

A Groundwater Planning Toolkit for the Main Karoo Basin:

Identifying and quantifying groundwater development options incorporating the concept of wellfield yields and aquifer firm yields

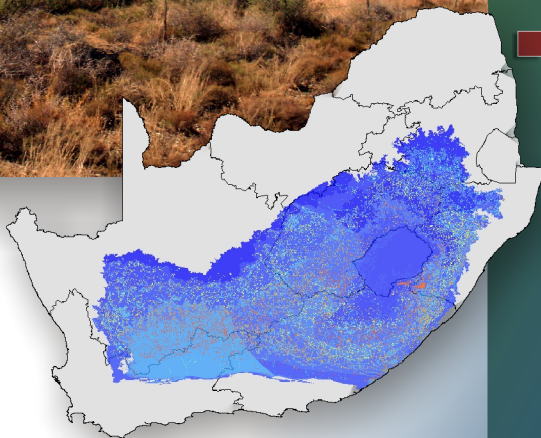


Main Karoo Basin Model Suite



This groundwater resource pack contains the following:

- Groundwater Quality Maps
- Transmissivity Maps
- Aquifer Firm Yield Model
- C-J Wellfield Model
- Wellfield Cost Model



FEBRUARY 2012

 **GROUNDWATERAFRICA**

Contents

Introduction,	pg 3
Study area,	pg 4
Tools for identifying and quantifying suitable groundwater targets,	pg 5
Groundwater quality maps,	pg 6
Groundwater targets,	pg 7
The transmissivity maps,	pg 8
Aquifer Firm Yield Model,	pg 9
Wellfield Model,	pg 12
Wellfield Cost Model,	pg 14
Conclusions,	pg 15

INSTALLATION NOTE

Option 1

Users with administrator rights on their PC's should install the software (GMS) through the autorun.exe which should start automatically once the disk has been inserted, depending on their personal settings. If the autorun.exe does not automatically launch, the user can do this manually by double clicking on autorun.exe

Option 2

Users without administrator rights should run deploy.exe from the disk by simply double clicking on deploy.exe and following the instructions. GMS will be extracted to the user specified directory. Once the extraction is complete the user can go to the selected directory and right click on GMS.exe, select "Send To" and choose "Desktop". This will create an icon on the desktop.

FAQ

1. If an error message appears stating that the user has insufficient privileges after following Option 1, it means that the user does not have sufficient rights and should follow Option 2.
2. If an error message occur stating that no changes can be made to the database, the user should change the User Account Control settings to "Never Notify" by following these steps:

Control Panel-> User Accounts-> Change User Account Control settings-> Select "Never Notify"

A system reboot is required for the system settings to take effect.



Introduction

Introduction

This project was initiated due to the need to place the existing pool of groundwater knowledge of the Karoo Basin within the realm of water resource planning. It focused on developing tools that will assist hydrogeologists in identifying and quantifying suitable groundwater targets for municipal supplies, and in presenting them in a manner accessible to engineers and planners.

The project aimed to identify favourable groundwater potential areas for bulk municipal water supplies, to provide a method to quantify them, and to package the information so that it is assessable for planning purposes. Although the target audience are hydrogeologists, some of the products are accessible to municipal planners.

The following tools developed during the project have been packaged for use in electronic format. The following tools are contained in this package:

- Groundwater Quality Maps which indicates water quality and treatment requirements.
- Transmissivity Maps which indicate favourable drilling targets and high permeability areas.
- The Aquifer Firm Yield Model which indicates the groundwater potential of an area.
- The C-J Wellfield Model which indicates how many boreholes are needed and the spacing required between them to get the required yield.
- The Wellfield Cost Model which helps to estimate the capital and O&M costs of developing a groundwater supply scheme.

The abovementioned tools, which are primarily aimed at hydrogeologists, have been packaged for use in electronic format.





Study area

The study area extends over 560 000 km², and is defined by the outcrop of the Main Karoo Basin (Figure i), but excludes the folded strata along the southern margin and areas in the north and north-eastern margin that are partly covered by Kalahari sediments.

