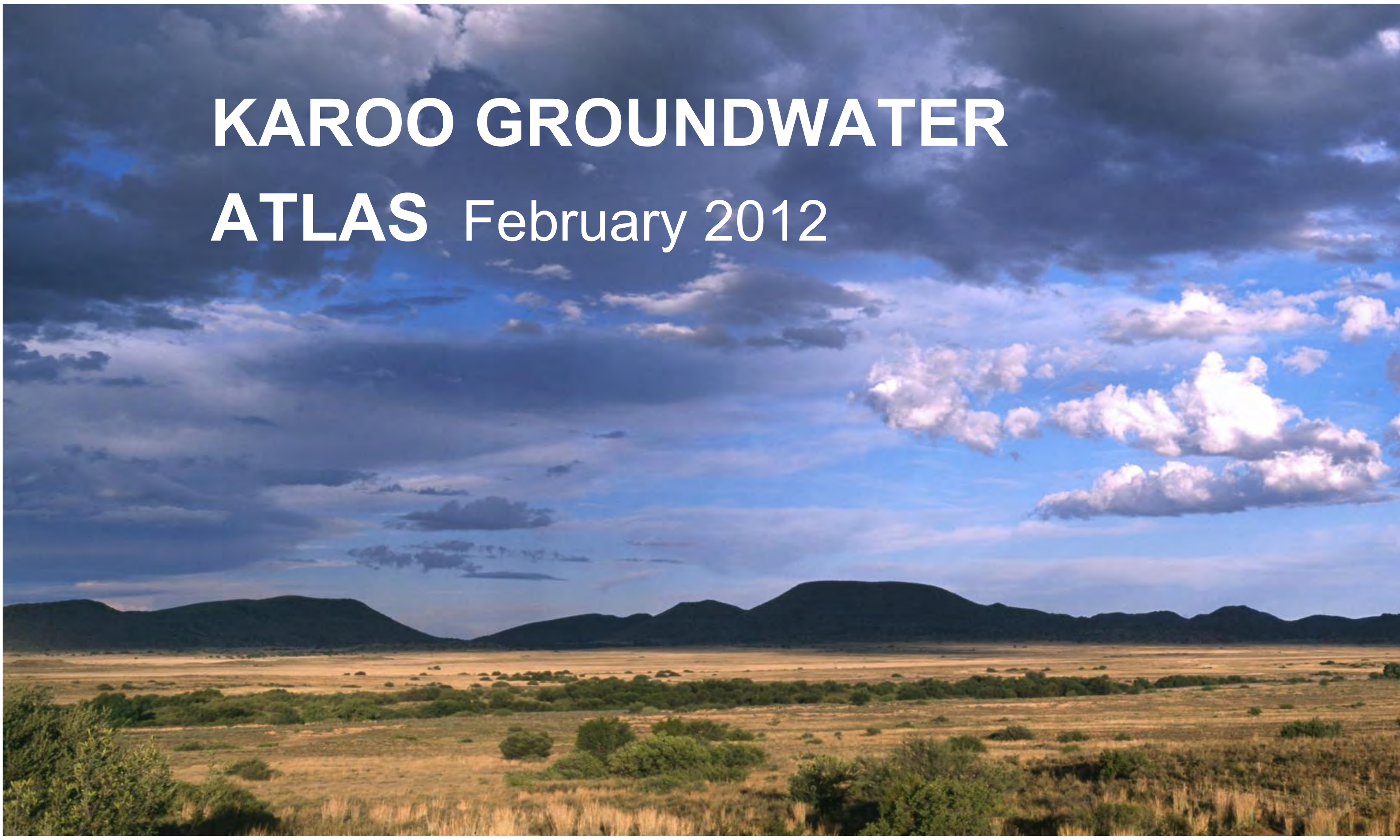
# KAROO GROUNDWATER ATLAS February 2012



**Report Prepared by**

srk consulting

GROUNDWATER AFRICA
GWA CONSULTING HYDROGEOLOGISTS cc T\A

***Prof G. Van Tonder***

RPS Aquaterra

# Karoo Groundwater Atlas: February 2012

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# Table of Contents



# List of Tables



# List of Figures

# Introduction

In support of Shell's application for shale gas exploration licences across the Karoo Region, Shell has committed to identify, assess and manage the associated groundwater issues related to the Karoo Gas Exploration Project. This Stage 1 Project was undertaken by a consortium of hydrogeologists led by SRK Consulting South Africa and covers a desk study and workshop to identify and agree on key groundwater attributes and their ranking and weighting in terms of significance to Karoo Aquifers. A GIS database, series of groundwater maps and a 3-D conceptual model has been produced to form a Karoo Groundwater Atlas. This covers the three exploration precincts that Shell has applied to obtain exploration licences for, (see Environmental Management Plan for licence application precincts http://www.golder.com/af/en/modules.php?name=Pages&sp_id=1236).

### Investigative Approach

This Stage 1 Project was motivated by:

- the need to obtain a full understanding of the hydrogeology of the exploration precincts and surrounds;
- the reliance of communities in the Karoo on groundwater for domestic, stock watering and irrigation use;
- the ecological sensitivity of the Karoo region;
- the need to minimise environmental impacts of exploration;
- the presence of major and sole source aquifers;
- the need to have a defensible strategy to inform selection of exploration drill sites;
- the intense public interest in shale gas exploration; and
- the need to establish an interactive database with baseline data.

To achieve these objectives, a multi-phased approach is planned, the first of which uses a consortium of local specialists, totalling over 250 years of joint experience and each individually with over 10 years of experience in Karoo groundwater resources management (see **Table 1** below) to map the key groundwater attributes in the Karoo area.

This approach was followed so that the output could be technically defensible and sufficiently robust to withstand peer review and public scrutiny. SRK was chosen to lead this consortium because of their track record in managing similar technical teams. This document provides an executive summary of the results of the Stage 1 desk study and workshop. Further outputs and stages will be made available upon completion.

# Scope of Work

Stage 1 comprised:

- Compilation of existing information (e.g. from geological/hydrogeological maps, national groundwater archives and reports);
- A workshop to present, debate, assess and quantify a preliminary approach to groundwater mapping;
- The production and compilation of the above into an atlas of regional hydrogeological maps to support the preliminary assessment of key groundwater attributes; and

- The development of a conceptual site model (3-D) through technical debate.

A key component of the existing data sets was the definitive research work carried out by Alan Woodford (*et al*) on Karoo Aquifers[1]. In acknowledgement of this, Alan was invited by Shell to participate in the workshop and flew in from Perth to take part in the deliberations. Before the workshop SRK compiled the relevant hydrogeological data and worked with Shell to merge this with the main Karoo Project Geographic Information System (GIS). Once the data inputs were aligned, SRK circulated a GIS framework for the consortiums' consideration and a starting position for debate at the workshop (RHM1).

