.W.A., Meyer R., (1991). CSIR report EMI-C 91179, Geohydrological and Geophysical Investigation in the Tosca-Vergelee area, 1991.
8. DWAF National Groundwater Database (NGDB);
9. DWAF Regional Database (Kimberley) - data of groundwater and irrigation monitoring in the area during 2001 to 2003.
10. DWAF report, GH2986. Groundwater conditions in the Pomfret Mining Area – Molopo, 1967.
11. Ellington R.G., Usher B.H. and van Tonder G. J., (2004) Quantification of the impact of irrigation on the groundwater resources underlying heavily irrigated areas, Water Research Commission Rep in preparation, WRC.
12. Godfrey L, van Dyk G.S. du T., (2002). CSIR rep no ENV-P-C 2002-031, Reserve determination for the Pomfret_Vergelegen Dolomitic aquifer, North West Province, Part of catchment D41C, D, E, F.
13. Jacobs K.L., Holway J.M., (2004). Managing for sustainability in an arid climate: lessons learned from 20 years of groundwater management in Arizona, USA, Hydrogeological Journal Volume 12 Number 1.
14. Moseki M.C., (2001). Impact of Lead Zinc mining activities on groundwater resources in the Pering mine compartment, PhD Thesis, Univ Free State.
15. National Water Act 1998, Act 36 of 1998. Republic of South Africa Government Gazette, Vol. 398, Cape Town.
16. Parken M., (1993). Micro Economics second edition, Addison Wesley publishing company.
17. Sandoval R., (2004), A participatory approach to integrated aquifer management: The case of Guanojuato State, Mexico, Hydrogeological Journal Volume 12 Number 1.
18. Schaffner B, Chen Y.Y.,. Kelepile T, Kinzelbach W., Carlson L and Mannathoko I., (2000). Scientific support for sustainable groundwater management: A modeling study in Botswana

using environmental tracers. *IAH 2000 Conference proceedings: Groundwater Past Achievements Future challenges* P291-296.

19. Smit, PJ., (1977). Die Geohidrologie in the opvanggebied van die Moloporivier in the Noordelike Kalahari. PhD Thesis, Univ Free State.
20. Tredoux G., Clarke S., Cavè I., (2003). Feasibility of in situ groundwater treatment for low cost water supply. WRC project K5/1325,
21. van Dyk G. S. du T., (1992). DWAF report, GH3767. Grondwater ondersoek vir Suid-Afrikaanse Weermag Pomfret, Distrik Vryburg.
22. van Dyk G. S. du T., (1993). DWAF report, GH3813. Geohydrological investigation for SADF Pomfret. District Vryburg, Drainage Region D410.
23. van Tonder G.J., Bean J.A., (2003). Challenges in estimating groundwater recharge, Contribution paper for United Nations Educational, Scientific and Cultural organization (UNESCO).
24. Wood W.W ,(1999). Use and misuse of the chloride mass balance method in estimating ground water recharge. Ground Water 37,1,2-3
25. van Tonder G.J. and Xu Y, (1999). A guide for the interpretation of pumping tests and estimation of sustainable yields of boreholes in fractured rock aquifers. Technical report GH3927. Department of Water Affairs and Forestry.

LIST OF APPENDICES

Appendix 1 The Tosca Molopo area.



Appendix 2 Aquifer tests

G39684

FC-METHOD : Estimation of the sustainable yield of a borehole | Main | Deriv | Inflection point method

G39684

Extrapolation time in years = (enter)	2	1051200	Extrapol.time in minutes	
Effective borehole radius (r_e) = (enter)	51.97	51.97	Est. r_e	From r(e) sheet
Q (l/s) from pumping test =	20.1	9.35E-05	S-late	Change r_e
s_a (available drawdown), sigma_s = (enter)	28		Sigma_s from risk	Down
Annual effective recharge (mm) =	0	28.00	s_available working drawdown(m)	
t(end) and s(end) of pumping test =	540	8.96	End time and drawdown of test	
Average maximum derivative = (enter)	2.9	2.8	Estimate of average of max deriv	
Average second derivative = (enter)		0.0	Estimate of average second deriv	
Derivative at radial flow period = (enter)	1.89	1.86	Read from derivative graph	
	T-early[m^2/d] =	168.15	Aqui. thick (m)	
T and S estimates from derivatives	T-late [m^2/d] =	109.59	Est. S-late =	2.31E-03
(To obtain correct S-value, use program RPTSOLV)	S-late =	2.31E-03	S-estimate could be wrong	

BASIC SOLUTION

(Using derivatives + subjective information about boundaries)

(No values of T and S are necessary)

		Maximum influence of boundaries at long time		
	No boundaries	1 no-flow	2 no-flow	Closed no-flow
sWell (Extrapol.time) =	18.50	28.04	37.58	66.19
Q_sust (l/s) =	30.42	20.07	14.98	8.50
	Best case			Worst case

Average Q_sust (l/s) = 16.70

with standard deviation= 9.26

(If no information exists about boundaries skip advanced solution and go to final recommendation)

G39669

FC-METHOD : Estimation of the sustainable yield of a borehole

Main | Deriv | Inflection point method

G36669

Extrapolation time in years = (enter)	2	1051200	Extrapol.time in minutes	
Effective borehole radius (r_e) = (enter)	47.79	#DIV/0!	Est. r_e	From r(e) sheet
Q (l/s) from pumping test =	5.3	2.69E-06	S-late	Change r_e
s_a (available drawdown), sigma_s = (enter)	30		Sigma_s from risk	Down
Annual effective recharge (mm) =	0	30.00	s_available working drawdown(m)	
t(end) and s(end) of pumping test =	540	24.52	End time and drawdown of test	
Average maximum derivative = (enter)	15.8	15.8	Estimate of average of max deriv	
Average second derivative = (enter)	0.0	0.0	Estimate of average second deriv	
Derivative at radial flow period = (enter)		#NUM!	Read from derivative graph	
	T-early[m^2/d] =	#DIV/0!	Aqui. thick (m)	
T and S estimates from derivatives	T-late [m^2/d] =	5.30	Est. S-late =	2.48E-03
(To obtain correct S-value, use program RPTSOLV)	S-late =	2.48E-03	S-estimate could be wrong	

BASIC SOLUTION

(Using derivatives + subjective information about boundaries)

(No values of T and S are necessary)

		Maximum influence of boundaries at long time		
	No boundaries	1 no-flow	2 no-flow	Closed no-flow
sWell (Extrapol.time) =	76.49	128.46	180.43	336.34
Q_sust (l/s) =	2.08	1.24	0.88	0.47
	Best case			**Worst case**

Average Q_sust (l/s) =	**1.02**
with standard deviation=	0.68

(If no information exists about boundaries skip advanced solution and go to final recommendation)

G39691

FC-METHOD : Estimation of the sustainable yield of a borehole

Main | Deriv | Inflection point method

G39691

Extrapolation time in years = (enter)	2	1051200	Extrapol.time in minutes	
Effective borehole radius (r_e) = (enter)	46.52	46.52	Est. r_e	From r(e) sheet
Q (l/s) from pumping test =	10	6.97E-04	S-late	Change r_e
s_a (available drawdown), sigma_s = (enter)	90		Sigma_s from risk	Down
Annual effective recharge (mm) =	0	90.00	s_available working drawdown(m)	
t(end) and s(end) of pumping test =	540	23.65	End time and drawdown of test	
Average maximum derivative = (enter)	22.1	22.1	Estimate of average of max deriv	
Average second derivative = (enter)	0.1	0.1	Estimate of average second deriv	
Derivative at radial flow period = (enter)	4.45	4.45	Read from derivative graph	
	T-early[m^2/d] =	35.53	Aqui. thick (m)	
T and S estimates from derivatives	T-late [m^2/d] =	7.15	Est. S-late =	7.43E-03
(To obtain correct S-value, use program RPTSOLV)	S-late =	7.43E-03	S-estimate could be wrong	

BASIC SOLUTION

(Using derivatives + subjective information about boundaries)

(No values of T and S are necessary)	No boundaries	Maximum influence of boundaries at long time: 1 no-flow	2 no-flow	Closed no-flow
sWell (Extrapol.time) =	96.88	169.58	242.27	460.35
Q_sust (l/s) =	9.29	5.31	3.71	1.96

Best case → **Worst case**

Average Q_sust (l/s) =	**4.35**
with standard deviation=	3.13

(If no information exists about boundaries skip advanced solution and go to final recommendation)

G39693

FC-METHOD : Estimation of the sustainable yield of a borehole

Main | Deriv | Inflection point method

G39693

Extrapolation time in years = (enter)	2	1051200	Extrapol.time in minutes	
Effective borehole radius (r_e) = (enter)	37.13	37.13	Est. r_e	From r(e) sheet
Q (l/s) from pumping test =	14.15	7.60E-05	S-late	Change r_e
s_a (available drawdown), sigma_s = (enter)	60		Sigma_s from risk	Down
Annual effective recharge (mm) =	0	60.00	s_available working drawdown(m)	
t(end) and s(end) of pumping test =	1440	20.17	End time and drawdown of test	
Average maximum derivative = (enter)	5.9	5.9	Estimate of average of max deriv	
Average second derivative = (enter)		0.0	Estimate of average second deriv	
Derivative at radial flow period = (enter)	6.77	6.77	Read from derivative graph	
	T-early[m^2/d] =	33.05	Aqui. thick (m)	
T and S estimates from derivatives	T-late [m^2/d] =	37.92	Est. S-late =	4.95E-03
(To obtain correct S-value, use program RPTSOLV)	S-late =	4.95E-03	S-estimate could be wrong	

BASIC SOLUTION

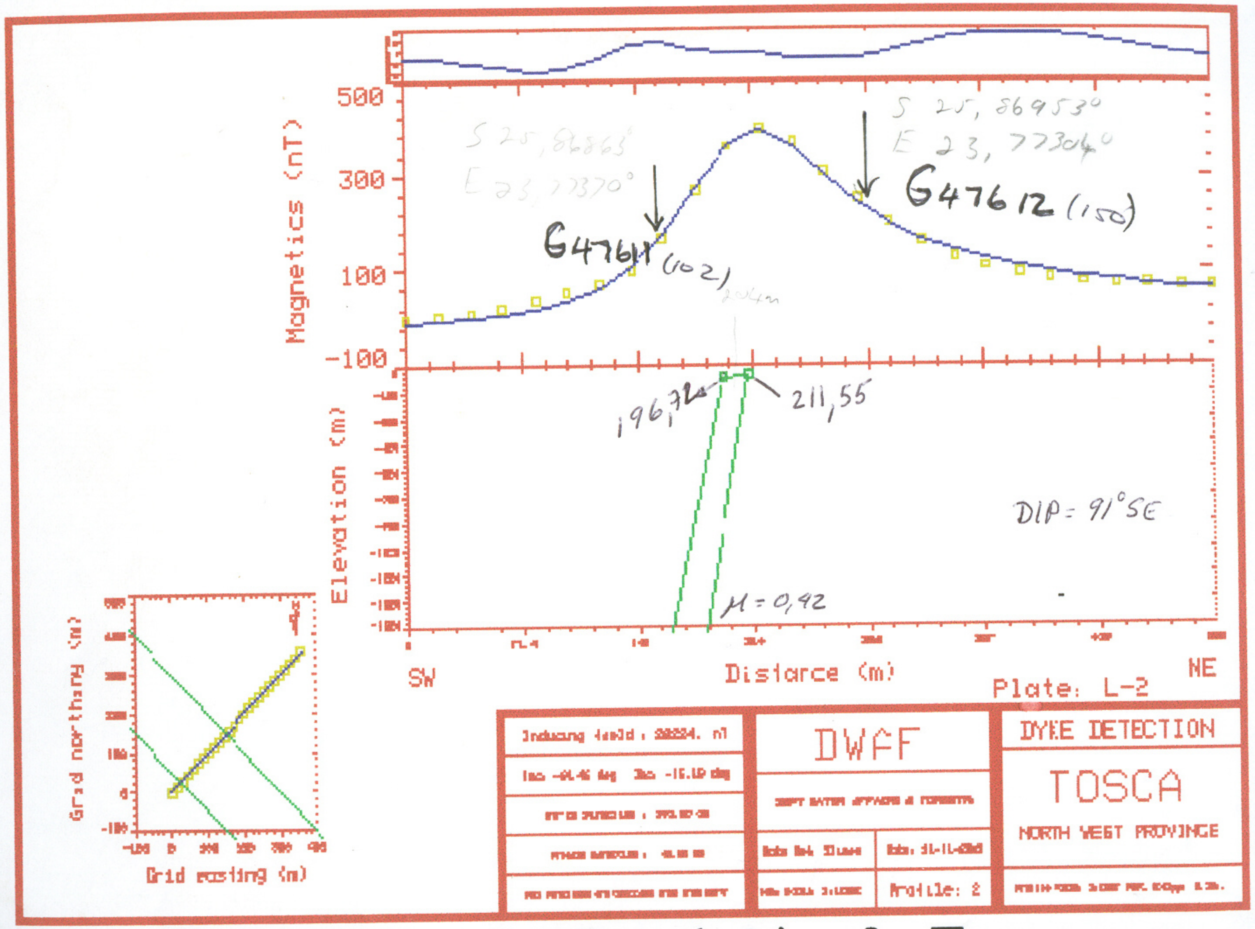
(Using derivatives + subjective information about boundaries)		Maximum influence of boundaries at long time		
(No values of T and S are necessary)	No boundaries	1 no-flow	2 no-flow	Closed no-flow
sWell (Extrapol.time) =	37.06	53.96	70.85	121.53
Q_sust (l/s) =	22.91	15.73	11.98	6.99
	Best case			Worst case

Average Q_sust (l/s) =	**13.18**
with standard deviation=	6.71

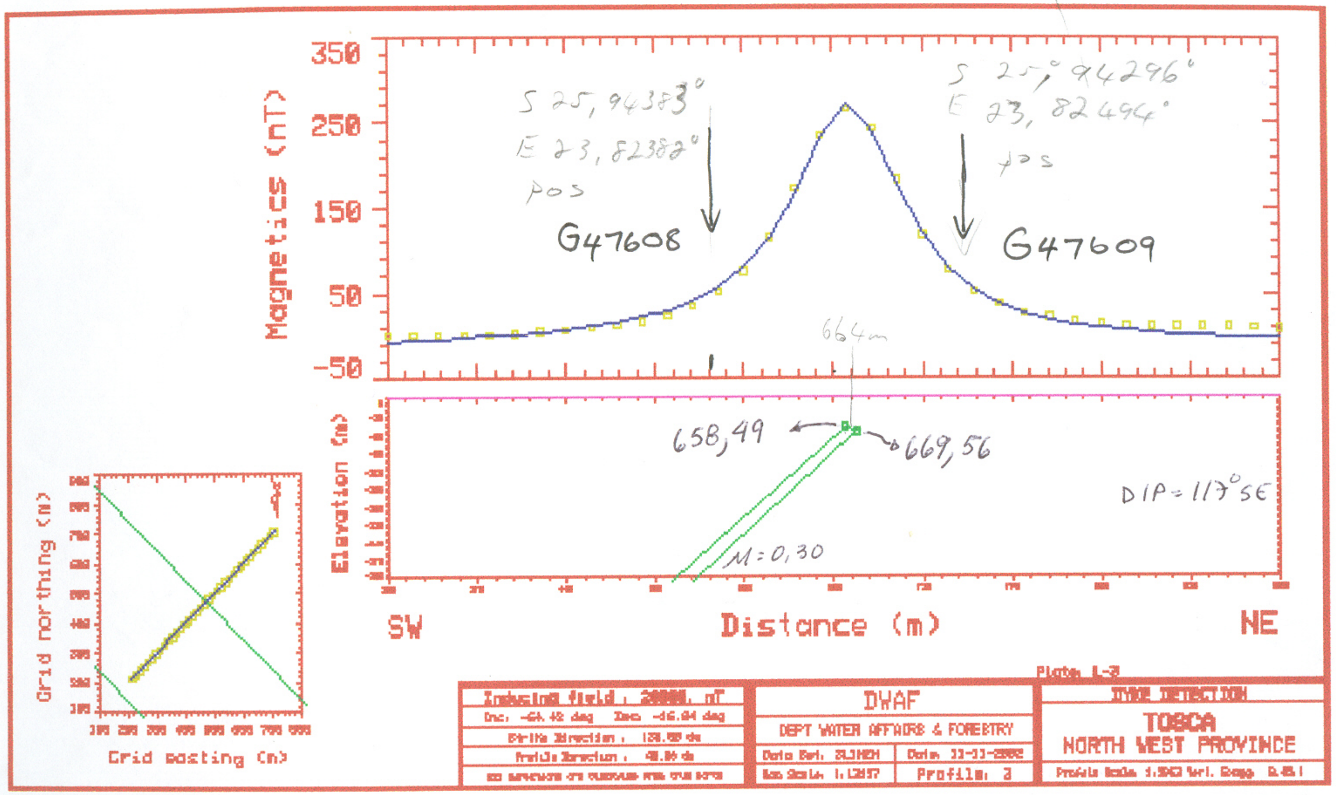
(If no information exists about boundaries skip advanced solution and go to final recommendation)

Appendix 3 Magnetic profile across dykes to confirm presence and position.

