UNESCO WORKSHOP

Integrated Urban Water Management in TC – Temperate Climates

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Managing water supply resources in karstic environment (temperate climate)

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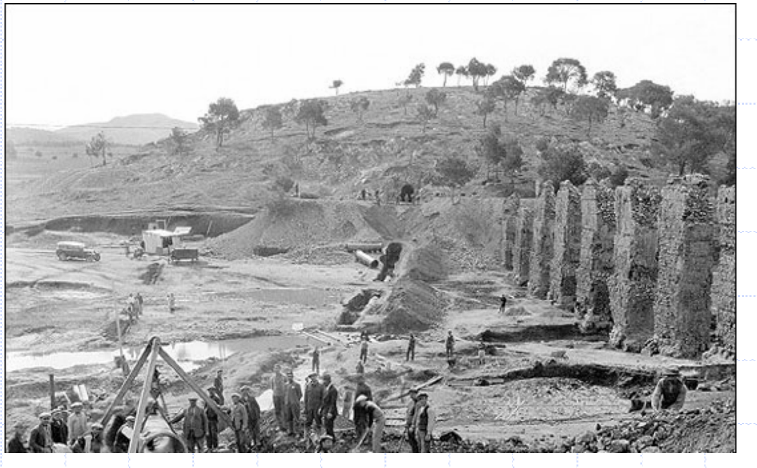
Presentation structure

- 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.

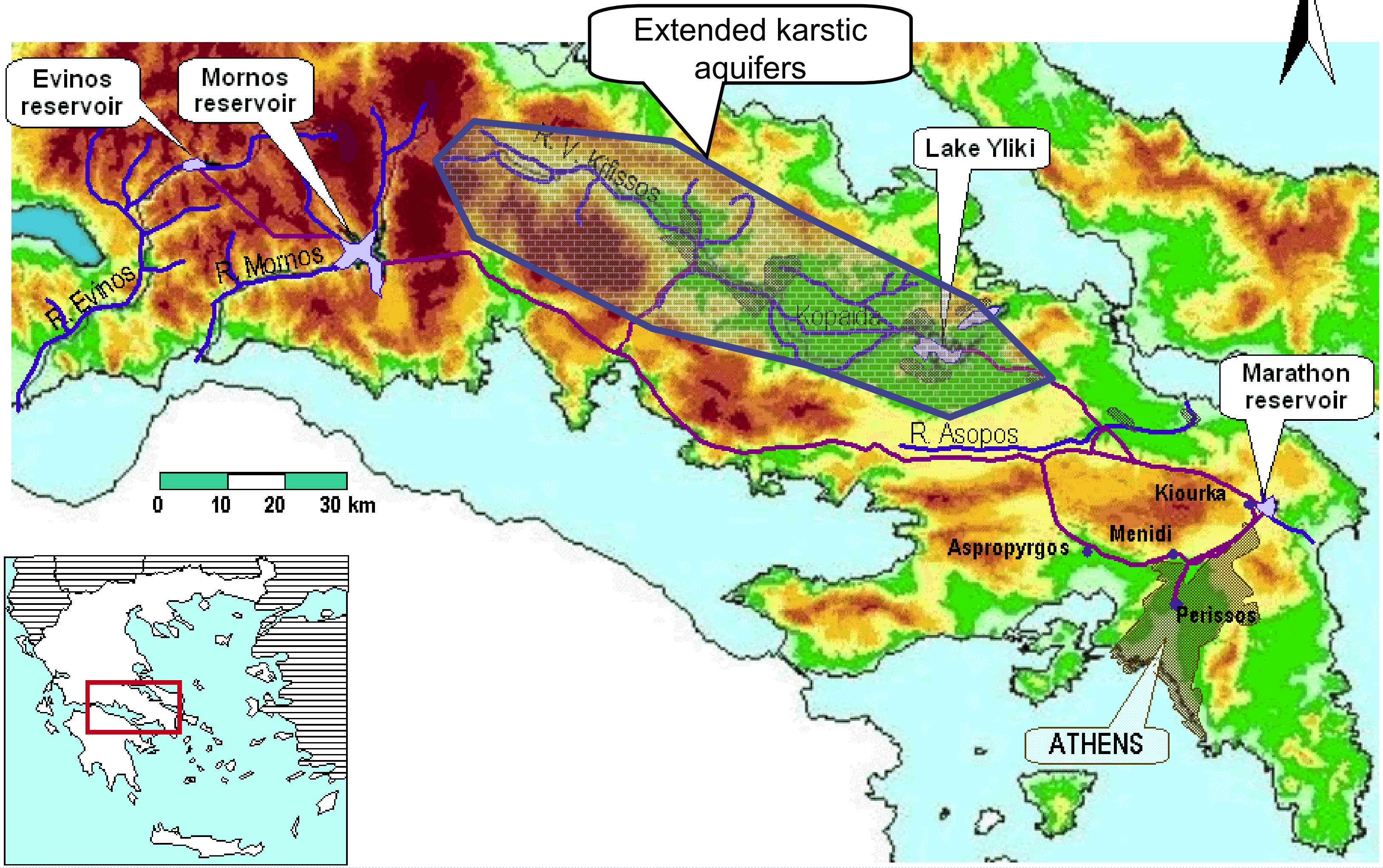
Peisistratean aqueduct uncovered during the excavations for the Metro.



Hadrianian aqueduct maintenance in 1929.