The workshop was held on 24 and 25 October 2011 in Melkbosstrand, Cape Town and comprised of, *inter alia*, a core team of key Karoo hydrogeologists as shown in **Table 1** below. The key objective of the workshop was to bring together the leading Karoo groundwater specialists for open debate, discussion, experience sharing and learning.

A draft set of groundwater attributes and a ranking and weighting methodology was presented for debate and then shallow and deep conceptual models were discussed and broad agreement was obtained between the participants. These discussions were led by Peter Rosewarne of SRK.

This culminated in qualification and then quantification of the major attributes that characterise Karoo Aquifers and confirmation of the key characteristics of the deep conceptual 3-D model. The intent of the consortium approach was to bring diverse hydrogeological opinions together, capture uncertainties for the next phases of work and develop outputs founded on local knowledge and sound science. The initial data sets and maps (RHM1) were updated during the workshop with the results of the group discussions, and are presented in the following sections.

# Workshop Results

## Key Factors and Ranking

Ten key factors were agreed to be significant in contributing to groundwater/aquifer attributes in the Karoo. These were ranked and weighted to give a cumulative score of 100 by each participant, as shown in **Table 2**. The table shows the generally good agreement amongst the consortium on the importance and weighting of the criteria. This gives further credence to the mapping process followed. It also shows that the first four criteria account for 60 per cent of the median weighting, these being (see **Figures 1-4**):

- Aquifer yield
- Depth to water table
- Quality
- Dolerite intrusions

This GIS-based data set is a unique compilation that can be utilised in many ways to interrogate the attributes of Karoo Aquifers. By changing the weighting to reflect a particular query, various hydrogeological attributes can be highlighted, e.g. areas of high or low groundwater exploitation potential (non-competing). The quality weighting will vary depending on the end-use, e.g. domestic or drill site supply.

[1] Examples: Hydrogeology of the Main Karoo Basin: Current Knowledge and Future Research Needs. Water Research Commission Report TT 179/02; Regional Characterisation and Mapping of Karoo Fractured Aquifer Systems. WRC Report 653/1/02

## Table 1: Stage 1 Karoo Aquifers Workshop Key Participants and Roles/Inputs

| Name (years of experience) | Affiliation | Role | Responsibility |
|---|---|---|---|
| Peter Rosewarne (35) | SRK | Team leader. | Overview on SRK project, ranking. Technical input/steering/project management |
| Millie Goes (12) | SRK | GIS operative/hydrogeologist | Presentation on GIS layers/ranking/weighting analysis. Conceptual 3-D model |
| Chris Esterhuyse (28) | SRK (Kimberley) | Project hydrogeologist | Site specific Karoo hydrogeology/monitoring/wellfields. Conceptual 3-D model |
| Des Visser (25) | SRK | Project hydrogeologist | Karoo hydrogeology/groundwater resources management |
| Alan Woodford (25) | RPS Aquaterra (Australia) | Technical review | Karoo hydrogeology overview in opening session. Steering and technical input on ranking/weighting analysis. Conceptual model |
| Prof Gerrit van Tonder (35) | Consultant (University OFS Bloemfontein) | Technical review | Karoo hydrogeology perspective. Steering and technical input on ranking/weighting analysis. WRC fracking project overview. |
| Dr Ricky Murray (21) | Groundwater Africa | Project hydrogeologist | Karoo hydrogeology perspective/steering on ranking/weighting analysis |
| Graham Hubert (38) | Golder & Associates (Jhb) | EMP hydrogeologist | EMP interface |
| Neil Andersen (38) | GEX (Jhb) | Consulting geologist | Input on geology/structure and ranking importance. Gas management experience |
| Non consortium participants | | | |
| Philippa Scott (35) | Shell | RHM Project Manager Hydrogeologist | Project Steerage, Technical Assurance |
| Robert Dunfey | Shell | Geomatics Consultant | Integration of RHM with Main Karoo GIS |
| Dr Chiedza Musekiwa | Council for Geoscience | Consulting geologist | Observer for Stage 1 Hydrogeological analysis/modelling |
| David Shandler | ERM | Facilitator | Facilitator |
| Andreas Stoll | ERM | Technical Scribe | Production of minutes of workshop |
| Martin Bell | Shell | Karoo Surface Manager | Overall Accountability for Water Management – Karoo Shale Gas Exploration Project. |
| Marja Prinsloo | Shell | Sustainable Development Manager | Karoo EIA Co-ordinator |
| Janine Nel | Shell | Upstream Communications | Karoo Communications |

## Table 2: Weighting of Significant Factors.

| Criteria | SUM | MIN | MAX | AVE | MEDIAN | STD DEV |
|---|---|---|---|---|---|---|
| Aquifer yield | 154 | 3 | 25 | 15.4 | 17.5 | 7.06 |
| Depth to water table | 138 | 3 | 20 | 13.8 | 16.0 | 6.78 |
| Quality | 150 | 10 | 20 | 15.0 | 15.0 | 4.71 |
| Dolerite intrusions | 140 | 8 | 25 | 14.0 | 11.0 | 5.75 |
| Faults | 83 | 5 | 15 | 8.3 | 8.0 | 3.59 |
| Folded lithologies | 88 | 5 | 14 | 8.8 | 7.5 | 4.16 |
| Lithology/Group | 70 | 3 | 12 | 7.0 | 5.5 | 3.16 |
| Depth to main water strike | 63 | 1 | 14 | 6.3 | 5.0 | 4.22 |
| Depth of weathering | 58 | 3 | 10 | 5.8 | 5.0 | 2.35 |
| Soil type | 56 | 1 | 12 | 5.6 | 5.0 | 3.78 |

## Consideration Zones

Some of the criteria do not have fixed boundaries and may have zones of influence extending beyond their mapped positions (e.g. dolerite intrusions) or coordinates (e.g. boreholes). To accommodate such variation the concept of consideration zones was derived. These zones were agreed during the workshop and do not represent exclusion zones, but rather areas where groundwater is considered to be more significant. Therefore, more detailed assessment of these zones will be required should any operations be conducted in or near them.