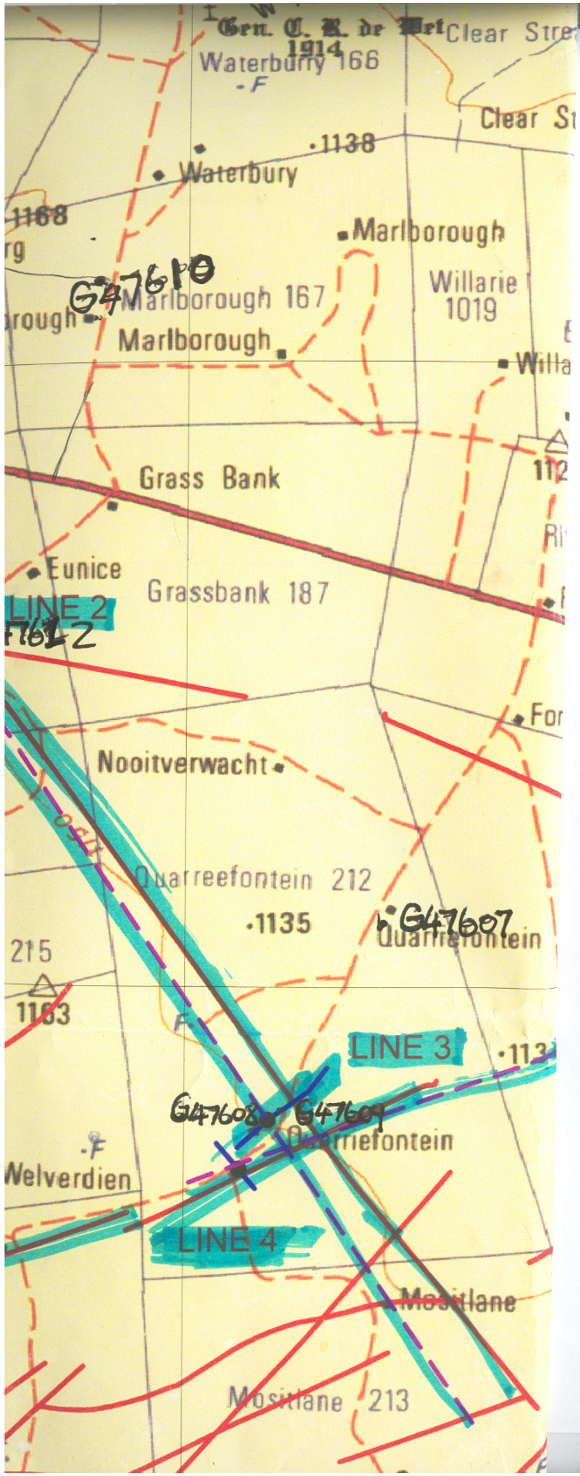
- Line 2 Millbank
- Line 3 Quarreefontein
- Line 4 Quarreefontein
- Line 5 Ascot
- Line 6 Buxton

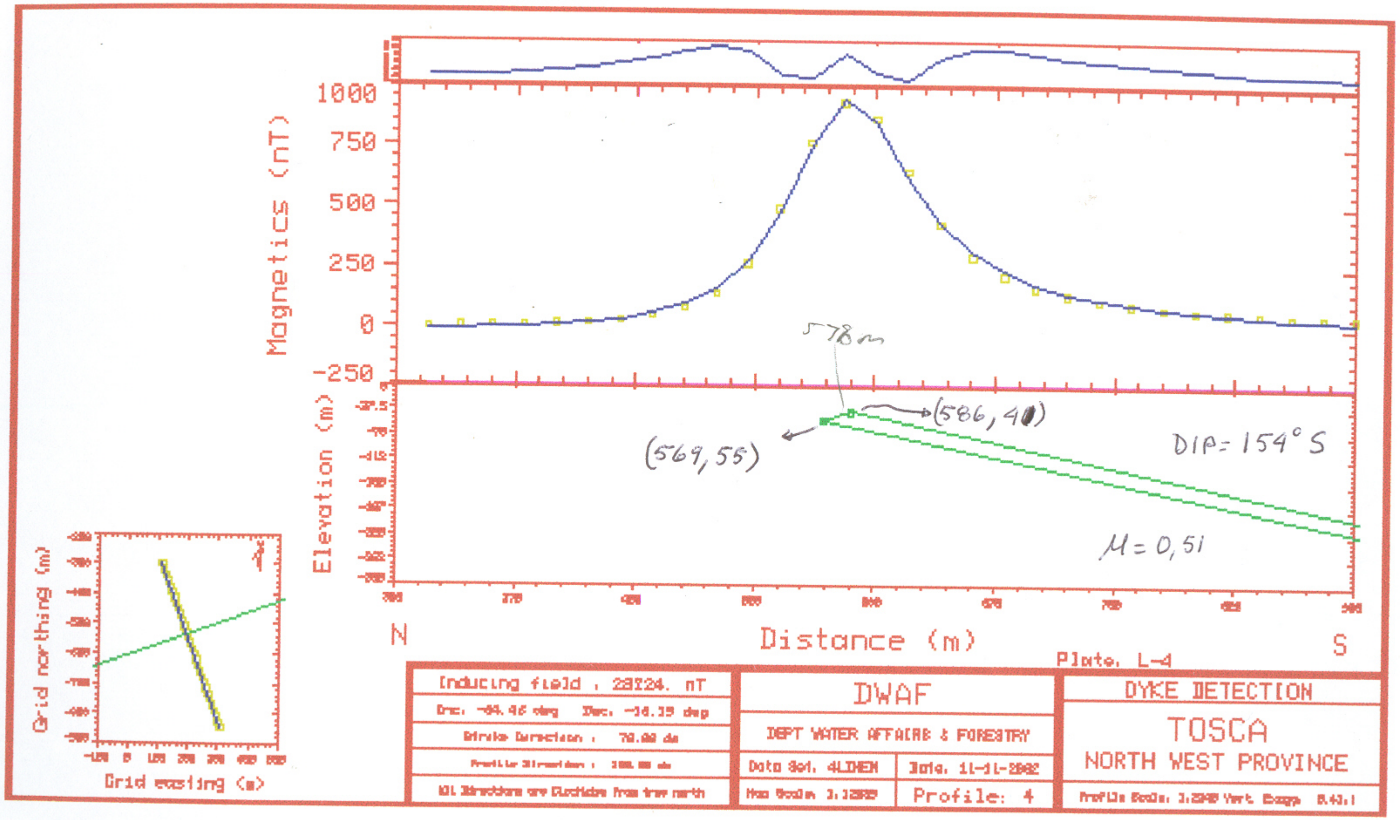


Magnetics Result Line 2. Tosca.

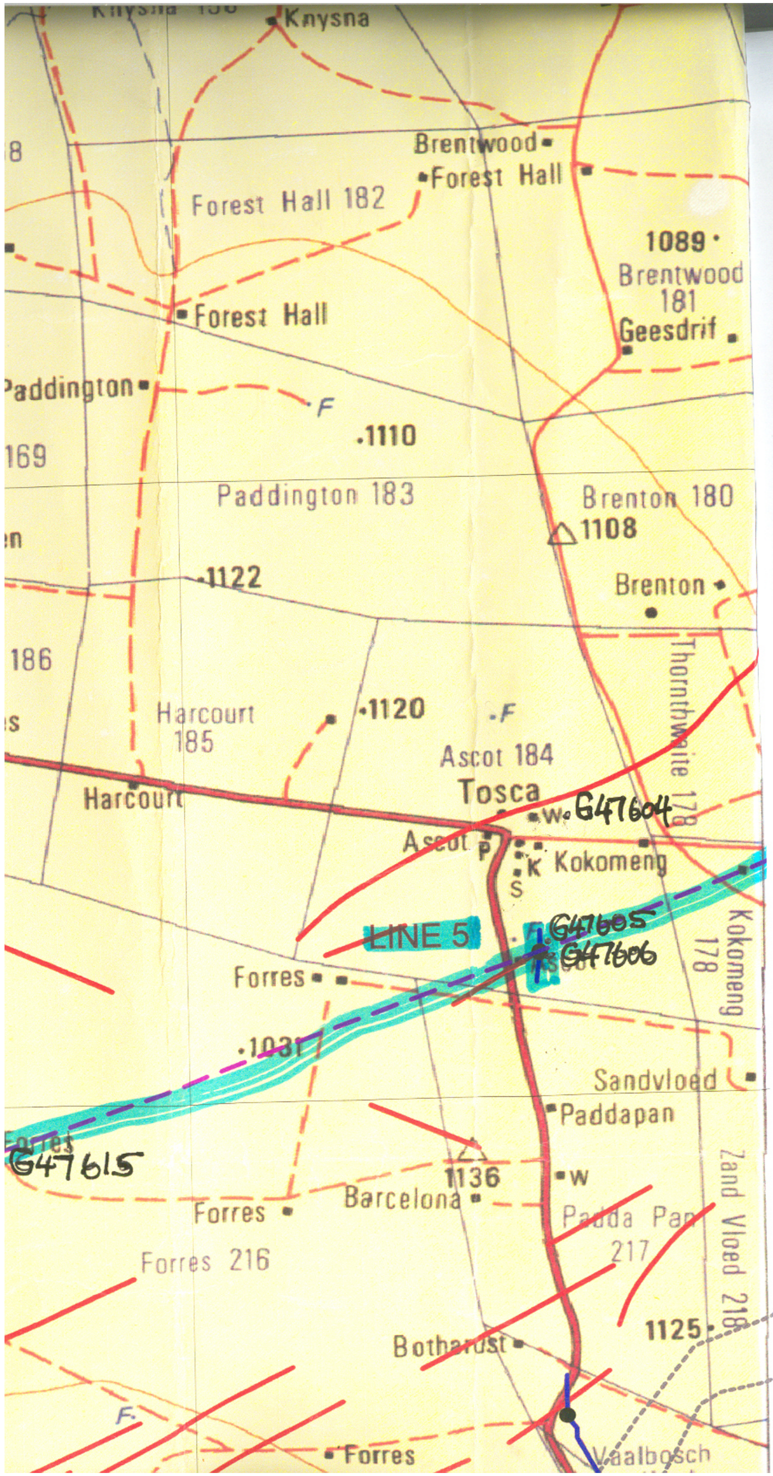


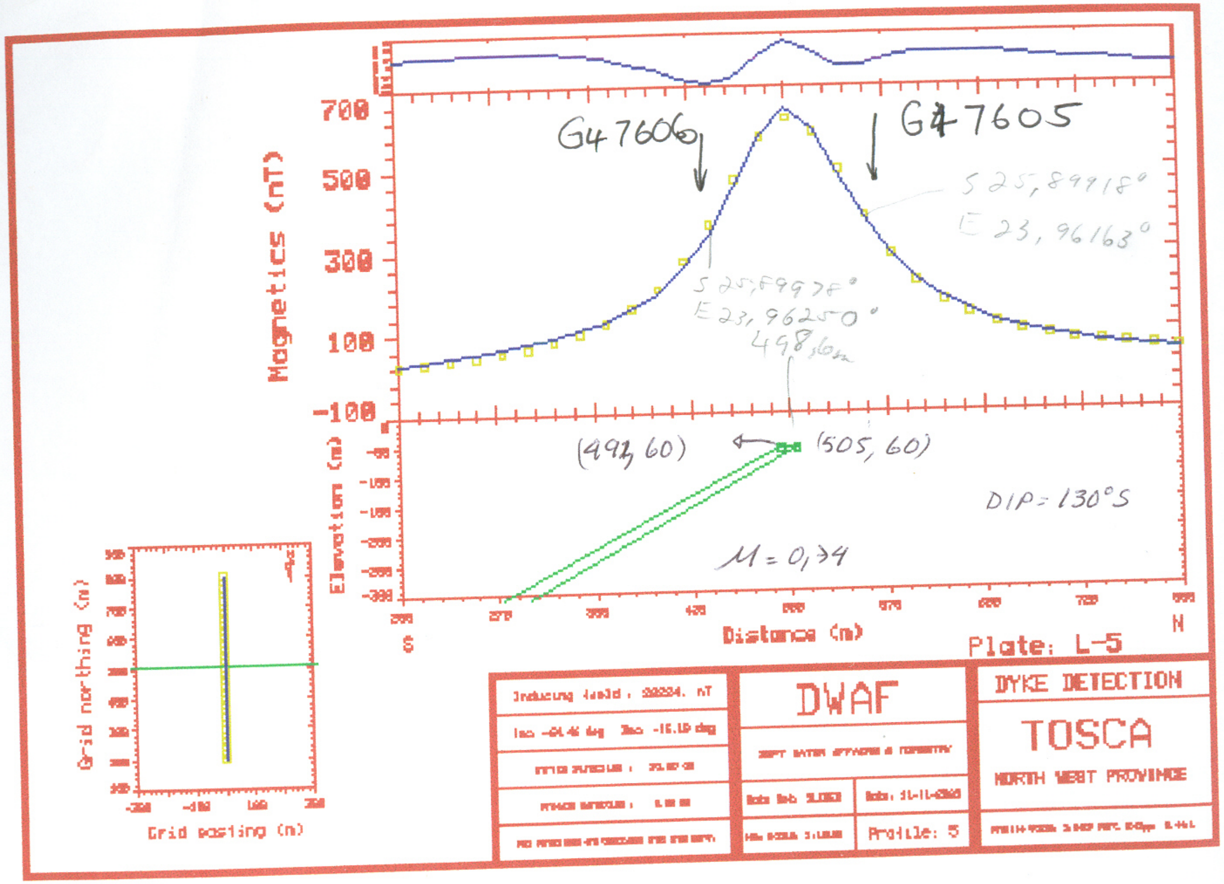
Magnetics Result Line 3. Tosca.



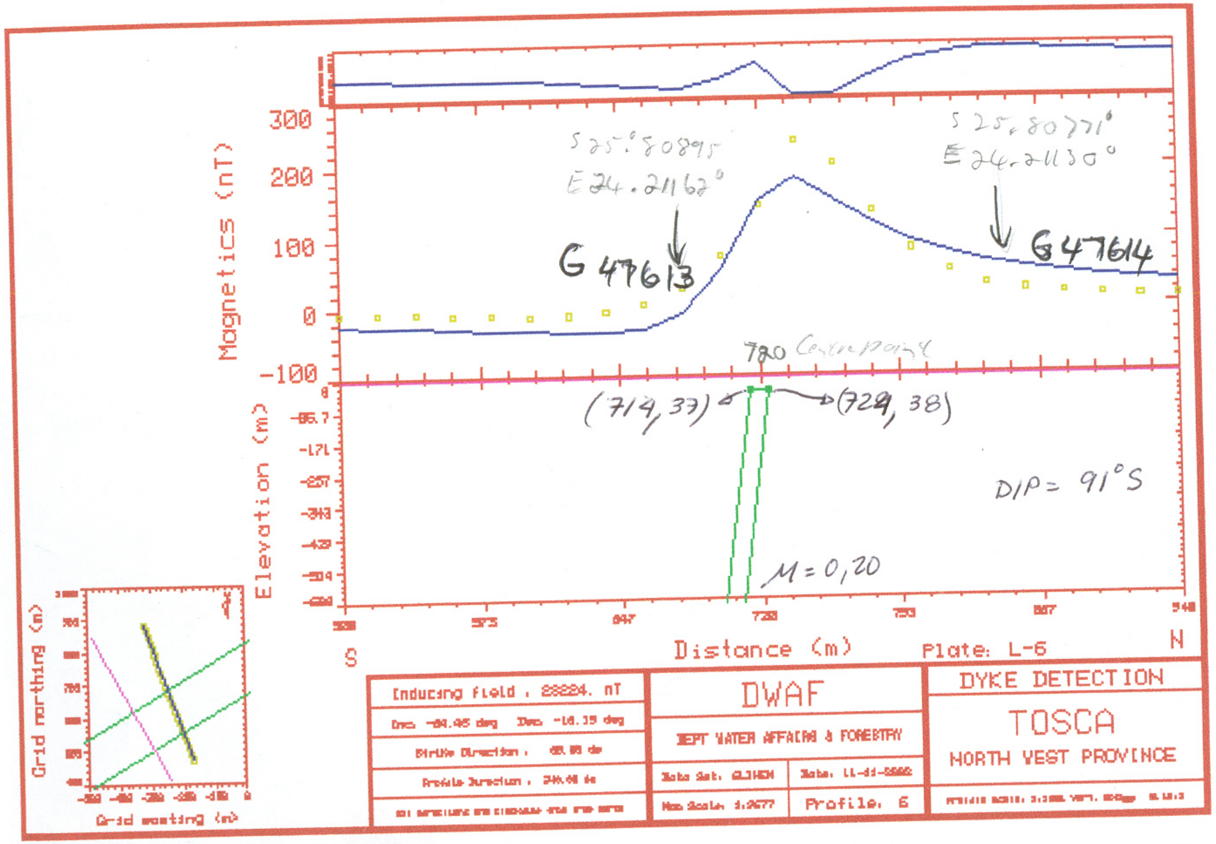


Magnetics Result Line 4. Tosca.





Magnetics Result Line 5. Tosca.



Magnetics Result Line 6. Tosca.

Appendix 4 Monitoring boreholes and water level records

Boorgat	Plaasnaam	Lat	Long	Alt Map	Apr-90	Apr-01	Aug-01	Jan-02	Apr-02	Aug-02	Mar-03	Aug-03	Apr-04
G39663	Thornthwaite	25.87782	24.0190	1100	19.65	29.82	bye	26.64	26.33	26.44	28.4	29.98	
G39664	Thornthwaite	25.8764	24.0191	1100	21.02	32.78	30.61	28.23	28.22	28.04	30.64	22.26	
G39665	Thornthwaite	25.8777	24.0190	1110	29.83	29.85	30.94	28.52	28.5	28.32	30.91	32.55	
G39666	Thornthwaite	………	………	1110	27.12							…….	
G39667	Vaalboschhoek	25.97224	23.9841	1128	17.43	19.44	18.8	18.5	18.54	18.68	19.26	hekgesluit	
G39668	Vaalboschhoek	25.96995	23.9794	1132	18.56	20.47	19.95	19.73	19.72	19.93	20.58	hekgesluit	
G39669	Marstone	25.88219	24.1134	1065	11.6	16.37	15.4	20.82	15.08	15.16	16.42	17.20	
G39670	Marstone	25.88143	24.1152	1080	17.53	22.07	21.05	15.02	20.71	20.74	22.11	22.82	
G39671	Elchester	25.84426	24.0988	1069	41.24	toe	52.95	53.78	62.23		65.05	66.60	
G39672	Belvidere	25.72285	23.9776	1079	43.02	46.43	46.05	43.81	45.2	45.98	46.94	47.40	
G39673	Blackheath	25.72102	24.2392	1086	71.2	75.99	76.09	76.11	76.19	76.22	76.59	76.70	
G39674	Belvidere	25.72919	23.9785	1079	47.73	52.71		53.26	53.58	53.85	54.84	toegeseel	
G39675	Grassbank	25.86012	23.8237	1130	24.5	droog			Toegeval	Toegeval	Toegeval	toegeval	
G39676	……………	………… ….	…………	1045	28	………						…….	
G39677	Waterbury	25.79589	23.8077	1120	30.73	35.32	37.02	36.05	38.66	pumping	Pumping	41.63	
G39678	Forres	25.98289	23.9416	1147	13.25	17.97	31.75		17.78	17.85	18.41	18.71	
G39679	Forres	25.94031	23.9343	1137	19.3	35.65	36.21	38.09	38.22	Toegeval	37.47	36.47	
G39680	Grassbank	25.83446	23.8390	1124	23.34	toe	67.53		Cable hakvas			kabelhak vas	
G39681	Forres	25.92779	23.9254	1134	18.75	46.55	45.24	43.93	46.39	Toegeval	Toegeval	toegeval	
G39682	Grassbank	25.8532	23.8387	1130	21.64	toe	……			73.7		kabelhak vas	
G39683	Forres	25.92356	23.9264	1132	22.5	42.13	42.5	42.63	42.85	42.91	43.64	43.97	
G39684	Quarreefontein	25.94892	23.8259	1161	6.6	5.87	4.73	4.47	4.77	Closed	5.93	6.67	
G39685	Forres	25.88696	23.8546	1123	25.86	68.57	65.79	71.31	73.87	72.69	83.22	86.27	
G39686	Kokomeng	25.89818	24.0077	1108	11.07	19.7	15.79	15.38	14.86	15.25	18.5	20.18	
G39687	Brentwood	25.79398	23.9755	1091	45.65	63.86	62.26	64.8	66.67	65.74	70	70.24	
G39688	Kokomeng	25.89811	24.0075	1108	11.21	19.39	15.69	15.35	14.83	15.11	18.14	19.88	
G39689	Kokomeng	25.89826	24.0078	1108	11.35	wortels	toegeval	toe geval	Toegeval	Toegeval	Toegeval	toegeval	
G39690	Zandvloed	25.93098	24.0429	1108	16.53	16.77	1613	14.93	13.53	13.87	15.68	17.12	
G39691	Thornthwaite	25.8767	24.0190	1100	19.38	33.01	28.41	26.66	26.39	26.46	28.49	30.30	
G39692	Thornthwaite	25.87797	24.0189	1100		29.71	bye	dry	26.24	26.31	28.37	30.01	
G39693	Knapdaar	25.67413	24.1444	1079	56.9	76.95	69.97	75.82	81.58	68.67	92.04	72.98	
G39694	Thornthwaite	25.87751	24.0190	1100	19.54	29.71	28.29	bye	26.23	26.34	28.38	29.90	
HK1	Hurstpark	25.78151	24.0553	1056		49.48	kabelhak vas	kabel hakvas	Cable hakvas	Cablehak vas	pumping	kabelhak vas	
HK2	Hurstpark	25.79156	24.0565	1070		53.62	72.38	55.92	57.6		pumping	Pumping	
BH1	Blackheath	25.68436	24.2376	1078		75.49	63.88	kabel hakvas	75.84	62.66	pumping	72.26	
BH2	Blackheath	25.68426	24.2318	1081		81.93	70	81.53	82.06	68.85	pumping	78.32	
FS1	Forres	25.93267	23.9224	1133		45.91	44.87	45.43	45.66	44.91	47.06	46.47	
FS2	Forres	25.93965	23.9311	1134		46.75	45.13	bye	47.33	45.35	48.1	47.04	
WD1	Westward	25.6482	24.2140	1065		65.2	55.24	bye	bye	55.82	bye/pumping	60.00	
GK1	Grassbank	25.85297	23.8389	1123		71.41	69.13	78.52	bye	73.72	94.15	60.14	
GK2	Grassbank	25.84345	23.8011	1123		74.7	68.67	79.57	sealed	Sealed	sealed	92.44	
RS2	Rhodes	25.8754	23.8660	1123		65.93	63.98	68.5	bye	70.36	78.73	80.90	
HT1	Harcourt	25.86621	23.9029	1122		66.25	62.52	bye	74.21	68.74	bye	85.14	
BE2	Buttermere	25.7918	24.0874	1068		55.03	52.86	52.97	54	50.1	pumping	52.78	
BE1	Buttermere	25.81397	24.1258	1078		63.13	62.25	63.56	Cable hakvas	Cablehak vas	cablevas	67.87	
AY	Albury	25.7424	24.0587	1055		49.3	38.35	40.33	49.85	38.13	pumping	41.07	
NI1	Nokani	25.96451	23.7483	1165		15.49	12.89	14.39	13.24	12.19	roots block	wortels	
FS1	Forres	25.91099	23.8727	1131		63.41	61.4	63.95	66.06	64.87	47.06		
VM1	Veerstriem	25.79173	23.8848	1105		48.96	54.34	64.9	73.52	50.72	86	67.09	