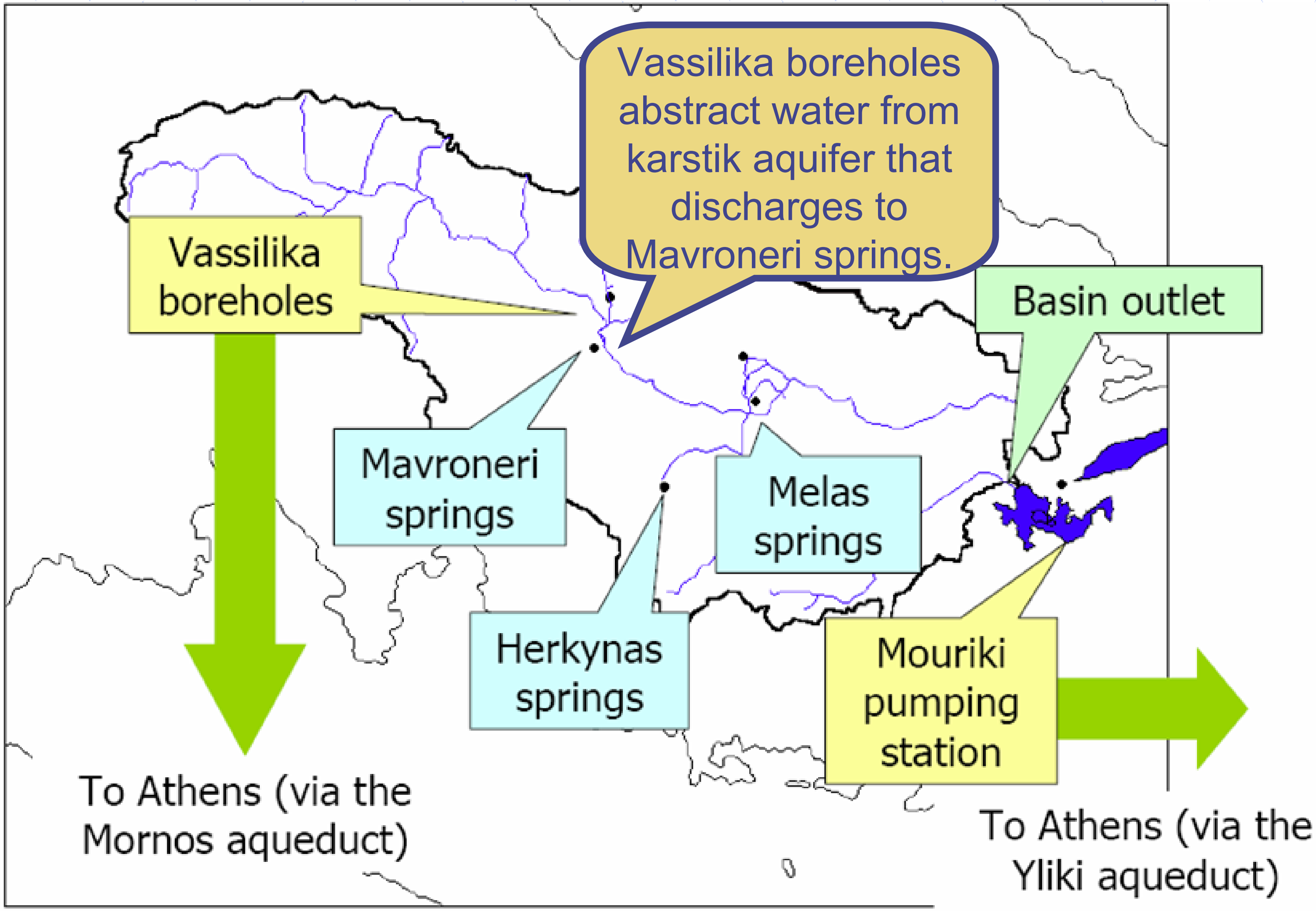
Athens water supply system

- Important karstic aquifers in modern times



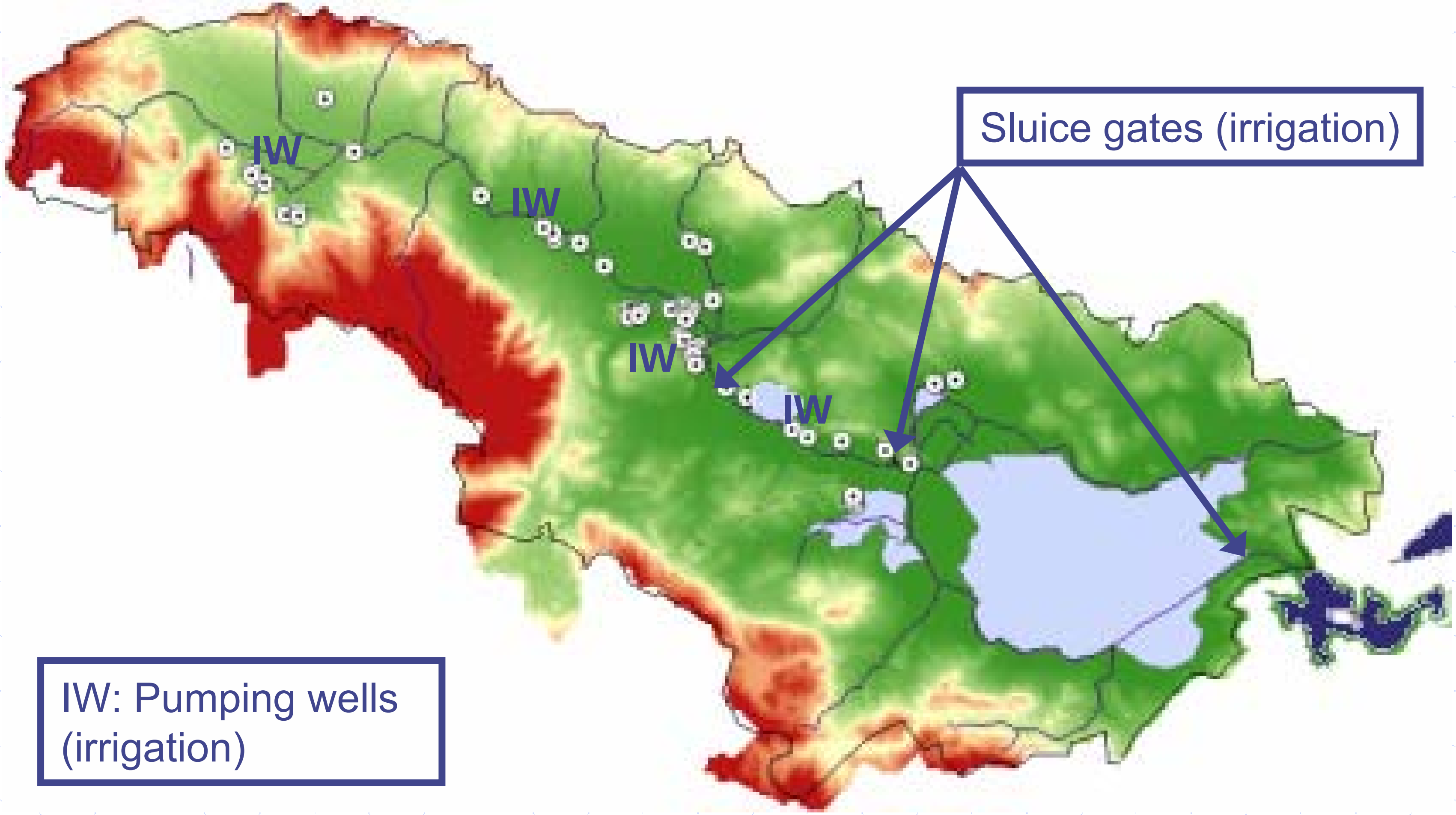
Boeoticos Kephisos water basin

- **Abstractions for water supply**



Boeoticos Kephisos water basin

❑**Abstractions for irrigation**



Water basin model

❑**Karstic aquifer peculiarities**

The design of a hydrological model of a water basin which includes karstic aquifers should take account of the following:

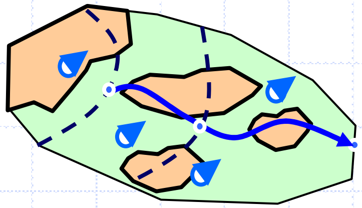
1. Karstic aquifers have great interaction with surface water (conjunctive simulation).
2. Karstic aquifers have small response times (good description of human intervention, e.g. abstractions)
3. Karstic aquifers may have significant influence to basin budget by importing/leaking water from/to other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

