Improved groundwater monitoring through GRACE

As part of a project funded by the Water Research Commission (WRC), the Gateway Wellfield at Hermanus was used to test a novel method of groundwater monitoring, using a global positioning system (GPS) to measure minute movements in the land surface above aquifers. Sue Matthews reports.

The project, 'Development and application of Global Navigational Satellite Systems (GNSS) methodology for groundwater resource assessment', was initiated by Umvoto Africa in 2008 as a collaborative study with the then Chief Directorate: Surveys and Mapping (CDSM, now National Geo-spatial Information), Hermanus Magnetic Observatory (HMO, now SANSA Space Science), and the Department of Earth and Atmospheric Sciences at Purdue University in Indiana, USA.

Continuously operating GPS (cGPS) stations were installed at three boreholes in the wellfield with the aim of quantifying any vertical and horizontal surface deformations associated with groundwater abstraction and seasonal rainfall, which would recharge the aquifer. TrigNet, the CDSM's array of permanent cGPS stations distributed throughout the country, was used as the reference system, with the beacon at the HMO serving as the base station.

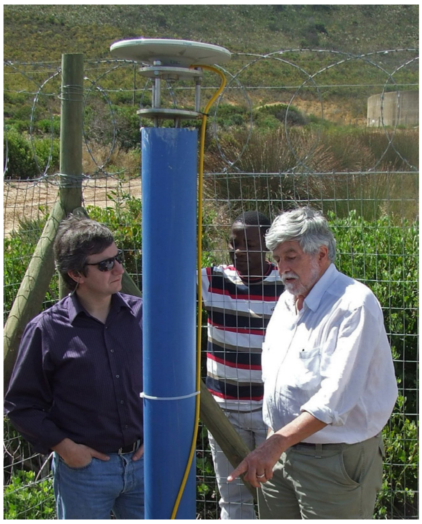
Dr Chris Hartnady, Research and Technical Director at Umvoto Africa, reports that the project did not yield conclusive results, probably due to a number of unforeseen circumstances. "The project was opportunistic in the sense that we had a wellfield that had just started and was about to go through a testing phase, so we thought it would be a good opportunity to try the technology there. In retrospect – hindsight being the perfect science – it wasn't a good place to do it, mainly because the Gateway Wellfield is so close to the ocean. The potential for saline intrusion with over-pumping meant that we couldn't draw down enough to have a big impact."

"Secondly, we had to retrofit our geodetic monuments onto existing plinths at the boreholes, and although we tried to stabilise them as best we could, there was a noise factor, given that they had not been designed and integrated into the plinths during their construction. There are all kinds of things at the boreholes that could potentially influence them," Dr Hartnady explains.

"Another factor was that initially our idea was to set up our GPS monitoring system during the testing phase of the wellfield and stage various experiments, starting up pumping and then shutting it down at particular times so we could really hone in on responses. What complicated the whole issue was a drought, because in early 2010 Hermanus had reached crisis stage, and was going to be out of water by April, long before the winter rains came. Suddenly there was going to be no testing phase – the wellfield just had to go into production – and we hadn't even fully set up the monitoring stations yet! And of course we then had no experimental control at all over pumping."

Something else that could not possibly have been anticipated to have an effect on the project was the Haiti earthquake. Purdue University's representative on the project, Professor of Geophysics Eric Calais, was seconded to the island state for a year as a United Nations scientific adviser, and had to put the Hermanus project on the backburner.

"His research group helped a lot, and much of the data processing was done with their assistance, but Eric was out of the project," says Dr Hartnady. "In the end it was a nice experiment, and there were a few places where it looked as if things were happening, but to relate any particular little signal in the GPS to a pumping episode was iffy."


Umvoto Africa

Dr Chris Hartnady of Umvoto Africa discusses technical details of the cGPS monitoring station at one of the Gateway boreholes with Purdue University's Prof Eric Calais.


SANSA

The TrigNet beacon at the Hermanus Magnetic Observatory .

Fortunately, the development of the Blossoms Wellfield near Oudtshoorn presents another opportunity to use GPS for groundwater resource monitoring. The wellfield is the culmination of the Deep Artesian Groundwater Exploration for Oudtshoorn Supply (DAGEOS) project, which Umvoto Africa was contracted to lead in April 2000. The project was funded or otherwise supported by the WRC, the Department of Water Affairs (DWA), the Oudtshoorn Municipality and the Development Bank of South Africa.

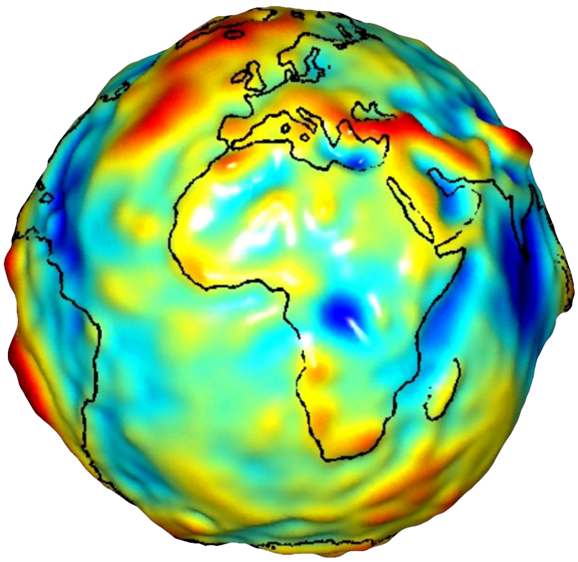
Here, the wellfield is situated on an anticline of the Peninsula Formation where the top of aquifer is approximately 300 m below the surface at its shallowest point. A network of monitoring boreholes has been established by DWA in the area between the wellfield and the Outeniqua recharge zone, but these only target the upper Skurweberg aquifer used by the local farmers. Drilling down to more than 500 m is just too expensive and logistically difficult for monitoring purposes.