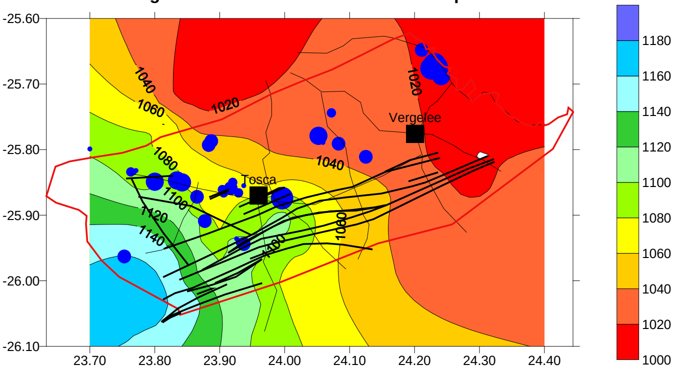
VM2	Veerstriem	25.79118	23.8845	1105		49.62	kabelhak vas	65.9	Cable hakvas	Cablehak vas	pumping	kabelhak vas	
FS3	Forres	25.92764	23.8746	1131		61	60.98	60.03	59.47	60.57	62.52	61.38	
WG2	Wynberg	25.83467	23.7656	1138		35.97	32.38	36.85	35.1	33.59	32.28	kabelhak vas	
WG1	Wynberg	25.82842	23.7797	1135		33.53	30.3	bye	33.82	Toegeval	Toegeval	toegeval	
JP1	Jakkalskop	25.80711	23.7020	1129		47.07	47.16	48.22	49.45	49.6	48.51	kabelhak vas	
BH3	Blackheath	25.67576	24.2401	1070			Kabel hakvas			Cablehak vas	sealed	toegeseel	
BH4	Blackheath	25.67988	24.2360	1070			Kabel hakvas		sealed	Cablehak vas	pumping	kabelhak vas	
TO2	Toledo	25.81819	24.3057	1078			64,71	75.03	75.24	65.59	pumping	71.43	
TO1	Toledo	25.8396	24.2907	1097			82,78	kabel hakvas	82.8	Cablehak vas	cablevas	kabelhak vas	
KD1		25.8359	24.3328	1080			69,40	75.41	79.59	69.47	pumping	80.88	
RN1	Rebon	25.83866	24.3449	1085			76,30	75.79	85.81	85.9	pumping	76.18	
NE 2	Navarre	25.79252	24.2193	1090			71,30	71.18	71.91	71.78	72.25	73.45	
NE 1	Navarre	25.7499	24.2269	1086			72,30	73.42	74.53	73.07	pumping	75.96	
NE 3	Navarre	25.78084	24.2125	1090			52,05	69.9	54.07	69.62	pumping	69.45	
SD 3	Stresfod	-25.781	24.213	1080							99.02	96.15	
SD 2	Stresfod	25.89272	24.2095	1095			47,31	47.31	47.40	47.7	-	47.93	
SD 1	Stresfod	25.8983	24.1872	1095			49,00	49.02	51.31	49.37	49.47	49.54	
SD 4	Stresfod	25.8873	24.2200	1092			41,35	41.35	41.25	41.19	41.61	41.59	
ID 1	Ierland	25.90943	24.2944	1101			81,70	81.5	83.97	81.78	pumping	82.11	
ID 2	Ierland	25.9121	24.2983	1100			92,43	92.1	92.11	92.09	dry	toegeval	
ID 3	Ierland	25.9107	24.2998	1100			92,00	toe geval	Toegeval		Toegeval	droog	
BN 1	Burton	25.88702	24.3058	1104			119,00	dry	dry				
VL 1	Vogel	25.87687	24.2900	1097			75,92	75.75	75.72	76	75.86	75.80	
VL 2	Vogel	25.88806	24.2723	1082			75,53	bye	56.98	57.7	62.29	58.05	
BN 2	Burton	25.90743	24.2729	1094			61,48	bye	61.51	61.65	61.45	61.36	
BY 3	Bradbury	25.90171	24.2239	1083			41,50	41.69	41.76		43.79	42.05	
BY 2	Bradbury	25.90726	24.2085	1094			59,05	56.25	55.04		52.93	51.72	
BY 1	Bradbury	25.89989	24.2279	1096			59,29	55.42	104.2		58.17	54.14	
HT 2	Harcourt	25.87772	23.9220	1126			61,53		72.89	67.87	81.55	82.32	
HT 3	Harcourt	25.88243	23.9279	1125			61,68	Sealed	sealed	Sealed	sealed		
HT 4	Harcourt	25.68008	23.9167	1125			63,68	Sealed	sealed	Sealed	sealed	kabelhak vas	
HT 5	Harcourt	25.85905	23.9163	1124			65,13	Sealed	sealed	Sealed	sealed	kabelhak vas	
QN1	Quarreefontein	25.8981	23.8365	1135			68.35		70.97	72.78	sealed	86.10	
QN2	Quarreefontein	25.8954	23.8479	1134			68.56	68.49	71.19	72.14	sealed	toegeseel	
MK1	Millbank	25.83957	23.7671	1138			35.48	38.23	36.9	35.46	41.58	37.61	
GK3	Grassbank	25.84554	23.8462	1130				78.9	85.9	73.56	94.3	90.58	
HT6	Harcourt	25.88367	23.8364	1125				68.72	sealed	Sealed			
VE1	Vrede	25.9677	23.7902	1171				8.57	7.85	Cablehak vas	cablevas	11.78	
VE2	Vrede	25.9613	23.8061	1167				6.57	7.89	Bee	bye	18.95	
HN1	Hulpalleen	25.9911	23.7363	1171				3.12	5.09	5.73	10.24	19.23	
QN3	Quarreefontein	25.9061	23.8933	1133				68.12	71.28	72.51	sealed	86.92	
QN4	Quarreefontein	25.89	23.8391	1133				68.98	71.6	73.18	79.85	droog	
QN5	Quarreefontein											80.96	
GE1	Gosike	25.84583	23.7333	1136				29.27	sealed		sealed	hekgesluit	
BM 1	BLENHEIM	25.7678	23.7490	1118					68.84	pumping	pumping	kabelhak vas	
BM 2	BLENHEIM	25.7673	23.7483	1118					60.84	58.6	10.6	60.48	
DN 1	DUNCAN	25.7509	23.7210	1104					124.02	121.71	120.08	126.79	
DN 2	DUNCAN	25.7229	23.7106	1091					140.02	pumping	pumping	113.15	
ST 1	SANDHURST	25.721	23.7713	1092					88.82	88.71	89.08	88.35	
EW 1	EUCHRE-HOLLOW	25.7139	23.7174	1088					149.64		pumping	111.39	
EW 2	EUCHRE-HOLLOW	25.7025	23.7113	1085					116.87	115.83	pumping	144.35	
EW 3	EUCHRE-	25.6807	23.7071	1078					150m		pumping	kabelhak	

	HOLLOW								cable-short			vas	
EW 4	EUCHRE-HOLLOW	25.6815	23.7072	1078					108.6	108.49	108.17	107.70	
ST 2	SANDHURST	25.718	23.7875	1088					90.92	90.04	90.36	89.32	
MD 1	MILLWOOD	25.711	23.8574	1084					52.01	51.47	81	51.17	
SR 1	SWEETWATER	25.7133	23.8999	1072					68.85	69.61	cable vas	kabelhak vas	
SR 2	SWEETWATER	25.7162	23.8861	1080					72.72	73.28	73.76	kabelhak vas	
KA 1	KYNSNA	25.7507	23.9234	1084					53.74	gate closed	54.75	55.11	
KA 2	KYNSNA	25.7549	23.9267	1084					53.72	gate closed	55.37	56.04	
MD 2	MILLWOOD	25.719	23.8243	1088					81.35	dry	50.43	80.82	
JP 2	JAKKALSKOP	25.8065	23.7015	1127					51.16	51	50.96	49.94	
JP 3	JAKKALSKOP	25.8078	23.7007	1128					72.02	dry	pumping	kabelhak vas	
GK 4	GRASSBANK	25.8429	23.8017						86.45	76.71	95.13		
GK 3	GRASSBANK	25.8429	23.8017	1133						73.56	94.3		
G44407		25.6119	23.4066							132.44	132.49	132.51	
G44405		25.3146	23.4753							96.4	97.13	96.82	
G44406		25.538	23.3907							119.32	119.63	119.31	
G44408		25.6757	23.2383							139.25	139.63	139.17	
G44409	Voorstershoop	25.8301	23.0136							bee	bye	....	
NI 2	Nokani	25.9629	23.7488	1183						12.19	14.3	....	
TT 8	Tennant	-25.667	23.974	1062							56.85	....	
GK 2	Gosike	-25.829	23.715	1146							33.49	hekgesluit	
MK 2	Millbank	-25.841	23.762	1151							44.13	46.87	
MK 5	Uenice(Millbank)	-25.857	23.787	1161							99.13	96.86	
DE 1	Deelfontein	-25.93	23.754	1175							6.89	7.81	
DE 2	Deelfontein	-25.93	23.754	1170							6.78	7.59	
RK 5	Molopo River	-25.727	24.284	1086							4.76	......	
RK7	Molopo River	-25.715	24.312	1089							72.76	......	
HK 3	Hurstpark	-25.791	24.056	1078							63.53	62.00	
BW 5	Birnanwood	-25.742	24.059	1083							46.14	....	
KS 5	Kameeldoorn	-25.773	24.773	1084							47.79	......	
RP 1	Roukoop	-25.636	24.115	1087							48.66	.....	
MY 1	Mcgaysfolly	......	....	......								4.92	
MY2	Mcgaysfolly	....	.	...								12.19	
MY 3	Mcgaysfolly	......	....	......								12.19	
MK 6	Uenice(Millbank)	....	....	...								40.19	
HT 7	Harcourt	......	....	......								70.60	

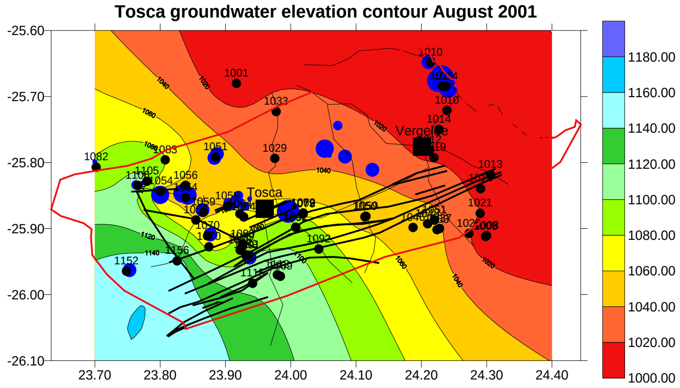
Appendix 5 Ground water level elevation maps.

Groundwater elevation contour maps for pre-1974, 1990, April 2001, Aug 2001, April 2002 and April 2003 to indicate the flow dynamics. (Prepared with Surfer C 8.02 Oct 02 from approximately 100 monitoring boreholes. The April 2003 contours were prepared with the dyke fault line option which is a better representation.

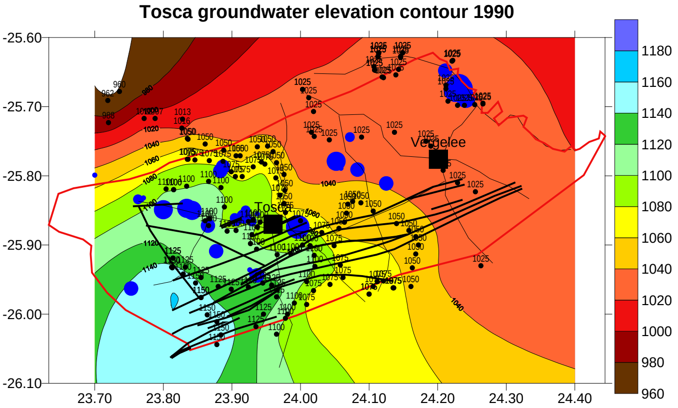
Tosca groundwater level elevation contour pre 1974



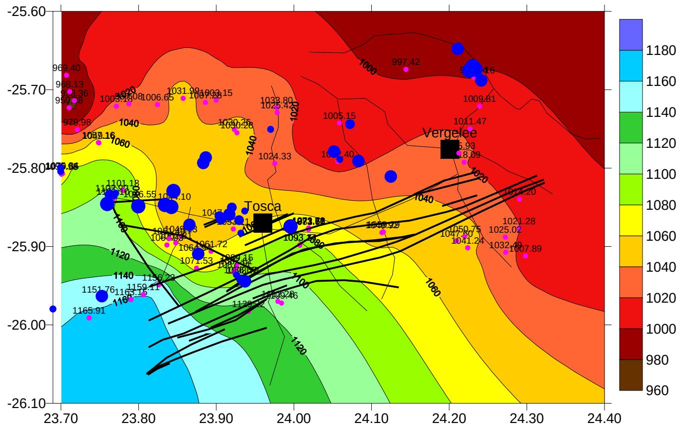
Tosca groundwater elevation contour August 2001



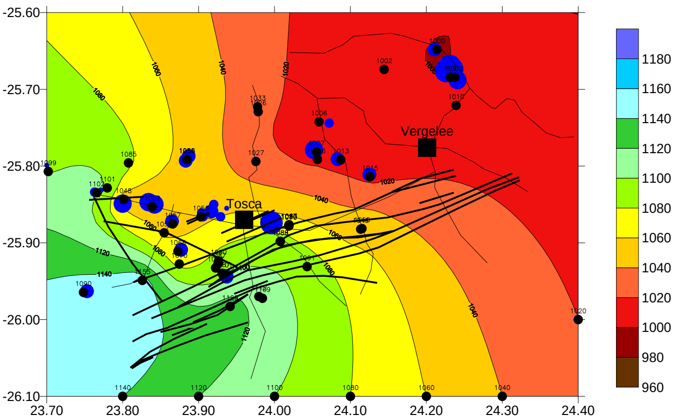
Tosca groundwater elevation contour 1990



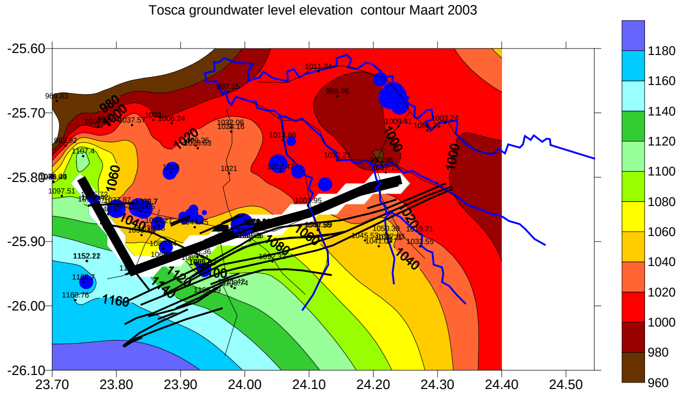
Tosca groundwater level elevation contour April 02



Tosca groundwater elevation level contour April 2001



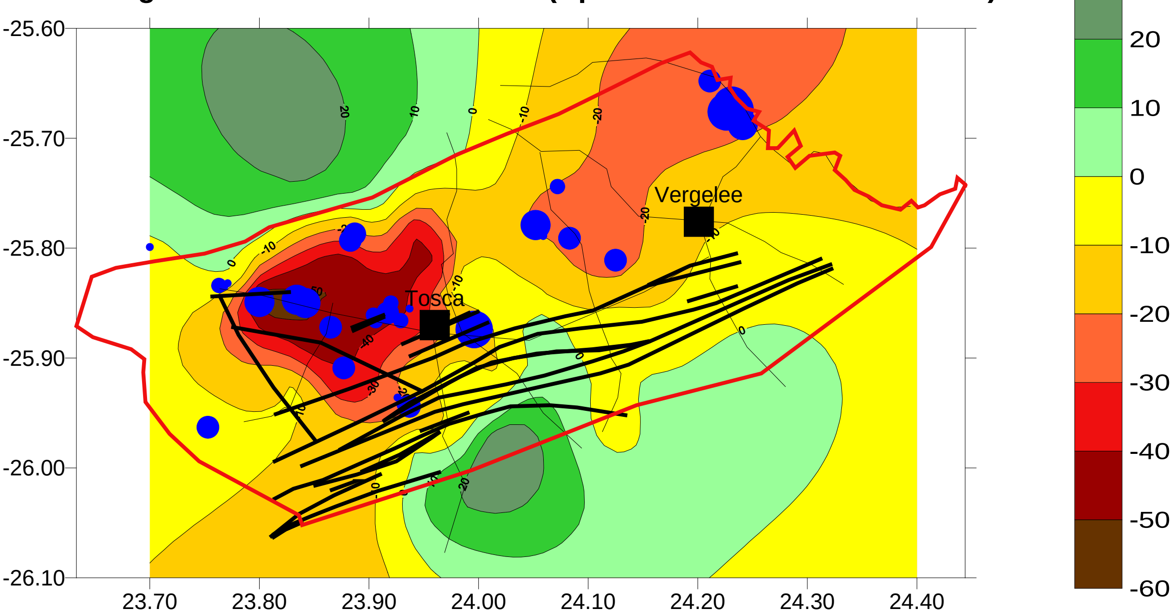
Tosca groundwater level elevation contour Maart 2003



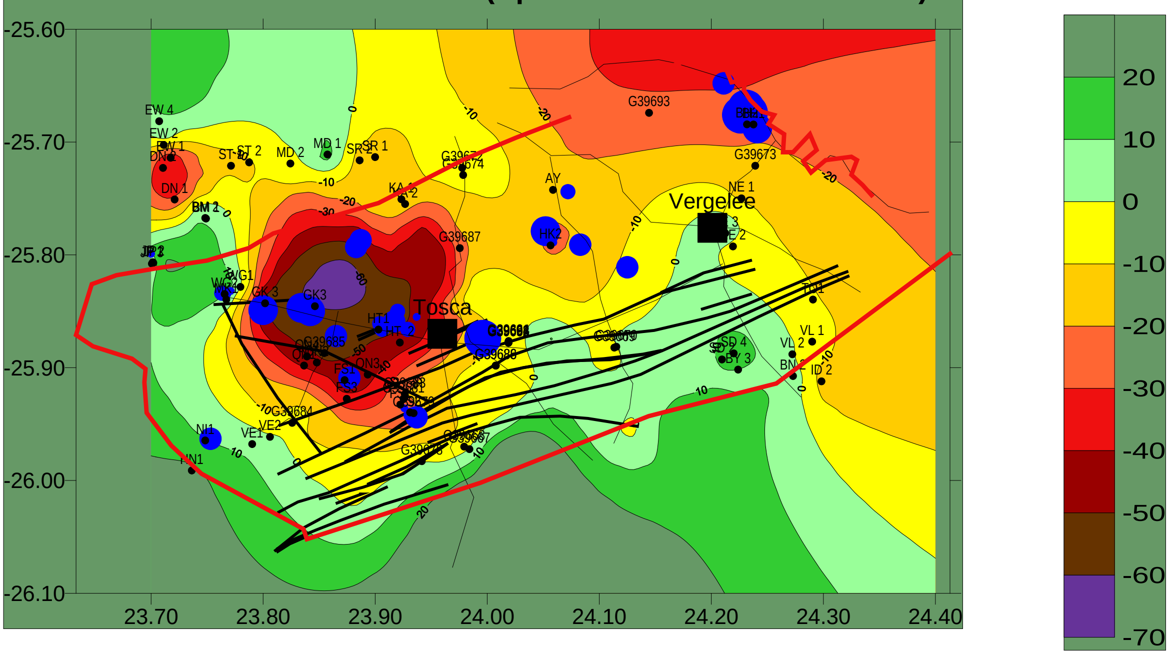
Appendix 6 Groundwater elevation difference contour maps.