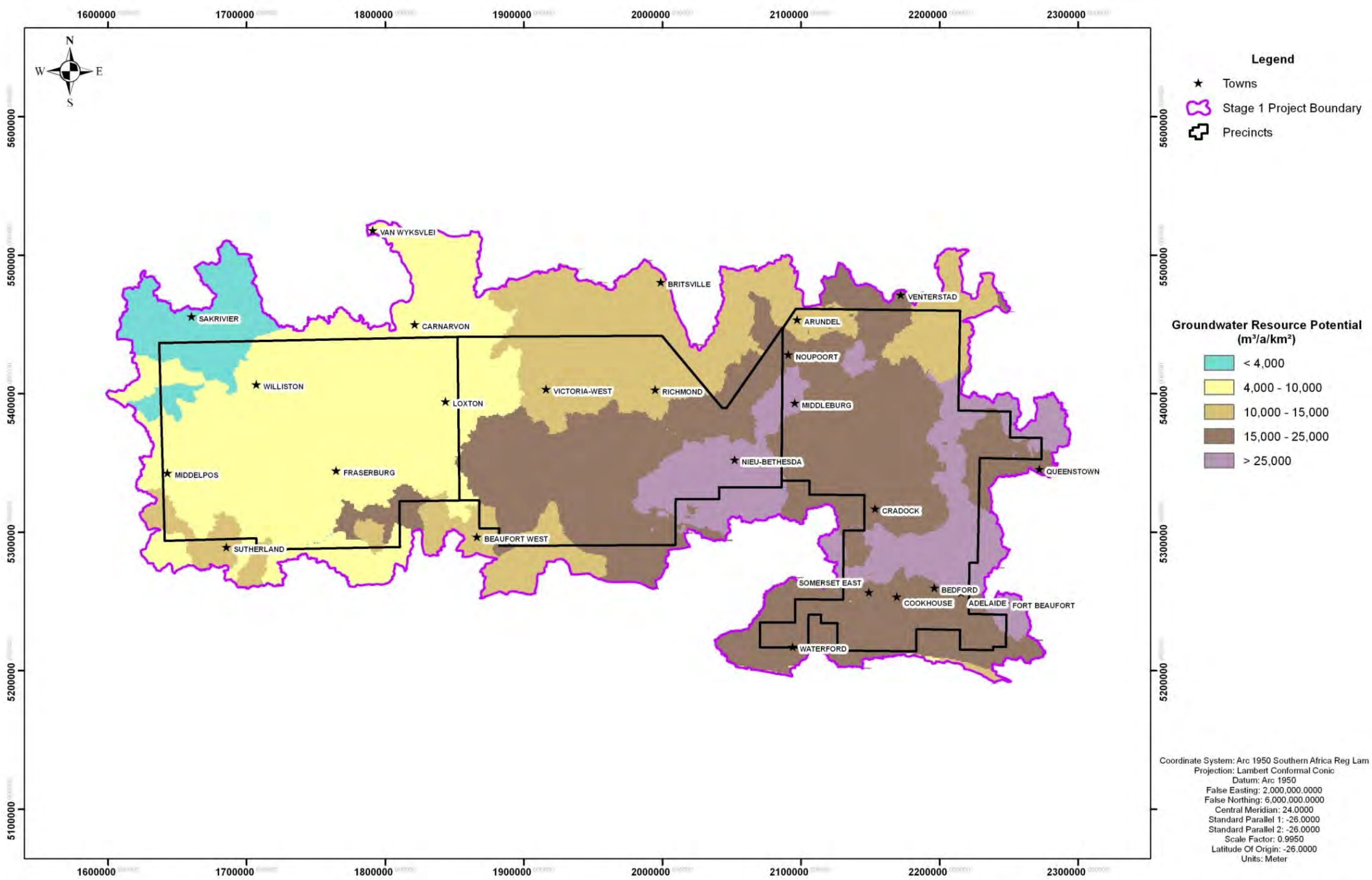
**Table 3** presents a list of features for which consideration zones will be generated and the widths of the zones, as agreed at the workshop. These will be further refined during later stages of the project and used to inform management plans.

**Table 3: Consideration Zone Widths.**

| Structure | Consideration Zone Width (m) |
|---|---|
| Dykes | 250 |
| Other intrusions | 250 |
| Faults | 250 |
| Production boreholes | 1 000 |
| Hot springs | 1 000 |
| Hydrothermal plugs | 100 |
| Kimberlites | 100 |

## Groundwater Maps

A series of 10 maps have been produced of the key attributes agreed, the four most important of which (as determined by the ranking/weighting process) are reproduced at a reduced scale below for this summary report (A3 size maps are contained in the complimentary Stage 1 Karoo Groundwater Atlas report). The weighting of significant factors will be used in the next stage of the project to produce further groundwater attribute maps to inform exploration activities.

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Projection: Lambert Conformal Conic
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Central Meridian: 24.0000
Standard Parallel 1: -26.0000
Standard Parallel 2: -26.0000
Scale Factor: 0.9950
Latitude Of Origin: -26.0000
Units: Meter

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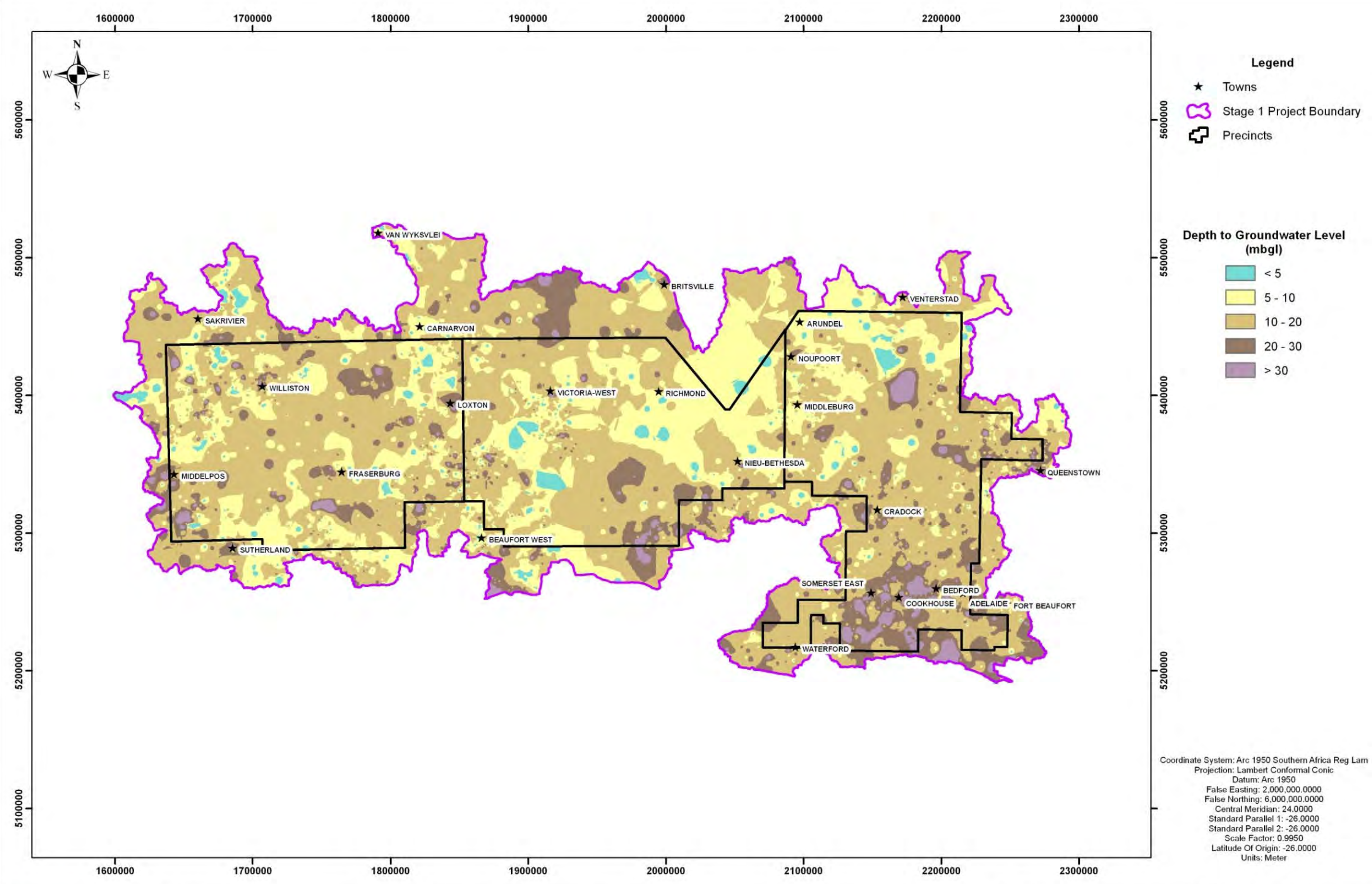
Revision: A Date: 07 11 2011




