WATER RESEARCH COMMISSION

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The WRC operates in terms of the Water Research Act (Act 34 of 1971) and its mandate is to support water research and development as well as the building of a sustainable water research capacity in South Africa.

TECHNICAL BRIEF

Groundwater

Table Mountain Group Aquifer

A research initiative of the WRC aimed to conceptualise groundwater flow and storage within the Table Mountain Group Aquifer.

TMG aquifers: groundwater resources of great value

The Table Mountain Group (TMG), located at the southernmost extremity of the African continent, constitutes a major regional aquifer system in South Africa. The TMG aquifer has long been regarded as a significant water supply option for this largely semi-arid part of the country on account of its good water quality and high potential for water abstraction from the high-yielding fractured sandstones.

The TMG aquifer comprises a thick sequence of hard sedimentary rocks, dominated by fractured sandstones. The large-scale distribution of the TMG over various geological structures, extending from the northwest of the Western Cape to the northeast of the Eastern Cape, leads to a vast diversity in its hydro-geological properties which influence the dynamics of groundwater recharge, discharge and storage. A realistic estimation of these properties, with a focus on aquifer porosity, permeability and storativity, is important for the sound evaluation and sustainable utilisation of the groundwater resources in the TMG.

Although there have been many studies that have contributed to the characterisation of TMG aquifers with important implications for groundwater utilisation in the region, the conceptual understanding of the TMG, particularly with regard to aquifer properties and flow and storage dynamics, has until recently remained limited. This is because of the geometric and physical complexity of this fractured rock aquifer at various scales.

A recent research initiative, undertaken with the purpose of enhancing understanding of the TMG aquifer, aimed to conceptualise groundwater flow and storage within such aquifers.

Research: approaches and methodologies

The research was based largely on geological and geomorphological surveys, the examination of core samples from the drilling of boreholes, observations of well-field performance, the identification of groundwater flow dynamics and the characterisation of aquifer media at various scales. Improved understanding of the TMG aquifers at both regional and local scales was sought through the classification of hydrogeological units, the analysis of their aquifer properties and the quantification of groundwater recharge, discharge and storage.

Data from previous studies as well as data from current research were collated and analysed to facilitate development of the conceptual models and to quantify hydrogeological properties such as the hydraulic conductivity. Information on hydrogeological settings and aquifer types, together with interpretations of aquifer hydraulic tests, revealed that the hydraulic properties of the TMG aquifers are largely controlled by geological formations and structures occurring at various scales.

By analysing fracture networks and their associated patterns, it became clear that the most important single factor that controls groundwater flow in the TMG aquifers is the connectivity of the fractures. A detailed study of aquifer media, with the main focus on the nature of the fractures and fracture networks, was therefore conducted. The conceptual models of the fractured media, consequently developed on the basis of field observations and stochastic analyses, have emerged as helpful tools for the enhanced understanding of aquifer characteristics, including flow and storage-related behaviour in the TMG aquifers.

Aquifer hydraulic properties

By interpreting information derived from field measurements in conjunction with remote sensing data, it was possible to estimate the anisotropic hydraulic properties of the fractured aquifers using a hydraulic conductivity tensor technique. Considering that the fracture connectivity and the nature of fractured media at a given site may vary with depth, a tensor model was developed to estimate the hydraulic properties both on the surface and at depth through the incorporation of aquifer physical conditions.

The resulting estimates of hydraulic conductivity at most sites fell in the range of 10^{-2} –10^{-3} m/d, which was consistent with most pumping test results. However, estimated values decrease with depth according to a negative power law, which implies that the majority of fractures display a tendency towards closure at greater depths. Site hydraulic tests also showed a similar vertical variation of the hydraulic conductivities.

The study revealed that fracture networks on a site scale occur as various fracture blocks nested within the system, rather than being evenly connected as originally postulated. A simulation of fracture connectivity in the TMG aquifers using a 3D model of discrete fracture face analysis demonstrated that only a limited proportion of fracture networks under consideration allowed groundwater circulation at both local and regional scales. Multiple approaches were employed to estimate the aquifer porosity and associated aquifer storativity. Results show that the porosity of the TMG sandstones is strongly scale-dependent. Laboratory tests on core samples yielded upper limit values of 1.0%~3.6%. The porosity values from *in-situ* fracture measurements fell in the mid-range of 0.05%~0.6%, whilst the application of lineament interpretation from remotely sensed data produced the lower limit of aquifer porosity of 1.2×10^{-8}%.

Resource evaluation

For resource evaluation purpose, clarity was obtained regarding the nature of the TMG aquifer types, including their classification into confined and unconfined aquifers.

The spatial distribution of the TMG aquifers (including the Peninsula Aquifer and the Nardouw Aquifer) in both areal and vertical extent was, for the first time, quantified using a GIS technique. This provided the foundation for both the visualisation of the aquifer geometry and the estimation of groundwater storage capacity. Different definitions of groundwater storage capacity, including total storage capacity, usable storage capacity, available storage capacity and sea level-related storage capacity, were distinguished and the corresponding values estimated for the TMG aquifers.

For the purpose of evaluating the TMG aquifer in its entirety, the ***quantification of the bulk groundwater resource*** was based on assumptions that the TMG aquifers are homogeneous at a regional scale, and that an average storativity value is applicable across all aquifers. Based on the estimated regional aquifer storage, it appeared reasonable to propose that an overall available yield not exceeding 1×10^{9} m^3/year be accepted as a guideline for exploiting groundwater from TMG aquifers. This result suggests that the previously postulated bulk groundwater storage of TMG may have been overestimated, as a result of using an aquifer storativity value that had been derived at the local scale.

Groundwater recharge estimation was largely based on recent results of local research on this topic, after these results had been verified and re-assessed through an appropriate case study.

The main groundwater discharges from TMG aquifers, namely spring flow, groundwater abstraction and stream baseflow, were quantitatively estimated. The quantification of the former two components was accomplished by hydrocensus analyses. Investigations of surface water and groundwater interactions yielded results which allowed baseflow separations to be performed in order to determine the order of magnitude of groundwater discharge into streams.

The response of TMG aquifers to pumping stresses in the areas of the Kammanassie Mountains (Southern Cape) and Rawsonville (Southwestern Cape) was successfully investigated with the help of groundwater flow modelling. This was done after the construction of 3D hydrogeological conceptual models which helped to verify the understanding of the hydrogeological settings. Detailed groundwater-related data analyses were then performed on the basis of previous and current field data sets, following which a numerical model was configured to simulate the aquifer response to stresses which included various pumping scenarios.

Significance of the research

The findings of the research have provided a solid platform for continuing to build an understanding of groundwater flow dynamics and potential utilisation of the TMG aquifer system in terms of aquifer media and spatial variations. The information acquired makes it feasible to focus future investigations on specific groundwater issues that would further promote the sustainable utilisation of the distributed groundwater resources within the TMG.

Further reading:
To obtain the report, *Groundwater Flow Conceptualisation and Storage Determination of the Table Mountain Group Aquifers* (**Report No: 1419/1/09**), contact Publications at Tel: (012) 330-0340; Fax: (012) 331-2565; E-mail: orders@wrc.org.za; or Visit: www.wrc.org.za to download a free copy.