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Springflow Simulator
BARADA Spring

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Karst groundwater

- In Mediterranean karst groundwater has potentially important reserve which represents a high interest for the future in numerous countries under global and climatic changes.
- Karst water is generally captured for water supply at the level of their springs; due to the important temporal variations of spring discharges, water pumping through boreholes intercepting the water saturated karst conduit allows carrying out an active management.
Modelling of karst system

- Modelling of karst system is very complicated especially with the heterogeneity in karst and scarcity of data.
- The traditional models based on water movement in porous media (i.e. Modflow) could not simulate properly the hydrograph of karst spring.
- There are at least two types of porosity, micro pores in the rock matrix, and fractures, channels and conduits. Whereas groundwater flow in the matrix is typically slow and laminar, flow in karst conduits is often fast and turbulent.
The hydrogeological conceptual model of karst Spring is based on the recharge of the karstic system by rainfall and snow melting. The infiltrated water is divided in two parts:

- a flow through the conduits and fractures (fast flow) and
- a slow flow fed by groundwater stored in the epikarst, infiltration, narrow karst features and rock matrix which delay the flow.
Reservoir model

Therefore, an empirical reservoir model was developed whose aim was:

- (i) to simulate as well as possible the high and low flow rates,
- (ii) to propose a management tool capable of predicting the evolution of the discharge in different climate conditions

The guiding principle was to build a simple model representing the transmissive and storing functions of the aquifer solely on the basis of hydrograph analysis.
Consequently, the conceptual model contains two transfer reservoirs,
- one for the slow discharge corresponding to the low flow stage and
- one for fast flow mainly feeding the flood flow.
The infiltration water is shared between these two parts according to the sharing coefficients X1 and X2 allocated to each reservoir. The model is running using rainfall time series as the system input. The model will simulate the discharge time series. These coefficients are fixed in the model and defined by calibration.
The Soil reservoir

- The infiltration is determined by the **Soil reservoir** which allows the calculation of infiltration. The infiltration then feeds the transfer reservoirs. It is calculated from rainfall and ETR.
- The Soil reservoir can only provide infiltration for transfer when rainfall occurs, i.e. when $H_{soil\ reservoir}$ is higher than $H_{to}$.

\[
(H_{soil\ reservoir})_{t1} = (H_{soil\ reservoir})_{to} + Rainfall_{t1} - ETR_{t1} - Infiltration_{t1}
\]
The quantity of water leaving this type of reservoir is proportional to the height of water in the reservoir. The discharge proceeds according to Maillet’s law which corresponds to the emptying of a reservoir through a porous outlet. In these conditions, the variation in the quantity of discharged water (transformed into height) is written as follows:

\[(H_{\text{out}})^t = (H_{\text{out}})_0 \cdot e^{-\alpha t}\]

where \((H_{\text{out}})^t\) is the discharged water height at time \(t\) (m/d); \((H_{\text{out}})_0\) is the discharged height at \(t = 0\) (m/d); \(\alpha\) is discharging or recession coefficient of the reservoir (d\(^{-1}\)).
The discharging coefficient $\alpha_1$ is calibrated in the model to give the best representation of the low flow stages. $X_1$ is defined from calibration on the low flow stages. Then $\alpha_2$ is calibrated in order to present the high yields and flood peaks.
This type of model presenting two discharge reservoirs was tested on several karst springs in Europe (Fleury, 2005) and Lebanon (El Hakim, 2005) and seems to be well appropriated to model karst spring hydrograph. The model proved particularly well suited to the simulation of discharges from karstic springs where it successfully represented both the high and low flow rates.
Barada Spring is an important karst spring in Syria as it constitutes an important resource for the drinking water supply of Damascus, with a mean annual flow around 3\(\text{m}^3/\text{s}\) and a high low flow stage, usually exceeding 1\(\text{m}^3/\text{s}\). It discharges the Jurassic aquifer outcropping in the Anti-Lebanon ridge. Barada watershed is at 1400 m elevation in average and receives more than 800 mm of rain and snow.
Modeling of Barada spring hydrograph

The study of this spring is essential for understanding the functioning of the aquifer, especially since pumping groundwater becomes very important with the growth of the population supplied primarily by the spring of Figeh.