srk consulting

Project: KAROO GROUNDWATER ATLAS

Title: INTERPOLATED DEPTH TO GROUNDWATER LEVEL (mbgl)

| | |
|---|---|
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| Scale | 1:2,500,000 (0 25 50 100 km) |
| Compiled by | GOES |
| Date | 2011/11/07 |
| Reviewed by | ROSW |
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| Project No | 439159 |
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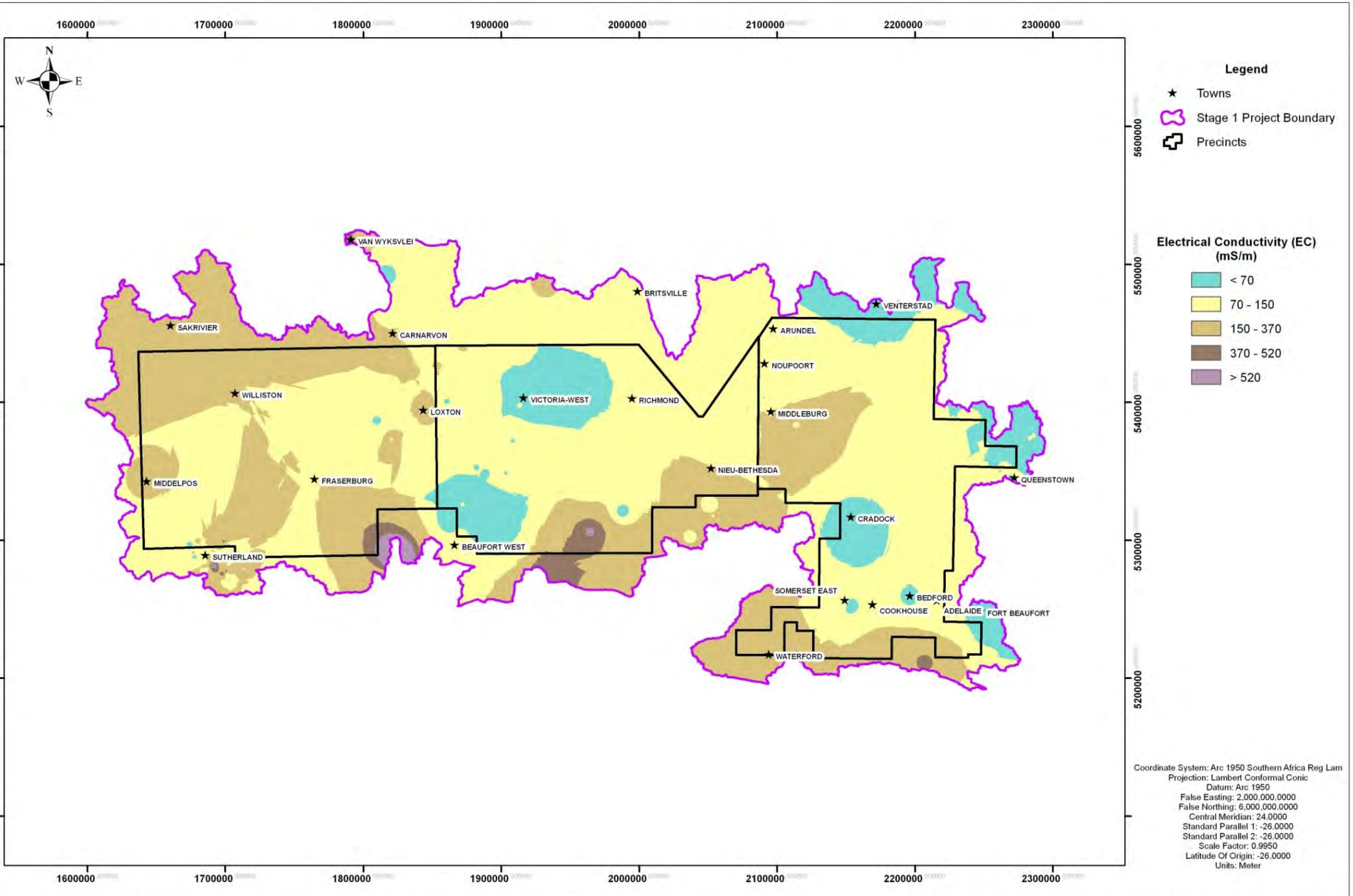


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|---|---|---|---|---|---|
| | Title: GROUNDWATER QUALITY MEASURED AS ELECTRICAL CONDUCTIVITY (EC) (mS/m) | | | Reviewed by: ROSW | Date: 2011/11/07 |
| | | | | Project No: 439159 | Fig No: 3 |

