Hydrogeological characterisation of crystalline basement aquifers within the Limpopo Province, South Africa

by

Martin Holland

Submitted in the fulfilment of the requirements for the degree Doctor of Philosophy in the Faculty Natural and Agricultural Sciences

University of Pretoria

Pretoria, South Africa

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

February 2011

Acknowledgements

The research was financially supported by the Water Research Commission (WRC) for the period 2007-2010. I would like to express my sincere gratitude to Dr. Shafick Adams from the WRC for his arrangements and support of the Limpopo basement aquifer project. The contribution of the members of the Steering Committee is also gratefully acknowledged. I also want convey my appreciation to the hundreds of rural communities I visited during this research and allowing me to go about my tasks without any objection.

I have received immense support during my research and would like to express my thanks to the following individuals:

- First and foremost, my supervisor, Prof. Kai Witthüser, for his continuous support, amicable mentorship and the main reason I pursued a career in Hydrogeology.
- To my co-supervisor, Prof. Louis Van Rooy, for his support in managing the arrangements of the WRC workshops and research deliverables. In this regard I also need to mention the help of Ms. Melinda de Swardt, the kingpin of the Department of Geology's administration.
- Special thanks to, Mr. Willem Du Toit and Mr. Robert Whitehead from the Limpopo (Department of Water Affairs) regional office, who supported this study fully and provided additional funding, in the form of drilling and geophysics. These individuals are the true 'groundwater hunters' of the Limpopo Province.
- The Limpopo (GRIP) consultants, who does a great job at maintaining and improving on one of the best groundwater datasets in the country, and especially to Mr. Reinhardt Weidemann, for sharing his expertise gained in this challenging hydrogeological environment.
- My colleagues at Water Geosciences Consulting, for the generous time allocations to complete my research, and to Mr. Jude Cobbing for improving on the English phrasing of my thesis.
- Most importantly, I would like to thank my loving wife and children for their belief in me and the sacrifices made during the time it took to complete this research (you are truly my inspiration).
- By far my biggest appreciation goes to my parents, who taught me the morals of life and molded me into the person I am today.
- Finally, I want to express my sincere gratitude to my sister, relatives and friends for your continuous support and encouragement.
- Comments on the manuscript from the external reviewers are greatly appreciated.

"Some people dream of worthy accomplishments, while others stay awake and do them."
- Anon

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Hydrogeological characterisation of crystalline basement aquifers within the Limpopo Province, South Africa

by

Martin Holland

Supervisor:	Prof. K.T. Witthüser
Co-supervisor:	Prof. J.L. Van Rooy
Department:	Geology
Degree:	PhD Engineering and Environmental Geology

Declaration

I, Martin Holland declare that the thesis, which I hereby submit for the degree Doctor of Philosophy (Engineering and Environmental Geology) at the University of Pretoria, is my own work and has not previously been submitted by me for a degree at this or any other tertiary institution.

Signature: _____ Date: _____

Abstract

Geologically complex crystalline aquifers are distributed extensively in Africa and also underlie large parts of the semi-arid Limpopo Province where some of the greatest groundwater needs in South Africa occur. The importance of these basement aquifers makes it vital to identify high yielding hydrogeological zones that can be targeted for water supply, to sustain areas of high population density with few or no alternative water sources. The biggest challenge is to understand the factors that determine the secondary permeability of these weathered-fractured rock aquifers. The focus of this study was therefore to systematically analyse regional factors that may influence borehole yields and aquifer transmissivities.

The study covered four distinct geological and morpho-structural domains within the Limpopo Province, covering about 23 500 km^2. The borehole dataset compiled for the study consisted of over 8 000 boreholes contained in the Groundwater Resources Information Project (GRIP) Limpopo database of the South African Department of Water Affairs. Approximately 3 000 of these boreholes have been hydraulically tested and the lithology has been recorded in 1 200 cases. A commonly encountered problem of pumping tests analysis in crystalline aquifers is in choosing an appropriate model that best fits the observed drawdown response. In this thesis modern methods are proposed for the analysis of pumping test data in weathered-fractured rock aquifers and highlight the importance of diagnostic plots, especially derivatives, for the detection of flow regimes and the choice of the correct 'theoretical' model. Based on the classification no single analytical method can be universally applied to crystalline basement aquifers when considering the analysis of pumping test data.

The GRIP borehole dataset was analysed in conjunction with spatial information to identify the relationship of regional factors such as - geology, hydrology, weathering thickness, topography, geomorphology, neo-tectonic stresses, and structural lineaments - on groundwater occurrence. Geology has a clear influence, with boreholes exploiting alluvial aquifers composed of highly permeable material, and certain rock types such as pegmatite, showing generally higher borehole productivities. Favourable borehole locations from a topographical point of view are predictably along rivers and valleys. Other identified favourable groundwater targets are the metamorphic aureoles of younger granite intrusions. Despite the local importance of the regolith as a recharge and storage mechanism for the underlying fractured bedrock, no correlation between borehole yields and depth of weathering was found. The pattern of lineament and dyke orientations in the different morpho-structural domains led to a more complex conceptual model of groundwater occurrence. This model is inconsistent with the predicted regime based on regional stress field data and suggests that local variations have a strong influence on groundwater occurrence. Due to the complex geological history of the area, it is difficult to link open discontinuities to a distinct recent or past tectonic event. It can be concluded that regional stress field data, as in this case, may not account for local, possibly highly significant, stress field variations. The hydrogeological importance of several factors on groundwater occurrence presented in this study can be used as a working reference for future groundwater development programmes.

Table of contents

List of tables

List of figures

List of abbreviations

CRD	Cumulative Rainfall Departure
CFC	Chlorofluorocarbon
CMB	Chloride Mass Balance
CGS	Council for Geoscience
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
EC	Electrical Conductivity
SAWS	South African Weather Services
GIS	Geographical Information System
IAEA	International Atomic Energy Agency
GNIP	Global Network of Isotopes
SMOW	Standard Mean Ocean Water
GMWL	Global Meteoric Water Line
LMWL	Local Meteoric Water Line
TU	Tritium Unit
GRF	Generalised Radial Flow
GRIP	Groundwater Resources Information Project
K	Hydraulic Conductivity
MAP	Mean Annual Precipitation
MRT	Mean Residence Time
NGDB	National Groundwater Data Base
NWA	National Water Act (Act 36 of 1998)
S	Storativity
T	Transmissivity
WRC	Water Research Commission
WMA	Water Management Area

Units of measurements

b	aquifer thickness [L]
d	depth to top of pumping well screen [L]
d'	depth to top of observation well screen [L]
l	depth to bottom of pumping well screen [L]
l'	depth to bottom of observation well screen [L]
Q	pumping rate [L^3/T]
r	radial distance [L]
s	drawdown [L]
t	time (T)
K_z/K_r	vertical to horizontal hydraulic conductivity anisotropy
H_o	initial displacement (head)
a	annum
cm	centimetre
d	day
m/d	hydraulic conductivity
m^2/d	transmissivity
mg/l	milligram per litre
ha	hectare
km^2	square kilometre
ℓ/s	litre per second
N	Population
m	metre
m^3/s	cubic metre per second
mamsl	metres above mean sea level
m.b.g.l	metres below ground level
Mm^3/a	million cubic metres per annum
fmol/l	femtomol per litre
pptv	parts per trillion volume
pmol/l	picamol per litre
mmol/l	millimol per litre
mm	millimetre
Ωm	ohm metre
mS/m	milliSiemen per metre