Water basin model

❑Conjunctive simulation

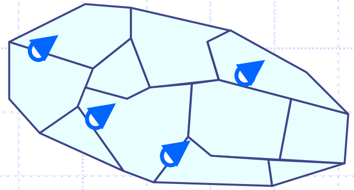
Surface model

•Modified Thornthwaite soil moisture model



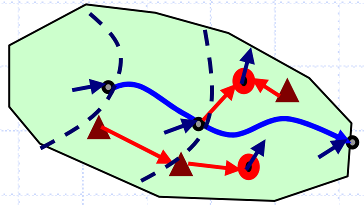
Groundwater model

•Modified multicell model



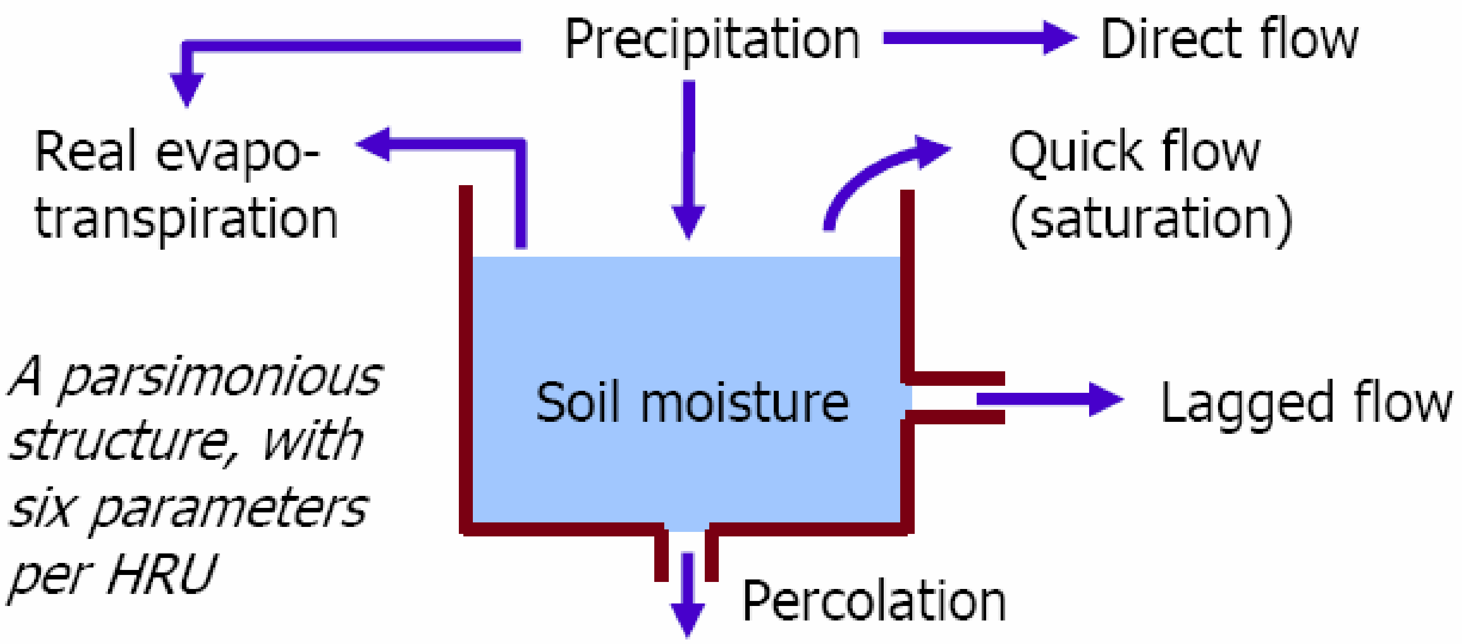
Hydrosystem model

•Digraph representation



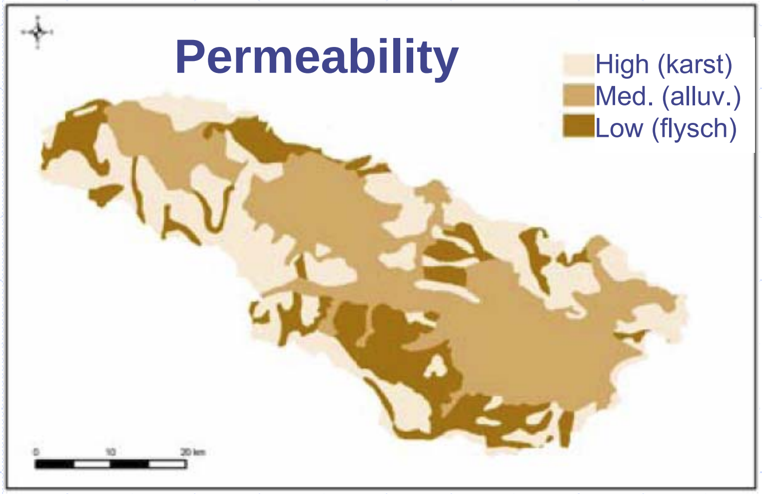
Water basin model

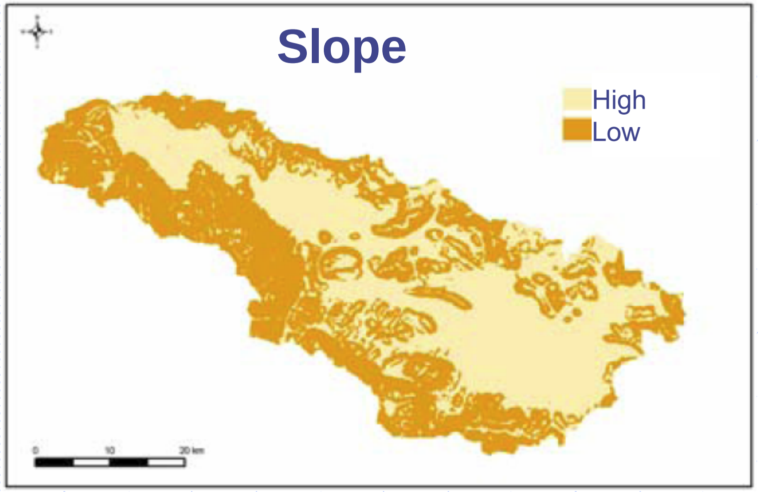
❑**Surface model**



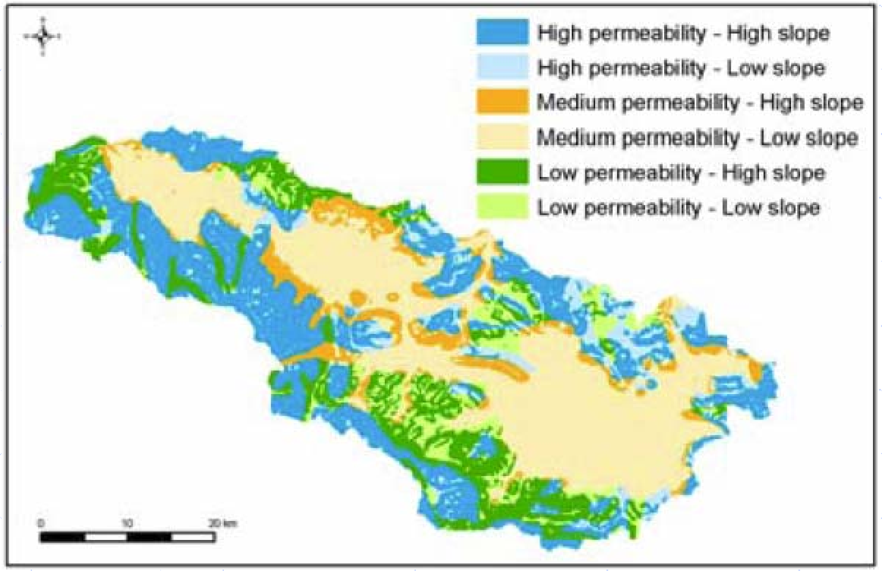
Water basin model