Groundwater elevation difference contour maps to indicate how the water level declined

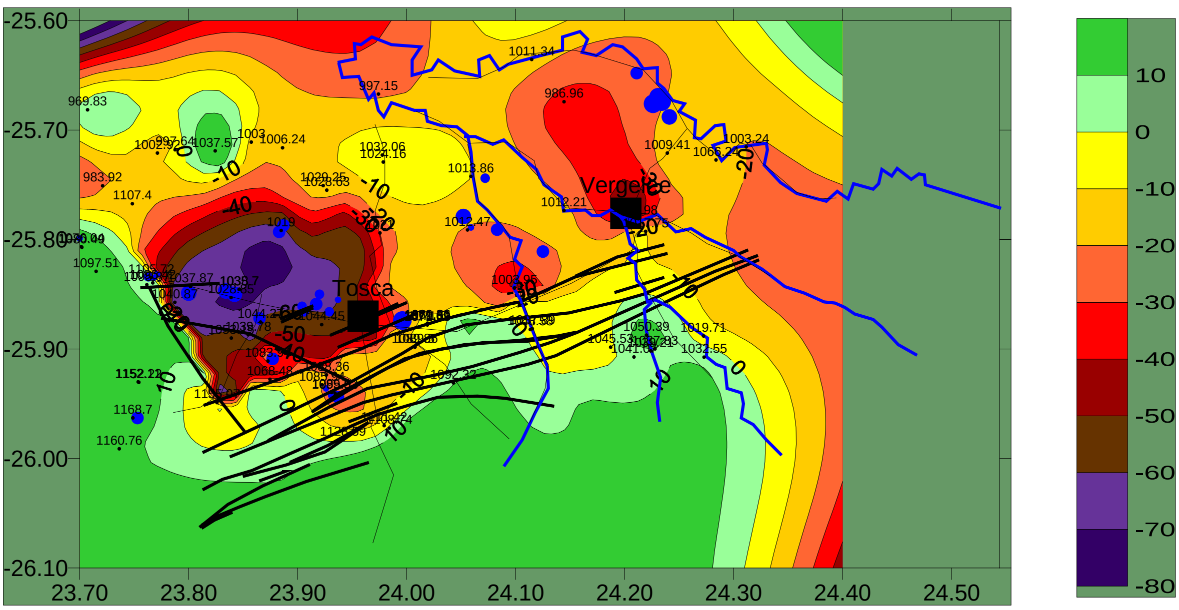
Tosca groundwater level difference (April 2001 m below 1990 levels)



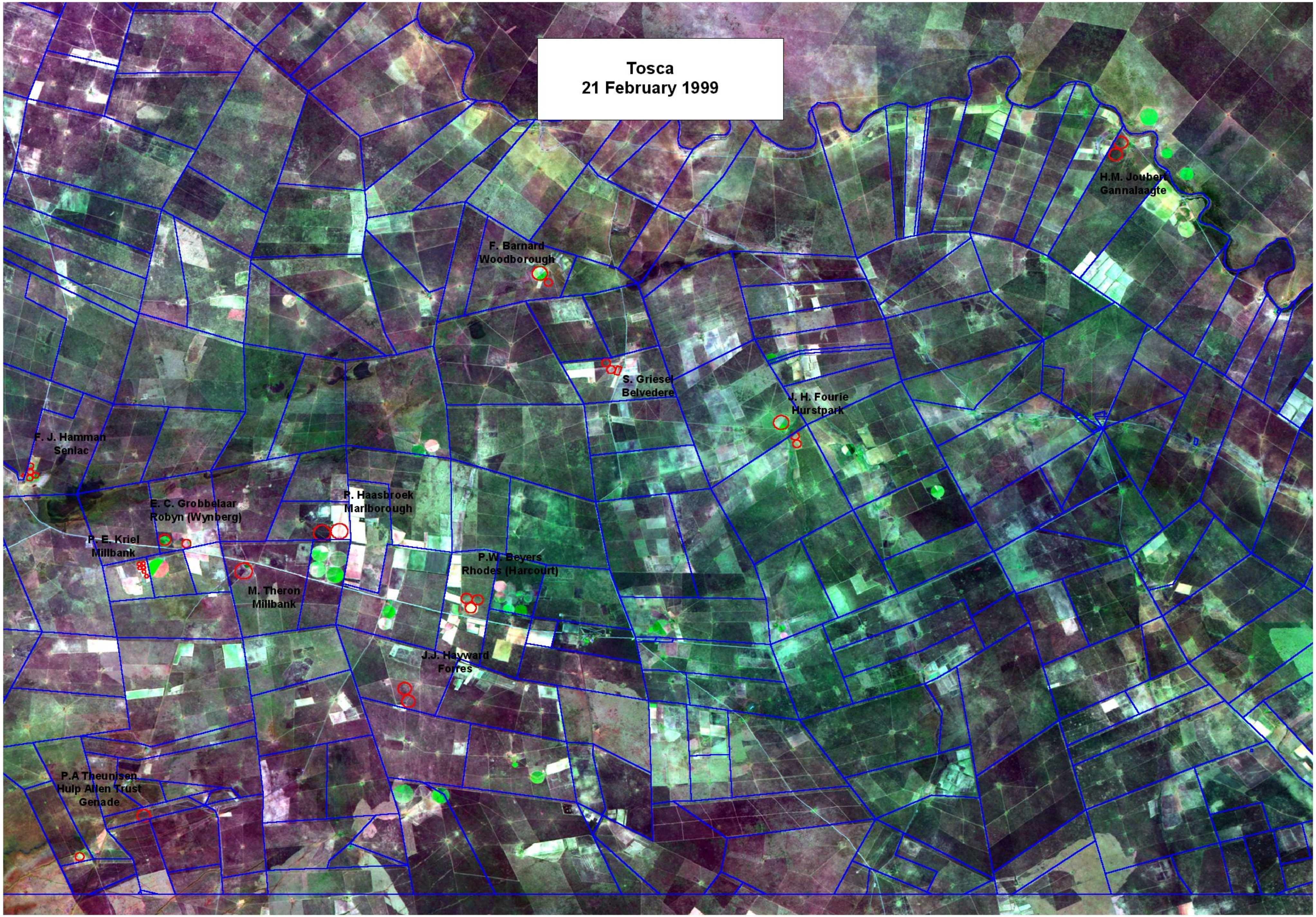
Tosca waterlevel difference (April 2002 m below 1990 levels)

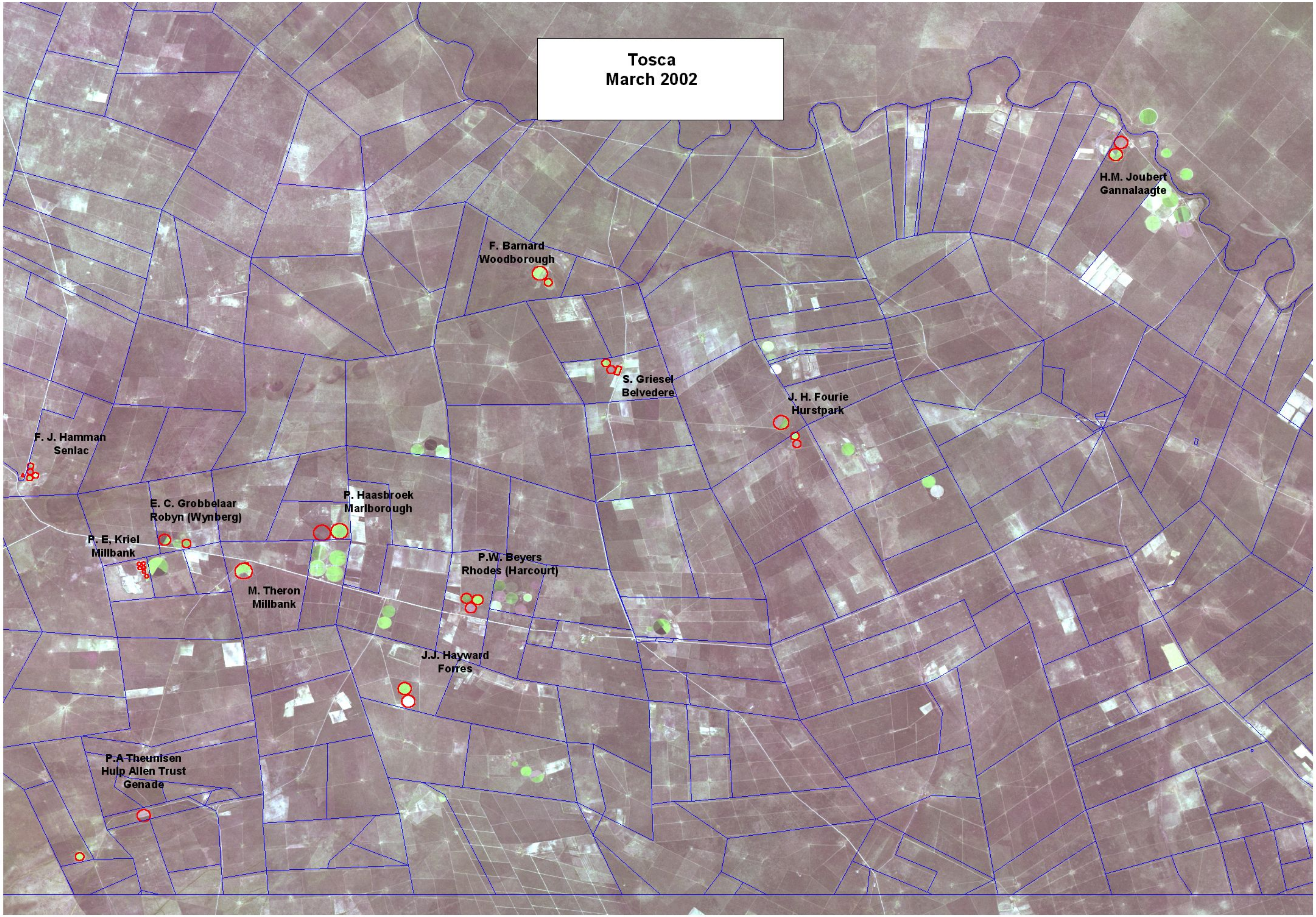


Tosca groundwater level difference (Maart 2003 m below 1990 waterlevels)



Appendix 7 Satellite Images from February 1999 and March 2002 used to identify areas developed after Oct 1998.


Tosca
21 February 1999
H.M. Joubert
Gannalaagte
F. Barnard
Woodborough
S. Griesel
Belvedere
J. H. Fourie
Hurstpark
F. J. Hamman
Senlac
P. Haasbroek
Marlborough
E. C. Grobbelaar
Robyn (Wynberg)
P. E. Kriel
Millbank
P.W. Beyers
Rhodes (Harcourt)
M. Theron
Millbank
J.J. Hayward
Forres
P.A Theunisen
Hulp Allen Trust
Genade


Tosca
March 2002
H.M. Joubert
Gannalaagte
F. Barnard
Woodborough
S. Griesel
Belvedere
J. H. Fourie
Hurstpark
F. J. Hamman
Senlac
P. Haasbroek
Marlborough
E. C. Grobbelaar
Robyn (Wynberg)
P. E. Kriel
Millbank
P.W. Beyers
Rhodes (Harcourt)
M. Theron
Millbank
J.J. Hayward
Forres
P.A Theunisen
Hulp Allen Trust
Genade

Appendix 8 Schedule of authorized users and volume as in April 2004.

Reg no:	Name	Farm Description	Title deed number	Volume Registered (m3/a)	Use exceeding 75000 (m3/a)	Total restricted use (m3/a)
25009473	F.V.Z. Engelbrecht	Albury farm no. 171 portion no. 2	T2601/1994	264000	189000	188400
10081001	Tosca Trust	Ascot farm no. 184 portion no. 0-remaining extent	T302/2000	187000	112000	142200
10082527	Fanie Griesel Trust	Belvidere Farm No. 157	T63/2000	65760	0	65760
25021949	W.H. Simmons	Belvidere farm no. 157 portion no 1	T3027/2002	51393	0	51393
10081225	Carroll Family Enterprises	Blackheath farm no. 90 portion no. 0-remaining extent	T1802/2001	1735000	1660000	1071000
25017213	J.H. Fourie	Blanco Farm no. 173 portion no. 1	T3321/1999	64543	0	64543
10081378	J.C.C. Grobbelaar	Brenton farm no. 180 portion no. 0-remaining extent	T1352/1979	69954	0	69954
25007821	Avon Trust	Brentwood Farm No 181 Portion 1	T4173/2000	74112	0	74112
10081252	Eben Du Toit	Brentwood farm no. 181 portion no. 0-remaining extent	T215/1996	74112	0	74112
10081412	J.P. van den Berg	Buttermere farm no. 1017 portion no. 0	T1913/1998	1035000	960000	651000
25007698	Clearstream Trust	Clearstream Farm No. 168 Portion No. 0	T493/2000	585000	510000	381000
25021976	K. van der Heever	Deelfontein Farm no. B215 remaining extent	T857/1986	102780	27780	91668
10081298	P.M. Fourie	Elchester farm no. 174 portion no. 1	T1283/2001	112080	37080	97248
25006831	Johan en Esta Theron Familie Trust	Forres	T489/2000	90000	15000	84000
10081190	W.C. Kriel	Forres farm no. 216 portion no. 2	T285/1989	335950	260950	231570
25008679	J.J. Hayward	Forres farm no. 216 portion no. 5	T1467/1997	95458	20458	87275
25021280	Zenith Ranch (Pty. Ltd)	Forres farm no. 216 portion no. 8	T1663/2000	258300	183300	184980
25000310	Leamy Family Trust	Forrest Hall farm no. 182 portion no. 0	T2109/2001	153870	78870	122322
10081181	H.M. Joubert	Gannalaagte farm no. 6 portion no. 0	T2667/1996	90250	15250	84150
25017972	Hulp Alleen Familie	Genade Farm 209 Portion 0 - Remaining extent		130500	55500	108300

25021412	Fransua Stolz Trust	Grassbank Farm No. 187 Portion No. 0-Remaining extent	T742/1995	1202500	1127500	751500
10081216	Emtron Bdy	Grassbank farm no. 187 portion no. 2	T1725/1999	367500	292500	250500
	K. van der Heever	Harcourt farm no. 185 portion no. 0-remaining extent	T603/1968	37242	0	37242
New Owner	Beyer Trust	Harcourt farm no. 185 portion no. 0-remaining extent	T1466/2003	360000	285000	246000
10081350	Leniesdeel Trust	Harcourt farm no. 185 portion no. 1	T2840/1995	655100	580100	423060
25003638	M. Hamman	Hastings farm no. 142 portion no. 0-remaining extent	T931/1988	35000	0	35000
10081323	J.H. Fourie	Hurstpark Farm No. 170	T212/1988	255400	180400	183240
25002675	S.G. Griesel	Kokomeng farm no. 178 portion no. 2	T148/2001	18000	0	18000
	Rose	Kokomeng		68100	0	68100
25021930	I de Beer	Koodooskop farm no. 206 portion no. 0-remaining extent	T1715/2001	67560	0	67560
25004753	A.C.J. Du Plessis	Libertas-Zand vloed farm no. 218 portion no. 1-remaining extent	T1589/1983	79800	4800	77880
25021921	P J Haasbroek	Marlborough farm no. 167 portion no. 0-remaining extent	T2010/2001	42818	0	42818
10081261	P.E. Kriel	Millbank farm no. 188 portion no. 1-remaining extent	T635/1994	124250	49250	104550
25001514	M. Theron	Millbank farm no. 188 portion no. 2	T2209/1999	25710	0	25710
10084865	Sandtrap Boerdery	Millbank farm no. 188 portion no. 3		525000	450000	345000
	I de Beer	Nokani		67560	0	67560
25018203	F.J. Hamman	Nokani Farm No. 208 Portion No. 2-Remaining extent	T2693/1997	15420	0	15420
10081243	P.A. Theunissen	Nokani farm no. 208 portion no. 3-remaining extent	T1015/1988	225000	150000	165000
25022573	Centwise BK	Nokani farm no. 208 remaining extent	T191/1988	74250	0	74406
25018196	Pretorius	Quareefontein Farm No. 212 Portion No.1	T2665/2001	77097	2097	76258
25007028	J.H. Nieuwoudt	Quareefontein farm no. 212 portion no. 2	T4582/1998	145000	70000	117000
25021404	Fransua Stolz Trust	Rhodes Farm No. 186 Portion No. 0	T1421/2000	411000	336000	276600
10081314	F.J. Hamman	Senlac farm no. 143 portion no. 0-remaining extent	T350/1977	212800	137800	157680
25003503	W.H.A. Hamman	Stilton farm no. 189 portion no. 23	T2278/1996	127000	52000	106200

25020726	JAS Simmons	Tennant farm no. 152 portion no. 0-remaining extent	T648/1967	45600	0	45600
10081387	D.B. Grobbelaar	Thornthwaite farm no. 179 portion no. 0	T973/1978	482000	407000	319200
10081163	Kwagga Molopo Trust	Thornwick farm no. 175 portion no. 0-remaining extent	T2787/2002	121600	46600	102960
10081430	A.M. Steyn	Vaalboschoek Farm 227 Portion 1	T452/1995	114000	39000	98400
25021912	G H Stolz trust	Willarie 1019 portion no. 0		61671	0	61671
10081289	F. Barnard	Woodborough farm no. 159 portion no. 0	T374/1987	487500	412500	322500
25007732	Avon Trust	Woodborough farm no. 159 portion no. 1	T1115/2003	120000	45000	102000
10081369	E.C. Grobbelaar	Wynberg farm no. 165 portion no. 1	T1046/1977	612000	537000	397200
				12838540	**9329735**	**9106802**

Appendix 9 Survey of irrigation areas.