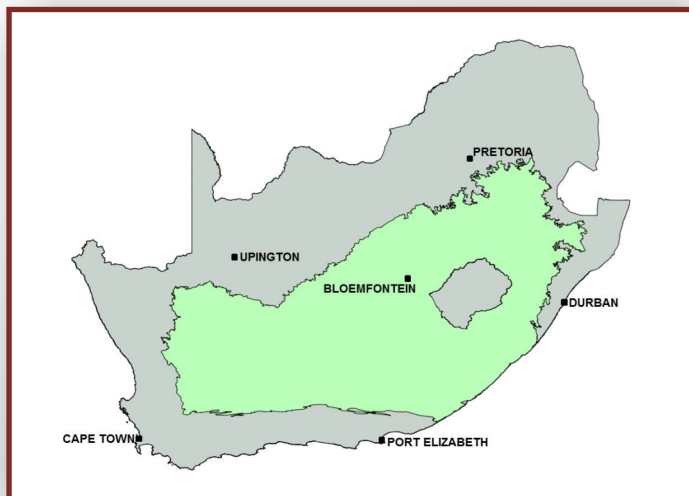


Figure i The Main Karoo Basin

Tools for identifying and quantifying suitable groundwater targets

The recommended process for identifying and quantifying suitable groundwater targets is outlined in [Figure ii](#). The items in *italics* on the right hand side of the diagram are the resources or “tools” that are supplied in this toolkit.

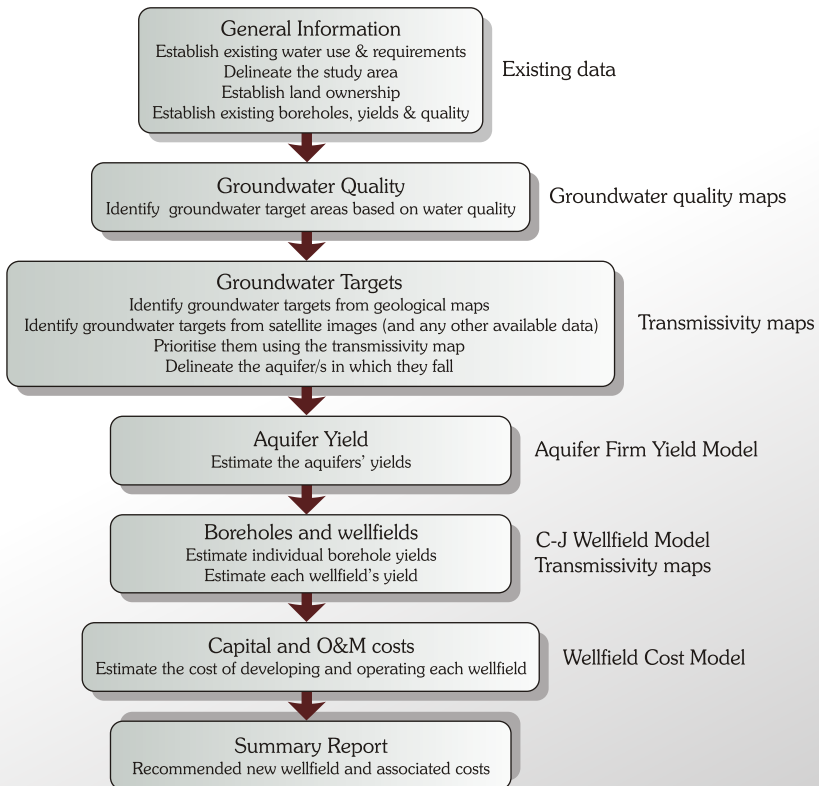


Figure ii The process and tools developed to identify and quantify suitable groundwater targets

Groundwater quality maps

This component of the project aimed to provide guidance on two key questions:

- i. What is the likely quality of the groundwater?
- ii. Is it necessary to treat it, and if so, how much will it cost?

In order to provide guidance on both questions, all accessible groundwater quality data was assessed, merged and mapped; and based on this information, treatment requirements and associated costs were mapped. Sufficient data was available for the mapping of the following determinands:

salinity (electrical conductivity); sodium; calcium; magnesium; sulphate; fluoride; iron; nitrate; arsenic.

An example of the electrical conductivity map that was produced is shown in Figure iii.

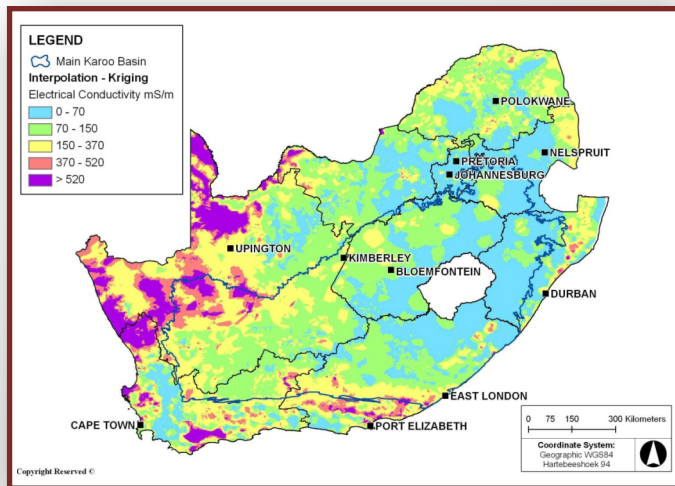


Figure iii Interpolated groundwater electrical conductivity

Groundwater targets

Areas of relatively high permeability in the Main Karoo Basin (MKB), and thus favourable drilling targets, are predominantly associated with:

- Dolerite dykes
- Dolerite rings
- Dolerite sill margins (especially inclined sheets)
- Thick alluvial deposits
- Folded and faulted formations

Dolerite intrusions can have the effect of baking, deforming and fracturing the sedimentary rocks thereby allowing transmissive zones to develop along these geological contacts.

Alluvial deposits, if sufficiently coarse grained allow for easy flow through the aquifer. If these deposits are expansive, thick and permeable they form highly productive aquifers (for example the Cedarville Flats). Where these deposits overlie fractured hard-rock aquifers, the groundwater potential is likewise substantial.

Folded and faulted formations owe their permeability to deformation and fracturing. While faulting in the MKB is rather limited, the southern margin of the Basin is highly folded where it meets the excessively deformed Cape Fold Belt.

The other factor that dictates the exploitation potential of hard-rock Karoo aquifers is the *type of host* rock that has undergone deformation. From the borehole yield data it is evident that the groundwater potential is higher where the host rocks are predominantly sandstones rather than mudstones. This is because fractured sandstones are more permeable than fractured mudstones, and because fractures within sandstones are more extensive than in the more ductile mudstones.

During this project, the 1:250 000 published geological maps were used to develop seamless maps (GIS data sets) of the MKB for dolerite dykes, dolerite sills, faults and alluvial deposits. Folded areas were not done due to the complexity of this task, and this remains a task that should be done in future. These maps/data sets show the areas of high groundwater potential. They are effectively maps of geological structures that are commonly associated with higher permeability. For the purpose of generalising about the hydraulic characteristics of areas within the Main Karoo Basin, the Basin was divided up into domains that reflect lithological, metamorphic and depositional areas of commonality. Together with the maps/data sets of favourable geological structures, they were used to delineate transmissive areas and can be used to identify potentially high-yielding groundwater targets.

While permeability (or transmissivity) is considered the main factor that limits groundwater potential in the MKB, the overall potential of groundwater resources is a function of recharge and storage. For this reason, it is necessary to assess an aquifer's potential in these terms as well as a wellfield's

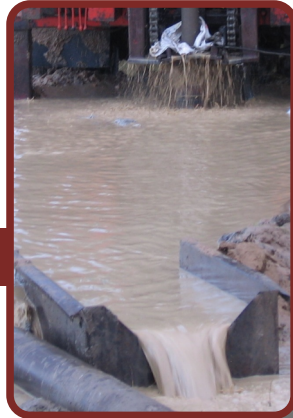
localised groundwater potential. Two tools were developed for these purposes: The Aquifer Firm Yield Model and the C-J Wellfield Model.

The transmissivity maps

The reason why a transmissivity map is of great value is because of the direct correlation between the yield of a borehole and the transmissivity of the aquifer, the yield increasing as the transmissivity increases and vice versa.

Transmissivity maps (GIS data sets) of the Main Karoo Basin were developed to provide guidance on potential borehole yields. Whilst this is seemingly an impossible task owing to the heterogeneous nature of fractured rocks, the approach took both existing borehole yields and geology into account, and provides a range of possible values. In using these maps, the appropriate value would need to be selected based on local borehole yields or experience of the area. Because the maps are based on geology, they can also be used as a starting point in locating high groundwater potential areas and possible drilling targets. The map provides ranges of transmissivity values for each hydrogeological domain (based on lithologies and in some cases, sub-divided lithologies), dolerite dykes and sills, fractured margins of sills and areas of thick alluvium.

An example of a transmissivity map is shown in [Figure iv](#). This example shows how the maps can be used in electronic format to provide guidance in identifying groundwater targets and selecting transmissivity values.



