RECENT DEVELOPMENTS IN UNDERSTANDING OF KAROO AQUIFERS AND THE DEEPER UNDERLYING FORMATIONS

By

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Introduction

The possibility of large reserves of shale gas underlying the Karoo and their exploitation has focused attention on, *inter alia*, the groundwater resources and aquifers of this region. Much is known about the relatively shallow aquifers (<300 m) which supply many local municipalities and farmers with water for domestic, stock and irrigation use. Conversely, very little is known about the deeper formations (>500 m) and associated groundwater occurrence and its possible interconnection to the shallow systems. This brief technical article attempts to indicate what is known, what is unknown/speculation and what is being done to investigate and understand these unknowns. The latter will then enable informed decisions to be made by the relevant parties on the way forward, based on sound science.

In September 2011 a group of groundwater experts was formed (initially known as the Water Expert Group or WEG) to establish the current understanding of Karoo hydrogeology. The current group (Karoo Groundwater Expert Group or KGEG) is comprised of *Peter Rosewarne, Alan Woodford, Chris Esterhuyse, Dr Gideon Tredoux, Millie Goes, Des Visser, Siep Talma and Richard O'Brien. Between them this group represents a cumulative experience of about 240 years, much of it related to research and work on Karoo Aquifers. Other members will be co-opted as required.

A series of workshops have been held to debate current knowledge and data gaps and agree on a detailed investigation programme into Karoo Aquifers and the deeper underlying formations. This is to assist with the assessment of risks and precautionary measures related to possible shale-gas development activities. The KGEG is supported by Shell and the output of the group will be made available to the wider hydrogeological community and regulators. This is in order to ensure that the benefits of this work are disseminated as widely as possible and to demonstrate that the work being carried out is transparent and open for discussion and debate. The latter will be welcomed and actively encouraged to ensure that all aspects are dealt with thoroughly.

A Karoo Groundwater Atlas was produced by the WEG and released for general circulation in early 2012 (http://www-static.shell.com/static/zaf/downloads/media/karoo_groundwater_atlas.pdf). This Atlas presents a hierarchy of hydrogeological features of importance in Karoo Aquifers, e.g dolerite intrusions, lithology, water quality and recharge, and visualized through a series of Geographical Information System (GIS)-based groundwater attribute maps depicting these features. The atlas was the result of GIS-based analysis of existing data. Figure 1 below shows the location of the study areas and other key regional features.

Shallow Aquifer

The upper shallow (c. 300 m) aquifer system is relatively well researched and some of the initial findings of this work can be summarized as follows:

- These aquifer systems are well understood based on decades of detailed research, groundwater exploration, use and monitoring, much of it by members of the WEG/KGEG;
- Key attributes have been defined and ranked in order of importance for characterisation of groundwater occurrence, the four most important being:
    - Aquifer yield (potable)
    - Depth to water level
    - Groundwater quality
    - Dolerite intrusions and their contact zones
- Some point or linear features, such as boreholes and dykes, have potential 'capture' or preferential pathway zones, respectively, for groundwater flow. The application of a surrounding 'consideration zone' to take into account the areas of influence beyond mapped coordinates or boundaries of the feature is therefore proposed. Within these consideration zones, exclusion zones may be identified where no gas wells should be sited.
- Preliminary features and associated consideration zones (to be further refined) put forward are:

Dykes	250 m
Other dolerite intrusions	250 m
Faults	250 m
Production boreholes	1 000 m
Hot springs (and their recharge zones)	1 000 m
Hydrothermal plugs	100 m
Kimberlites	100 m

- Some broad trends identified are that aquifer potential increases, dolerite intrusions become more common, the water levels get shallower and groundwater quality improves from west to east, and from south to north in the eastern Karoo.
- The occurrence of methane gas in existing supply boreholes and thermal springs in the Karoo is a relatively common phenomenon. Available isotope data confirm a thermogenic (deep) origin for the methane.