ID	AREA (Ha)	LANDID	FARMID	FARMNAME	Initial	Surname	Type irrigation	Crop
1	4.41	T0JM00000000018900004L1	T0JM00000000018900004	HASTING	H	HAMMAN	SPRINKEL	UK
2	2.64	T0JM00000000018900004L2	T0JM00000000018900004	HASTING	H	HAMMAN	SPRINKEL	UK
3	8.49	T0JM00000000018900004L3	T0JM00000000018900004	HASTING	H	HAMMAN	SPRINKEL	UK
4	6.58	T0JM00000000014300000S4	T0JM00000000014300000	SENLAC	N	HAMMAN	SPILPUNT	UK
5	6.58	T0JM00000000014300000S3	T0JM00000000014300000	SENLAC	N	HAMMAN	SPILPUNT	KORING
6	6.48	T0JM00000000014300000S2	T0JM00000000014300000	SENLAC	N	HAMMAN	SPILPUNT	PAPRIKA
7	6.48	T0JM00000000014300000S1	T0JM00000000014300000	SENLAC	N	HAMMAN	SPILPUNT	KORING
8	2.36	T0JM00000000018900001S1	T0JM00000000018900001	MILLBANK	PE	KRIEL	SPILPUNT	PAPRIKA
9	2.36	T0JM00000000018900001S2	T0JM00000000018900001	MILLBANK	PE	KRIEL	SPILPUNT	UK
10	2.36	T0JM00000000018900001S3	T0JM00000000018900001	MILLBANK	PE	KRIEL	SPILPUNT	UK
11	2.36	T0JM00000000018900001S5	T0JM00000000018900001	MILLBANK	PE	KRIEL	SPILPUNT	UK
12	2.36	T0JM00000000018900001S6	T0JM00000000018900001	MILLBANK	PE	KRIEL	SPILPUNT	UK
13	2.36	T0JM00000000018900001S4	T0JM00000000018900001	MILLBANK	PE	KRIEL	SPILPUNT	UK
14	72.28	T0JM00000000018800000S4	T0JM00000000018800000	MILLBANK	RA	PRETORUIS	SPILPUNT	UK
15	20.24	T0JM00000000018800000S3	T0JM00000000018800000	MILLBANK	J	THERON	SPILPUNT	UK
16	20.24	T0JM00000000018800000S2	T0JM00000000018800000	MILLBANK	J	THERON	SPILPUNT	UK
17	14.15	T0JM00000000018800003S2	T0JM00000000018800003	WYNBERG	N	GROBBELAAR	SPILPUNT	UK
18	13.73	T0JM00000000018800003S1	T0JM00000000018800003	WYNBERG	N	GROBBELAAR	SPILPUNT	PAPRIKA
19	24.01	T0JM00000000018800003S3	T0JM00000000018800003	WYNBERG	N	GROBBELAAR	SPILPUNT	UK
20	29.94	T0JM00000000021000001S1	T0JM00000000021000001	HULP-ALLEEN	P	THEUNISSEN	SPILPUNT	KORING
21	12.63	T0IM00000000020900000S1	T0IM00000000020900000	KOEDOESKOP	P	THEUNISSEN	SPILPUNT	KORING
22	51.21	T0JM00000000018800000S1	T0JM00000000018800000	MILLBANK	M	THERON	SPILPUNT	UK
23	50.75	T0JM00000000018700000S3	T0JM00000000018700000	GRASBANK	G	SCHOLZ	SPILPUNT	PAPRIKA
24	50.75	T0JM00000000018700000S4	T0JM00000000018700000	GRASBANK	G	SCHOLZ	SPILPUNT	UK
25	48.99	T0JM00000000018700000S6	T0JM00000000018700000	MALBOROUGH	P	HAASBROEK	SPILPUNT	UK
26	48.99	T0JM00000000018700000S5	T0JM00000000018700000	MALBOROUGH	P	HAASBROEK	SPILPUNT	UK
27	50.76	T0JM00000000018700000S2	T0JM00000000018700000	GRASBANK	G	SCHOLZ	SPILPUNT	UK
28	50.76	T0JM00000000018600000S2	T0JM00000000018600000	GRASBANK	G	SCHOLZ	SPILPUNT	UK
29	50.76	T0JM00000000018600000S1	T0JM00000000018600000	GRASBANK	G	SCHOLZ	SPILPUNT	UK
30	50.76	T0JM00000000018700000S1	T0JM00000000018700000	GRASBANK	G	SCHOLZ	SPILPUNT	PAPRIKA
31	30.00	T0JM00000000021600005S2	T0JM00000000021600005	RHODES	G	SCHOLZ	SPILPUNT	UK
32	30.00	T0JM00000000021600005S1	T0JM00000000021600005	RHODES	G	SCHOLZ	SPILPUNT	UK
33	30.64	T0JM00000000021600004S1	T0JM00000000021600004	FORES	J	HAYWARD	SPILPUNT	UK
34	30.64	T0JM00000000021600004S2	T0JM00000000021600004	FORES	J	HAYWARD	SPILPUNT	UK

35	20.71	T0JM00000000018500000S2	T0JM00000000018500000	RHODES	PW	BEYER	SPILPUNT	UK
36	20.71	T0JM00000000018500000S3	T0JM00000000018500000	RHODES	PW	BEYER	SPILPUNT	PAPRIKA
37	20.71	T0JM00000000018500000S1	T0JM00000000018500000	RHODES	PW	BEYER	SPILPUNT	KORING
38	22.88	T0JM00000000018500002S10	T0JM00000000018500002	HARCOURT	J	FOURIE	SPILPUNT	UK
39	22.88	T0JM00000000018500002S9	T0JM00000000018500002	HARCOURT	J	FOURIE	SPILPUNT	UK
40	22.88	T0JM00000000018500002S8	T0JM00000000018500002	HARCOURT	J	FOURIE	SPILPUNT	UK
41	25.19	T0JM00000000018500002S3	T0JM00000000018500002	HARCOURT	J	FOURIE	SPILPUNT	UK
42	25.19	T0JM00000000018500002S4	T0JM00000000018500002	HARCOURT	J	FOURIE	SPILPUNT	UK
43	23.08	T0JM00000000018500002S7	T0JM00000000018500002	HARCOURT	J	FOURIE	SPILPUNT	UK
44	23.08	T0JM00000000018500002S6	T0JM00000000018500002	HARCOURT	J	FOURIE	SPILPUNT	UK
45	23.08	T0JM00000000018500002S5	T0JM00000000018500002	HARCOURT	J	FOURIE	SPILPUNT	UK
46	10.69	T0JM00000000018500002S1	T0JM00000000018500002	HARCOURT	J	FOURIE	SPILPUNT	KORING
47	51.56	T0JN00000000017900000S1	T0JN00000000017900000	THORNTHWAITE	DB	GROBBELAAR	SPILPUNT	KORING
48	30.27	T0JN00000000017500000S2	T0JN00000000017500000	THORNWICK	K	VAN DE BERG	SPILPUNT	UK
49	30.27	T0JN00000000017500000S1	T0JN00000000017500000	THORNWICK	K	VAN DE BERG	SPILPUNT	PAPRIKA
50	30.38	T0JN00000000017200000S1	T0JN00000000017200000	BUTTERMERE	K	VAN DEN BERG	SPILPUNT	UK
51	12.34	T0JN00000000017300000S2	T0JN00000000017300000	HURSTPARK	JH	FOURIE	SPILPUNT	KORING
52	12.34	T0JN00000000017300000S1	T0JN00000000017300000	HURSTPARK	JH	FOURIE	SPILPUNT	UK
53	40.24	T0JN00000000017000000S1	T0JN00000000017000000	HURSTPARK	JH	FOURIE	SPILPUNT	KORING
54	20.18	T0JN00000000017100000S6	T0JN00000000017100000	ALBURY-SONOP	FVZ	ENGELBRECHT	SPILPUNT	GRAS
55	20.18	T0JN00000000017100000S5	T0JN00000000017100000	ALBURY-SONOP	FVZ	ENGELBRECHT	SPILPUNT	GRAS
56	20.18	T0JN00000000017100000S1	T0JN00000000017100000	ALBURY-SONOP	FVZ	ENGELBRECHT	SPILPUNT	GRAS
57	20.18	T0JN00000000017100000S3	T0JN00000000017100000	ALBURY-SONOP	FVZ	ENGELBRECHT	SPILPUNT	RUS
58	20.18	T0JN00000000017100000S2	T0JN00000000017100000	ALBURY-SONOP	FVZ	ENGELBRECHT	SPILPUNT	GRAS
59	20.18	T0JN00000000017100000S4	T0JN00000000017100000	ALBURY-SONOP	FVZ	ENGELBRECHT	SPILPUNT	AARTAPPEL
60	12.51	T0JM00000000018100000S1	T0JM00000000018100000	BELVEDERE	SG	GRIESEL	SPILPUNT	KORING
61	12.51	T0JM00000000015700000S1	T0JM00000000015700000	BELVEDERE	SG	GRIESEL	SPILPUNT	UK
62	11.22	T0JM00000000015800000S2	T0JM00000000015800000	WOODBOROUGH	F	BARNARD	SPILPUNT	UK
63	40.35	T0JM00000000015800000S1	T0JM00000000015800000	WOODBOROUGH	F	BARNARD	SPILPUNT	UK
64	47.67	T0JN00000000009000000S1	T0JN00000000009000000	BLACKHEATH	CJ	CAROL	SPILPUNT	UK
65	39.60	T0JN00000000009000000S7	T0JN00000000009000000	BLACKHEATH	CJ	CAROL	SPILPUNT	UK
66	39.60	T0JN00000000009000000S6	T0JN00000000009000000	BLACKHEATH	CJ	CAROL	SPILPUNT	GRAS
67	39.60	T0JN00000000009000000S5	T0JN00000000009000000	BLACKHEATH	CJ	CAROL	SPILPUNT	UK
68	39.60	T0JN00000000009000000S3	T0JN00000000009000000	BLACKHEATH	CJ	CAROL	SPILPUNT	KORING
69	39.60	T0JN00000000009000000S4	T0JN00000000009000000	BLACKHEATH	CJ	CAROL	SPILPUNT	KORING
70	47.67	T0JN00000000009000000S2	T0JN00000000009000000	BLACKHEATH	CJ	CAROL	SPILPUNT	UK
71	2.81	T0JN00000000009000000L2	T0JN00000000009000000	BLACKHEATH	CJ	CAROL	DROE LAND	UK
72	2.41	T0JN00000000009000000L1	T0JN00000000009000000	BLACKHEATH	CJ	CAROL	DROE LAND	UK

73	4.77	T0JN00000000017900000L1	T0JN00000000017900000	THORNTHWAITE	DB	GROBBELAAR	SPRINKEL	KORING
74	1.00	T0JM00000000018700000L4	T0JM00000000018700000	GRASBANK	G	SCHOLZ	SPRINKEL	GRAS
75	1.17	T0JM00000000018700000L2	T0JM00000000018700000	GRASBANK	G	SCHOLZ	SPRINKEL	GRAS
76	0.35	T0JM00000000018700000L1	T0JM00000000018700000	GRASBANK	G	SCHOLZ	SPRINKEL	GRAS
77	0.85	T0JM00000000018700000L3	T0JM00000000018700000	GRASBANK	G	SCHOLZ	SPRINKEL	GRAS
78	1.19	T0JM00000000021600005L1	T0JM00000000021600005	RHODES	G	SCHOLZ	SPRINKEL	UK
79	3.07	T0JM00000000021600005L2	T0JM00000000021600005	RHODES	G	SCHOLZ	SPRINKEL	UK
80	0.78	T0JM00000000018800000L1	T0JM00000000018800000	MILLBANK	M	THERON	SPRINKEL	GRAS
81	2.33	T0JM00000000018800000L2	T0JM00000000018800000	QUARRIEFONTEIN			SPRINKEL	PAPRIKA
82	1.22	T0JM00000000014300000B1	T0JM00000000014300000	SENLAC	N	HAMMAN	DRIP	OLYFBOOM
83	30.24	T0JM00000000101600000S3	T0JM00000000101600000	FORREST HALL	D	VAN ZYL	SPILPUNT	UK
84	29.99	T0JM00000000101600000S2	T0JM00000000101600000	FORREST HALL	D	VAN ZYL	SPILPUNT	UK
85	29.99	T0JM00000000101600000S1	T0JM00000000101600000	FORREST HALL	D	VAN ZYL	SPILPUNT	UK
86	31.15	T0JN00000000000700000S1	T0JN00000000000700000	WESTWARD HO	V	LE ROUX	SPILPUNT	KORING
87	30.49	T0JN00000000000700000S2	T0JN00000000000700000	WESTWARD HO	V	LE ROUX	SPILPUNT	KORING
88	10.69	T0JM00000000018500002S2	T0JM00000000018500002	HARCOURT	J	FOURIE	SPILPUNT	UK
1	1.49	T0JM00000000018100000L1	T0JM00000000018100000	BRENTWOOD	E	DU TIOT	DRIP	UK
2	9.88	T0JM00000000018100000L1	T0JM00000000018100000	BELVEDERE	SG	GRIESEL	SPRINKEL	GRAS
Total	**1993.41**							

Appendix 10 Example abstraction control by means of an agreement between the responsible authority and user and reporting by the user to the responsible authority. (Afrikaans)

Gebruiker

NAAM	REG NR	VOLUME	PLAAS	AREA	AKTE	ALG. MAGTIG	TOT	Mielie @7500	Grondbone @ 7000	Paprika @ 12000	Aartapples @ 7000	Koring @7500	Lusern @11400	Ander @volume
Mr. P.E. Kriel	10081261	89180	Millbank	856.5	T2667/1996	51392	17.5	3.5	14					
Volume		**124250**						26250	98000					
Beplan	2003/2004	**Hektaar gewas**												
Beplan	Volume													

Verduidelik hoe u beoog om die volume wat u besproei weekliks te meet of kies uit die onderstaande :

1. n Vloeimeter met ‘n outomatiese volume registreerder op elk van u produksie boorgate wat gekalibreer, verseel en ‘n verskaffers sertifikaat van akkuraatheid het.
2. ‘n Grootmaat Vloeimeter met ‘n outomatiese volume registreerder wat die volume meet wat die versamel dam of verlaat of ingaan of op die besproeiings toestel
3. ‘n Gesertifiseerde water sisteem vloei/ behoefte sertifikaat van die verskaffer van die besproeiings toestel asook ‘n uur meter wat die hoeveelheid ure wat besproei word registreer en /of

‘n Gekalibreerde Eskom kilowatt-hour meter wat spesifiek registreer die ure wat die besproeiings sisteem in gebruik is.

Vanaf weeklikse volume metings moet maandeliks teen laaste dag van die maand aangeteken word die volume besproei

Maand	2003	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Volume gebruik kubiek meter													
Maand	2004	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Volume gebruik kubiek meter													

Verklaring deur watergebruiker: Hiermee verklaar ek dat my besproeiing beplanning gedoen is teen aanbeveelde gewas behoeftes binne die toegekende volume. Die werklik gepompde volumes is gemeet akkuraat soos per voorgeskryfde metode en maandeliks korrek aangeteken.

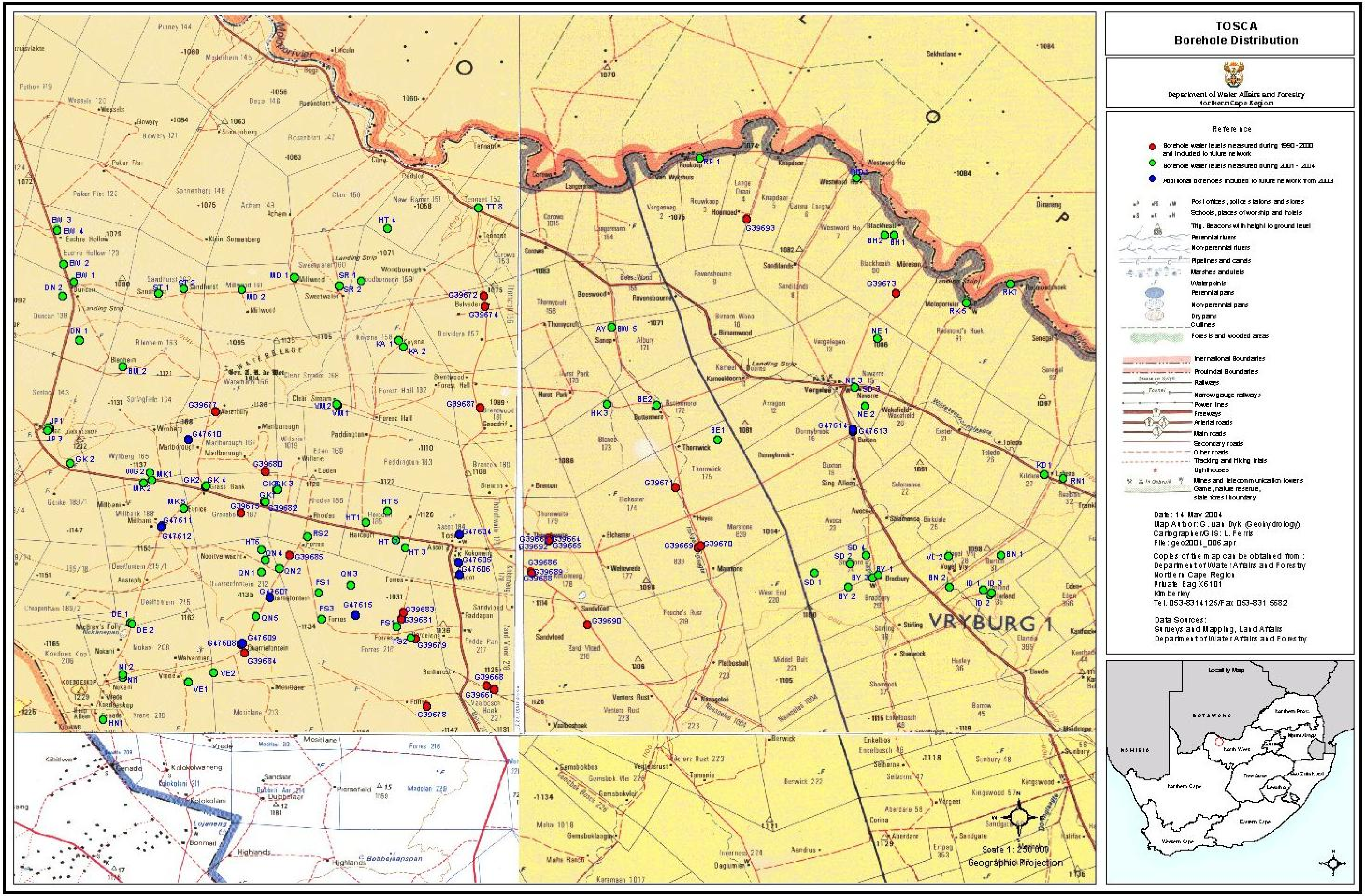
Handtekening:

Datum:

Appendix 11 Proposed water level monitoring network.

Borehole	Farmname	Lat	Long	Alt GPS	Alt Map	Equipment
G39663	Thornthwaite	-25.8778	24.01897	1116	1100	oop-bg
G39664	Thornthwaite	-25.8764	24.01911	1112	1100	00p-bg
G39665	Thornthwaite	-25.8777	24.01897	1120	1110	oop-bg
G39667	Vaalboschhoek	-25.9722	23.98411	1158	1128	oop-bg
G39668	Vaalboschhoek	-25.97	23.97935	1160	1132	oop-bg
G39669	Marstone	-25.8822	24.11341	1106	1065	oop-bg
G39670	Marstone	-25.8814	24.11524	1110	1080	oop-bg
G39671	Elchester	-25.8443	24.09883	1093	1069	mono
G39672	Belvidere	-25.7229	23.97763	1103	1079	oop-bg
G39673	Blackheath	-25.721	24.23915	1119	1086	oop-bg
G39674	Belvidere	-25.7292	23.97851	1096	1079	oop-bg
G39675	Grassbank	-25.8601	23.82374	1139	1130	oop-bg
G39677	Waterbury	-25.7959	23.80765	1153	1120	mono
G39678	Forres	-25.9829	23.94156	1172	1147	domple/p
G39679	Forres	-25.9403	23.93427	1148	1137	oop-bg
G39680	Grassbank	-25.8345	23.839	1153	1124	mono
G39681	Forres	-25.9278	23.92537	1158	1134	oop-bg
G39682	Grassbank	-25.8532	23.83869	1148	1130	mono
G39683	Forres	-25.9236	23.92636	1169	1132	oop-bg
G39684	Quarreefontein	-25.9489	23.82593	1172	1161	oop-bg
G39685	Forres	-25.887	23.85463	1145	1123	Logger
G39686	Kokomeng	-25.8982	24.00768	1136	1108	oop-bg
G39687	Brentwood	-25.794	23.9755	1130	1091	Logger
G39688	Kokomeng	-25.8981	24.00754	1132	1108	oop-bg
G39689	Kokomeng	-25.8983	24.0078	1127	1108	oop-bg
G39690	Zandvloed	-25.931	24.04289	1128	1108	w/p
G39691	Thornthwaite	-25.8767	24.01904	1133	1100	oop-bg
G39692	Thornthwaite	-25.878	24.01894	1130	1100	oop-bg
G39693	Knapdaar	-25.6741	24.14435	1103	1079	Logger
G39694	Thornthwaite	-25.8775	24.01898	1127	1100	oop-bg
G47604	Ascot	-25.8743	23.9625	1115	1115	oop-bg
G47605	Ascot	-25.8918	23.9616	1120	1120	oop-bg
G47606	Ascot	-25.8997	23.9625	1120	1120	oop-bg
G47607	Quarrefontein	-25.9138	23.8418	1133	1133	oop-bg
G47608	Quarrefontein	-25.9438	23.8238	1150	1150	Logger
G47609	Quarrefontein	-25.9429	23.8249	1145	1145	oop-bg
G47610	Marlborough	-25.7755	23.8236	1140	1140	oop-bg
G47611	Millbank	-25.8686	23.7737	1145	1145	oop-bg
G47612	Millbank	-25.8695	23.7730	1145	1145	oop-bg
G47613	Buxton	-25.8089	24.2116	1082	1082	oop-bg
G47614	Buxton	-25.8077	24.2113	1079	1079	oop-bg
G47615	Forres	-25.9250	23.8961	1135	1135	oop-bg

Appendix 12 Locality of proposed water level monitoring network.