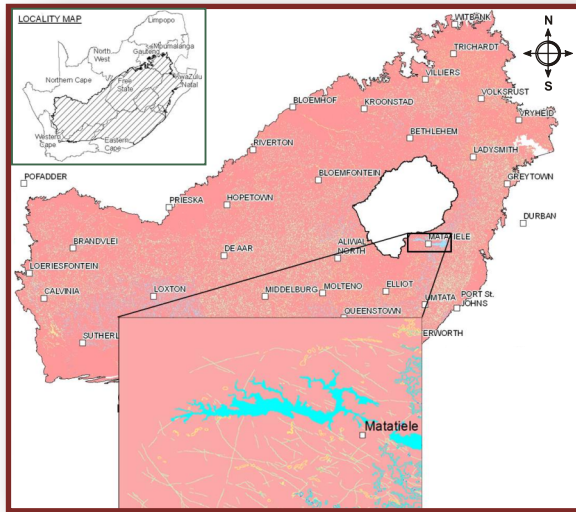


Figure 4
A “zoomed-in” area around Matatiele showing areas of high transmissivity

Aquifer Firm Yield Model

Geohydrologists traditionally provide a single, time-invariant estimate of the average safe or sustainable yield of an aquifer using average inputs and outputs (i.e. mean annual recharge and evapotranspiration etc.). The Department of Water Affairs' Harvest Potential and the Groundwater Resource Assessment Phase II (GRAII) are commonly used examples of these static data sets. The practical usefulness of such estimates of 'safe groundwater yield' to water planning is limited, especially in the arid and semi-arid areas of South Africa where the rainfall is extremely variable (including the Karoo Basin). For this reason it was deemed necessary for groundwater resource assessments to be brought on par with that applied by surface water planners.



The Aquifer Firm Yield Model (AFYM) was developed to provide the historic firm yield of an area. The model is a single-cell, lumped-parameter models and make use of a critical management water level below which aquifer storage levels cannot be drawn down to provide estimates of the aquifer's firm yields. This level defines the volume of water held in aquifer storage that is available for abstraction and would take into account various physical, legal, societal or environmental constraints. Figure v shows the essential components of the lumped box model. This model is only intended for use during the early planning stages of groundwater resources assessment studies where spatial and temporal hydrogeological information is scarce and perhaps several alternative schemes for increasing water supply are being considered.

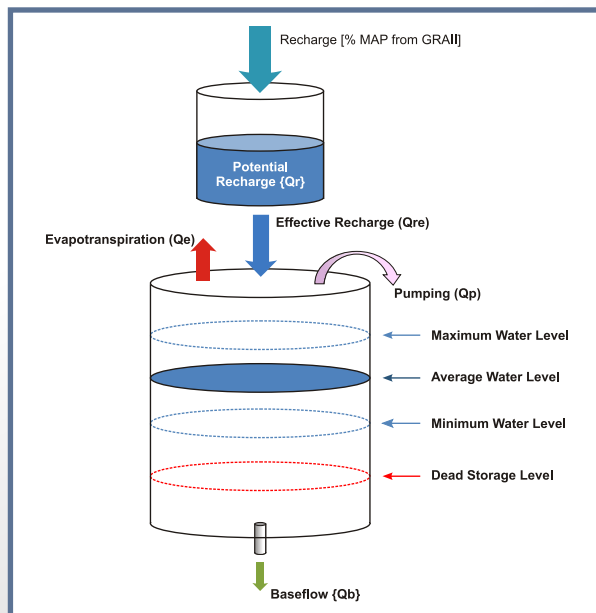


Figure v Aquifer Firm Yield lumped box model

Yields of the Aquifer Firm Yield Model (AFYM) were compared to GRAI and Harvest Potential yields, and the results were comparable, particularly when recommended recharge threshold values are used. Likewise, the AFYM provides good yield estimates when compared with aquifers that have been studied in detail such as De Aar and Dewetsdorp.



Figure vi shows the firm yields for all Karoo Basin quaternary catchments using the default parameter values developed during this project.

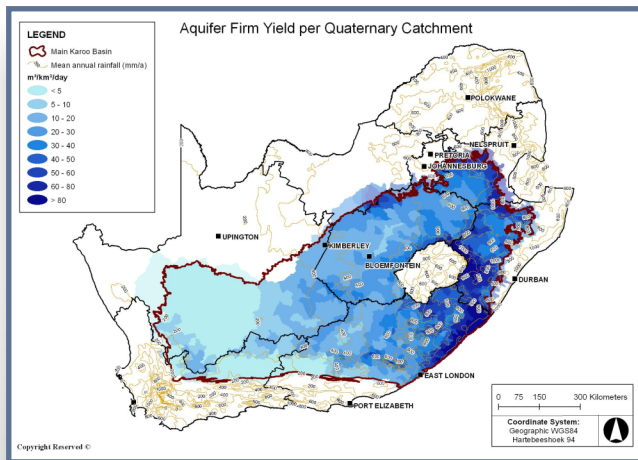


Figure vi Aquifer Firm Yields per Quaternary Catchment

Wellfield model

When designing a wellfield a number of factors need to be considered such as the number and location of production and monitoring boreholes, the pumping rates and daily pumping duration of each borehole, borehole interference and spacing, environmental considerations such as potential impacts on surface water bodies and groundwater dependant ecosystems, and potential impacts on existing users.