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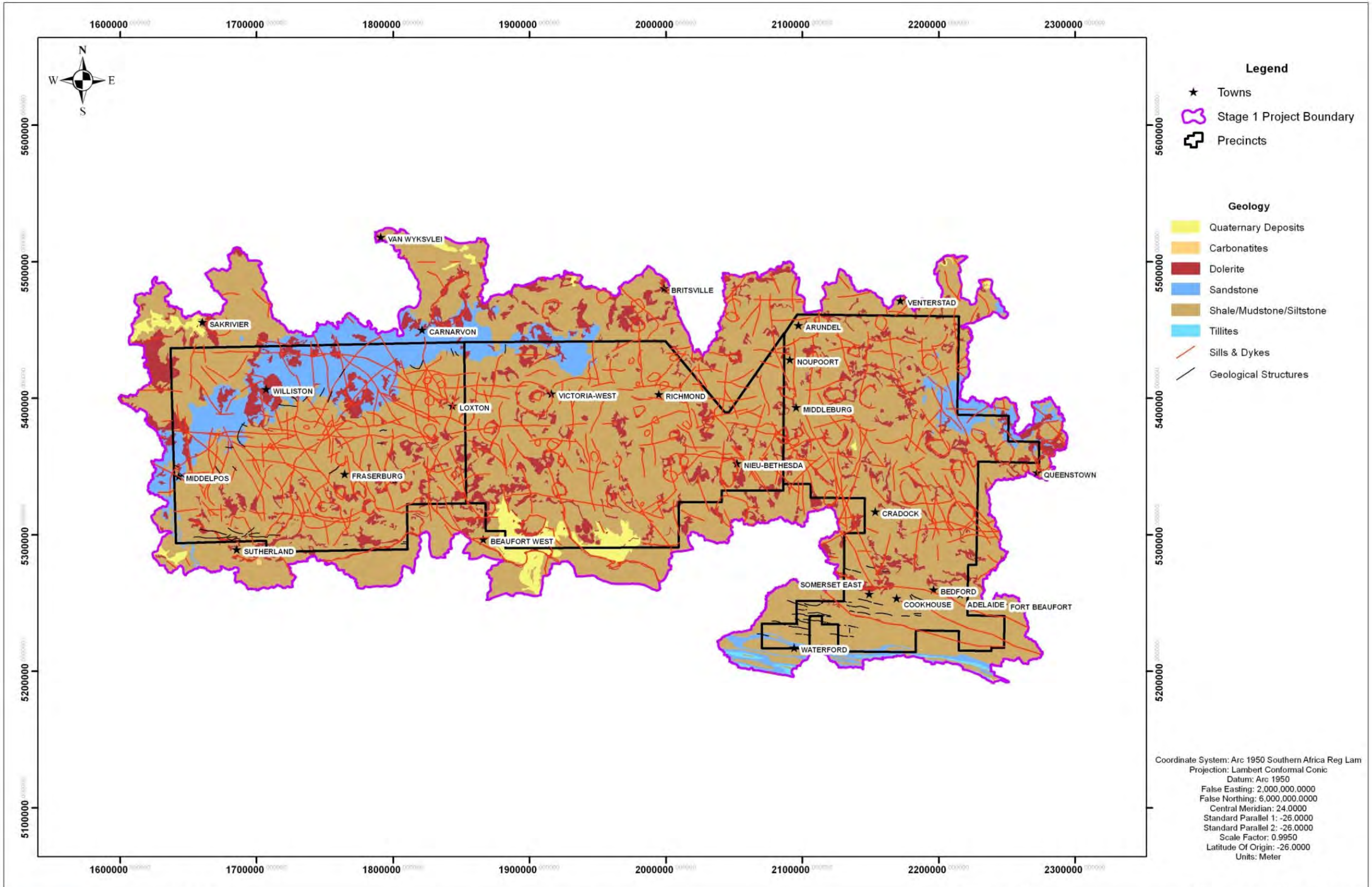


| srk consulting | Project: KAROO GROUNDWATER ATLAS<br>Title: GEOLOGY | Data Source/Notes: 1/250,000 Geological Maps (Council for Geoscience) | Scale: 1:2,500,000<br>0 25 50 100 km | Compiled by: GOES, Date: 2011/11/07<br>Reviewed by: ROSW, Date: 2011/11/07<br>Project No: 439159, Fig No: 4 |
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# Conceptual Models

There is limited 3-D information available on the deep (>300 m) geology and hydrogeology (in particular) of the main Karoo Basin. Relevant information was presented and debated at the workshop which was used to inform the Conceptual Site Model in the Stage 1 Report. Contrastingly, there is a wealth of information available on the shallow (<300 m) aquifer zone. This is reflected in the series of cross-sections sourced from various publications which are presented initially below to conceptualise the shallow regional aquifer, followed by specific “type” structures of interest, e.g. dykes and ring dykes. A summary of the key deliberations on the deep conceptual model arising from the workshop, and a conceptual 3-D block model, are then presented. However, as was agreed by the workshop delegates, there is so little data available below 300 m that it is difficult to “populate” the deep conceptual model, beyond making intelligent hypotheses. This uncertainty is indicated by the liberal use of question marks (?).

## Shallow Model

The shallow aquifer zone essentially comprises sediments of the Beaufort Group, with associated alluvium (limited extent), dolerite intrusions and weathered zones. **Figure 5** and **Figure 6** (poor quality due to scanning and reduction in size) illustrate the occurrence of groundwater in the Beaufort West (west) and Queenstown (east) areas, respectively. These sections show the general sequence of lithologies, the occurrence of dolerite sills and dykes and their influence on groundwater.

**Figure 7** shows the components of a ring complex intrusion with a combination of dyke and sill intrusives, enhanced permeability at contacts and groundwater occurrence and levels. The Institute for Groundwater Studies at the University of the Orange Free State developed a test site called Meadhurst in the Bloemfontein area to study the hydrogeological characteristics of a dyke intrusion into Karoo sediments. Numerous boreholes were installed in the dyke contact zones and the surrounding aquifer and test pumping and other tests carried out to determine, *inter alia*, hydraulic parameters, extent of fracturing and the zone of influence of pumping. The data obtained from this research could be of use in the more detailed site-specific investigations that will take place in Stage 2 and beyond.

Detailed water point surveys (hydrocensus) will be required to provide ground-truthing and to fill data gaps so that the attributes mapping and consideration zones can be better defined and the shallow model updated.

## Deep Model

**Figure 8** shows the general sequence of strata from northeast to southwest through the Karoo Basin. It shows thickening of sediments to the south and the influence of the Cape Fold Belt in the south. The line of the southernmost extent of Karoo dolerites runs just to the south of Beaufort West, trending in a south-easterly direction. The sedimentary sequence is dominated by alternating shales/mudstones and sandstones of the Beaufort Group, followed by the Ecca Group (shales/mudstones with some sandstones) and then the Dwyka Tillite Formation sitting on a granite basement.