TOSCA
Borehole Distribution
Department of Water Affairs and Forestry
Northern Cape Region
Reference
Borehole water levels measured during 1990 - 2000 and included to future network
Borehole water levels measured during 2001 - 2004
Additional boreholes included to future network from 2003
Post offices, police stations and stores
Schools, places of worship and hotels
Trig. Beacons with height to ground level
Perennial rivers
Non-perennial rivers
Pipelines and canals
Marshes and vleis
Waterpoints
Perennial pans
Non-perennial pans
Dry pans
Gullies
Forests and wooded areas
International Boundaries
Provincial Boundaries
Railways
Narrow gauge railways
Power lines
Freeways
Arterial roads
Main roads
Secondary roads
Other roads
Tracking and Hiking trails
Lighthouses
Mines and telecommunication towers
Game, nature reserve, state forest boundary
Date: 14 May 2004
Map Author: G. van Dyk (Geohydrology)
Cartographer/GIS: L. Ferris
File: geo2004_006.apr
Copies of the map can be obtained from:
Department of Water Affairs and Forestry
Northern Cape Region
Private Bag X6101
Kimberley
Tel. 053-8314125/Fax 053-831 5682
Data Sources:
Surveys and Mapping, Land Affairs
Department of Water Affairs and Forestry
Locality Map
VRYBURG 1
Scale 1: 250 000
Geographic Projection

Appendix 13 Draft of publication to effect water restrictions.

GOVERNMENT NOTICE

NO.

RESTRICTIONS ON THE TAKING OF WATER FROM THE TOSCA MOLOPO DOLOMITE AQUIFER.

By virtue of the powers vested in me under section 63 read together with section 72 of the National Water Act 1998 (Act No 36 of 1998), I, Arnold Michael Muller, in my capacity as Director-General of the Department of Water Affairs and Forestry:

(a) Believe that a water shortage exists in the Tosca Molopo dolomite aquifer; and

(b) Limit, in terms of Item 6(1)(i) of Schedule 3 of the National Water Act, 1998, the taking of water from the aforementioned aquifer on the farms and for the volumes set out in Table 1.

(c) Direct that the restriction will be applicable for the period 1 August to 31 July of any given year commencing from 2004, until I repeal this restriction.

DIRECTOR-GENERAL
DEPARTMENT OF WATER AFFFAIRS AND FORESTRY
DATE:

Appendix 14 Establishment of the Tosca/ Molopo WUA as published in the Government Gazette 16 July 2004.

No. 828 **16 July 2004**

ESTABLISHMENT OF THE TOSCA/MOLOPO WATER USER ASSOCIATION, MAGISTERIAL DISTRICT OF VRYBURG, NORTH WEST PROVINCE, WATER MANAGEMENT AREA NUMBER 10

I, Buyelwa Patience Sonjica, Minister of Water Affairs and Forestry, hereby in terms of section 92(1) of the National Water Act, 1998 (Act No 36 of 1998), declare that-

(a) the Tosca/Molopo Water User Association is established;

(b) the Association's name is the Tosca/Molopo Water User Association;

(c) the area of operation of the Tosca/Molopo Water User Association includes all properties in respect of which any person is entitled to use underground water by virtue of entitlements in terms of section 22(1) of the Act, with the following boundaries:

(i) Northern boundary: The water-parting formed by the Water Mountains from and including the farm Knapdaar 5 up to and including the farm Stilton 189;
Western boundary: The water-parting formed by Koedoeskop from and including the farm Stilton 189 up to and including the farm Dubbel Aar 21;
Southern boundary: The line between the farms Dubbel Aar 21 and Nimrods Vlei 93;
Eastern boundary: The Molopo River from and including the farm Nimrods Vlei 93 up to and including the farm Knapdaar 5;

(ii) any other water resource situated outside the area described in paragraph (c)(i) above, which water resource and accompanying area the Department of Water Affairs and Forestry or the responsible authority may require the Association to control,

which is situated in Water Management Area number 10 in the North West Province; and

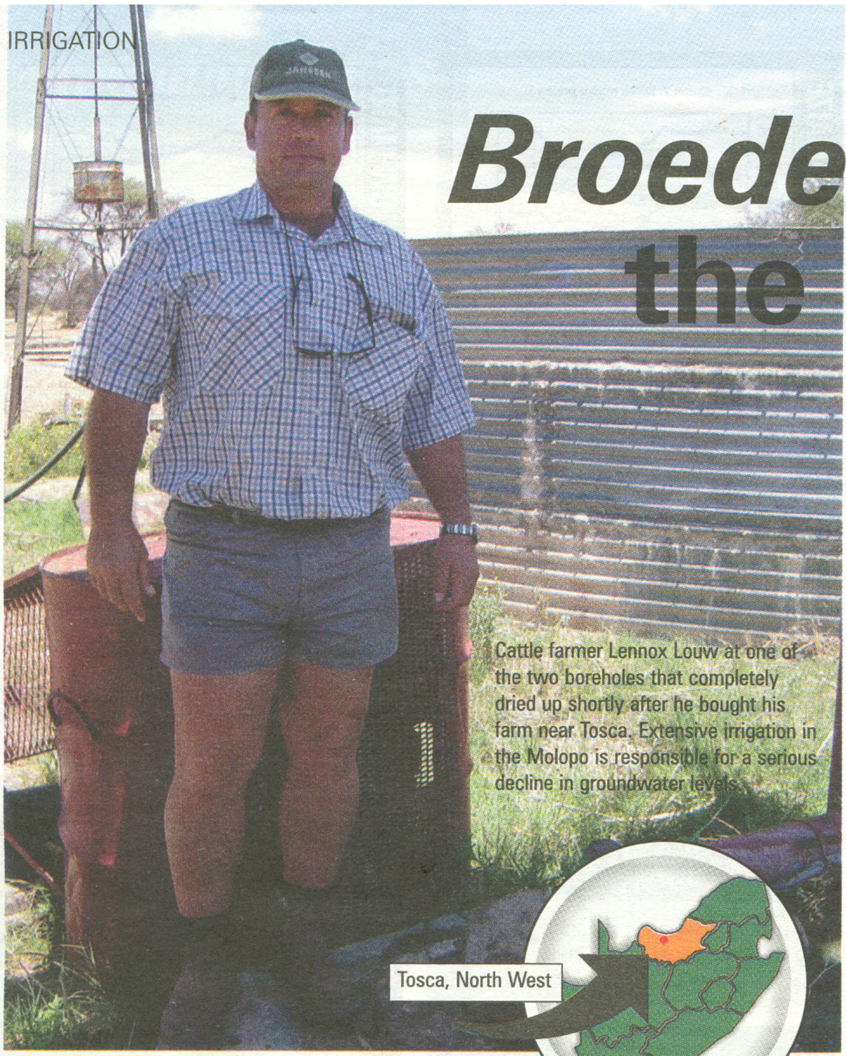
(d) the constitution of the Tosca/Molopo Water User Association has been approved.

28/06/2004

BUYELWA PATIENCE SONJICA
MINISTER OF WATER AFFAIRS AND FORESTRY

Appendix 15 Articles and letters published in general papers and magazines.

Broedertwis in the Molopo



Cattle farmer Lennox Louw at one of the two boreholes that completely dried up shortly after he bought his farm near Tosca. Extensive irrigation in the Molopo is responsible for a serious decline in groundwater levels.

Tosca, North West

Pictures: Chris Louw

BELOW: Here to stay? This billboard in Tosca is an indication of the extent of water-thirsty paprika production in the semi-arid Molopo.

Water – or the lack of it – has pitted brother against brother in the semi-arid Molopo. **Chris Louw** visited the area and found that with boreholes drying up, cattle farmers and irrigation farmers are at loggerheads.

TENSION is growing between cattle farmers and irrigation farmers in the dry Tosca region of North West, on the Botswana border, about the scarcest commodity in the area – water. A dramatic increase in irrigation in recent years has led to accusations that groundwater is being over-exploited to the point of near-depletion. Cattle farmers complain that their boreholes are drying up on an unprecedented scale. And although irrigation farmers admit that the present use of underground water exceeds the natural replacement, they believe the situation can be rectified.

What irks cattle farmers is that many irrigators are openly defying the country's water legisltion. The short-term gain of high crop yields and increased profits, it is said, weigh heavier than long-term sustainability.

Exploitation exceeds replacement

Tests by the Department of Water Affairs and Forestry (DWAF) indicate that in the past two years alone, in areas near irrigation systems, underground water levels have declined by between 50 and 60m. The regional decline since April 2001 is between 10 and 20m. According to the DWAF, the current exploitation of water exceeds natural replacement by a massive 40%.

Gawie van Dyk of the DWAF's Kimberley office says the unsustainable abstraction of groundwater may result in permanent damage to the aquifer and the environment.

The only two boreholes on cattle farmer Lennox Louw's property dried up completely shortly after he bought the farm. Louw was forced to drill another borehole at a cost of R25 000, this time only finding water at 180m – about three times as deep as the previous average depth of water-yielding boreholes.

Since the introduction of irrigation farming in the Molopo in the past decade, boreholes have to be drilled ever deeper to reach water. This is confirmed by former driller and now irrigation farmer Sarel Kriel, who was responsible for drilling over 500 boreholes in the area. Previously, he says, water could be found at between 40 and 60m. "Now we have to drill 200m and deeper through the dolomite to find water."

One cattle farmer says the "rampant exploitation" of scarce groundwater has taken on the proportions of an "irrational gold-rush", with even church-elders joining the fray, illegally setting up centre pivots in open defiance of the law, showing scant regard for the long-term effects of their "mining" of the Molopo's most valuable and limited resource. What used to be the arid domain of cattle farmers, now produces wheat (41%), paprika (19%), peanuts and maize (30%), and potatoes and alfalfa (10%), all under irrigation.

Mining fossil water

Outspoken proponents of irrigation like Gert Stoltz, chairperson of the interim water users' association in Tosca and by far the largest irrigator in the area, agree that the sustainable use of water – which is estimated at 18 million cubic metres a year – is presently over-exploited by no less than 40%. Some of this water is "fossil" water, contained for centuries in separate dolomite compartments in the Ghaap plateau formation deep underground.

Research done in 2002 by the Council for Scientific and Industrial Research (CSIR) estimated the recharge of the aquifer in the Tosca area at between 0,5% and 2% of the annual precipitation. The area northwards between Tosca and Vergeleë is over-exploited by more than twice its capacity: current abstraction is 15 million cubic metres a year, while the natural yearly recharge is only seven million cubic metres.

More than this, rainfall in the area is extremely low, with precipitation in Vergeleë averaging 400mm a year, declining to the west to an average of 385mm at Pomfret. According to DWAF's Gawie van Dyk, evaporation in the extremely hot climate exceeds rainfall four- to five-fold, at between 2 050 and 2 250mm a year. (Rugby legend Frik du Preez, who farms cattle in the area, jokes that during the biblical deluge the Molopo only experienced lightning in the distance.)

The low rainfall sustains a semi-arid vegetation of savannah-type acacias. Before, the area was used almost exclusively for cattle farming. The situation changed in the late 1980s with the introduction of electricity to Tosca, which allowed for the erection of centre pivots.

This coincided with a 1990 CSIR study, which characterised the water resources as "high-yielding". While some farmers immediately saw this as scientific proof that irrigation was sustainable, DWAF says they ignored a warning by the CSIR that while quality and isotope samples cast doubt on the sustainability of the water, stating that some of it was in fact fossil water.

In 1990 there were only two irrigation systems in the area. This has increased to no less than 45 in 2002. The area under irrigation has increased from 100ha in 1990 to an astonishing 2 075 ha by 2002. The rapid rate at which irrigation developed, says DWAF's Van Dyk, has led to an increase in water use from 0,77 million cubic metres in 1990 to close to 19 million cubic metres last year – an astonishing 2 500% increase in 12 years.

During the same period both human consumption and stock-watering stayed constant at a mere 500 000m^3.

Tensions in church

Tosca is a close-knit society, a harsh and isolated part of the world where the people depend on each other. But the water feuds have already led to enormous tensions in the local NG Kerk, with irrigation farmers and cattle farmers set against one another. It has even pitted brother against brother. Irrigation farmer Noen Hamman half-jokingly warned me: "Write about the water issue and you will never set foot in the Molopo again." His brother, Marius Hamman, a cattle farmer who scarcely has enough water left for household use, declined to be interviewed. "These people are my family and friends. I have no choice – I will just have to go under with them when the water is gone."

Despite the crisis, some irrigation farmers, including the interim water-user association's Gert Stoltz, now apply all-year irrigation with the introduction of winter crops, including wheat. Stoltz, who owns an 800ha plot a few kilometres outside Tosca on the road to Jakkalskop, has 200ha under irrigation. He also cultivates paprika, a plant needing enormous quantities of water during its long nine-month growing season from August to March.

"Irrigation isn't to blame"

Talking to *Farmer's Weekly*, Stoltz dismissed DWAF's research as unscientific. According to him water levels in boreholes were measured after sustained periods of irrigation and then compared with previous levels which were measured when little or no water was used.

Stoltz also denies that the drying up of boreholes is directly linked to irrigation. Rather, he says, this is due to the natural exhaustion of these water resources.

continued on page 35

BELOW: Gert Stoltz, the largest irrigator in the Tosca district. He believes the official establishment of a water users' association will rectify the present over-use of groundwater.

Jaco's assistance, the problem would most likely have been categorised as "lameness", and there is a good chance that most of the cows would have been culled eventually without the farmer having had the opportunity to pinpoint the cause of the problem.

Hoof balance is important

The key to sound feet, says Jaco, lies in correct hoof balance. The heels of the split-hooves should be of equal length and the toes should not be too long. Because dairy cows do not walk a lot, especially in a system where they are fed a total mixed ration (TMR) and where they usually stand on unnatural surfaces, hoof management becomes crucial. The feet are not worn down naturally and this leads to unbalanced hooves.

Big in Japan

The Hoof Trimmers' Association of Japan recently invited Jaco to present a lecture at a hoof trimmers' seminar. The Japanese were especially interested in finding out more about the latest technological developments in the West.

"If one considers that there are about 1,5 million Holstein cows in Japan, compared to the estimated 55 000 dairy cows of all breeds in South Africa, one realises how huge the industry is in Japan and how small the industry is in South Africa. There are more than 300 dairy hoof trimmers in Japan, compared to the nine in South Africa."

In Japan, Jaco says, hoof trimming on cows is being done in much the same way that a horse would be trimmed. The foot is held between the legs and hoof knives are used to balance the feet. Although some individuals use immobilisation crates, these are very rudimentary and do not allow the hoof trimmer to do more than 15 to 20 cows per day. With his hydraulic crate, says Jaco, he is able to do up to a 100 cows a day. This has allowed him to reduce the fee he charges per cow.

"When I first started out, I had to charge about R70 per cow because I did no more than 20 cows per day. With my new system I am able to charge only R50 per cow. In cases where the farmer presents me with more than 70 cows, I charge him even less. I consider this reduction in my fees as my contribution to the profitability of the dairy industry. The long-term viability of the industry is at the end of the day to my own advantage as well."

• Contact Izak Hofmeyer on (012) 804 4800. FW


The wooden block is being glued onto the hoof by means of a special glue.


RIGHT: A cow with a sole fracture receives a special wooden block on the sound hoof to take the weight off the affected one. The block will stay on for about six weeks, giving the affected hoof time to heal.

from page 33

Broedertwis in the Molopo

He does, however, agree that present utilisation is in excess of annual recharge capacity. This, he says, can be addressed if illegal users – those who did not register their water use in terms of the National Water Act of 1998 – can be weeded out and the remaining legal users can be taught to utilise their water more effectively. Currently, he believes, only 60% of irrigation water is used efficiently. A reduction in the quantity of water used need not lead to reduced production, he says.

"Once the constitution for the local water users' association (WUA) is signed by the minister of water affairs and the WUA becomes official, we will be able to manage our water resources scientifically and in an orderly fashion." The WUA will then be in a position to get and implement recommendations from independent geohydrologists, says Stoltz.

Cattle farmer Lennox Louw, vice chairperson of the Tosca Molopo water users' steering committee, says he was livid when his boreholes dried up. "But at least we have made some progress, with irrigation farmers starting to acknowledge that a serious problem does exist, a fact previously denied. What is needed now is that DWAF should take drastic action against transgressors. They have been warned over and over again, and they know they are involved in wasteful exploitation. If the WUA is implemented but is not given the authority to act, it will be a toothless bulldog. In that case, I wouldn't like to be part of it."

Compulsory licensing

DWAF's Van Dyk is hopeful that a process of compulsory licensing in terms of the National Water Act will lead to a long-term solution, normalising the critical damage to the resource and the present conflict in the area. "Water users will have to license all of their abstractions, old and new, and a reallocation will take place with a strong emphasis on equity and sustainability."

In the meantime, DWAF is identifying illegal users through satellite images. Some of them have already indicated that they will refuse to cooperate and stop their activities. This means that DWAF will have to enforce the directives contained in the Water Act, including ensuring that activities requiring water on farms be stopped. The costs of these actions, says Van Dyk, will be recovered from the farmers.

Most cattle farmers remain skeptical. "DWAF has allowed the exploitation of water to continue unabated. We will only believe they are serious once we see them take definite action against criminal water users," said one. The National Water Act has now been in operation for five years but DWAF has had extremely limited success in identifying and acting against unregistered and unlawful water users. Insiders say this is mainly due to the protracted legal requirements of the Water Act, often coupled with a serious lack of capacity.

• The Northern Cape regional office of DWAF, responsible for monitoring the water situation in the Molopo, can be contacted on (053) 831 4125. FW

Briewe

Waarom nou eers aanvaarding van tegnologie?

GERT ERASMUS, *Vrystaatste Universiteit, skryf:*
Die artikel "Dohne-Merino maak opgang in Australië" (LW, 21 November) het betrekking. Die "vernuwing wat ongekend is in skaapteling" waaroor mnr. Cameron McMaster nou so opgewonde raak, is minstens 20 jaar gelede aan hom (toe nog rasdirekteur van die Dohne-Merino's), sy raad en lede voorgehou. Die weerstand teen verandering het só opgebou, dat dit byna tot persoonlike onmin gelei het.

Ek wil nie vermakerig wees nie, maar as dit 'n vooruitstrewende ras, soos die Dohne-Merino, 20 jaar kos om 'n wetenskaplike innovasie te aanvaar, moet daar êrens 'n skroef los wees.