This is why ACSAD and BGR commissioned a study on the possibility of modeling the functioning of "the Barada karst system", with the aim of simulating the spring discharge. The goals of this simulation are:
1. the prediction of the flows according to rainfall data on the catchment area,
2. the modeling of the effect of water abstraction by pumping.
The daily rainfall data were provided for four stations: Madaya, Zabadani, Serghaya and Bloudan from 1985 to 2007 (1980 to 2007 for Madaya). Unfortunately, the daily flow rate time series are shorter, not complete and their quality is questionable, especially for the years before the exploitation for water supply by pumping, in 1995.
Springflow simulator

- The reservoir model platform (Springflow simulator, 2007) was developed by ACSAD and BGR of the Barada karst system was applied.
Determination of the model parameters

Two models are provided for the periods before and after the beginning of pumping respectively. The two models have the same structure, but the parameters are different because the aquifer functioning changed after the beginning of the pumping.

Model before the pumping started
Six years divided in two equal parts and separated by a one-year gap were used. The first three years were used to calibrate the model and the remaining three years to validate it.

Model after the pumping started
Eight successive years were used. The model was calibrated based on data for the first 4 years and validated based on data for the last four years.
Calibration and Validation

- The model calibrated and validated over the period of before pumping gives fair results whereas the model covering the pumping period gives satisfactory results.
- The difference between the measured flow and the simulated flow may be due to three factors:
  - snow melting not accounted,
  - bad quality of flow measurement and
  - the functioning of the karst system itself.
Result of the simulation without pumping

GRAPH

Simulated flow m³: validation of Barada modeling without pumping
Qmes: validation of Barada modeling without pumping
PBrVmes: validation of Barada modeling without pumping
Result of the simulation with pumping
the delay and buffering between rainfall and discharge is not correctly accounted by the model. This is because snow melting plays a major role in the recharge process by delaying and distributing the infiltration. This can be solved, by introducing in the model a physical function linking the snow melting to the air temperature. This approach requires daily temperature time series (four years only) and snow and melting characteristics and the snow cover area. Unfortunately such data are missing.
Prediction Exercise

Syria's Initial National Communication to UNFCCC (2009)
Vulnerability Assessment and Possible Adaptation Measures of Water Resources
The model is used to predict the impact of climate change on Barada spring discharge. An annual decrease in rainfall of 5.1% at 2040 (according to the result of MRI-96 projection model for Serghaya Station, national communication report in Syria to UNFCCC 2009) accompanied with the same annual pumping of 2007 was applied using the same pattern of rainfall of year 2006-2007.

MRI-96 projection model for Serghaya Station

<table>
<thead>
<tr>
<th>Station Name</th>
<th>Average 1961-1990 (mm)</th>
<th>Rate of Change (%)</th>
<th>Average Change (mm)</th>
<th>Average 2041 (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Serghaya</td>
<td>572.4</td>
<td>-5.1</td>
<td>29.2</td>
<td>543.2</td>
</tr>
</tbody>
</table>
The model result showed the continuous decrease in spring discharge. The low flow period of the spring disappears gradually and the spring dishrags mainly in peak time. The model expected a decrease of 37% in annual discharge in 2039.
Conclusion

- Millions of people in the region live in karst areas and are supplied by drinking water from karst aquifers. These aquifers include valuable freshwater resources, but are almost always vulnerable to overexploitation and contamination, due to their specific hydrogeologic properties.
- Therefore, karst aquifers require increased protection and application of specific hydrogeologic methods for their investigation and management.
- Modelling is an important tool for effective management. Despite the difficulty in “mathematically” representing karst system, this type of resviour models proved particularly well suited to the simulation of discharges from karst springs where it successfully represented both the high and low flow rates.
- Several scenarios can be tested with such tool as:
  - Change in land use (changing ET)
  - Change in snow thickness & cover area (changing t)
THANK YOU!