Integrating Groundwater Models within a Decision Support System

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The geographical setting:
The Athens water supply system
The HYDRONOMEAS Decision Support System

Network management module

1. Nodes / reservoirs
2. Aqueducts
3. Energy units
4. Hydrologic series
5. Operational targets

Database

Control module

Dynamic visualisation module

Simulation module

Optimisation module

Results presentation module

Optimal solution

Parameters’ values

Performance measure

User’s options

Report

1. Nodes / reservoirs
2. Aqueducts
3. Energy units
4. Hydrologic series
5. Operational targets
The Boeotios Kephisos Basin: Why a groundwater model?

Map showing the following locations:
- Vassilika boreholes
- Mavroneri springs
- Polygyra springs
- Melas springs
- Herkynas springs
- Mouriki pumping station
- Basin outlet
- To Athens (via the Mornos aqueduct)
- To Athens (via the Yliki aqueduct)
Overview of the hydrological processes in the Boeoticos Kephisos Basin

Precipitation to the basin

Water demand for irrigation & water supply

River network + system of karstic aquifers of B. Kephisos Basin

Abstractions from boreholes

Spring runoff

Surface runoff
Mean annual flow rate of B. Kephisos River
(Hydrological years 1970-71 to 2000-01)

Upper Course Basin – Fed by Parnassos Springs
Infiltration zone (Tithorea Basin)

Middle Course Basin – Confluence of Mavroneri karstic springs and important torrents

Lower Course Basin – Confluence of karstic springs of Melas, Polygyra and Herkynas

- Papalouka bridge
- Modi
- Anthochori
- Chaironeia
- Orchomenos
- Basin outlet

Mean annual flow (hm³)
Distance (km)

Mean annual flow rate of B. Kephisos River (Hydrological years 1970-71 to 2000-01)
Pre-existing MODFLOW model: Adaptation to operational context

- 500×500 m² grid
- Modeling boundary conditions
- Using only MODFLOW.EXE
- Writing operational package

Further needs: surface hydrology model + water management model (operation rules)
- Performance rather poor
- High computing time
- High effort to use MODFLOW.EXE
Approach A: Lumped conceptual model (1)

Evapotranspiration + withdrawals for irrigation & water supply (according to heuristic operation rules)

Precipitation

Surface runoff

Infiltration

Mavroneri spring runoff

Melas + Polygyra spring runoff

Losses to the sea
Approach A: Lumped conceptual model (2)

- Small number of parameters (5)
- Calibration on the 5-year discharge data at the basin outlet (hydrological years 1984-85 to 1988-89)
- Validation on the 5-year discharge data at the basin outlet (hydrological years 1989-90 to 1994-95)
Approach B: Semi-distributed model (1)

- Precipitation
- Evapotranspiration
- Direct runoff
- Subsurface runoff
- Deep percolation
- Modified Thornthwaite model
- Upstream flow
- Outflow to the sea
- Darcian model
- Spring runoff
- Downstream flow
- Total runoff
- Abstractions from surface resources
- Total withdrawals
- Regulated according to operation rules

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Approach B: Semi-distributed model (2): Division into 4 cells

- Upstream Melas springs
- Kopais Plain
- Upstream Mavroneri springs
- Upstream Herkynas springs
Approach B: Semi-distributed model (3)

- Surface flow system upstream Mavroneri
- Groundwater flow system upstream Mavroneri
- Surface flow system Mavroneri-Melas
- Groundwater flow system Mavroneri-Melas
- Mavroneri spring runoff
- Polygyra spring runoff
- Melas spring runoff
- Groundwater flow system Herkynas
- Surface flow system Herkynas
- Herkynas spring runoff
- Surface flow system Kopais Plain
- Kopais Plain

Boeoticos Kefisos River

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Approach B: Semi-distributed model (4)

- Large number of control variables (18 model parameters + 6 initial conditions)
- Calibration on the 5-year discharge data at the basin outlet (hydrological years 1984-85 to 1988-89)
- Validation on the 5-year discharge data at the basin outlet (hydrological years 1989-90 to 1994-95)
Model performance criteria in calibration

Nash efficiency

Outlet 0.90 0.89
Mavroneri Springs 0.71 0.73
Polygyra Springs 0.26 0.52
Melas Springs 0.08 0.10
Herkynas Springs 0.39

Lumped
Semi-distributed
MODFLOW
Model performance criteria in validation

<table>
<thead>
<tr>
<th>Outlet Mavroneri Springs</th>
<th>Nash efficiency</th>
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<tr>
<td>Lumped</td>
<td>0.75</td>
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<tr>
<td>Semi-distributed</td>
<td>0.72</td>
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<td>MODFLOW</td>
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<thead>
<tr>
<th>Outlet Mavroneri Springs</th>
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### Basin mean annual water balance (through the multi-cell model)

<table>
<thead>
<tr>
<th>Component</th>
<th>$\text{hm}^3$</th>
<th>(%)</th>
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<tbody>
<tr>
<td>Precipitation</td>
<td>1835</td>
<td></td>
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<tr>
<td>Evapotraspiration</td>
<td>1128</td>
<td>61</td>
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<tr>
<td>Surface runoff</td>
<td>123</td>
<td>7</td>
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<tr>
<td>Infiltration</td>
<td>584</td>
<td>32</td>
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<td>Losses to sea</td>
<td>165</td>
<td>28</td>
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<tr>
<td>Spring runoff</td>
<td>183</td>
<td>31</td>
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<tr>
<td>Groundwater abstractions</td>
<td>236</td>
<td>40</td>
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<tr>
<td>Total runoff</td>
<td>306</td>
<td></td>
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<tr>
<td>Runoff at the outlet</td>
<td>212</td>
<td>69</td>
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<tr>
<td>Surface water abstractions</td>
<td>94</td>
<td>31</td>
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<tr>
<td>Water demand for irrigation and supply</td>
<td>330</td>
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<tr>
<td>Surface water abstractions</td>
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<td>28</td>
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<tr>
<td>Groundwater abstractions</td>
<td>236</td>
<td>72</td>
</tr>
</tbody>
</table>

- **Precipitation (100 units/year)**
  - Evapotraspiration: 32%
  - Surface runoff: 7%
  - Infiltration: 61%
Integration of hydrological models into HYDRONOMEAS

- Stochastic generator (CASTALIA)
- Areal precipitation at B. Kephisos Basin
- Rainfall and evaporation (to all reservoirs), inflows (to all reservoirs, initial for Yliki)
- Hydrological model of the B. Kephisos Basin
- Withdrawals
- Final inflows to Yliki
- Hydrosystem simulation and optimisation (HYDRONOMEAS)
Concluding remarks

- The ability of our DSS to manage water resource was enhanced through integrating hydrologic models into it.
- Three models were tested: a multi-cell model, a lumped model, and MODFLOW.
- Prediction accuracy for the multi-cell model and the lumped model was similar both in calibration and validation.
- One five-year simulation (with a monthly time step) lasts $1.5 \times 10^{-6}$ s, 0.5 s and 5 min for the lumped, the multi-cell and the MODFLOW model respectively (for PC Pentium III at 600 MHz).
- In the optimisation phase, HYDRONOMEAS can afford only the lumped model, while for a single simulation cycle the multi-cell model is proposed.
- Distributed models, although useful for better spatial information treatment, remain ineffective.