**Figure 9** shows a conceptualised 3-D block model of the study area. Liberal use is made of question marks and subdued colours to denote uncertainties, which cover the zones below about 300 m. Geological strata in the Karoo are generally horizontal, except in and adjacent to the Cape Fold Belt. This characteristic means that natural fracture occurrence is generally limited and vertical propagation of induced fracturing is likely to be limited because of successive layers of shales and mudstones.

Permeability along dykes (only nominally represented in the block model) with depth is dependent on host rock, i.e. intrusion contact zones in sandstone would typically be more permeable than those in mudstone. Permeability is likely to decrease with depth as the sediment load increases, causing compaction and closure of fractures. Evidence from the deep Soekor drilling of the 1960s supports this hypothesis with fairly limited groundwater occurrences being intercepted at depth, e.g. artesian flows from two boreholes of 0.3 and 3 L/s (reported, not proven) from depths of 1 006 and 2 975 to 3 206 m, respectively. There are also only two known hot springs in the Karoo where the temperature of the groundwater indicates an origin deeper than about 1 000 m below surface. It is therefore postulated here that there are three zones of groundwater occurrence, viz:

- The main shallow (<300 m) aquifer;
- An intermediate zone down to about 1 000 m;
- A deep zone down to the basement with pockets of hot, saline, confined groundwater.

Major east-west trending faults are postulated to be deep seated and could connect through the Karoo sediments to the basement. Kimberlite fissures are small-scale at the surface but deep-rooted. They tend to rise straight up and if there is a dolerite dyke close to one, it could be an indication of deep connection.

This is as far as the deep conceptual model can be taken with current knowledge and ground-truthing, e.g. deep geophysics (seismics, magneto-tellurics), airborne geophysics (e.g. gravity, magnetics) and exploratory drilling, would be required to further refine these initial generalisations.

# Conclusions

The following preliminary conclusions can be drawn at this interim stage in the project:

- Ten key factors contribute to characterising groundwater attributes of Karoo Aquifers, the most important being depth to water level, groundwater quality, presence of dolerite intrusions and aquifer yield. These four factors together make up 60 per cent of the median weighting derived at the workshop;

- Aquifer yield, groundwater quality and recharge generally increase/improve from west to east and from south to north in the Eastern Precinct;

- The weighting of significant attributes and ground-truthing will be used in the next stage of the project to produce further groundwater maps to inform exploration activities;

- Consideration zones of varying widths have been assigned to features such as dykes and boreholes to reflect the potential importance of their zones of influence;

- The shallow (<300 m depth) aquifer is well understood and documented but some ground-truthing will be required, in the form of a series of borehole surveys, to fill in gaps and update the attributes maps;

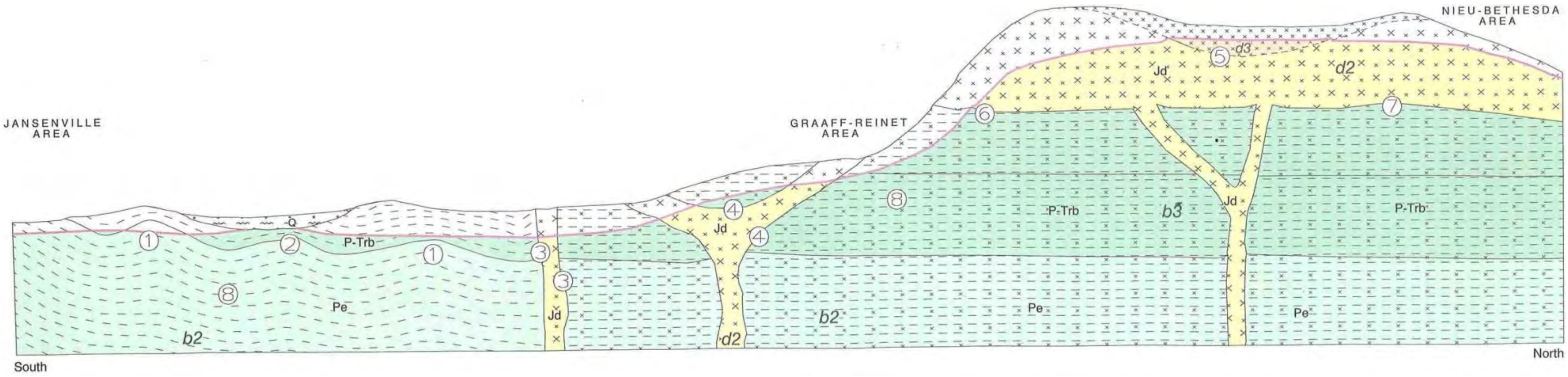
- The deeper geological/hydrogeological model is less well understood and further work, such as land and airborne geophysics and exploration drilling, would be required to obtain a better understanding of this environment.

Broad consensus was reached amongst the workshop participants on the above conclusions.

# Benefits

The key benefits of this Stage 1 Project are:

- Provides a comprehensive, versatile and interactive database;
- Builds on the EMP;
- Adds a meaningful new dimension to the literature available in the public domain on Karoo Aquifers, endorsed by a group of key hydrogeologists;
- Will assist in informing exploration activities;
- Provides evidence of Shell's commitment to an environmentally responsible approach to shale gas exploration;
- Provides guidance at a broad planning scale for the feasibility of groundwater exploitation (brackish/saline groundwater can be used by Shell, i.e. non-competing with local use).




① The effect of the Cape folding is evident in the prevalence of relatively minor east-west striking folds in the southern environs of the map. Groundwater yields of up to 5 l/s can be obtained from joints and fractures on the crests of anticlines

② There is ample evidence that even moderately thin occurrences of permeable alluvium in these areas facilitate groundwater recharge to the underlying shale and subordinate sandstone of the Ecca Group (Pe) and Beaufort Group (P-Trb). Although higher yields can be obtained, the groundwater quality in these areas is often poor, as conditions east of Beaufort West indicate

③ Jointed and fractured contact zones between sedimentary rocks and dolerite dykes are proven targets for groundwater development. Yields in excess of 5 l/s can be obtained from these zones

④ Dolerite ring structures are prevalent in the map area, and intensive investigations conducted on some of these structures revealed that, if optimally sited, high yielding boreholes with yields in excess of 5 l/s can be obtained alongside and within these structures

⑤ Groundwater occurs in both the weathered dolerite and in the transitional jointed zone between the weathered and solid dolerite