❑Surface model

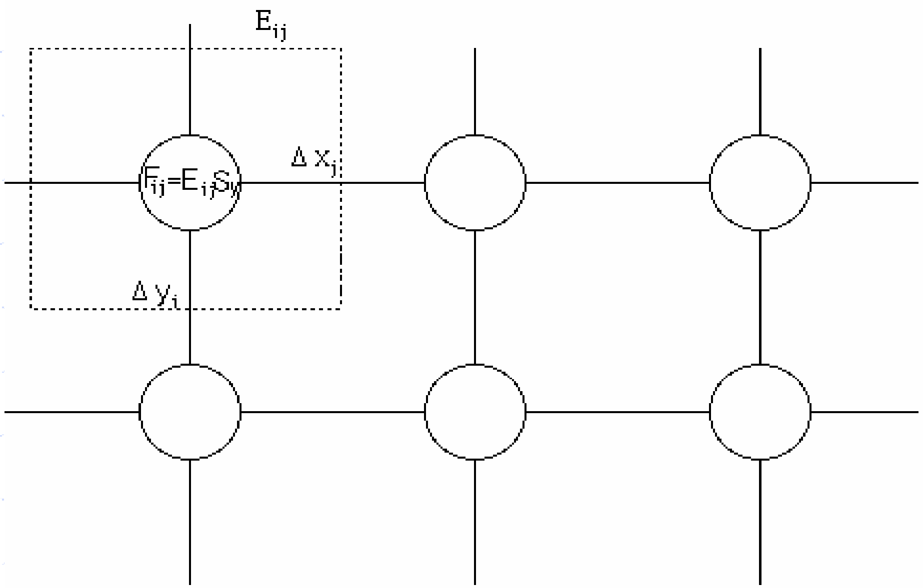




HRU=Permeability U Slope

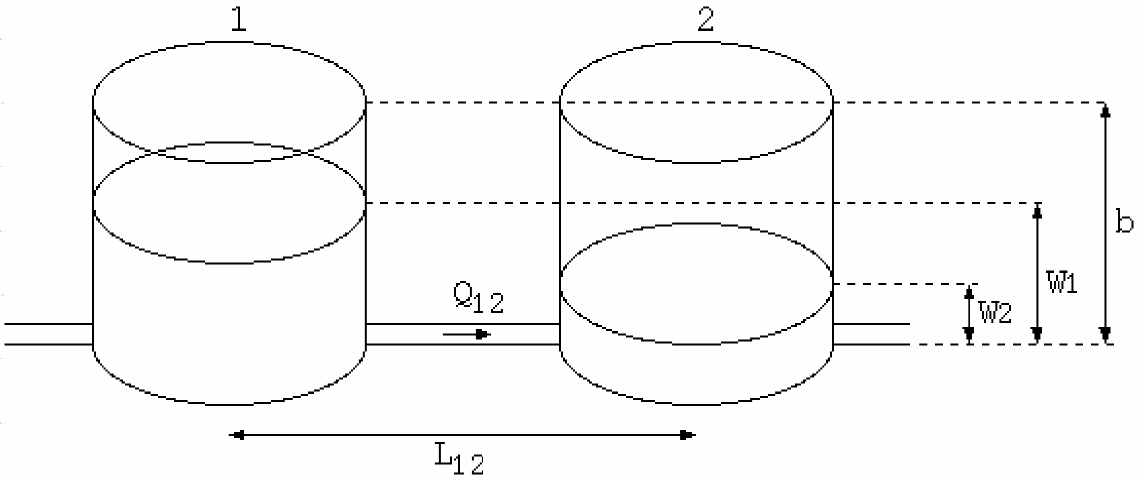


Water basin model

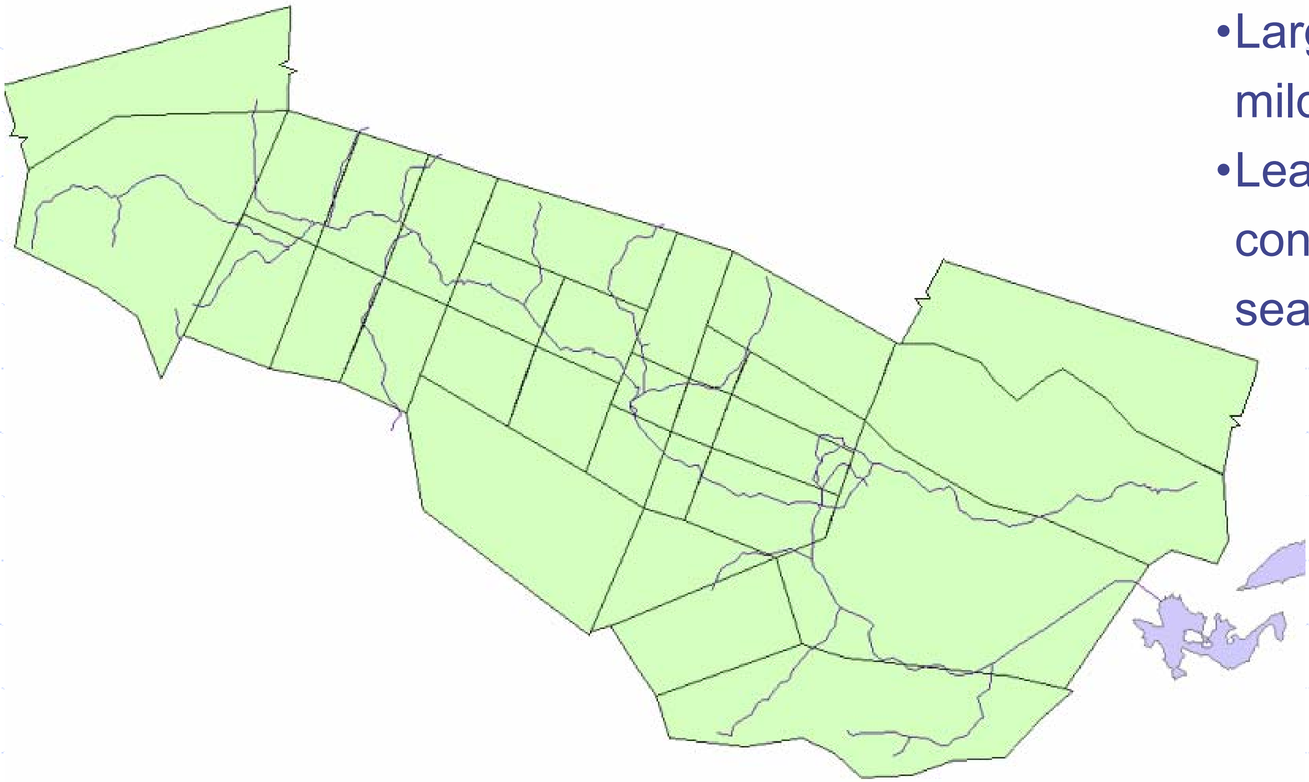


- **Groundwater model**

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



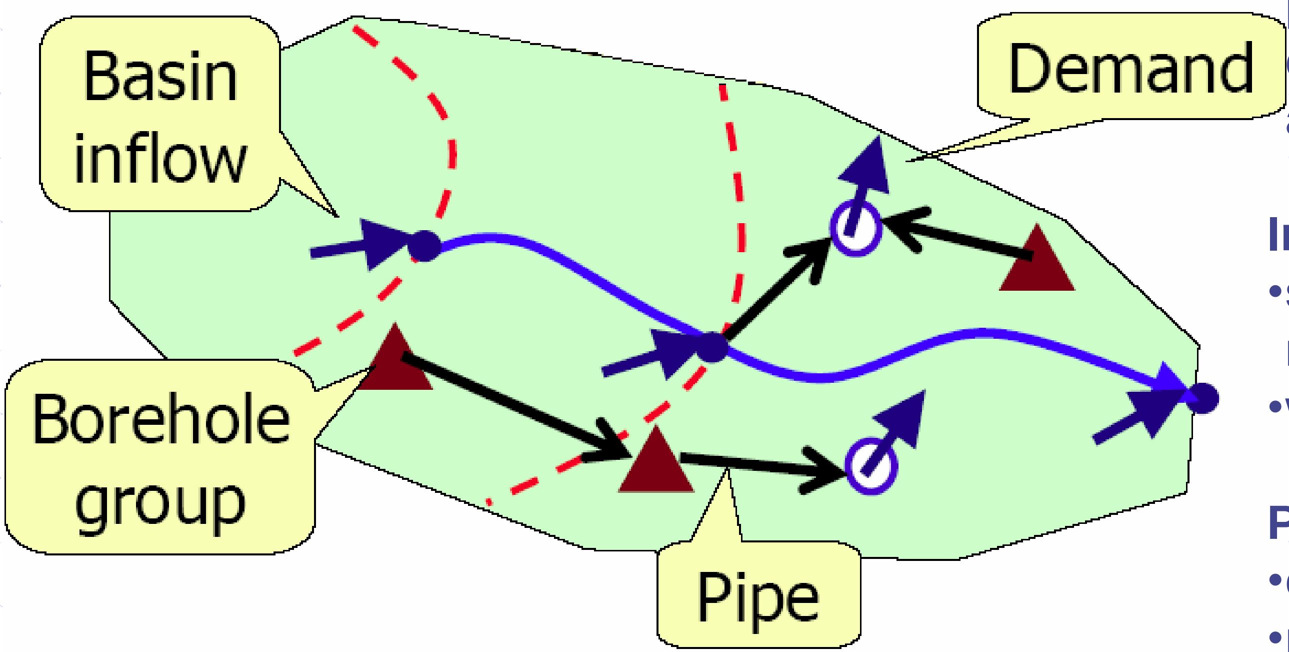
Water basin model



❑Groundwater model

- Limited number of cells.
- Large cells in areas with mild hydraulic gradient.
- Leakages from karstic conduits to the adjacent sea.

