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

A WRC-funded study underlined the potential for groundwater abstraction experiments to include a programme of observation and measurement of geothermal gradient, thermal conductivity and heat flow.

The Contribution of Geothermal Studies to Research of the TMG Aquifer

Groundwater exploration in the TMG Aquifer Group

The substantial groundwater potential of the Table Mountain Group (TMG) fractured-rock aquifers were recognised as early as 1970. However, it initially failed to trigger concerted interest in exploiting this resource.

Since the development of relatively deep (>250 m) artesian wells in the Citrusdal region during the late 1980s, however, there has been a strong research and development focus on the TMG groundwater resource as a potential long-term solution to increasing water scarcity in the Western Cape. This focus has also provided an incentive for development of deep drilling expertise and further development of groundwater exploration and reservoir-characterisation methodologies required for this unique type of fractured-rock aquifer. In this regard, special attention has been given to a methodology based on geothermal measurements.

Geothermal regimes within aquifers

Groundwater flowing naturally through an aquifer system transports heat, as well as solutes, and thereby alters the subsurface temperature field. Consequently, temperature – which is easy, quick, and inexpensive to measure compared to the use of chemical and isotopic measures – could be of value as a tracer in exploring and quantifying hydrogeological processes, and could also contribute information for the testing of conceptual groundwater-flow models.

Geothermal measurements should also throw light on the impacts of large-scale groundwater abstraction on the geothermal regimes around the abstraction site, as well as along the groundwater flow paths through the site, reflecting the abstraction-induced alteration of the natural flow regime.

A strong incentive therefore exists for groundwater abstraction experiments to include a programme of observation and measurement of geothermal gradient, thermal conductivity and heat flow. Since the advective transport of heat (i.e. heat transported in flowing water) in the shallower parts of the crust is not only a geophysical, but also an environmental and ecological issue, geothermal observations could also be carried out at any environmental monitoring sites associated with the abstraction borehole sites.

Prerequisite for fruitful geothermal investigations

A necessary prerequisite for determining:

a) the extent to which monitoring of borehole temperatures can be used to establish underground flow rates and effects on recharge/discharge rates; and
b) whether, where, and how utilisation of aquifers is likely to affect the subsurface geothermal regime;

is that **baseline information** on regional heat flow and thermal conductivity properties first be obtained from suitable reference sites in the TMG and Cape Fold Belt.

This was accomplished in a specific study carried out, firstly, to **establish background geothermal gradients and heat flux** in areas unaffected by underground water flow. Thereafter, a **theoretical and experimental basis** was prepared for the monitoring of changes in geothermal gradients and heat flux in regions where groundwater extraction is in progress. Then **specifications for future investigations** were prepared in which quantitative use is made of heat as a groundwater tracer through numerical modelling.

Prior to this study, no heat-flow studies had been accomplished on those parts of the Cape Fold Belt where large-scale groundwater abstraction could be contemplated. Previous borehole geothermal surveys in the Western Cape were mostly unsuccessful because evident disturbances due to underground water flow invalidated the establishment of baseline data. This study therefore focused on locating as many boreholes as possible that were undisturbed by water flow.

Geothermal baseline data

Good results were obtained from boreholes at the Skuifraam site near Franschhoek, the Birkenhead site near Stanford, and the Blikhuis site near Citrusdal. These results support the use of a heat flow of 76 mW m^{2} as being typical for the whole of the pre-Cape basement terranes in the Western Cape.

Using measured conductivity data it was further possible to arrive at provisional 'undisturbed' temperature gradients in the TMG quartzite (specifically the Peninsula Formation) and the Bokkeveld share, as follows:

Bokkeveld shale:	dT/dz = 22.2 K km^{1}
Peninsula quartzite:	dT/dz = 10.3 K km^{1}

These are the thermal gradients to be expected in the complete absence of any groundwater flow effects.

Monitoring and modelling opportunities

Water temperature measurements, not only in boreholes, but also in springs, provide a potentially important source of information about deep groundwater flow paths within the TMG aquifer system. The well-known hot springs found in the Western Cape, for which there is already a growing set of temperature measurements, are particularly useful in this regard.

Emergence temperatures of spring waters reflect the interaction between advective and conductive transport of heat in the host aquifer systems, aquifer permeability being the key factor. Where rock permeability is low, groundwater flow velocities are low, heat transport is dominantly conductive, and therefore spring temperatures are low.

In rocks with high permeability, flow velocities are high and advective transport of heat is the dominant process. However, high permeability also results in large volumes of circulating water, which also tends to keep spring temperatures low. Therefore, the warmest springs generally occur for an intermediate range of permeability.

With recent technological advances, inexpensive waterproof temperature loggers are widely available for subsurface temperature measurements. Groundwater temperature is now measured easily, rapidly and accurately, provided that instrumentation is kept properly calibrated and care is taken to ensure that the recorded temperature is representative of water in the aquifer and is not influenced by movement of water in the borehole. The newer Distributed Temperature Sensing (DTS) technology, based on fibre optics, enables the simultaneous online registration of temperature profiles along one or more boreholes.

The interpretation of combined temperature and flow measurements requires the development of an improved mathematical and computer-based modelling framework, within which a suite of data is related to aquifer properties and hydrogeological processes. Appropriate computer software programs to solve coupled groundwater flow and heat transport problems have indeed been developed and are readily available. Useful information on the characteristics of such software, as well as the pros and cons of using programs that employ either finite-difference or finite-element approaches, have been assembled for the benefit of potential users.

Recommendations

Coupled heat and groundwater flow can and should be undertaken within the TMG terrains of the Cape Fold Belt. The systematic recording of borehole temperatures and depth from a wide variety of locations within the Cape Fold Belt is recommended. Regular and standardise water temperature measurements, taken at key reference sites, may provide a simple first order indication of the contribution of deep groundwater systems to base flow.

Within these TMG terrains, which are also characterised by an abundance of perennial springs that maintain base flow during dry summer months, the emergence temperatures of spring water, in combination with their flow rates and discharge elevation (head), should be used within numerical models to solve the inverse problem relating to groundwater flow velocity and basin-scale hydraulic conductivity. Such information is essential to gauge the long-termpotential of TMG aquifers in helping to relieve urban water scarcity in the Western Cape.

Further reading:

Geothermal Studies of TMG Aquifer Systems (**Report No: 1403/1/07**). To order this report, contact Publications at Tel: (012) 330-0340; Fax: (012) 331-2565; E-mail: orders@wrc.org.za