Karst Hydrogeology in South Africa

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ENGINEERING HYDROGEOLOGY
PREDICTIONS, MANAGEMENT, DEWATERING AND LEGISLATION
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Location
Gautrain project

- Gautrain is an 80-kilometre mass rapid transit railway system under construction in Gauteng Province, South Africa.
- It will link Johannesburg, Pretoria, and OR Tambo International Airport.
Geology

- Dolomite
- Granite
- Shale
- Syenite

Karst

Selected information from map legend
Karstic dolomite aquifer
Groundwater Levels

- South – north direction of flow
- Controlled by springs
- Steeper gradients on margins
- Influence of dykes
- Natural fluctuation 2 - 4m
Water balance - outflow

- Pretoria Fountains
- Sterkfontein spring
- Grootfontein spring
- ZP13 borehole
- ZP16 borehole
- Kentron borehole
- Rietvlei boreholes
- Erasmia borehole
- Valhalla borehole
- All from late 1980's
- Up to 15m of water table lowering;
- Some relationship to rainfall – July to June (orange columns), CRD (grey line);
- Seven distinct periods of groundwater level change since the late 1980’s.
Cumulative Rainfall Departure (CRD)
Similar changes in monitoring boreholes across the dolomite aquifer;
Superimposed on the longer term fluctuations are fluctuations with shorter duration and smaller amplitude;
Same overall sequence of rising and falling water levels.
Example well hydrograph (24)

- Differences mainly in the amplitude or range rather than timing;
- Drawdown phases longer than the recovery periods;
- Levels generally recover fully following a drawdown phase.
Sinkholes

• One mechanism for sinkhole formation is lowered water table in karst
• We wanted to understand the causes of observed fluctuations in the water table and determine the risk of lowered water table
Water balance

\[ Q_{Ri} = Q_{pi} + Q_{outi} + \Delta h_i AS \quad (i = 1, 2, 3...N) \]

- where \( Q_{Ri} \) is recharge from rainfall in \( i \)-th month over aquifer area \( A \);
- \( Q_{pi} \) is the abstraction rate from pumped boreholes;
- \( Q_{outi} \) is natural outflow rate;
- \( \Delta h_i \) is water level change;
- \( S \) is storativity (specific yield).

Water level adjusts to changes in balance between recharge and outflow or to changes in pumping rate.
The Bredenkamp formula for recharge is given by:

\[ \frac{1}{\text{av}} \text{CRD}_i = \sum_{n=1}^{i} R_n - K \sum_{n=1}^{i} R_{\text{av}} \quad (i = 0, 1, 2, 3, \ldots N) \]

- Where \( \text{CRD} \) is the Cumulative Rainfall Departure;
- \( R \) is rainfall in \( i \)-th month and "av" the average;
- \( K \) is:

\[ K = 1 + \frac{(Q_p + Q_{out})}{A \cdot R_{\text{av}}} \]

- If \( K = 1 \) there is no pumping and/or outflow;
- If \( K > 1 \) there is pumping and/or outflow.
Bredenkamp formula relating recharge and storativity

\[ \Delta h_i = \left( \frac{r}{S} \right) \cdot (l_{av} \text{CRD}_i) \ (i = 0, 1, 2, 3, \ldots N) \]

- where \( \Delta h_i \) is the change in water level in the \( i \)-th month;
- \( r \) is a percentage of the CRD which results in recharge from rainfall;
- \( S \) is aquifer storativity.

Combining and rearranging:

\[ \Delta h_i = \left( \frac{r}{S} \right) \cdot \left[ \sum_{n=1}^{i} R_n - K \sum_{n=1}^{i} R_{av} \right] \]

We have a relationship between water level and rainfall which includes \( K \)
Well 13 – water levels generated by CRD
Well 64 – water levels generated by CRD

<table>
<thead>
<tr>
<th>Start Date</th>
<th>End Date</th>
<th>K Value</th>
<th>% Loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>01/10/1984</td>
<td>15/08/1992</td>
<td>1.2</td>
<td>20</td>
</tr>
<tr>
<td>15/08/1992</td>
<td>01/06/1995</td>
<td>1.4</td>
<td>40</td>
</tr>
<tr>
<td>01/06/1995</td>
<td>14/03/1997</td>
<td>0.4</td>
<td>-60</td>
</tr>
<tr>
<td>14/03/1997</td>
<td>07/08/1998</td>
<td>1.3</td>
<td>30</td>
</tr>
<tr>
<td>07/08/1998</td>
<td>20/07/1999</td>
<td>0.4</td>
<td>-60</td>
</tr>
<tr>
<td>20/07/1999</td>
<td>28/06/2005</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>28/06/2005</td>
<td>23/07/2006</td>
<td>0.4</td>
<td>-60</td>
</tr>
<tr>
<td>23/07/2006</td>
<td></td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>
Well 24 – water levels generated by CRD
Results

<table>
<thead>
<tr>
<th>BH No.</th>
<th>Storativity %</th>
<th>Steady State K</th>
<th>Recharge as % of Rainfall</th>
<th>Pumping Max K</th>
<th>Pumping as % of Rainfall</th>
<th>Recovery Max K</th>
<th>Recovery as % of Rainfall</th>
</tr>
</thead>
<tbody>
<tr>
<td>13</td>
<td>Varies with depth 10 to 6%</td>
<td>1.2</td>
<td>20%</td>
<td>1.6</td>
<td>200%</td>
<td>0.7</td>
<td>300%</td>
</tr>
<tr>
<td>64</td>
<td>10</td>
<td>1.2</td>
<td>20%</td>
<td>1.4</td>
<td>100%</td>
<td>0.4</td>
<td>600%</td>
</tr>
<tr>
<td>24</td>
<td>40</td>
<td>1.2 - 1.4</td>
<td>20 to 40%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Estimates of storativity and its variation with depth
- Steady state K value gives recharge estimate as a proportion of rainfall
- Pumping phase K gives estimate of pumping as a proportion of recharge
- Not sure what recovery phase K indicates – proximity to pumping?
Conclusions

The results indicate that the:

• aquifer storativity is in the range 5 to 40% which may be uniform or decrease with depth.

• Recharge is approximately 20% of the monthly average rainfall (50mm/month).

• Pumping takes place at a rate in excess of 2 to 3 times the recharge
Thank you