# MANAGING THE IMPACT OF IRRIGATION ON THE TOSCA-MOLOPO GROUNDWATER RESOURCE, SOUTH AFRICA.

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**Abstract.** By the year 2000 abstraction from groundwater resources in the dolomite aquifers of the Tosca Molopo area increased to approximately 16.1 M $m^3$/a or irrigation area of 2000 ha. This abstraction from high yielding deep boreholes, led to water levels declining 10 to 20 m regionally and up to 60 m proximate to intensive irrigation. In an area were historically basic human and stock watering from shallow boreholes was the main water use, all water use is at risk. The recharge to the aquifer and its different resource units were estimated to be 0.5 to 3 % of the annual precipitation by rapid methods like the chloride method. The water use was quantified through the NWA (National Water Act) by registration of water use, verification of this water use and authorization of any new water use to be 16.1 M $m^3$/annum. The establishment of a water users association to monitor and manage the water use and resource was initiated and all communication was done through this establishment process. A model of the aquifer was constructed from 10 years of abstraction and water level data. Prediction scenarios for 10 years to 2014 indicated that abstraction from the aquifer exceeds recharge by 40% and restriction on water use with firm abstraction control to prevent further damage to the aquifer and protect all water users is essential.

**Keywords:** water use, declining water levels, regulation

## INTRODUCTION

From 1990 to 2000 rapid development of irrigation from groundwater resources in dolomite aquifers took place in the Tosca Vergeleë 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 paper reports on the qualification and quantification of the impact, determination of water use and regulating use to ensure sustainable future use.

## LOCATION, TOPOGRAPHY, DRAINAGE AND GEOLOGY

The Tosca Vergeleë area is located in South Africa proximate to the Botswana border.

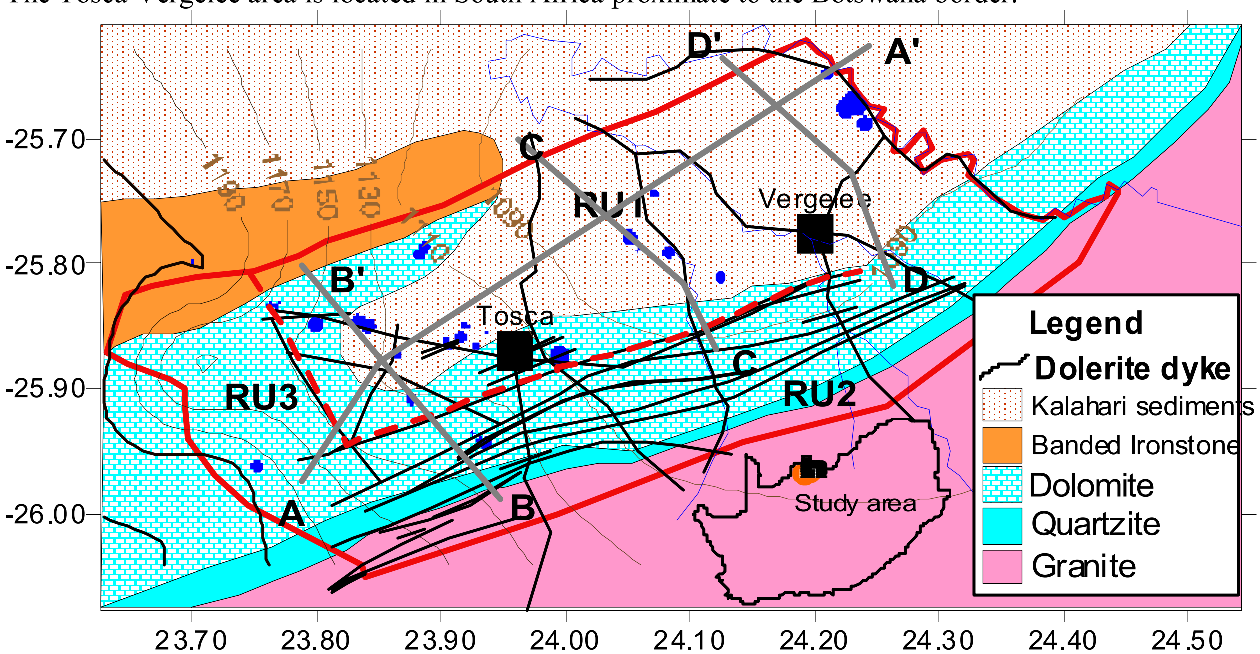



Figure 1. Location of the study area (inset map), topography, drainage, geology, position of irrigation and resource units

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 (Figure 1). A number of non-perennial rivers drain the area, and although insignificant as surface water resources they play a major role in groundwater recharge.

