Numerical simulation of managed aquifer recharge into a karst groundwater system at the Wala reservoir, Jordan

Julian Xanke¹, Hervé Jourde², Tanja Liesch¹ and Nico Goldscheider¹

¹Karlsruhe Institute of Technology
²Montpellier University, Laboratoire Hydrosciences
Demographic growth and semi-arid climate challenge Jordan’s water management

population and …

< 1 million people (1960)
6.5 million people (2013)
~ 9.5 million people (2015)

… economic growth

Water use
2014 (%)
Domestic 51
Agriculture 45
Industry 4

high variability …

… in water availability
Jordan’s water facts

2014 (MCM)

Water demand ~1,400

**Water supply** 973

Surface water 259
Treated wastewater 125
Groundwater (~70% from karst aquifers) 589

**Water deficit** 427

Jordan’s water strategy promotes the application of managed aquifer recharge

increase groundwater availability in summer
Wala reservoir stores flood water and recharges it to the underlying karst aquifer

<table>
<thead>
<tr>
<th></th>
<th>Total [MCM]</th>
<th>Annual average [MCM]</th>
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</thead>
<tbody>
<tr>
<td><strong>Water balance</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(2002-2012)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inflow</td>
<td>136</td>
<td>129</td>
</tr>
<tr>
<td>Overflow</td>
<td>52</td>
<td>4.7</td>
</tr>
<tr>
<td><strong>Recharge</strong></td>
<td>74</td>
<td>6.7</td>
</tr>
<tr>
<td>Evaporation</td>
<td>7.8</td>
<td>0.7</td>
</tr>
<tr>
<td><strong>Abstraction</strong></td>
<td>129</td>
<td>11.7</td>
</tr>
</tbody>
</table>

Proportion of recharge on abstraction = 56%

Water level at the downstream Hidan wellfield is increased

- Drinking water supply to the capital Amman, Madaba city and adjacent communities

The model is used to better understand the characteristic aquifer hydraulics

Obtained by Calibration

- Reproduce water level fluctuations in the aquifer
- Identify the driving factors of water level fluctuations at the wellfield

Obtained by scenarios

- Predicted infiltration decrease caused by reservoir sedimentation
- Provide a basis for optimized water resources management

Two climate scenarios for a dry and a wet period, each 10 years

Two well management scenarios for each climate scenario
The model domain is projected onto a 2-dimensional profile along the wadi.

(Source: Xanke et al. 2016)
Recharge model: subdivision into hydraulic zones simplifies the calibration procedure

- Approach: finite element method (FEFLOW) – saturated flow conditions - confined setting (cross sectional model)

Superelevated presentation – K values are in m/s

(Source: Xanke et al. 2016)
Recharge model: in-transfer rate $\Phi$ regulates infiltration from Wala reservoir

- Infiltration increases exponential with water level
- In-transfer rate ($\Phi = K/d$) was manually adapted

(Source: Xanke et al. 2016)
Abstraction model: strong water level fluctuations are controlled by changes in the mean pumping depth

- A fault at Hidan wellfield has a damming effect on groundwater flow
- Inherent problems in representing pumping rates in a 2D vertical model
  
  statements about the magnitude of fluctuations have to be considered carefully

Superelevated presentation – K values are in m/s

(Source: Xanke et al. 2016)
Lowering of annual average groundwater level of about 2.7 meters at recharge wells …

- satisfying accordance of measured and simulated groundwater level fluctuations at recharge wells

(Source: Xanke et al. 2016)
... and probably a greater depletion at the wellfield

- satisfying accordance of measured and simulated groundwater level fluctuations at Hidan wellfield

(Source: Xanke et al. 2016)
Conclusions

Numerical model

- **Reliable simulation results** were achieved with 2D vertical profile models.

- Subdivision into **hydraulic zones** allows the simulation of the **karst characteristic flow pattern**.

Management

- The Wala reservoir poses a **successful example** of **managed recharge into a karst aquifer**.

- Technical measures are required to **reduce the sedimentation rates** and to remove sediments from the reservoir.

- The **wellfield** requires an **improved management** in terms of monitoring and abstraction.
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Publications


Contact: julian.xanke@kit.edu