Water basin model



❑**Hydrosystem model**

Topology

•river, aqueduct, pumping capacities, demand areas, connectivity

Input

•surface and spring runoff

•water needs

Parameters

•constraints

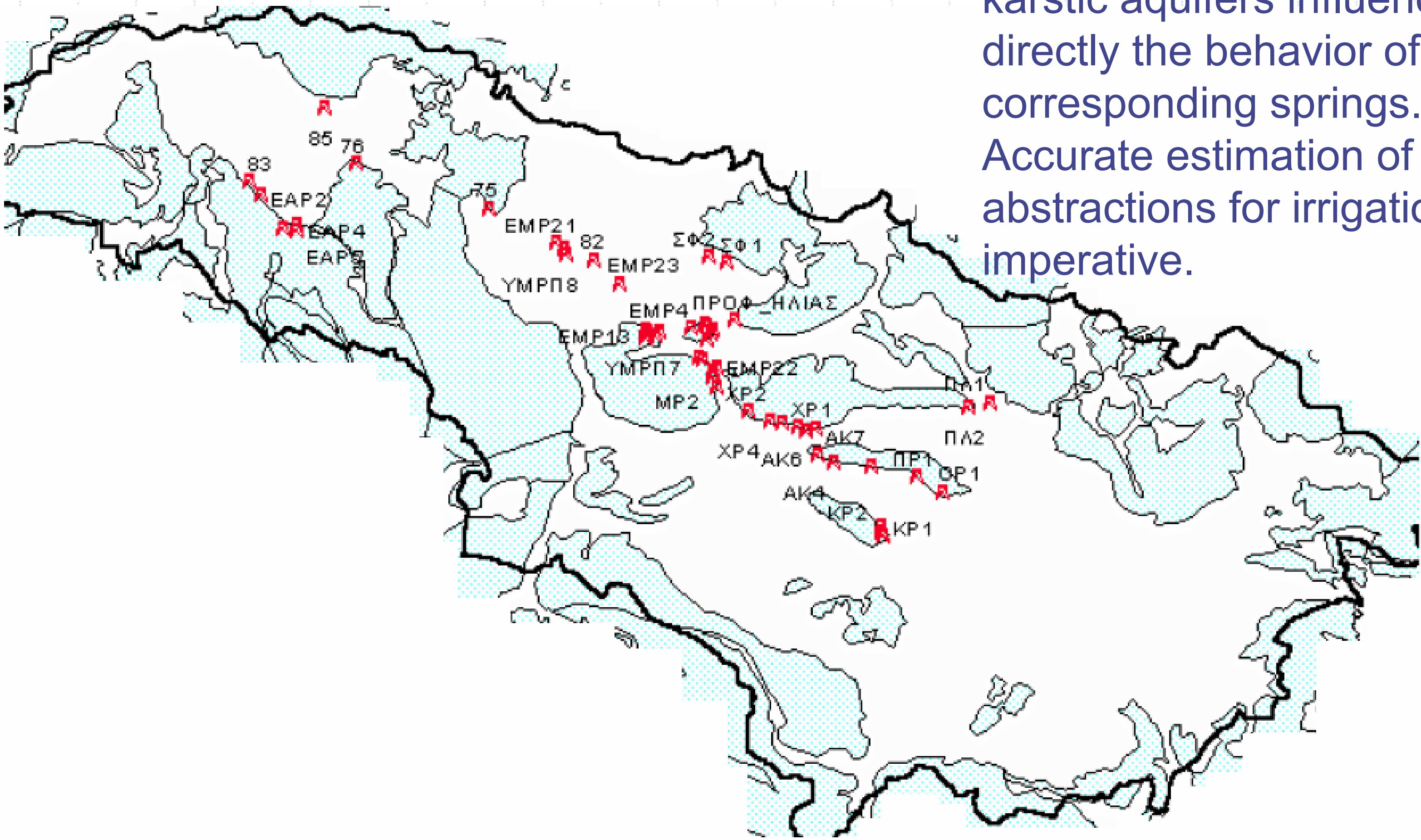
•priorities

•unit cost values

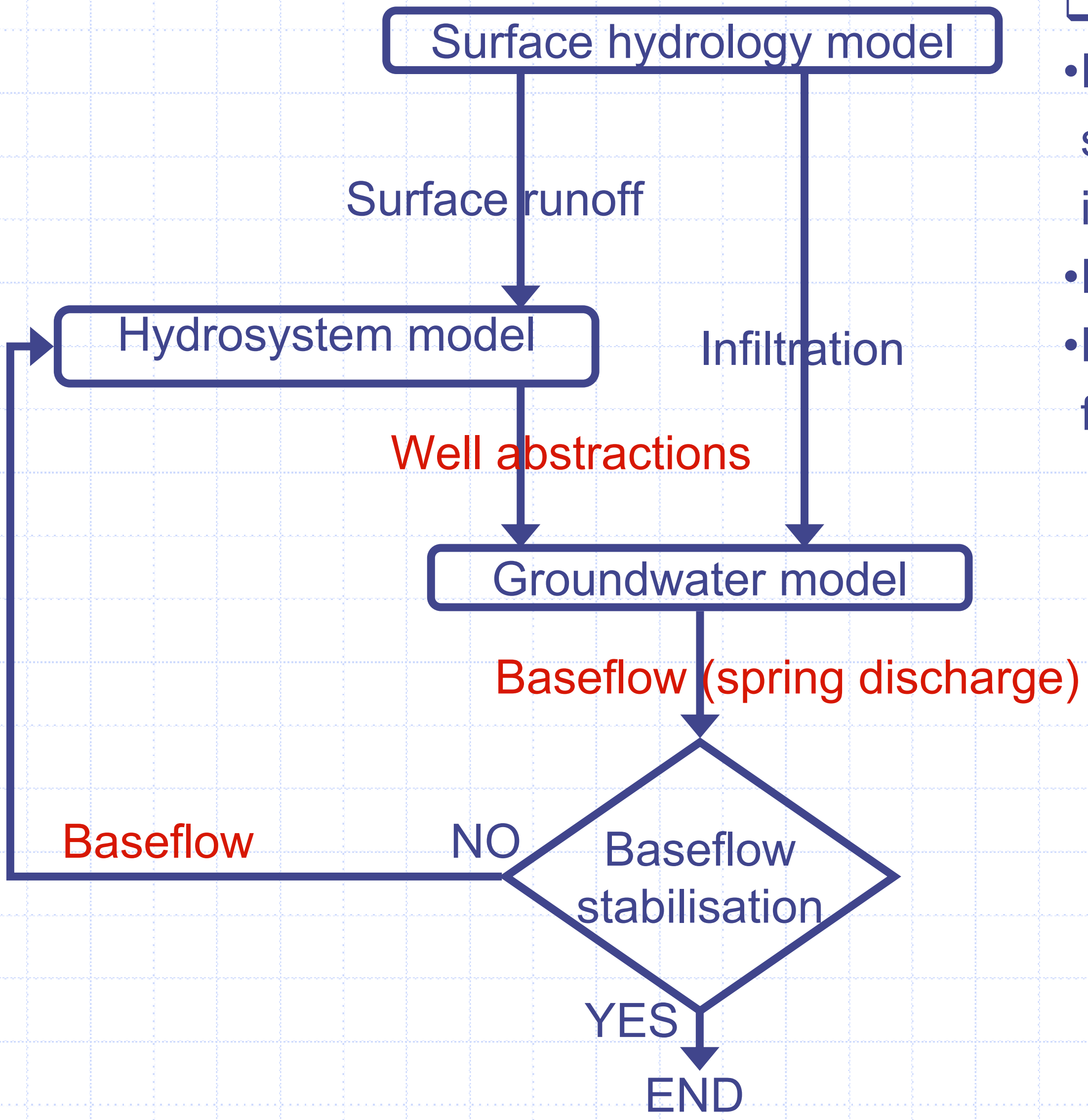
Water basin model

❑**Karstic formations, and pumping wells for irrigation**

Well abstractions from karstic aquifers influence directly the behavior of corresponding springs. Accurate estimation of well abstractions for irrigation are imperative.



