Estimation borehole sustainable yield in a typical confined porous aquifer

Prof. M Gomo
Institute of Groundwater Studies,
University of the Free State
South Africa
Introduction

- Estimation of borehole sustainable yield is important in order to operate a borehole in a manner which can maintain the aquifer productivity.
- Other terms which are used interchangeably with borehole sustainable yield are safe and reliable yield.
- For the purposes of this study and proposed application, borehole sustainable yield is defined as the constant discharge rate at which a borehole can be pumped during its operating life with without causing aquifer dewatering.
Introduction

- In a typical porous confined aquifer, dewatering occurs when water level drop below the top of the aquifer.
- This dewatering due to pumping can empty the aquifer causing the borehole to dry.
- It is therefore important to ensure that borehole operational pumping rates that do not result in aquifer dewatering are used for borehole operation purposes.
- In principle, this can be achieved when borehole operational yield does not cause the water level to drop below the top of the confined aquifer.

- This principle has been used in the Flow Characteristics (FC) method for estimating borehole sustainable yield in fractured-rock aquifers (van Tonder et al. 2001). The applicability of this approach in porous and confined aquifers is investigated in this study.
Approach

- The first component of the paper present the principle basis for applying the FC method approach in porous confined aquifer.

- Thereafter MODFLOW numerical modelling is used to illustrate how this approach can be applied.
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The method determine the sustainable yield (Qs) of a borehole in fractured-rock aquifer based on the following equation:

\[
Q_{\text{Sustainable}} = Q_{\text{pump test}} \frac{s_{\text{available}}(t = t_{\text{long}})}{s_{\text{pump test}}(t = t_{\text{long}})}
\]

- Where \( t_{\text{long}} \) describes the maximum operation time in which the drawdown \( s \) shall not exceed a maximum drawdown \( s_{\text{available}} \) during operation period of the borehole,

- The extrapolation of the measured pumping test drawdown is used to determine the \( Q_{\text{sustainable}} \)
Extrapolation of pumping test drawdown

- The drawdown measured during a pumping test is the sum of the drawdowns due to the production well \( s_{\text{well}} \) and the boundaries \( s_{\text{boundary}} \)

\[
s(t = t_{\text{long}}) = s_{\text{well}} + s_{\text{boundary}}
\]

- If other pumping wells exist, their drawdown should also be included

- Where \( s_{\text{well}} \) is extrapolated by a Taylor series expansion
FC – method (van Tonder et al. 2001)

- FC method considers 3 scenarios of the following impermeable/no flow boundaries:
  - Single no-flow boundary,
  - 2 no-flow boundaries
  - Closed-no flow boundaries

- To cater for the boundary FC considers an imaginary well taking equal amount of water to the abstraction well
FC – method (van Tonder et al. 2001)

Extrapolation of pumping test drawdown

- $s_{well}$ is extrapolated by the expansion using a Taylor series (only first 2 terms) around the late measurement points of the drawdown at $t = t_{EOP}$ (EOP - end of pumping test).

$$
s_{well}(t = t_{long}) 
\approx s(t = t_{EOP}) + \left[ \frac{\partial s}{\partial \log t} \right]_{t = t_{EOP}} (\log t_{long} - \log t_{EOP})
$$

$$
+ \frac{1}{2} \left[ \frac{\partial^2 s}{\partial (\log t)^2} \right]_{t = t_{EOP}} (\log t_{long} - \log t_{EOP})^2
$$

Average maximum first derivative

Average second derivative
Proposed application of FC method in Typical porous confined aquifers

The idea is to determine the operational pumping rate that will not result in drop the water level below the top of the confined aquifer to prevent dewatering of the aquifer.
Model simulation of constant discharge pumping test

The pumping test data is then used to estimate the sustainable borehole yield using the FC method.

<table>
<thead>
<tr>
<th>Model property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model dimensions (length x width)</td>
<td>10000m x 10000m</td>
</tr>
<tr>
<td>Storativity</td>
<td>0.001</td>
</tr>
<tr>
<td>Aquifer thickness (m)</td>
<td>15</td>
</tr>
<tr>
<td>Initial head (m)</td>
<td>24</td>
</tr>
<tr>
<td>Transmissivity (m²/day)</td>
<td>38</td>
</tr>
<tr>
<td>Pumping well discharge (m³/day)</td>
<td>950.4</td>
</tr>
<tr>
<td>Pumping well discharge (L/s)</td>
<td>4</td>
</tr>
<tr>
<td>Duration of pumping (days)</td>
<td>14.3</td>
</tr>
<tr>
<td>Predicted Theis drawdown (m)</td>
<td>&lt;0.00005</td>
</tr>
</tbody>
</table>
Simulated drawdown from constant discharge pumping test
Using simulated drawdown to estimate sustainable borehole yield using the FC method
Evaluating the performance of estimated borehole yield

- Use MODFLOW numerical modelling to evaluate the performance of estimated borehole yield
- Best case – 3.0 L
- Worst case – 1.31 L
Simulated drawdown from operational pumping

Available drawdown – 9m

332 days
Conclusions

- The study illustrates how FC method initially meant for typical fractured rock aquifers can be used to estimate borehole sustainable yield in a typical confined porous aquifers.
- The emphasis should be on groundwater levels monitoring and adjust the operational yield accordingly.