Emerging Science and Technology for Deep Groundwater Resource Assessment

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Background & Outline

• Overstrand Municipality investigating groundwater potential of Greater Hermanus Area, for augmentation to supply

• Outline:
  – Global Navigational Satellite Systems (GNSS) in Africa
  – Principle of confined aquifers: How to squeeze water out of rock
  – Table Mountain Group (TMG) hydrogeology and the Gateway wellfield, Hermanus
  – International linkage to Global Geodetic Observing System (GGOS)
Global Navigational Satellite Systems (GNSS) in Africa
Plate-boundary model

- Based on seismicity patterns
- Northern part of LW-SO boundary through Comores volcanic belt
- Branched LW-SO in south indicates convergent zone (incipient
South African TrigNet system

- Network of permanent continuously operating GPS (cGPS) base stations
- Distributed throughout South Africa at approximately 200 – 300 km spacing
- All stations record 1-second epoch data on both GPS frequencies (L1 and L2) through geodetic-standard choke ring antennas
- 21 stations stream data continuously to TrigNet control centre in Chief Directorate: Surveys and Mapping
- Available within 30 minutes after each hour for 24 hours a day
TrigNet residuals wrt SNuRF

- Jun 2007 result

- TG-NU model

lat = 31.160 +/- 5.99
lon = -159.328 +/- 1.61
ang = 0.0645 +/- 0.0261

reduced chi2 = 1.2988
[chi2 = 24.677, dof = 19]

mean wrms (11 sites):
E = 0.59 +/- 1.22
N = 0.80 +/- 1.28
Trignet station HERM

- Hermanus Magnetic Observatory

Weather station

TMG bedrock
Principle of confined aquifers:
How to squeeze water out of rock
Confined Aquifers (1)

• Effective Stress Concept

“For a porous rock to undergo compression, there must be an increase in the grain-to-grain pressures within the matrix; oppositely, for it to expand, there must be a decrease in the grain-to-grain pressure.”

A simple analogy by Terzaghi & Peck, 1948
Confined Aquifers (2)

- Spring (length z) carrying Load A
- Spring is placed inside water tight cylinder
- Spring supports Load A & water is under pressure of its own weight as shown by manometer tube

Initial Hydrostatic Pressure
Confined Aquifers (3)

- Load B added on top of Load A
- Water cannot escape; \(\therefore\) spring cannot compress, i.e., additional load borne by water
- \(\therefore\) Water level in manometer rises above hydrostatic pressure level

- Plug removed & water allowed to escape
- Water pressure lowers & spring compresses in response to additional Load \(B\), i.e. transfer of stress from fluid to spring
- Water level in manometer drops back to original hydrostatic pressure level
Confined Aquifers (4)

- System reaches equilibrium
- Compressed spring reflects added Load B
- Drop in hydrostatic pressure indicates level of water removed

Classic Jacob Relation (assuming solely vertical strain in aquifer)

\[ S_s = \rho_w \ g \ (\beta_p + n \beta_w) \]

- \( S_s \) = Specific Storage
- \( \rho_w \) = mass density of water (kg m\(^{-3}\))
- \( g \) = gravitational acceleration (m s\(^{-2}\))
- \( \beta_p \) = skeletal compressibility of aquifer matrix (Pa\(^{-1}\))
- \( \beta_w \) = compressibility of water (Pa\(^{-1}\))
- \( n \) = effective porosity

Water Cylinder = Aquifer Storage
Spring = Compressibility of Aquifer Matrix
Plug = Borehole

NB: \( S_s \) component due to pore compressibility does not involve porosity
Table Mountain Group (TMG) hydrogeology and the Gateway wellfield, Hermanus
Cape Fold Belt setting of TMG

Cape Town depends on mountain hinterland for its water supply
Digital Geology-Topography
Geological profile

Gateway wellfield in confined Peninsula Formation between Hermanus and Attakwaskloof faults
Monitoring Components

- Water level monitoring in fractured rock aquifer
- Water level monitoring in the primary alluvium aquifer
- Water quality monitoring in the fractured rock aquifer
- Monitoring of spring and surface water flow and quality
- Rainfall, temperature and air-pressure monitoring
- Recording of abstraction rates and volumes
Confined aquifer monitoring

Water level – key hydrogeological indicator

- Low-amplitude seasonal response
- Slow, muted recovery after rainfall

Water level (m AMSL)

- GWP01
- GWP02
- GWE06
- GWE10b
2005 test-pumping experiment

~2-week wellfield test of 3 abstraction boreholes (GWP01, GWP02, GWE06)

No connection to fractured-rock aquifer across fault (GWE08b)

Note: 8b scale magnification
Along-fault response

GWE09, GWE10b show strong, prompt response to wellfield pumping
Gateway and HMO

Gateway wellfield

Hermanus Magnetic Observatory
International linkage to Global Geodetic Observing System (GGOS)
Geodetic observations

• Relate to 3 fundamental areas, i.e., gravity field, shape and rotation of Earth, and changes in time

• Show that, at time scales from weeks to decades, hydrological loading of Earth's surface dominates non-secular variation in each fundamental area

• Provide integral constraints on global water cycle at multiple spatial and temporal scales; sensors capture signals of variation in entire fluid envelop of solid Earth, including terrestrial water storage
Global Geodetic Observing System (GGOS)

- International Association of Geodesy (IAG) initiative
- Capability to monitor mass transport in Earth system and **potential to develop into system for monitoring hydrological cycle on global to regional scales**
- Gravity satellite missions (e.g., GRACE), which measure temporal variability of Earth's gravity field, are cornerstone
- Utilization of full suite of geodetic observations hampered by model insufficiencies, inconsistencies, lack of integration of different space-geodetic techniques
GGOS research project

• Address combination of space-geodetic observations, in particular GPS and GRACE, in order to exploit their individual strengths and mitigate their weaknesses;

• Improve geodetic modeling underpinning processing of observations and extraction of highly accurate information on changes in terrestrial water storage;

• Prepare assimilation of observations in integrated predictive models of hydrological cycle;

• Interpret space-geodetic observations in terms of regional groundwater and soil moisture changes;

• Support capacity building in field of space geodetic data processing, modeling of hydrological cycle, and interpretation of the observations in terms of terrestrial water storage;

• Promote practical use of products for regional water management through interaction with water management authorities, particularly in developing countries
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