Managing water supply resources in karstic environment (temperate climate)

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Presentation structure

- Historical flashback
- The Athens water supply system as a case study
- The Boeoticos Kephisos basin (a karst basin)
- Hydrological modelling
- Water resources management
- Results
- Conclusions
Historical flashback

Throughout history, karstic aquifers have had an important role in urban development around the Mediterranean. In ancient Athens (a great example of sustainable water management), water supply was based on two main aqueducts, the Peisistratean and the Hadrianian (partly functioning till today), conveying water from karstic springs at foothills of surrounding mountains.

Peisistratean aqueduct uncovered during the excavations for the Metro.

Hadrianian aqueduct maintenance in 1929.

Athens water supply system

- Important karstic aquifers in modern times

Map showing the extended karstic aquifers, Mornos reservoir, Evinos reservoir, Lake Yilki, Marathon reservoir, and Athens.
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Boeoticos Kephisos water basin

- **Abstractions for water supply**
  - Vassilika boreholes abstract water from karstik aquifer that discharges to Mavroneri springs.

- **Abstractions for irrigation**
  - Sluice gates (irrigation)

IW: Pumping wells (irrigation)
The design of a hydrological model of a water basin which includes karstic aquifers should take account of the following:

1. Karstic aquifers have great interaction with surface water (conjunctive simulation).
2. Karstic aquifers have small response times (good description of human intervention, e.g. abstractions).
3. Karstic aquifers may have significant influence to basin budget by importing/leaking water from/to other basins.
4. Karstic conduits network is irregular and difficult to describe; therefore it is preferable to be modelled using a conceptual (rough) approach.

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**Surface model**
- Modified Thornthwaite soil moisture model

**Groundwater model**
- Modified multicell model

**Hydrosystem model**
- Digraph representation

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Water basin model

- Surface model

Precipitation ➔ Direct flow

Real evapotranspiration

Quick flow (saturation) ➔ Lagged flow

Percolation

Soil moisture

A parsimonious structure, with six parameters per HRU

HRU = Permeability U Slope

Permeability:
- High (karst)
- Med. (alluv.)
- Low (flysch)

Slope:
- High
- Low
Water basin model

- **Groundwater model**
  - Representation of flow with a hydraulic analogous.
  - Flow in pipes may be described with Darcy or non-Darcy equations.

Water basin model

- **Groundwater model**
  - Limited number of cells.
  - Large cells in areas with mild hydraulic gradient.
  - Leakages from karstic conduits to the adjacent sea.
Well abstractions from karstic aquifers influence directly the behavior of corresponding springs. Accurate estimation of well abstractions for irrigation are imperative.
Water basin model

- **Estimate well abstractions**
  - Deficit between surface + baseflow and needs is covered with pumps.
  - Pumps effect on baseflow
  - Less baseflow results in need for more pumping.

- **Simulated spring discharge, basin outlet**

  - Mavroneri Sim.
  - Mavroneri Obs.

  - Basin outflow Sim.
  - Basin outflow Obs.
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### Water basin model

#### Estimated water budget

- **Mean annual precipitation**: 1575 hm³.
- **Evapotranspiration**: 48%
- **Outflow**: 14%
- **Abstractions**: 13%
- **Leaks**: 25%

<table>
<thead>
<tr>
<th>Feature</th>
<th>Capacity (hm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mornos reservoir</td>
<td>630</td>
</tr>
<tr>
<td>Evinos reservoir</td>
<td>112</td>
</tr>
<tr>
<td>Lake Yliki</td>
<td>585</td>
</tr>
</tbody>
</table>

Water resources management

#### Water supply system characteristics

- **Evinos reservoir**: 112 hm³
- **Mornos reservoir**: 630 hm³
- **Lake Yliki**: 585 hm³, Leaks (level depended) through karstic conduits
- **Marathon reservoir**: 32 hm³
- **Mornos aqueduct**: 188 km (gravity flow)
- **Yliki aqueduct**: 67 km (pumps)
Water resources management

- Water supply system schematisation
  - Digraph representation
  - Minimize cost function with Simplex algorithm

Results

- Parametric rules for reservoirs system control (scenario 1 – medium demand)
  - Water from Yiliki is used with low priority to reduce cost
Conclusions

1. In water basins with extended karst formations conjunctive surface water and groundwater simulation is compulsory.
2. Accurate physically based modelling of karst aquifers may be infeasible; however, a conceptual approach may suffice.
3. The water exchange between adjacent karst basins and the leakage to the sea may be a significant component of the water budget and requires a careful approach.
4. Good description of the human intervention (e.g. of well abstractions) in karstic aquifers may improve noticeably the model performance.
5. The management of a hydrosystem including some karst areas should be holistic; for example, karst formations in a single reservoir influence greatly the operation rules of the whole system.
References


Modelling the hydrosystem

**Groundwater model**

Use of an alternative flow equation was proved advantageous in simulation of water level fluctuation but the accuracy in calculations of fluxes was not improved.

\[ Q = C \left( \frac{y}{D} \right)^\alpha \cdot i^{0.5} \]

\( Q \): generalised conductivity \([\text{L}^3\text{T}^{-1}]\).
\( \alpha \): constant between 1 and 2.
\( i \): hydraulic gradient when \( y > D \), slope when \( y \leq D \).

Results

[Graphs showing water level fluctuations and simulated vs observed data for Herkynas and Melas sources.]

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