Deeper Formations

There are no detailed 3D geological or hydrogeological models publically available for the main Karoo Basin for depths of >300 m to >4 000 m. However, based on existing data, e.g. logs of Soekor boreholes (thousands of metres deep) from the 1960s and some extrapolations by the KGEG, the following generalisations are considered reasonable:

- Geological strata in the Karoo are generally sub-horizontal (1-2 degree southward) , except adjacent and sub-adjacent to the Cape Fold Belt.

- A thick sequence of multiple layers of shale and mudstone, with subordinate sandstones, and thick dolerite sills, are likely to limit the vertical propagation of fractures due to shale gas development.

- The thickest sill penetrated by a Soekor well is c. 250 m but the vast majority are <20 m thick.

- Dykes and their contact zones extend for up to tens, even hundreds (E-W), of kilometres on surface but their vertical continuation (important for assessing possible contaminant migration pathways) is uncertain. Regional E-W trending 'shear' dykes as well as a number of regional NW trending 'feeder' dykes, e.g. the Middelburg Dyke, could possibly extend to the base of the Karoo sediments

- Hydraulic conductivity (K) along dyke contact zones will vary with depth and strike dependent on host rock and it is unlikely that K-values will be constant along such zones given the multiple layers of alternating mudstone, siltstone, shale and sandstone that make up the Karoo sedimentary sequence.

- Groundwater salinity generally increases with depth due to a combination of gravity, longer residence time due to longer flow paths, lower K (both of which promote interaction with and dissolution of minerals in the host rocks), and direct recharge from rainfall to the shallow aquifer.

- There are only two known hot springs in the Karoo area which are estimated to originate deeper than 1 000 m below surface (based on their water temperature). The water from these springs is not saline, the Aliwal North spring having Total Dissolved Solids of about 1 200 mg/l, for example.

- Groundwater is unlikely to occur in a continuous aquiferous zone from the <300 m shallow aquifer zone to the deep formations where warm to hot (defined as >25^{o}C), brackish to saline water occurs under pressure. The shallow aquifer may be separated from this deeper groundwater (Dwyka and below) by zones of low K rock, possibly hundreds to thousands of metres thick, varying from area to area.

- Deep (up to 4 658 m) exploration drilling by Soekor in the 1960s indicated isolated occurrences of deep, saline groundwater in the Karoo formations and fresher groundwater from the underlying Witteberg Group. Fairly weak, hot (43-76^{o}C) free-flowing water at a rate of 0.3 to 3.0 l/s was reported from a few such boreholes in the southern Karoo, below the Great Escarpment and within the zone of influence of the Cape Fold Belt. However, this flow only started after drilling into the Dwyka Group.

Concluding Remarks

Collation of existing data has shown that there is a wealth of information on groundwater in the Karoo. This is predominantly related to exploitable water supplies for municipal and farm use.

Preliminary hydrocarbon exploration in the 1960s has provided insights into the deeper formations from 20 boreholes which are widely spaced across the Karoo.

Many gaps in hydrogeological understanding remain. The intention is to build the understanding in a structured way, at a measured pace. This will allow for robust peer review, rigorous debate and defensible interrogation of data. The aim is to provide assurance that baseline conditions are understood, potential risks identified and risk management plans developed, based on sound science.

As a first step the concepts for shallow aquifers listed above will be applied at the local scale to assess the effectiveness of the adopted approach. Follow up site work will be scheduled thereafter.

The concepts for shallow aquifers listed above are currently being applied to potential shale gas exploratory areas to assess results and the effectiveness of the approach. Follow-up site work and scenario modelling is then required to further refine the above hypotheses. This may include a variety of reconnaissance surveys, geophysics, drilling, testing and water sampling to understand the potential risks associated with possible future gas extraction.

The KGEG is committed to continuing to build on the solid foundation laid by previous work (see references below) by carrying out rigorous, scientific work and to sharing new information gained on a regular basis through various suitable forums. The KGEG has no preconceptions and its views on the way forward will be informed solely by this professional and methodical approach. One of the main aims is to promote a broader participation and mentorship of students and recent graduates in research work, plus the dissemination of progress and results, in order to inspire and assist with training of a new generation of hydrogeologists.