The GPS monitoring method offers a practical alternative, and in this case Umvoto have ensured that the equipment will be sound by incorporating the design and installation of the plinths into the borehole drilling programme.

"Our GPS antennae are keyed into bedrock tens of metres below the surface, so these should be much better geodetic monuments than TrigNet beacons," explains Dr Hartnady. The GPS monitoring will be complemented with satellite remote-sensing using InSAR – interferometric synthetic aperture radar – which can measure centimetre-scale deformations in the land surface at a spatial resolution of 20 m. InSAR has been likened to a 'geodetic camera', used to produce detailed colour images of the Earth's topography.

"Geodetic monitoring is really about precisely measuring positions on the land. InSAR gives an overall picture, but GPS provides calibration at particular sites on the surface, so one reinforces the other, notes Dr Hartnady."

Umvoto will also be collaborating with the Council for GeoScience, which has recently purchased new meters for measuring microgravity. Being able to detect minute variations in gravity caused by differences in subsurface mass (and hence



This visualisation of a gravity model was created with data from the Gravity Recovery and Climate Experiment (GRACE) and shows variations in the gravity field across Africa and Europe. Red shows the areas where gravity is stronger than the standard value and blue reveals areas where gravity is weaker.

density) allows underground cavities, geological structures and groundwater to be mapped at high resolution, with repeated surveys over time offering the potential to monitor changes.

In combination, GPS and microgravity monitoring can be used in pumping experiments to measure the compaction of an aquifer and the corresponding surface subsidence, in order to determine skeletal-framework compressibility and specific storage.

"And that's what we're really trying to measure, because ultimately we need to be able to get some quantitative handle on storage and whether it changes spatially, and how the loss of pressure in the artesian aquifer spreads," notes Dr Hartnady.

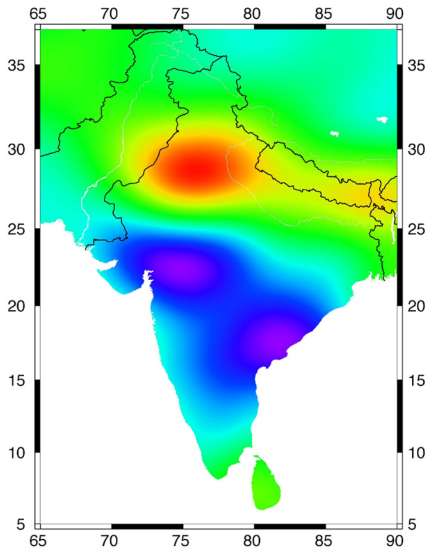
Providing the aquifer host-rock behaves elastically, pressure can generally be restored to its original state by replacing the volume of abstracted water through either artificial or natural recharge. Since test-pumping and free-flow tests have indicated effective elastic behaviour of the confined Peninsula Aquifer in the Klein Karoo, Umvoto have recommended an aquifer management strategy for the Blossoms Wellfield relying on alternating withdrawal and recovery intervals.

Dr Hartnady adds that the microgravity monitoring has broader application too. "Having *in situ* gravity measurements on the ground will link with anything we can tie into GRACE in future."

GRACE is the Gravity Recovery and Climate Experiment, a joint US-German mission that maps variations in the gravity field on a monthly basis, using twin satellites orbiting 220 km apart some 500 km above the Earth. Launched in 2002 with a planned lifespan of five years, the satellites are still collecting and transmitting data, although failing batteries result in periodic power outages. A follow-on mission, GRACE-FO, is planned for 2017.

The data has been used to study global ocean circulation, major earthquakes and glacier ice loss, but has also revealed shocking levels of groundwater depletion in northern India and Pakistan, parts of the Middle East and California's Central Valley.

GRACE quantifies changes in total terrestrial water storage, which includes snow, surface water, groundwater and soil moisture. The most likely source of error in



Groundwater changes in India during 2002-08, with losses in red and gains in blue, based on GRACE satellite observations. The estimated rate of depletion of groundwater in north-western India is 4 cm of water per year, equivalent to a water table decline of 33 cm per year. Increases in groundwater in southern India are due to recent above-average rainfall, whereas rain in north-western India was close to normal during the study period.

using it to determine groundwater storage is in separating out the soil moisture component, although the latter can be measured using other remote-sensing techniques. It also has limited application to aquifer management at present because the spatial resolution is currently > 150 000 km^2, but it is expected that this will be reduced to < 50 000 km^2 for GRACE-FO.

"Right now GRACE only works for entire subcontinents and massive basins like the Congo or Amazon, but the follow-on mission with the new satellites has significant potential – not at individual wellfields or even particular artesian basins like the Klein Karoo Basin, but at least as far as the whole of the TMG Aquifer within the southern Cape is concerned," explains Dr Hartnady. "This is something we really look forward to, which is why we're eager to start not only with the GPS and InSAR work, but also to begin to get a handle on the microgravity story."

The initial monitoring will take place over the coming months during testing of the existing production well. However, full commissioning of the Blossoms Wellfield will likely only occur during 2015, once additional production boreholes have been drilled and the pipeline connection to Oudtshoorn completed. ❑