CAMERON McMASTER, *Dohne-konsultant, antwoord:*
Ek is dankbaar dat prof. Erasmus op ons verslag van die Dohne se welslae in Australië gereageer het. Prof. Erasmus was jare lank die departement se verteenwoordiger in die Dohne-raad – 'n pos wat hy met groot onderskeiding beklee het. Dit was gedeeltelik aan hom te danke dat die ras in 'n innoverende rigting gestuur is, terwyl hy ons voortdurend geïnspireer en aangemoedig het om hoër doelwitte en beter metodes en stelsels na te streef.

Hy is duidelik een van die pioniers waarna in die huldeblyk aan die einde van die artikel verwys word – een van heelparty mense wat daarvoor verantwoordelik was dat die Dohne die ontwikkelingsvlak bereik het wat tans só dramaties deur die ras se prestasies in Australië geïllustreer word.

Ek kan my nie herinner dat daar enige weerstand teen verandering tydens sy termyn in die Dohne-raad was nie en daar was beslis geen wrywing nie. Trouens, die Dohne-raad het sy werk altyd in 'n gees van eensgesindheid en gedeelde doelwitte gedoen. Daar was nooit onenigheid oor die gebruik van nuwe tegnologie wat beskikbaar geraak het nie. Daar was egter aansienlike geldelike en infrastrukturele beperkinge.

Desondanks het die genootskap daarin geslaag om 'n suksesvolle kudde-aantekeningstelsel te ontwikkel wat, van vroeg af al, volle prestasie- en stamboomaantekeninge van alle diere deur alle telers ingesluit het – iets wat destyds taamlik uniek was in skaapteling. Die stelsels word steeds voortdurend verbeter en aangepas om vir nuwe evalueringstegnieke, soos BLUP, voorsiening te maak.

Met die tegnologie en kundigheid tot die Australiërs se beskikking, kon hulle 'n nasionale databasis opstel wat dit moontlik gemaak het om interkuddeteelwaardes vir elke aangetekende skaap te bereken – waardes wat maandeliks bygewerk word namate nuwe inligting van elke opeenvolgende ouderdomsgroep in elke stoetery ingevoer word. Die "vernuwing wat ongekend is in skaapteling" waarna ek verwys (die opmerking waaroor prof. Erasmus met my verskil), was die feit dat die Australiese Dohne-genootskap vandag waarskynlik die enigste skaaptelersgenootskap is wat nasionale interkudde-teelwaardes vir elke skaap in elke stoetery kan verstrek en wat hierdie teelwaardes aan almal beskikbaar stel danksy die internet.

Dit is 'n situasie waarna alle telersgenootskappe streef en wat Suid-Afrikaanse telers ongetwyfeld binnekort sal bereik. Die meeste telersgenootskappe verskaf wel teelwaardes vir sommige diere in sommige kuddes. Word hierdie aantekeninge egter gepubliseer? En wanneer sal nasionale teelwaardes vir elke individuele dier beskikbaar wees?

Belasting op munisipale grond

SAM LAS, *Beachweg 24, Pacaltsdorp, skryf:*
Die brief "Belasting op belasting: Waar hou dit op?" (LW, 7 November) het betrekking.

Ek huur tans meentgrond van my plaaslike munisipaliteit. In my geval is die grondbelasting meer as die huurgeld. Die probleem is egter dat daar geen grensheinings om die grond is nie en daar is ook gruisgate waarvan die bolaag van die grond op hope gestoot is.

Ek het by die munisipaliteit aangeklop om hulp sodat ek die heinings kan oprig en die gate kan toestoot – sonder sukses.

Betaal 'n mens belasting as jy 'n huurder is en waarom só baie? As iemand my kan help, bel my asseblief by sel 082 739 0850.

Watervloeisyfer 'blote duimsuiery'

CHAS WESTLEY, *Posbus 314, Port Nolloth, skryf:*
In die berig "Genoeg water vir almal langs die Molopo-rivier" (LW, 7 November) sê mnr. Gert Stoltz, voorsitter van die tussentydse Waterverbruikersvereniging in Tosca, dat boorgate opdroog deur natuurlike uitputting.

Wat hy egter nie sê nie, is dat boorgate begin opdroog het ná die grootskaalse oprigting en bedryf van spilpunte. Dit is moontlik dat die omgewing van Vosterhoop ook geraak kan word, asook dele wes en noord van Vergeleë.

Die ondersoek deur die WNNR en ander instellings het bevind dat die hele gebied om Tosca, Vergeleë en Pomfret nie geskik is vir besproeiing nie en dat die watervlakke in hierdie omgewing met 20 meter (van 40 m tot 60 m) gedaal het. Talle boorgate droog op en veeboere word in ellende gedompel.

Ek daag die WNNR uit om te bewys dat die invloei in die gebied 18 miljoen m^3 is. Dit is net 'n syfer wat pas by die spilpuntbedryf en is 'n blote duimsuiery.

Almal, insluitend die Departement van Waterwese en mnr. Stoltz, het erken dat die bedryf vir die dalende watervlak verantwoordelik is. Die departement reik egter nou nog kwotasies uit vir nuwe spilpunte.

Die waterverbruikersvereniging is 'n grote klug. Die staat moet ingryp en alle besproeiing deur spilpunte beëindig en die gebied 'n waterbewaringsgebied verklaar en só sorg dat hierdie pragtige gebied vir die nageslag behoue bly.

Kiwi-boere se plan teen ryp

F.C. SYMINGTON, *Posbus 72196, Lynnwoodrif, skryf:*
Dit is duidelik dat ons op rugbygebied heelwat van Nieu-Seeland kan leer. Toe ek en my kinders onlangs in Nieu-Seeland gekuier het, het daar iets gebeur wat my sterk laat wonder het of ons op landbougebied nie ook by hulle kan leer nie.

Dit het skielik ongewoon koud geword vir Oktober. Ek het gehoor daar is 'n rypwaarskuwing vir boere. Vroeër vanjaar het swartryp in die noordelike deel van Suid-Afrika miljoene rande se skade aan gewasse aangerig.

Die Nieu-Seelandse boer maak egter 'n plan. 'n Reuse-helikopter word ingespan om reg deur die nag oor die lande te vlieg en, siedaar, geen rypskade nie. Die helikopter se gebruik het 'n hele paar rand (dollar) gekos, maar dit is 'n nietigheid teenoor die skade wat die ryp andersins sou aangerig het.

Produksiekontrakte kan BTW-status beïnvloed

■ Deur NICO VAN BURICK

Boere moet bedag wees daarop dat sekere produksiekontrakte in die graanbedryf hul BTW-status in gedrang kan bring.

Agri Suid-Afrika en Graan Suid-Afrika het met die Nasionale Tesourie gepraat oor die implikasies van sulke produksiekontrakte en het onderneem om leiding hieroor aan hul lede te verskaf.

Mnr. Johan Pienaar, direkteur van ekonomie en handel by Agri SA, sê die probleem hou verband met die definisie van 'n ondernemer in die BTW-wet. Dit bepaal onder meer dat die ondernemer lewerings of verkope moet doen. As 'n boer bloot as 'n kontrakteur sou optree, sal sy BTW-status in gedrang kom.

Mnr. Fanie Brink, adjunkhoofbestuurder van Graan SA, sê dit sal die toegewing om bepaalde produksiemiddele teen 'n nulkoers te koop sowel as die terugbetaling op diesel in gedrang bring. Die gedeeltelike terugbetaling van dieselbelasting waarvoor boere in aanmerking kom, is op die BTW-stelsel gegrond.

Hy sê boere moet seker maak dat kontrakte duidelik spesifiseer wie vir die koop van produksiemiddele sowel as die lewering van produkte verantwoordelik is.

Mnr. Brink sê sekere kontrakte kan boere se voordele en kortings wat deur die georganiseerde landbou beding is, benadeel en daar moet seker gemaak word dat produksiekontrakte nie die stelsel bedreig nie.

Genoeg water vir almal langs die Molopo-rivier

■ Deur ANNELIE COLEMAN

Die ondergrondse dolomitiese waterbron by Molopo het genoeg water om aan die behoeftes van alle verbruikers in die omgewing van Tosca, Vergelegen en Pomfret in Noordwes te voldoen mits dit behoorlik bestuur word.

Só sê mnr. Gert Stolz, voorsitter van die tussentydse Waterverbruikersvereniging in Tosca. Hy het bewerings weerlê dat besproeiingsboere in dié gebied verantwoordelik gehou kan word vir boorgate wat opdroog.

Hy sê gevalle waar boorgate by Tosca opgedroog het, is ondersoek en die oorsake kan onder meer aan die natuurlike uitputting van die gate toegeskryf word. In sommige gevalle lewer boorgate enkele meters verder nog sterk water.

Dit is hoogs onwaarskynlik dat besproeiing uit die Molopobron vir die opdroging van boorgate in die omgewing van Vorstershoop verantwoordelik kan wees, gegewe die feit dat Vorstershoop sowat 200 km van die bron af geleë is.

Die ondergrondse dolomitiese waterbron by Molopo is deur die WNNR ondersoek en daar is bevind dat dié bron 'n aanvulling van sowat 18 miljoen kubieke meter water per jaar het. Dit is nie bekend hoe ver die bron in Botswana in strek nie. Sowat 1 500 ha word besproei en paprika, koring, mielies en lusern word verbou.

Mnr. Stolz het waterverbruikers in die gebied gevra om deel te word van die oplossing van die probleem deur by die Waterverbruikersvereniging in te skakel. Dié vereniging sal met die samewerking van die Departement van Waterwese toesien dat die water in die gebied ordelik en wetenskaplik volgens die aanbevelings van die WNNR bestuur word.

Die tussentydse vereniging sal binnekort deur 'n permanente verbruikersvereniging vervang word waarin alle besproeiingsboere, veeboere en ander verbruikers verteenwoordiging sal hê.

Die Departement van Waterwese het in September met die toepassing van die regulasies van die Waterwet van 1998 in die omgewing begin. Dié wet sal op 'n grondslag van billikheid, die gevestigde belange en die waterbron beskerm, aldus mnr. Stolz.

Vergaderings oor uitvoervereistes

■ Deur NICO VAN BURICK

Die Departement van Landbou hou op die oomblik landwyd inligtingsvergaderings om uitvoerders en boere in te lig oor vereistes vir voedselveiligheid van landbouprodukte wat van 1 Januarie 2004 af na die Europese Unie uitgevoer word.

Konsepwetgewing wat die vereistes vir plantaardige produkte sal reguleer, is nou beskikbaar en tree in Januarie in werking. Dit staan bekend as die "Standaard vir Voedselhigiëne en Voedselveiligheid van Gereguleerde Landbouvoedselprodukte van 'n Plantoorsprong en Bestem vir Uitvoer".

Landbouprodukte wat geraak word, is vars, ingemaakte en bevrore vrugte en groente, droë vrugte, grondbone, graan, rooibos- en heuningbostee.

Agri Suid-Afrika wys uitvoerders daarop dat hulle die Raad van Toesig op die Uitvoer van Bederfbare Produkte (PPECB) voor 21 November van inligting oor hulle verskaffers (plase, pakhuise op plase en ander pakhuise) moet voorsien.

Dié inligting sal gebruik word om 'n databasis en aksieplan te skep waarvolgens verskaffers se minimum voedselveiligheidstandaarde geouditeer sal word. Die oudit begin ook op 1 Januarie.

Die reeks vergaderings om betrokkenes oor die vereistes en implikasies in te lig en vrae te beantwoord, word kosteloos aangebied en duur tot 18 November.

Die program is: 3 Nov., Nelspruit en Hluhluwe; 4 Nov., Nkwalini en Hoedspruit; 5 Nov., Tzaneen; 6 Nov., Tshipise; 7 Nov. Brits; 10 Nov., Ficksburg; 11 Nov. Kakamas; 12 Nov., Marble Hall en Katrivier; 13 Nov., Gamtoos; 14 Nov., Sondagsrivier; 17 Nov., Hartswater; 18 Nov., George.

Vir meer besonderhede kan me. Portia Mahlangu by tel. 012 319 6048 gebel word of e-pos portiama@nda.agric.za.

Nuwe lede vir PPECB-beheerraad

■ Deur JOHAN COETSEE

Die Minister van Landbou en Grondsake, me. Thoko Didiza, het elf nuwe raadslede vir die Raad van Toesig op die Uitvoer van Bederfbare Produkte (PPECB) vir 'n tydperk van drie jaar aangestel.

Die nuwe lede is mnre. C.A. Atkins (mariene-bedryf), G. Booyens (vrugteverwerkersbedryf), H.P. Booysen (vleis- en volstruisbedryf), G.G. Burelli (subtropiese bedryf), A.J. du Preez (sagtevrugtebedryf en voorsitter), me. D.P. Engelbrecht (sagtevrugtebedryf), mnre. A. M. Hawes (sitrusbedryf en ondervoorsitter), S.E. Mokoene (georganiseerde landbou), mee. N. Nduli (ministeriële verteenwoordiger), E. Oberholzer (groentebedryf) en mnr. C.I. Painter (sitrusbedryf).

Me. Bongi Njobe, direkteur-generaal van die Departement van Landbou, het op die nuwe raad se eerste vergadering gesê 'n Suid-Afrikaanse beheerliggaam vir voedselveiligheid gaan gestig word en die PPECB sal waarskynlik 'n belangrike rol daarin speel.

Ooreenkomste hieroor is gesluit met verskeie staatsdepartemente, waaronder Landbou, Gesondheid en Handel en Nywerheid. 'n Loodskomitee, wat kwartaalliks vergader, is op die been gebring deur die PPECB en die Departement van Landbou om die proses te verhaas.

Stop over-exploitation of groundwater

by Gawie van Dyk, Department of Water Affairs and Forestry, Northern Cape (Kimberley) and Chris Moseki and Eberhard Braune, Department of Water Affairs and Forestry, Directorate: geohydrology, Pretoria

Groundwater in South Africa has been redefined from 'private water' (as per the previous Water Act of 1956) to that of a 'significant water resource' in terms of the new National Water Act (1998).

A new Act alone will not solve all the management problems that are associated with groundwater. It is clear that such a widespread and often highly localised resource should also be managed locally.

Throughout the world, groundwater is the preferred source for community water supply. It is also a useful poverty alleviation instrument since rural communities, which mostly constitute the poorest of our nation, depend on it for economic upliftment and survival.

Unlike surface water resources, groundwater resources are well spread out and can be managed locally by organised groupings and associations. These resources are also relatively protected from pollution and evaporation if precautions are taken to minimise negative impacts.

The 1956 Water Act linked groundwater rights to land ownership. Borehole water and small streams on a property were regarded as private resources and often neglected and wasted. In terms of the 1998 National Water Act (NWA) all components of the water cycle have equal status before the law. Thus, groundwater is a public resource that has to be developed, managed, conserved, protected, used and controlled in accordance with provisions of the NWA.

Groundwater use has been less pronounced in areas where yields are low, and under-utilised in certain areas due to availability of surface water sources. Yet, in other situations, groundwater resources are over-used to the point of near depletion.

It is also worth noting that more than 70% of all water use is for irrigated agriculture (see table 1). Countrywide, groundwater use represents only about 20% of the total water use. However, its importance should not only be seen in the volume supplied, but as the sole water source in many areas, offering extra security during droughts.

Water Use Sector	Use (Mm^3/a)
Urban use, including industrial and mining use from public sources	83
Rural domestic use	306
Stock-watering	100
Irrigation	1 424
Mining and quarries	100
TOTAL	**2 013**

Table 1: Groundwater use in 2000 per water use sector.

Resource management problems

Groundwater abstraction rates are seldom monitored, resulting in the depletion or overuse of the resource. Poor irrigation scheduling can also result in inefficient and ineffective water use.

Groundwater pollution from industries, mining, and urban and agricultural impacts present a major threat to scarce water resources. Groundwater is particularly vulnerable, because once polluted, remediation thereof is prohibitively expensive or difficult.

Typical groundwater quality impacts identified in the agricultural sector relate to fertiliser and pesticide application and these should be applied judiciously.

A very common phenomenon associated with irrigation in dry regions is that of salinisation of soil and the underlying groundwater resources, which in turn produce saline return flows to rivers. In the past, assessment was inadequate and information available is often incomplete and not always systematic. Data should enhance effective management.

Tosca

One area where groundwater resources have been over-used to the point of near depletion is the Tosca Vergelegen area, located 150 km north of Vryburg. The area was historically used for stock, cattle, and game farming. The rapid development of irrigation systems since 1990 transformed the socio-economic and environmental prospects.

Registration of irrigation activities enabled DWAF to use satellite images, surveys and reports submitted by farmers to establish that 2 075 ha were irrigated by 2002, consuming 18.9 million m^3 of water. The crops irrigated are corn (41%), paprika (19%), peanuts and maize (30%), and potatoes and alfalfa (ten percent).

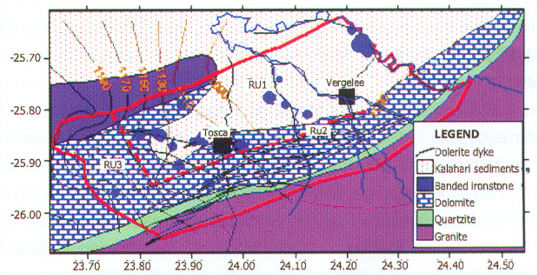


Figure 1. Topography, drainage and geology of the Tosca area.

• *From page 21*

Physical description

Precipitation at Vergelegen is at an average of 400 mm/a and decline to the west to an average of 385 mm/a at Pomfret. Summer rainfall in the form of thunderstorms occurs predominantly during February and March. Evapotranspiration exceeds the rainfall four to five fold at between 2 050 and 2 250 mm/a. The low rainfall sustains a semi-arid vegetation of savannah type Acacias.

Groundwater system description

Underlying the Kalahari formation is the high yielding dolomites of the Ghaap plateau formation. Within this formation, groundwater is associated with brecciated zones along faults with high yields; and fracture zones associated with the intrusion of post-Karoo dolerite dykes and sills along fault zones with high yielding fractures intersected. These dykes form dense boundaries within the dolomite aquifers, impeding the regional groundwater flow. This has led to the formation of separate compartments. These compartments have been named resource units 1, 2 and 3 after the water level reaction indicated their separation.

Groundwater development

A combination of factors led to the development of the resource for irrigation purposes. During 1990, the CSIR explored the resource and it was characterised as 'highyielding'.

Quality and Isotope samples taken from the water at the time did however flag the sustainability of the resources, characterising some of the water as fossil water. Farmers reacted by developing irrigation with high yields and increased income in mind. Table 2 indicates the rapid rate at which irrigation development took place.

Year	1990	1996	2000	2001	2002
Irrigation systems	2	22	32	40	45
Irrigation area (ha)	100	600	1182	1495	2075
Volume Irrigated (Mm^3) *	0.77	4.6	9.1	11.1	18.9#
Stock watering (Mm^3)	0.5	0.5	0.5	0.5	0.5
Human consumption (Mm^3)	0.5	0.5	0.5	0.5	0.5
Total (Mm^3)	1.8	5.6	10.1	12.1	19.9

** Estimated at 7 500 m^3/ha/annum*

 # Estimated after crop factors for the different crops used

Unsustainable abstraction

As early as 1994, concerned farmers realised the dangers in the uncontrolled exploitation of the groundwater and appealed to the Minister of Water Affairs and Forestry, and by 1998 the first indications of unsustainable abstraction were visible as boreholes started drying up proximate to intensively irrigated areas.

To determine the extent of this abstraction on the resource, groundwater levels were measured at approximately 90 boreholes in April 2001.

These levels were compared to groundwater levels measured by the CSIR in 1990. The same boreholes are still being measured every six months.

From the compared water levels in Figure 2, it is evident that an extreme decline in the water level has taken place. There has been a 10 to 20 m regional decline in the water level and a decline of between 50 and 60 m in areas proximate to irrigation.