Karoo Groundwater Expert Group, January 2013

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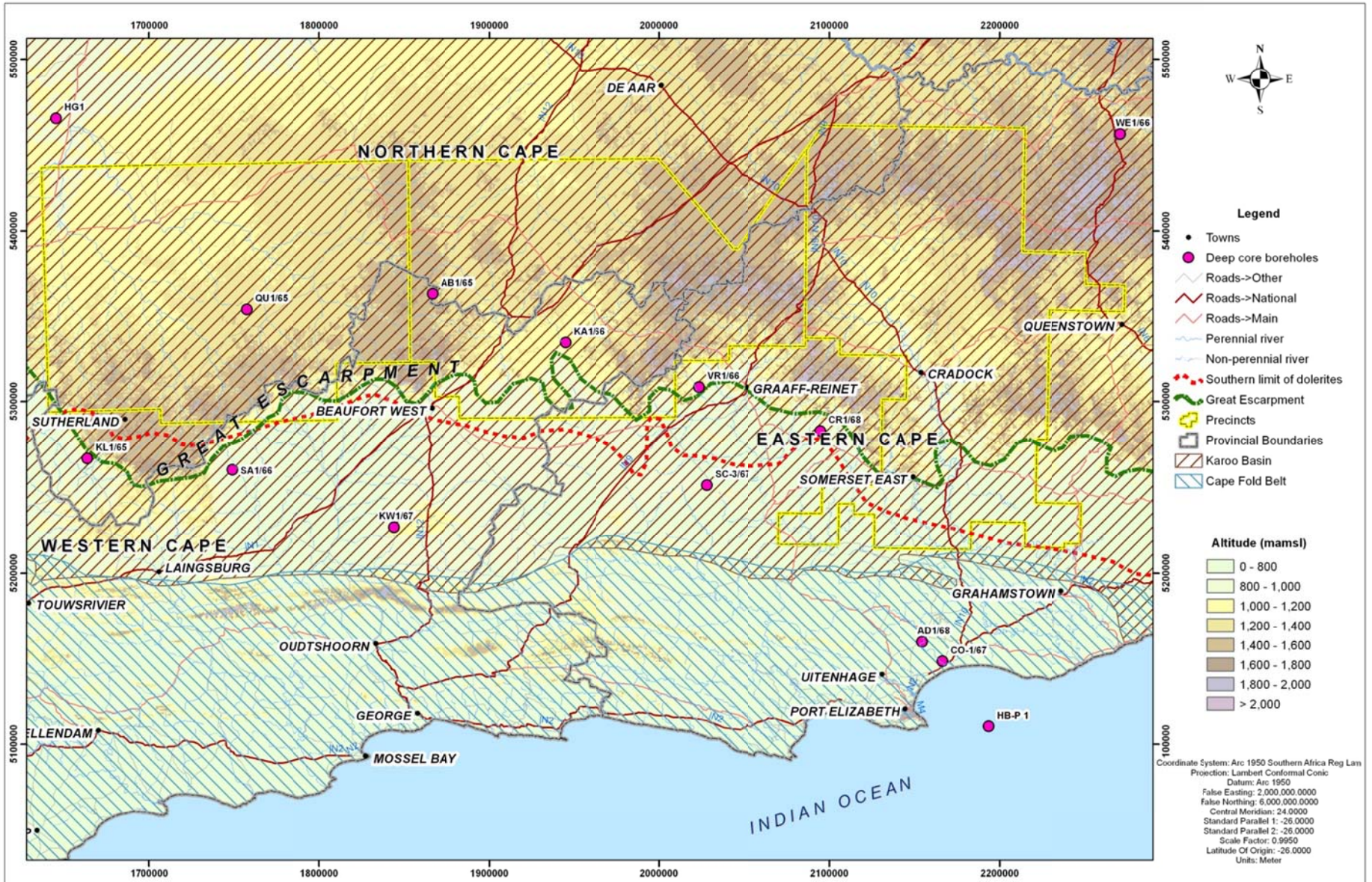

Karoo Groundwater Expert Group KGEG	LOCALITY MAP	Data Source/Notes	Scale 1:2,000,000 (0 12.5 25 50 km)	Compiled by FUBM Date 2011/11/07 Reviewed by ROSW Date 2011/11/07	Project No 443692 Fig No 1

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