## CLIMATE AND PRECIPITATION

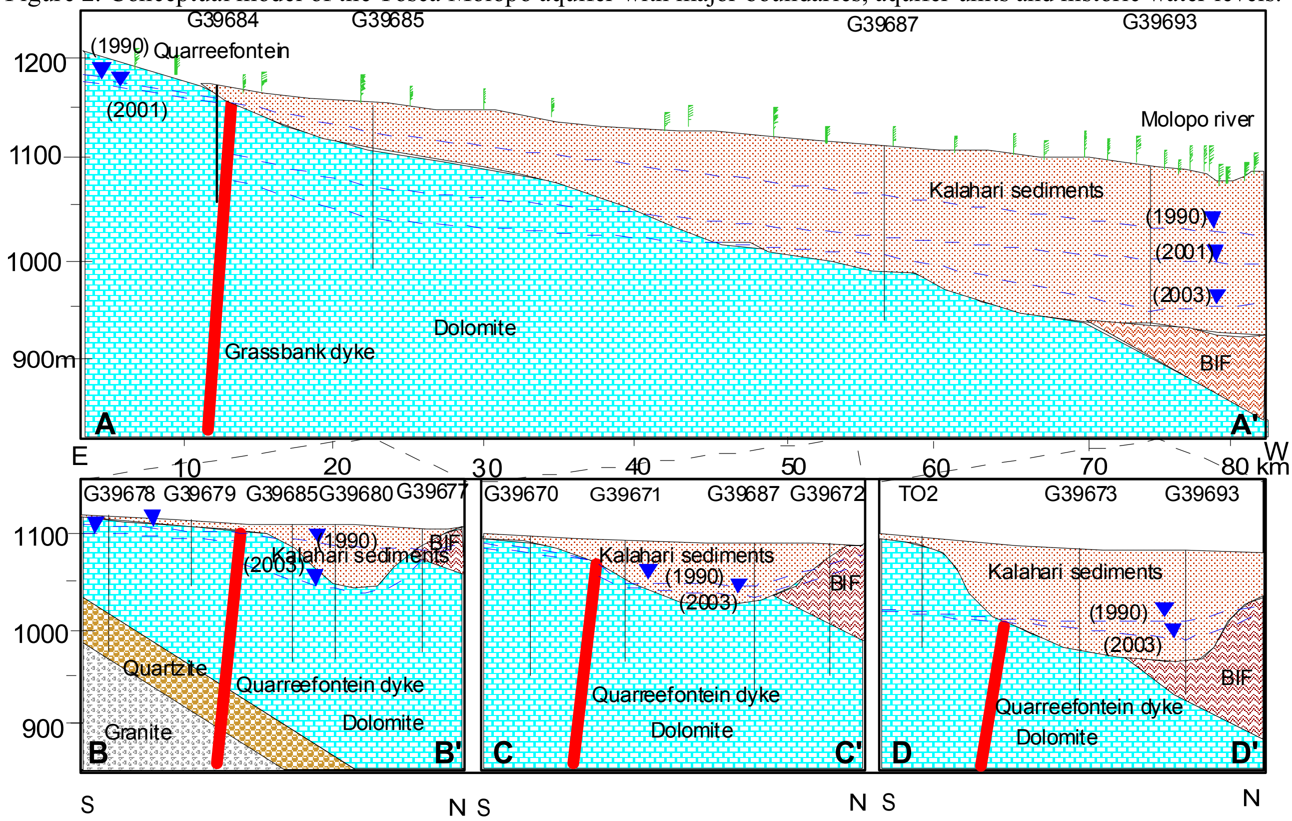
The study area is characterised by a low annual rainfall, varying from 399 mm in the east to 385 mm in the west. Evaporation in the area is high at between 2050 – 2250 mm/a (WRC, 1994) with only a small percentage of rainwater available to recharge groundwater. The average recharge is ranging from 0.5% to 3% of the annual precipitation.

## GROUNDWATER FLOW MODELLING

### *Conceptual model and model construction*

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 spatial dimensions are approximated in the conceptual model of Figure 2 with the position of these sections visible in Figure 1. 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.

Figure 2. Conceptual model of the Tosca Molopo aquifer with major boundaries, aquifer units and historic water levels.




The MODFLOW PMWIN 5.1.7 (Chang 2000) software was used to construct a 2-layer finite difference flow model. The model covering 50 km east west and 80 km north south or 4000 $m^2$ 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 dolomite with its fractured aquifer characteristics.

The first layer range from an elevation of 1160 mamsl to 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.

***Aquifer boundaries and parameters***

Of the number of dolerite dykes intruded into the dolomite the Grassbank and Quarriefontein 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 (Figure 2 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. 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.

The aquifer parameters for the unconsolidated sediments of layer 1 are tabled in table 1 with the parameters of the fractured and carstified dolomites of layer 2 in table 2.