The most problematic is the Grassbank area, where a cone of 20 km by 15 km, which is 60 m at the deepest, has formed. Figure 3 indicates that the cone had become larger by April 2002.

The severe declines in water levels as a result of unsustainable abstraction of groundwater has led to boreholes drying up, possible

Figure 2. Tosca groundwater elevation difference 2001 compared to 1990

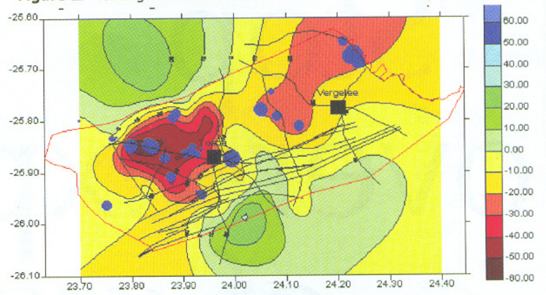
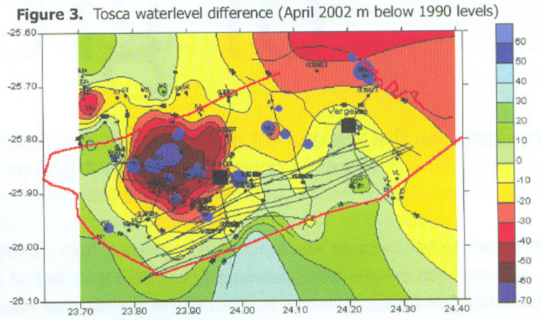


Figure 3. Tosca waterlevel difference (April 2002 m below 1990 levels)



permanent damage to the aquifer and possible future damage to the environment.

To reverse the situation, the water rights for basic water provision should be ensured and the water rights of irrigators who exploit groundwater should be decreased.

Water use potential of the aquifer

During 2002, the potential of the aquifer was determined by the CSIR. The characteristics of the groundwater resource was considered and divided into three groundwater units.

By comparing the chloride dissolved in groundwater samples with the chloride dissolved in rainwater, it was concluded the aquifer should be recharged through:

- geological lineaments (faults, not dykes)
- shallow outcrop and sub outcrop of dolomite (southwestern area)
- banded ironstone formation (northern border of study area)
- the alluvial channels of the Molopo River and tributaries.

Recharge to the aquifer was calculated at between 0.5 and 2% of the annual precipitation of 399 mm per annum.

The results of these calculations are summarised in table 3, with the resource units visible in Figure 1. Resource unit 1, where most of the irrigation is taking place, is heavily over-exploited with its present abstraction of 15 Mm^3 per annum against the natural recharge of about 7 Mm^3 per annum.

Boundaries & types			Recharge					Confidence Level
Resource unit		Aquifer type	Total area (km^2)	% Recharge	MAP (mm/a)	Recharge (Mm/a)	Total Recharge (Mm/a)	
1	(i)	BIF/Dolomite	138	1.58	399	0.87	6.90	Medium
	(ii)	Dolomite	863	1.75		6.02		
2	-	Dolomite	624	0.69	399	1.72	1.72	Medium
3	(i)	BIF/Dolomite	254	2.08	371	1.96	10.95	Medium
	(ii)	Dolomite	1478	1.64		8.99		
Total							19.57	Medium

Table 3: Recharge calculations for the different resource units.

Registration

A number of users have registered use but have not developed yet, in order to reserve water rights for future use. However, only water use exercised before October 1998 can be registered as existing legal use. As the resource is under stress only general authorisation applicable in this area can be authorised. General authorisation in this area is 60 m/ha/annum.

By applying this principle, irrigation use would be reduced from potential development of registered use of 2.6 million m^3 (or 247 ha) to 0.6 million m3 of water under general authorisation. To date the regional registration office has not completed this action.

Verification

Only water use exercised before October 1998 is recognised as existing water use. All irrigators who developed their use after this date should have applied for water use licenses. DWAF is busy identifying illegal users by using satellite images.

Once a user is identified as a potential illegal water user, a communication process is followed, giving the user the opportunity to prove the legality of the use. In the Tosca area, 15 users have been identified and eight of these users could prove that they were using water legally.

> "Only water use exercised before October 1998 is recognised as existing water use."

Directives were issued against the remaining seven users, ordering them to stop their water use by a specific date. This action resulted in 250 ha of irrigated land being affected, which required 3.3 Mm^3 of water.

The water users may appeal to the water tribunal against the ruling, although they have indicated that they would not cooperate, which means DWAF would have to enforce the directives.

This will entail that DWAF will ensure that activities that require water on the farms be stopped, and the associated costs to do this will be recovered from the farmers.

What has been described is the start of the compulsory licensing process. Verifying existing use and eliminating illegal uses are essential preliminary steps.

Although these actions will help to normalise the critical damage to the resource and the eminent conflict in the area, the long-term solution will be a process of compulsory licensing in terms of the National Water Act.

In this case, every user will have to license all his/her abstractions – old and new – and a reallocation will take place, with a strong emphasis on equity and sustainability.

Water user association

A water user association is being establishment in the Tosca area and will enhance the capabilities for water use management in the long-term.

A draft constitution was submitted to the Minister of Water Affairs and Forestry by the Tosca Molopo steering committee, and pending the approval of the association, a management committee will be elected to prepare a business plan for the association to manage the water.

All the actions mentioned above will still not reverse the situation in the Tosca area and legal users will in future be restricted to 50% of their current use.

Dendron aquifer rehabilitated

In the 1960s, an extensive aquifer was discovered in deeply weathered granites in the otherwise fairly poor groundwater environment that is known as the Dendron area, Limpopo Province. This was long before the National Water Act.

The area quickly became a rich potato-growing enterprise. In the 1970s, Eskom Power made centre pivots a reality, but unknown to most, the aquifer declined rapidly.

By the time the farmers' union approached DWAF in the early 1990s, the department established that the system had been abstracted at almost three times the natural replenishment rate.

By working with groundwater specialists and by sharing the groundwater resource information among farmers, an initial attitude of hostility changed to one of complete co-operation.

Within one year, the local farmers' union had made an assessment of overall water-use based on power consumption, and convinced the regional services council to assist with the drilling of observation boreholes, which enabled monthly groundwater level readings.

DWAF contributed by using this data in a specially developed groundwater model to do forecasts of groundwater behaviour under various rainfall and abstraction scenarios.

This information had a tremendous impact on farmers and was the start of strategies, such as water saving through irrigation at night, and the consideration of alternative crops and construction of dams for the sole purpose of recharging the depleted aquifer.

The groundwater system has of late been showing signs of reversing the decline.

However, the voluntary measures have not been sufficient and have probably not been implemented by all farmers.

This is a further example where compulsory licensing in terms of the National Water Act will have to be introduced.

It is clear that a self-regulatory system without any form of higher level control is not feasible. On the other hand, the Dendron example shows that farmers will act in the common interest once they understand what is happening to their groundwater.

This is where water user associations have an important role to play. Water associations will offer tremendous mutual benefits to users of a common groundwater resource.

These associations are vital when there is more than one user group, such as farmers, municipalities and the community. Associations should not focus on one resource only.

Conjunctive use of groundwater and surface water has proved to be one of the most water conserving approaches. Improved local management of groundwater resources will not happen by itself.

Specialist support will have to be provided by DWAF and, in future, the 19 planned Catchment Management Agencies.

The more organised the farmer community, the easier it will be to support them. The private groundwater industry may also see their way clear to come in as a partner.

"WATEROORLOG" - DEPARTEMENT REAGEER

Tosca - Na aanleiding van die berig verlede week in die Stellalander oor 'n oorlog wat dreig in die omgewing oor water tussen veeboere aan die eenkant en besproeiingsboere aan die ander kant, het die Departement van Waterwese en Bosbou reageer.

Die strategie van die departement is om voort te gaan met die insameling van inligting wat die stand van die onderaardse waterbronne sal weergee, het Erika de Villiers aan ons gesê. So word daar elke drie maande 1oo watervlakke gemeet oor die gebied om stygings of dalings vas te stel.

Hierdie inligting word verwerk saam met die WNNR om te probeer bepaal wat die standhoudende volume water is wat onttrek kan word. Hierdie volume sal dan die basis vorm van watertoekennings aan verbruikers. 'n Vereniging word dan ook gestig om die bron te bestuur ingevolge die bepalings van die Nasionale Waterwet nommer 36 van 1998.

So kry drinkwater, klein tuine, munisipaliteite, dieregebruik en natuurlike water, soos fonteine, voorkeur en moet standhoudend wees. Indien die bron nog water kan lewer, eers dan kan besproeiing en industriële waterverbruik toekennings ontvang uit so'n bron.

Enige verbruiker wat na 1 Oktober 1998 water sonder 'n lisensie verbruik, kan vervolg word. Slegs verbruikers wat voor daardie datum water verbruik het en as sodanig geregistreer het, mag dit wettig onttrek.

nie.

"Dit is hoog tyd die grondwet her moet word om verseker dat daa balans is tus menseregte, strafre die regte van Jan l liek," het die Unie g

SIMBA-ATLETIEKBYEENKOMS

'n Baie geslaagde Simba atletiekbyeenkoms is Donderdag aangebied deur Lion King Kleuterskool op Vryburg. Elk van die meer as 120 deelnemertjies het 'n geskenpakkie ontvang van mnr Francois Strydom van Spar (links). Op die foto is 'n paar van die atleetjies met mev Poppie West, organiseerder, (middel agter) en mev Erna Strydom (regs).

Stellalander

Successes of Tsipa

Vryburg - SAPS Commissioner Ephraim Beetha on Monday highlighted the va ious successes of Operation Tsipa in February in which 51 roadblocks were co ducted, as well as one cordon off action and one air support operation.

During these operations more than 3000 vehicles were searched, 500 foot patro were conducted and 379 foot patrols.

More than 700 premises and more than 7000 persons were searched, in whic more than a thousand suspects were arrested for various crimes committed.

Ten vehicles were recovered as well as property to the value of more than R7 000,00.

Dagga, unlicensed firearms and ammunition was seized and the commissione thanked the communities for their support without which Operation Tsipa coul not have been successful.

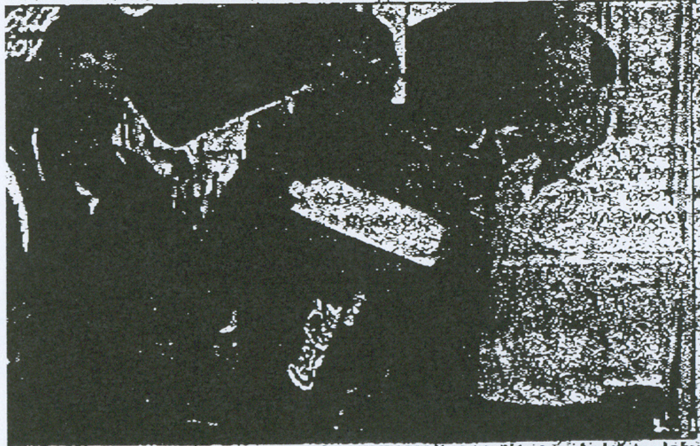
MARCH 2002

Stellalander 27 FEBR 2002

"Boere oorlog" op Tosca

— waterkrisis dreig

...osca. – Daar dreig 'n boere-oorlog" op ...osca, volgens een van ...e veeboere in die ...ngewing wat liefs ...onieme wil bly. Die ...de vir die onenig- ...heid en verdeeldheid ...nder die boere is ...aars ondergrondse ...ater. ... Stellalander het verle- ...week berig dat die ...e volumes grondwa- ...r wat jaarliks onttrek word in die omgewing drasties toegeneem die stigting van 'n wa- sedert 1990, en tans terverbruikersvereniging word so wat 40 ing genoodsaak het. 'n spilpunte gebruik om Vergadering in hierdie 1300 ha te besproei. verband is gister (Dins- As gevolg hiervan het dag) op Tosca gehou. watervlakke op plekke Onttrekking van met tot 60 meter gedaal grondwater deur be- en bees- en wildboere sproeiingsboere het in die omgewing begin die gevolg hiervan dra besproeiingsboere die wanneer boorgate op grondwater oorbenut droog en vee en wild se Dit het gelei tot span- drinkwaterbronne bed- ning tussen hierdie reig. boere en vee- en wild- Van hierdie water boere. brome bevat water wat Hierdie spanning kan 3000 jaar oud is, het breekpunt bereik oor Stellalander verneem. lewensbelangrike wa- Dit is duidelik dat die ter - immer 'n skaars hulpbron in die Molopo. Hoewel die staat sekere voorskrifte en wetgewing aangaande die beutting van ondergrondse water aangeneem het, is die regering skynbaar nie by magte om hierdie wetgewing volledig toe te pas nie en boere benut die water sonder die nodige lisensies en permitte, het Stellalander verneem.



...AT 'N KOELBRYS: Mnr. George Human (middel) het verlede week 'n ... Coca-Cola ... (Coca-Cola) en ... Bala...

Vier vry op borgtog

Vryburg – Die vier vermeende drowers wat verlede week in die hof verskyn het in verband met 'n voorval van gewapende roof, is elk op borgtog van R3000,00 vrygelaat ondanks die feit dat die staatsaanklaer, mnr. Cecil Makwela, gekant was teen die borgaansoek. Die vier, Leonard Sejake (26), Final Kgodumo (26), Patrick To... en Dominic Mo... word, is Kgodumo reeds deur die ANC Jeugliga geskors. Hy het glo op die uitvoerende komitee van die provinsiale organisasie gedien as adjunk-voorsitter. Die vier sal weer op 29 April in die hof verskyn op ... aanklag.

Kuruman seun in vlak graf gevind

MAREETSANE. Twee mans tussen die ouderdomme van 38 en 42 het verlede Donderdag 21 Februarie in die Mafikeng Distrikshof verskyn op klagte van moord. Die twee mans, Stof Musi en Jacob Musi, is ...

Kontrole is nodig vir water

Tosca - Die hoë volumes grondwater wat jaarliks in die omgewings van Tosca-Vergelegen, Louwna-Coetzersdam en Stella onttrek word, noodsaak die stigting van Waterverbruikersverenigings. Die verenigings sal bestaan uit lede wat afhanklik is van 'n gesamentlike waterbron en wat water verbruik vir alle doeleindes (huishoudelik, veesuipings, industriëel en besproeiing). Die doel van die verenigings is om die nuttige aanwending van water tot voordeel van alle gebruikers in hul gebied te verseker.

Tydens die stigtingsproses moet verseker word dat die sieninge van al die toekomstige lede in oorweging geneem word. Die voorneme om so 'n liggaam te stig moet tydens 'n openbare vergadering met die belangegroepe bespreek word (soos by Coetzersdam) waarna 'n loodskomitee gestig word, met die taak om 'n konsepgrondwet op te stel, waarna weer met lede gekonsulteer moet word (soos tans by Tosca). Die grondwet word dan aan die Minister van waterwese voorgelê vir goedkeuring (Stella se konsepgrondwet) waarna lede 'n bestuurskomitee kies.

Hierdie komitee stel 'n besigheidsplan op wat die werksaamhede van die vereniging uiteensit. Die vereniging word gefinansier uit heffings wat op waterverbruik in sy gebied geplaas gaan word. Die verenigings is verantwoordelik vir waterbestuur tot voordeel van waterbronne en afhanklikes van waterbronne. Die belange van groepe verbruikers sal verseker word in die beoogde Opvangsbestuursliggame wat in die toekoms gaan funksioneer.

Kommer oor grondwater..

Tosca - Onttrekking van grondwater in die Tosca-Vergelegen area het sedert 1990 drasties toegeneem om gewasse te besproei en tans word sowat 40 spilpunte gebruik om 1300 ha te besproei. Vir hierdie doel word bykans 11 miljoen kubieke meter water jaarliks onttrek.

Watervlakke het as gevolg hiervan met tussen 10 en 20 meter gedaal en in sommige gebiede tot soveel as 50 meter. Hieruit kan afgelei word dat grondwaterbronne in die gebied oorbenut word.

Waterverbruik deur mens, dier en die natuur moet standhoudend verseker word en daarvoor is besproeiers en industrie geleentheid gebied om waterverbuik voor 1 Oktober 1998 te registreer. Na 1 Oktober 1998 moet nuwe verbruikers gelisensieer wees deur die Departement van Waterwese in Kimberley.

'Landbou moet geleenthede beter aanwend'

Leeudoringstad - "Die oplossing van die probleme wat die landbousektor moedeloos maak, moet nie die doelwit wees nie, maar bloot sake wat hanteer moet word om geleenthede te kan benut." Sò skryf prof Herman van Schalkwyk, Hoof van die Departement Landbou Ekonomie aan die UOVS in die jongste uitgawe van die lyfblad van Suidwes Beleggings.

Prof Van Schalkwyk identifiseer die trae afhandeling van die grondhervormingsproses, die politieke situasie in Zimbabwe, algemene geweld en diefstal, min owerheidshulp, die agteruitgang van die platteland se infrastruktuur en die HIV/VIGS situasie as faktore wat die landbou tans negatief stem.

Die eerste stap na 'n beter toekoms, volgens prof Van Schalkwyk, is dat geleenthede raakgesien moet word. Geleenthede kan egter slegs benut word as dit op 'n georganiseerde wyse gedoen word. Hiervoor is samewerking in landboukringe broodnodig.

Daar is nie meer plek vir louwarm betrokkenheid nie, glo hy. Geleenthede duik gedurig op en kan slegs benut word deur diegene wat die vinger op die pols het. "Deur hierdie geleenthede te benut, kan meer werksgeleenthede geskep word, wat al 'n groot bydrae kan lewer in die oplossing van Suid-Afrika se baie probleme," meen Van Schalkwyk. "Landbou kan so dien as 'n voertuig tot ekonomiese groei."

KENNISGEWING VAN LOODSVERGADERING AANGAANDE DIE STIGTING VAN DIE VOORGESTELDE LOUWNA/COETZERDAM WATERVERBRUIKERS VERENIGING.

Datum: 12 Maart 2002

Tyd: 14:00

Plek: Ontspanningsaal te Louwna

Alle belanghebbendes word uitgenooi na bogenoemde vergadering en veral die volgende belangegroepe waterverbruikers moet bywoon.

- **Besproeiingsboere, Algemene Boere en moontlike Nywerhede van die volgende kadastrale plaaseiendomme binne die bedryfsgebied van die voorgestelde vereniging:**

Long Valley;	Mooirus;	Hartbeeslaagte;	Klipfontein;
Mooihoek;	Gannalaagte;	Swellendam;	Hoep Vlei;
Onbekend;	Vaallaagte;	Boshpan;	Kameelboomvlakte;
Panfontein;	Mistake;	Waterpan;	Caledon;
Boschbult;	Graspan;	Havelock;	Hendriksvlakte;
Taungs;	Rooilaagte;	Wildebeespan;	Schietpan;
Erfpag;	Nantes;	Brulpan;	Morgenzon;
Mooilaagte;	Vaalbosknop;	Kameelplaat;	Shamrock;
Doringlaagte;	Heriot;	Zoutpan;	Sans Souci;
Mamusa;	Dwaling;	Klein Tswaiing;	Schilpadkuil en
Nelspos;	Kromboom;	England;	Belladonna.
Doornpan;	Vergelegen;	Kafir Pan;	
Birnamwood;	Genut;	Harbro;	
Kaalplaats;	Fisher's Rust;		

- **Besighede en Nywerhede te Coetzersdam en Louwna**
- **Verteenwoordigers van huishoudelike waterverbruikers**
- **Verteenwoordigers van die Departement van Waterwese en Bosbou**

Navrae i.v.m. bg. vergadering kan gerig word aan:

Mnr Gawie van Dyk
Departement van Waterwese en Bosbou
Noord Kaapstreek
Kimberley
Tel. No.: 053 831 4125