Water basin model

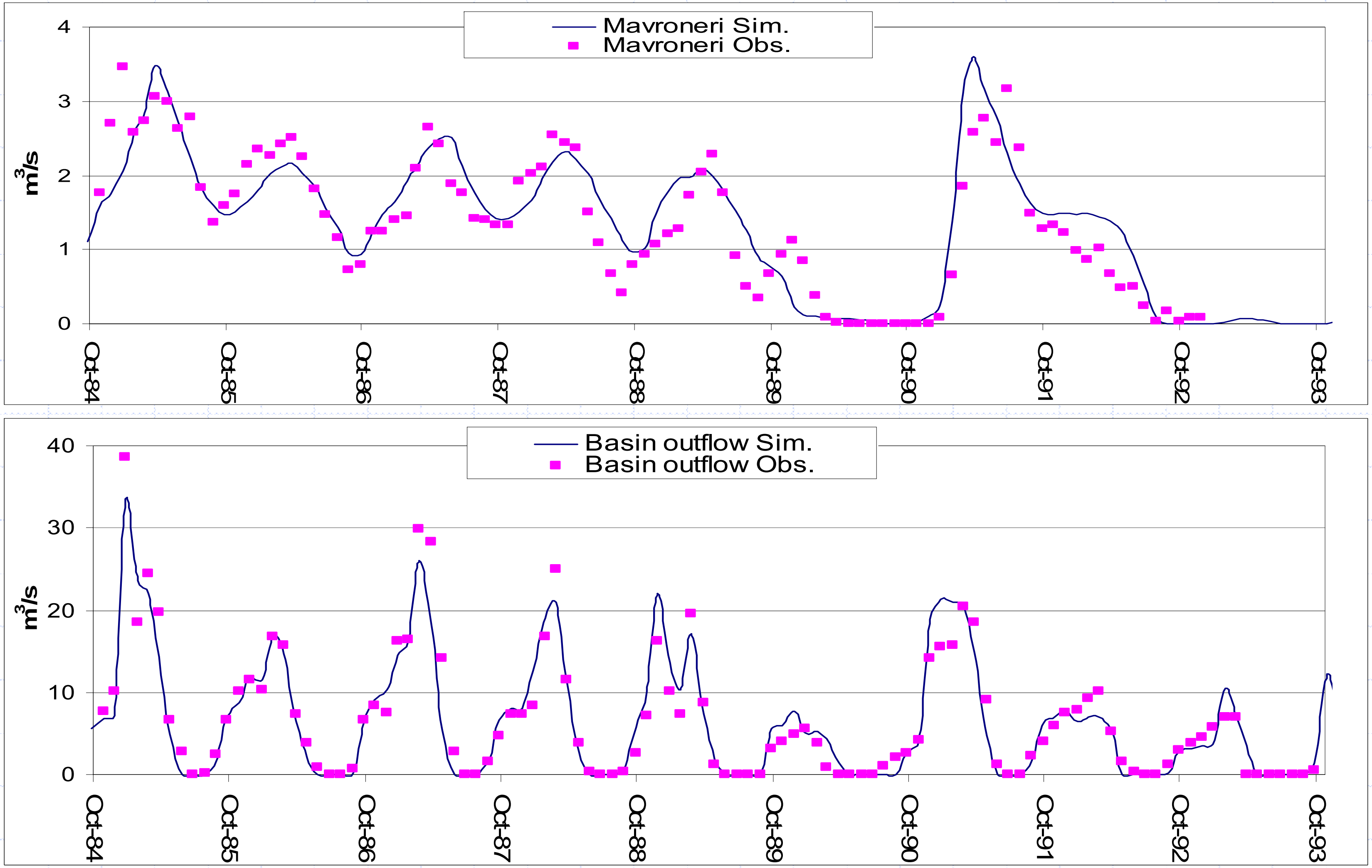


❑Estimate well abstractions

- Deficit between surface+baseflow and needs is covered with pumps.
- Pumps effect on baseflow
- Less baseflow results in need form more pumping.