⑥ Groundwater can be developed by penetrating dolerite sills at depths of less than 30 m, thus targeting jointed and fractured contact zones in the underlying sedimentary rocks. Yields in excess of 5 l/s are not uncommon and groundwater quality with electrical conductivities ranging between 70 and 300 mS/m can be anticipated

⑦ Unsuccessful results can be anticipated where boreholes penetrate thick dolerite bodies. Decomposition is generally absent at depths exceeding 30 m. The deep lower contact of the dolerite with the underlying sedimentary rocks often has no water-bearing fractures

⑧ Yields in excess of 2 l/s can often be obtained in joints and on bedding planes in shale and intercalated sandstone of the Ecca Group (Pe) and the Beaufort Group (P-Trb), even in the absence of dolerite intrusions

Weathered zone

Groundwater level

**Figure 5: Schematic Cross-Section to Illustrate Groundwater Occurrence in the Beaufort West Area (1/500,000 Hydrogeological Map Series, DWA).**

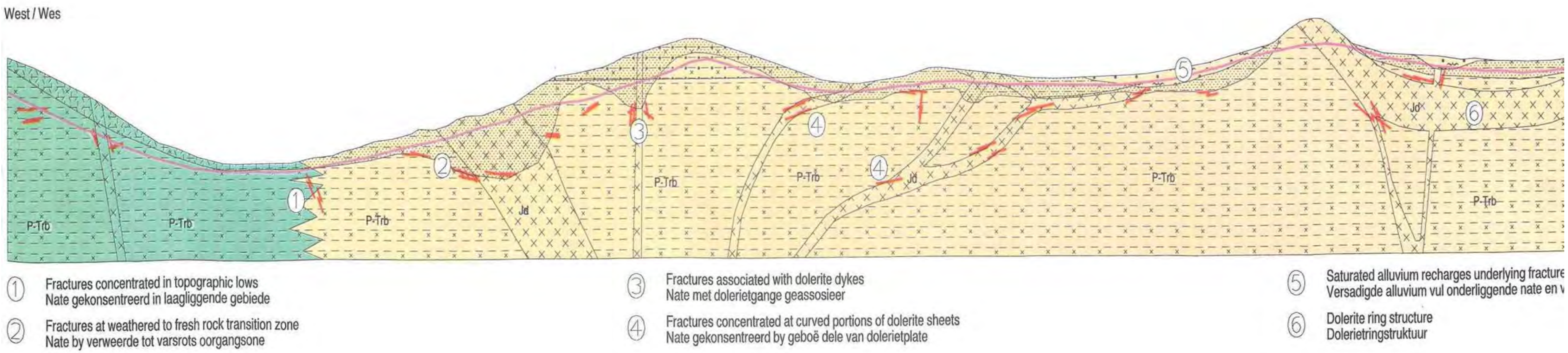



**Figure 6: Schematic Cross-Section to Illustrate Groundwater Occurrence in the Queenstown Area (1/500,000 Hydrogeological Map Series, DWA).**