Table 1.Transmissivity, storativity in zones of layer 1.

| **Zone** | **T ($m^2$/day)** | **S []** |
|---|---|---|
| Unconsolidated sediments | 17 | 0.005 |
| Thick calcrete, minor sand | 20 | 0.005 |
| Clay, calcrete, minor gravel | 9 | 0.005 |
| Calcrete along riverbeds | 27 | 0.005 |
| Basal gravel | 37 | 0.005 |
| Zone covering dolerite | 9 | 0.005 |

Table 2. Transmissivity, storativity in zones of layer 2.

| **Zone** | **T ($m^2$/day)** | **S []** |
|---|---|---|
| BIF | 5 | 0.002 |
| Dolomite with dolerite | 25 | 0.002 |
| Dolomite with chert | 40 | 0.002 |
| Dolomite, chert, shale, BIF | 60 | 0.002 |
| Lava and diamictite | 10 | 0.002 |
| Dolerite | 2 | 0.002 |

***Recharge to the aquifer and abstraction from the aquifer***

Recharge to the aquifer was determined with the chloride method with groundwater sample analysis with the $Cl_{rain}$ content 0.9 mg/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 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. Table 3 indicate the total volumes abstracted annually.

Table 3. Total water abstraction used for modelling purposes.

| Year/Season | Future | 04_03 | 03_02 | 02_01 | 01_00 | 00_99 | 99_98 | 98_97 | 97_96 | 96_95 | 95_94 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Total million $m^3$/a | 11.1 | 12.0 | 16.2 | 15.7 | 15.1 | 14.2 | 9.2 | 8.4 | 5.9 | 5.3 | 1.0 |

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.

***Scenario prediction from model***

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 4. 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 and regulation |
|---|---|---|---|---|
| Scenario 1 | 0.4 - 1.5 winter<br>1.5 - 8.3 summer | 16.1 | Decline regionally 20 to 30 m<br>Proximate to irrigation 60 to 110m declined | Not acceptable |
| Scenario 2 | 0.4 - 1.5 winter<br>1.5 - 8.3 summer | 11.1 | Decline regionally 10 to 20 m<br>Proximate to irrigation 30 to 60m declined | Acceptable with strong abstraction control. |
| Scenario 3 | 0.2-1.2 winter<br>1.2-6.7 summer | 11.1 | Decline regionally 20 to 30 m<br>Proximate to irrigation 60 to 110m declined | Acceptable with strong abstraction control. |
| Scenario 4 | 0.4 - 1.5 winter<br>1.5 - 8.3 summer | 0 | Full regional water level recovery<br>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.

## REGULATING AND MANAGING THE WATER RESOURCE

Based on the evaluation and modelling of the resource the regulating and management of abstraction was addressed within the legal framework provided by the NWA to obtain sustainable, equitable and fair 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 prove that they are authorized users through a communication process and submittance of 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 favour 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 or scale down with 40%.

| Description | Irrigation area (Ha) | Volume (million $m^3$/a) |
|---|---|---|
| Registered irrigation surface and volume | 2076 | 18.2 |
| Termination of unauthorized use | -451 | -2.0 |
| New water use authorization | 130 | 0.97 |
| Total irrigation areas after NWA reduction processes | 1755 | 17.17 |
| Restrict water use to 60% of authorization | -702 | -6.87 |
| Total future use | 1053 | 10.3 |

## CONCLUSIONS

- The NWA makes provision for local management structures to be established to manage their local water use such a Water User Association (WUA) is in the establishment process in the Tosca area and would on the long term be responsible for water use management.
- The resource is currently over allocated. Irrigation water use must 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 (NWA) would be the long-term solution in this area. Compulsory licensing is aimed at sustainable, equitable allocation of water rights.
- The WUA should ensure that all users comply with abstraction control and water level reaction should be gathered bi-annually at the boreholes of the monitoring network. By understanding the flow system and measuring aquifer reactions to abstraction informed decisions can be made regarding available recharge and abstraction schedules.

## REFERENCE


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.*

Duvenhage A.W.A., Meyer R., 1991, Geohydrological and Geophysical Investigation in Tosca-Vergelee area. *CSIR report EMI-C 91179.*

DWAF National Groundwater Database (NGDB, Kimberley) – Borehole information and data of groundwater and irrigation monitoring in the area during 2001 to 2003.

Moseki M.C., 2001. Impact of Lead Zinc mining activities on groundwater resources in the Pering mine compartment, PhD Thesis, University Free State.

National Water Act 1998. Act 36 of 1998. *Republic of South Africa Government Gazette*, Vol. 398, Cape Town.

Smit, PJ., 1977. Die Geohidrologie in the opvanggebied van die Moloporivier in the Noordelike Kalahari. PhD Thesis, University Free State.

Van Dyk G.S. du T., 2004. Managing the impact of irrigation on the Tosca Molopo groundwater resource. M.Sc Thesis., University Free State.

van Tonder G.J., Bean J.A., 2003. Challenges in estimating groundwater recharge. *Contribution paper for United Nations Educational*, Scientific and Cultural organization (UNESCO).

W.H Chaing& W. Kinzelbach, (1991-1999), Processing Modflow Version 5.1.7,

Schaffner B, Chen Y.Y.,. Kelepile T, Kinzelbach W., Carlson L and Mannathoko I., 2000. Scientific support for sustainable groundwater management: A modelling study in Botswana using environmental tracers. *IAH 2000 Groundwater Past Achievements Future challenges* P291-296.

Midgley D.C. Pitman W.V, Middleton B.J., 1994. Surface water resources of South africa1990. WRC report no 298/1/94. *Water research commission*.