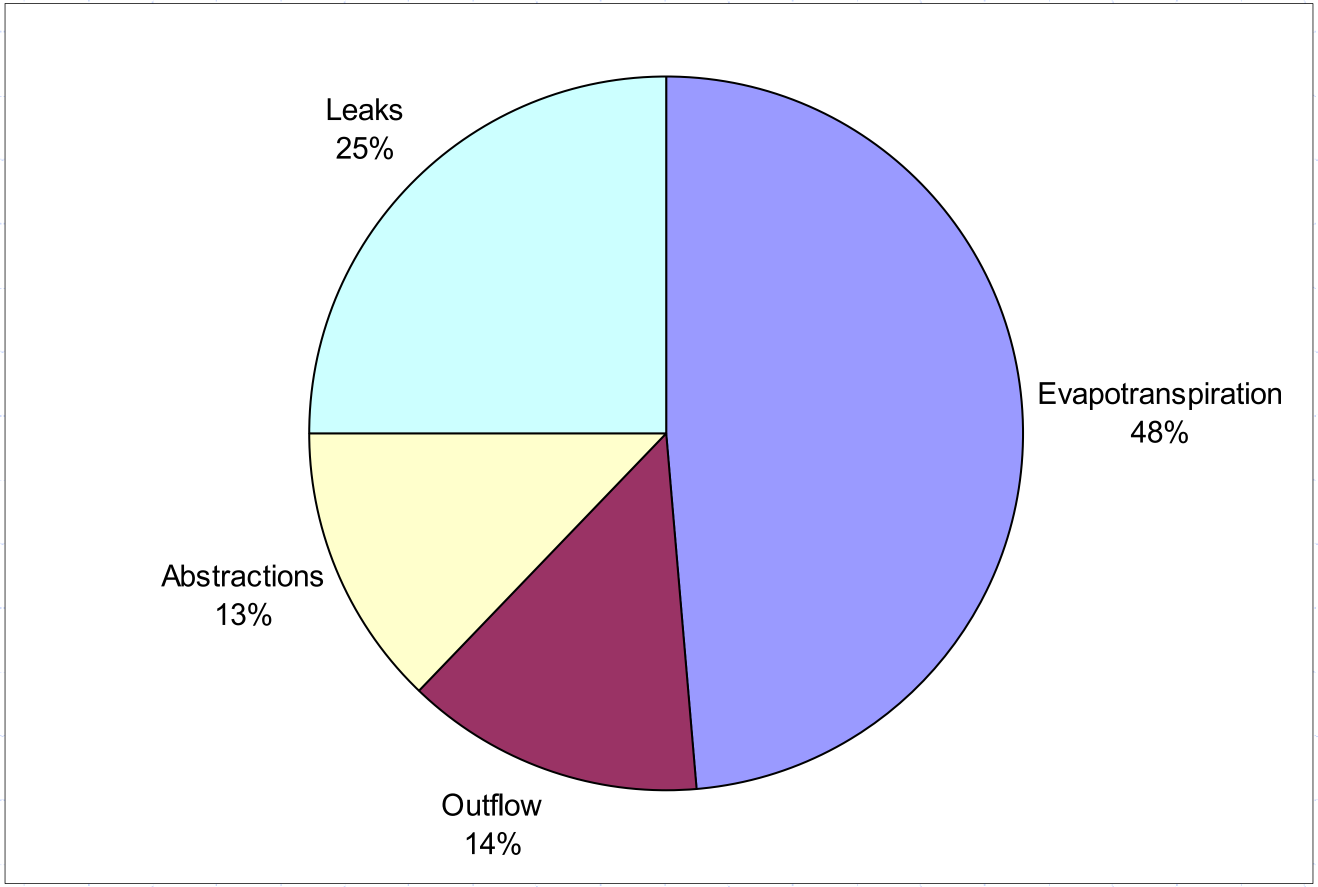
Water basin model

- **Simulated spring discharge, basin outlet**



Water basin model

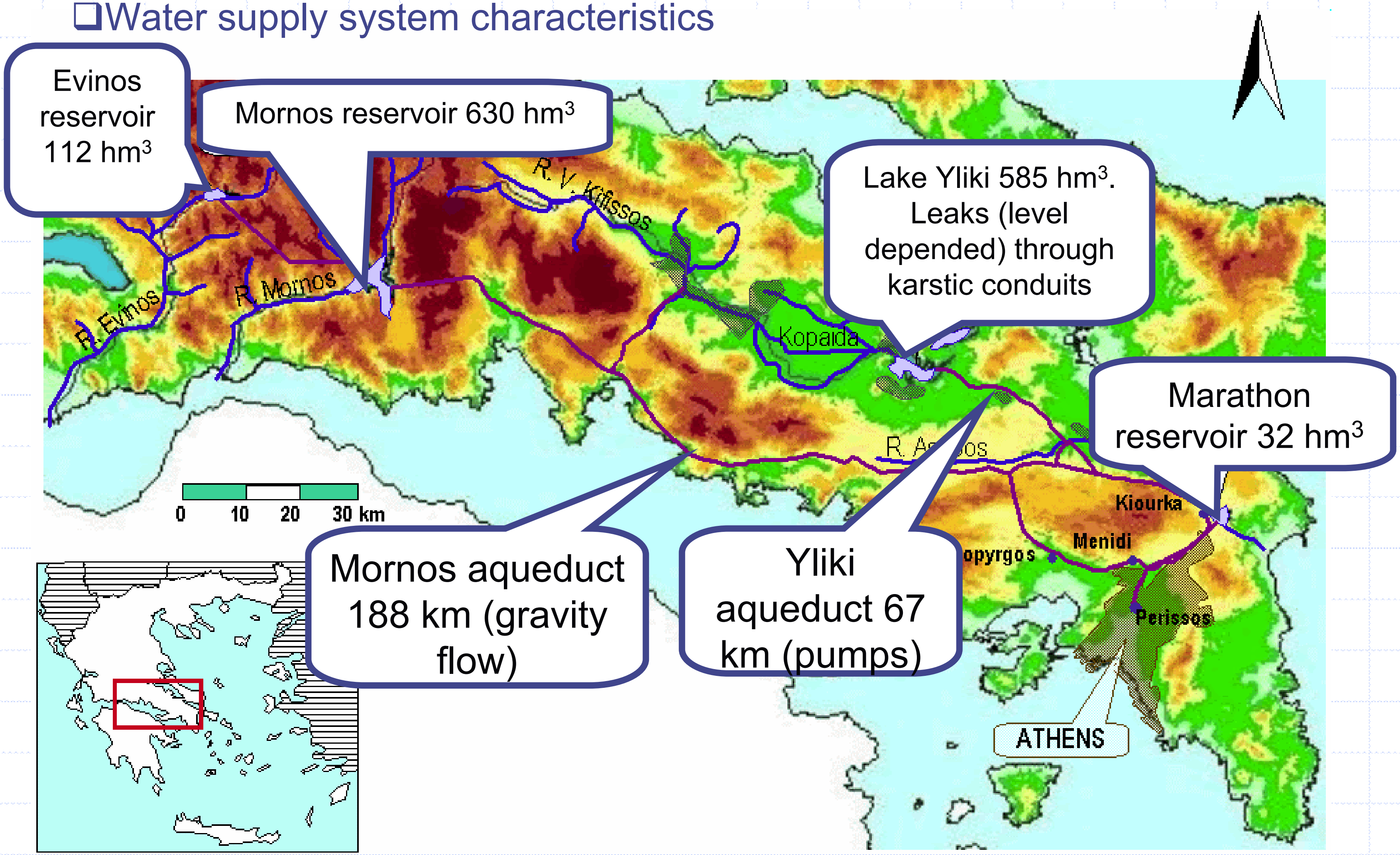
❑**Estimated water budget**