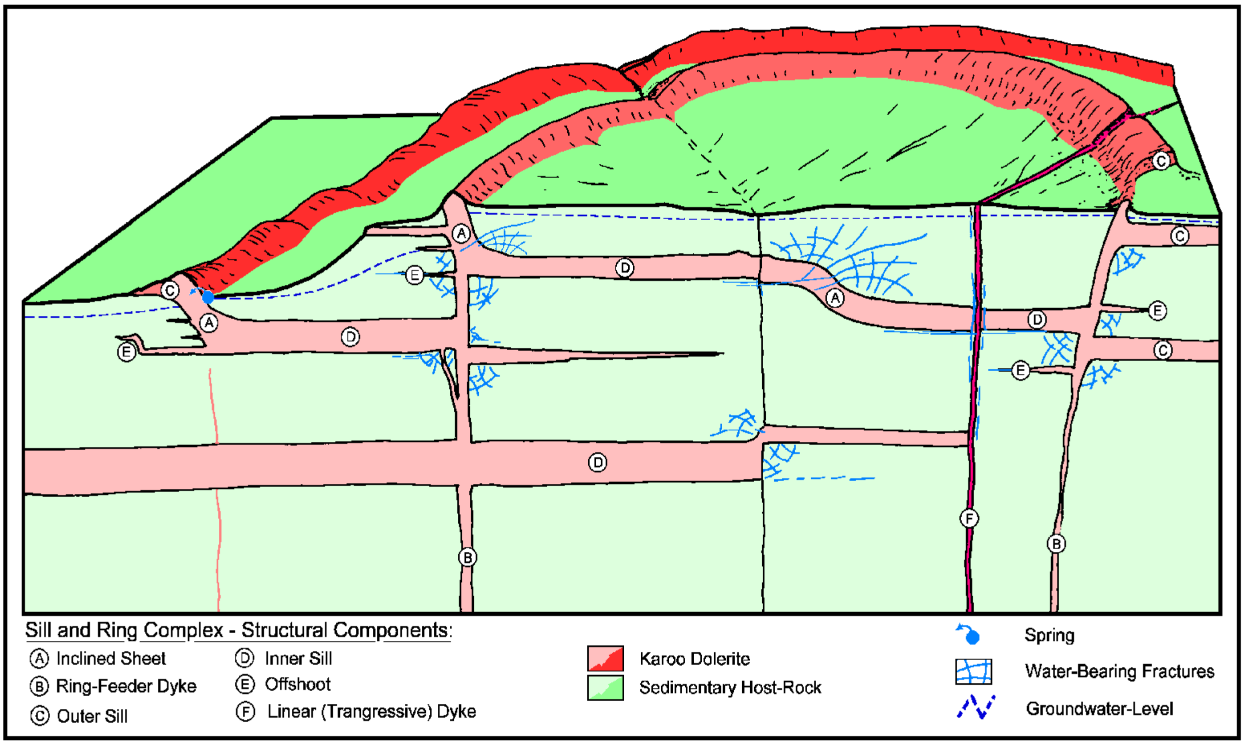



**Figure 7: Hydro-Morphotectonic Model of a Ring Complex (Chevalier *et al*, 2001).**

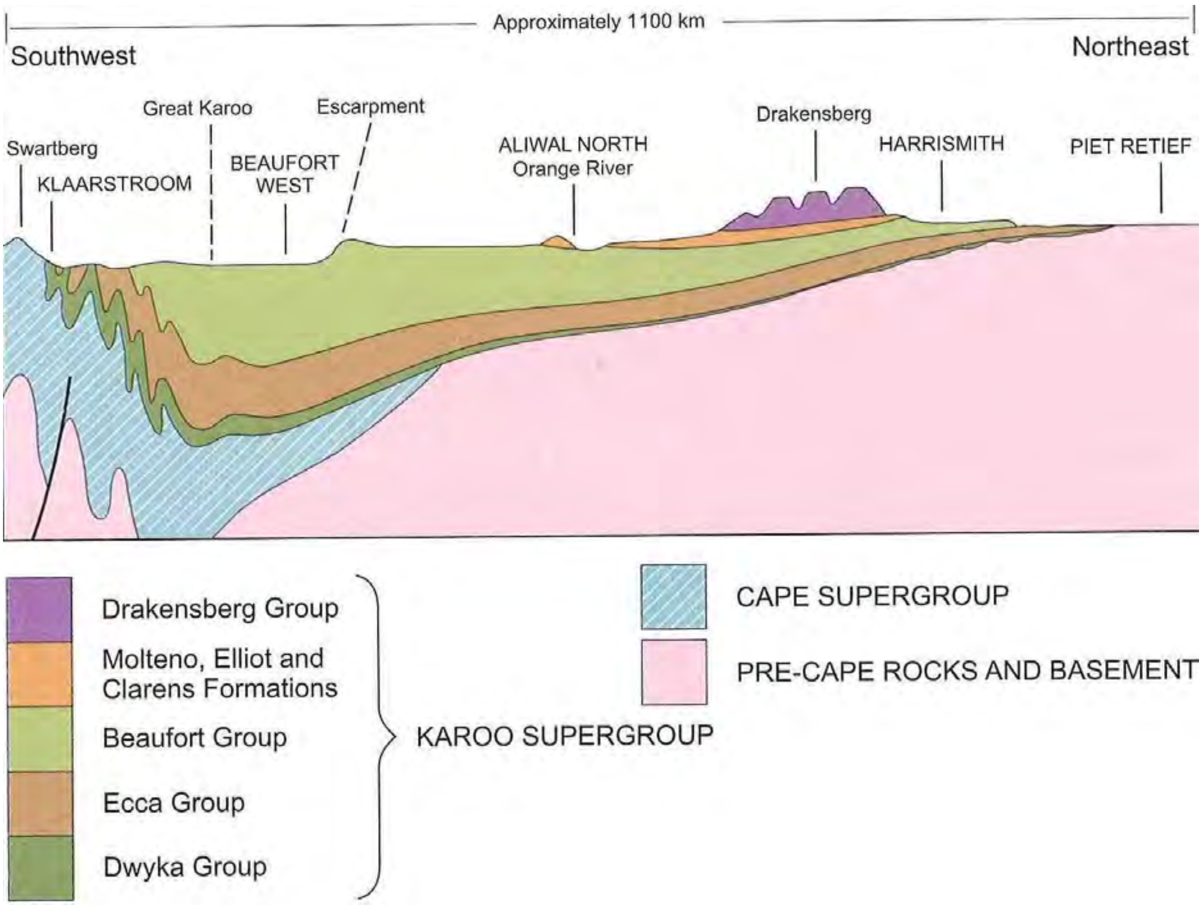



**Figure 8: Generalised Cross-Section Across the Main Karoo Basin from Mpumalanga to the Swartberg (Norman, N. and Whitfield, G. 2006).**

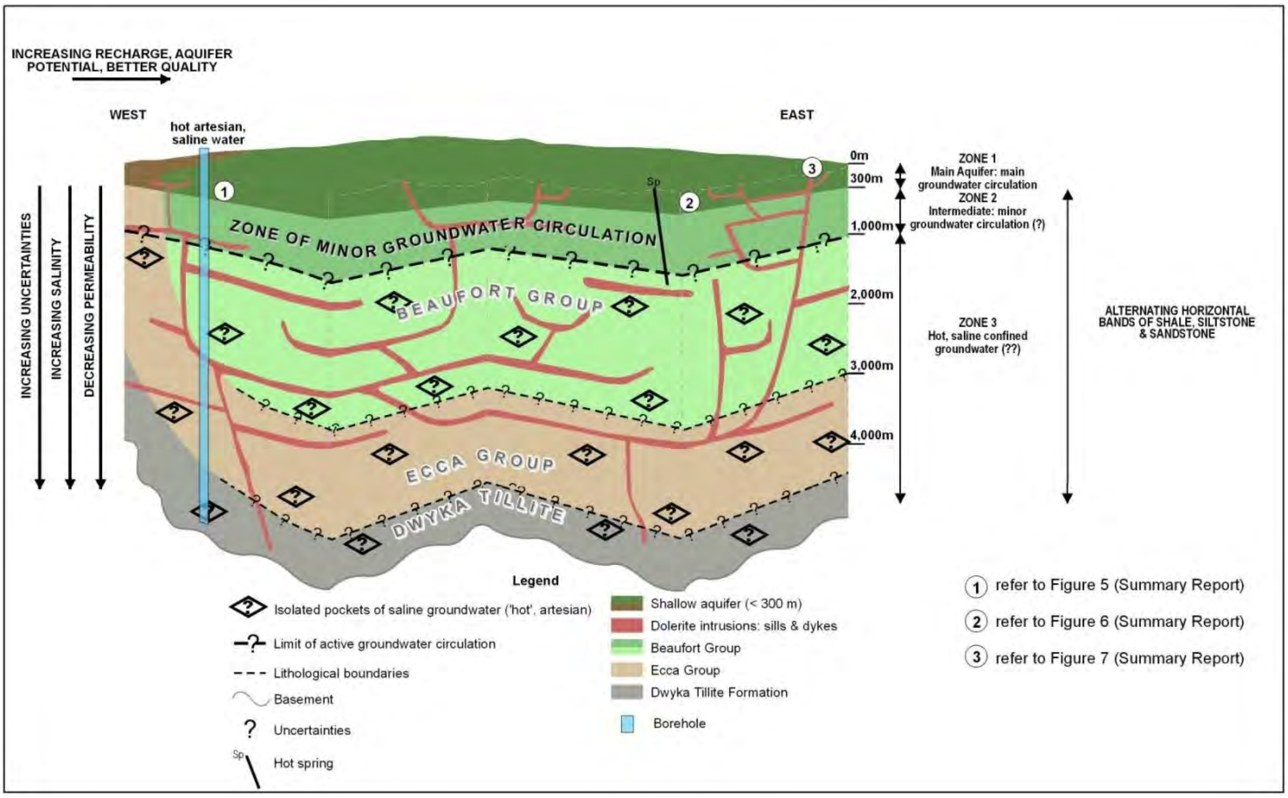



**Figure 9: Conceptualised Block Diagram to Illustrate 3-D Model Characteristics.**

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All data used as source material plus the text, tables, figures, and attachments of this document have been reviewed and prepared in accordance with generally accepted professional engineering and environmental practices.