Key to these factors is the effect of abstraction from one borehole on another and the optimization of borehole spacing. With correct abstraction rates and borehole spacings, a wellfield can yield a reliable flow with negligible impacts on other users and the environment. Although recharge to the aquifer and the wellfield area affects borehole water levels, for optimising borehole spacing it is aquifer permeability (or transmissivity) that is of paramount importance. Localised effects on borehole water levels such as impermeable boundaries and sources of likely recharge such as nearby rivers or lakes, should also be taken into account in wellfield design. If needs be, a sophisticated numerical model that takes recharge, hydraulic boundaries and spatial differences in aquifer parameters into account can be developed to predict aquifer water levels with various abstraction scenarios.

During this project a simple model, called the Cooper-Jacob Wellfield Model (or the C-J Wellfield Model) was developed, to assists in estimating borehole spacing for planning and costing purposes. The model is based on the commonly used Cooper-Jacob approximation of the Theis groundwater flow equation. Numerous borehole configurations were modelled and guidance on spacing with levels of water level interference given in the project's completion report.



Figure vii is an example of the model “view” with a geological map as the background and the simulated drawdowns in individual boreholes.

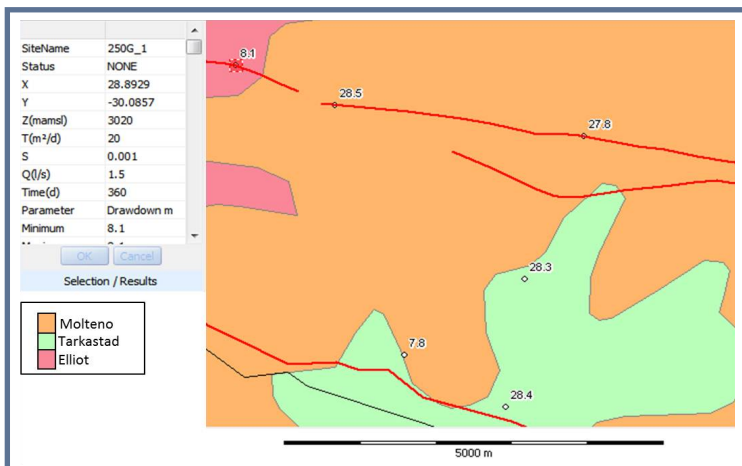
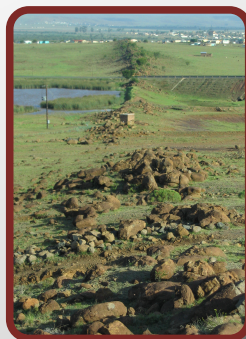


Figure vii An example of a “view” from the C-J Wellfield Model



Wellfield Cost Model

The Wellfield Cost Model (WCM) provides a means of rapidly evaluating the capital cost and operation and maintenance cost of a new wellfield. The WCM considers all infrastructure and associated fees required to establish a wellfield; from the identification of suitable borehole sites, to drilling, test pumping, pump installations and the construction of pipelines, water treatment facilities and bulk storage.

The model outputs comprise cost information and detail of the associated infrastructure. This information is presented on two levels of detail.

- i. The main cost information and infrastructure detail (Figure viii).
- ii. A full schedule of quantities of the different infrastructure components used to calculate the scheme cost.



Figure viii
Wellfield Cost Model -
example of summary results

RESULTS

Daily Water Supply	691.2 kl/ day
Considered Scheme Size	Medium
Total Pump Head	45 m
Power per BH Pump	0.9 kW
Total Power Required	4.4 kW
	6.2 kVA
Nominal Wellfield Pipe Dia	63 mm
Nominal Bulk Pipe Dia	110 mm
Reservoir Storage Volume	1382.4 kl
CAPITAL COST	R 5,128,389
PROFESSIONAL FEES	R 2,471,628
FEES Percentage	48.2%
SCHEME COST (incl. VAT)	R 8,664,019
UNIT COST (per KL)	R 34.34 /KL
O&M COST	
Start-Up Cost	R 0
Operational Cost	R 1, 058,079 /year
Maintenance Cost	R 148,164 /year
TOTAL O&M COST	R 1,206,243 /year
UNIT COST (per KL)	R 4.78 /KL

Conclusions

The following tools are contained in this package:

- Groundwater Quality Maps which indicates water quality and treatment requirements.
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This groundwater resource pack emanates from the Water Research Commission project (WRC Project No. K5/1763):

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Layout and design by DTP Solutions

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