Mean annual precipitation 1575 hm^3.

Water resources management

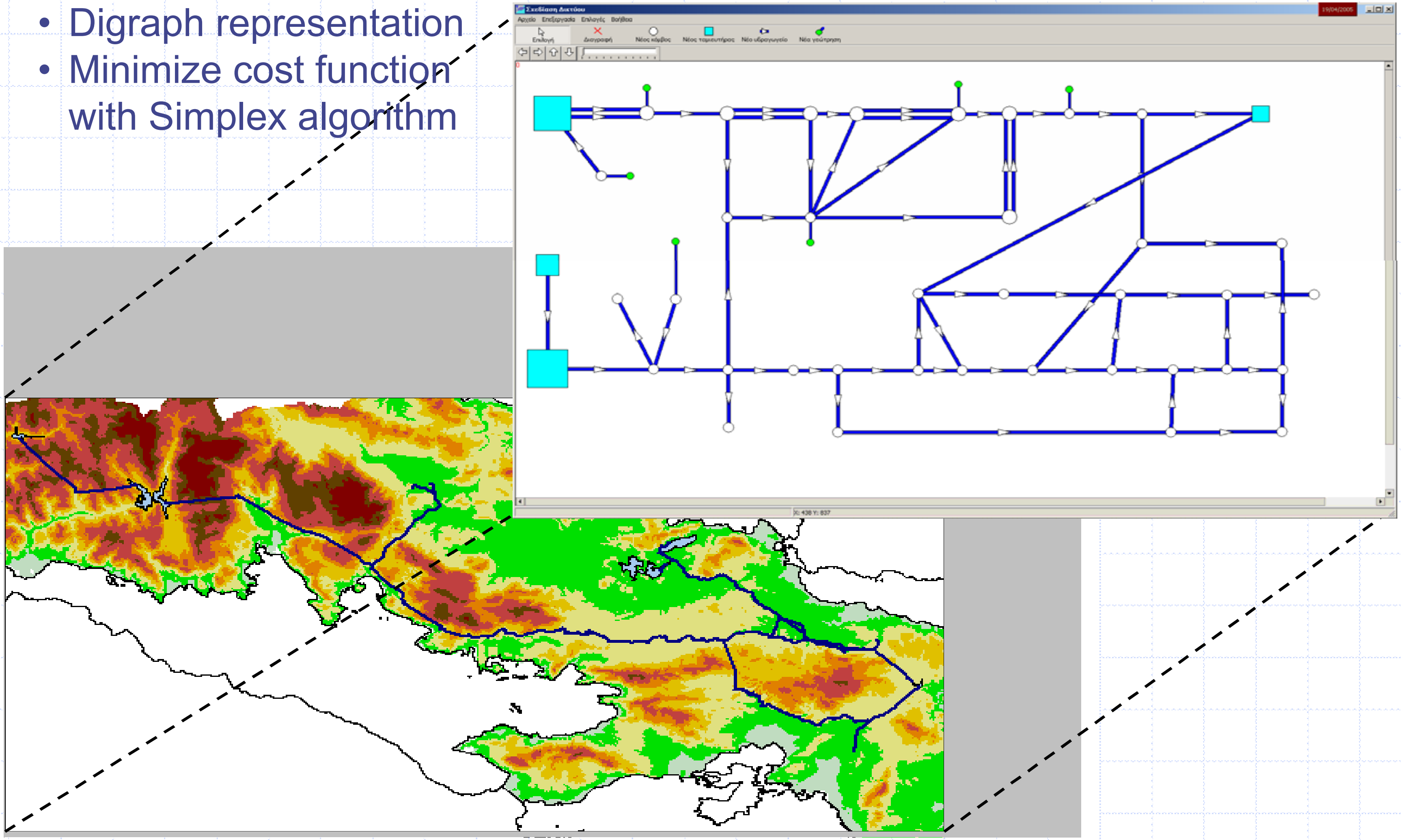
❑ Water supply system characteristics



Water resources management

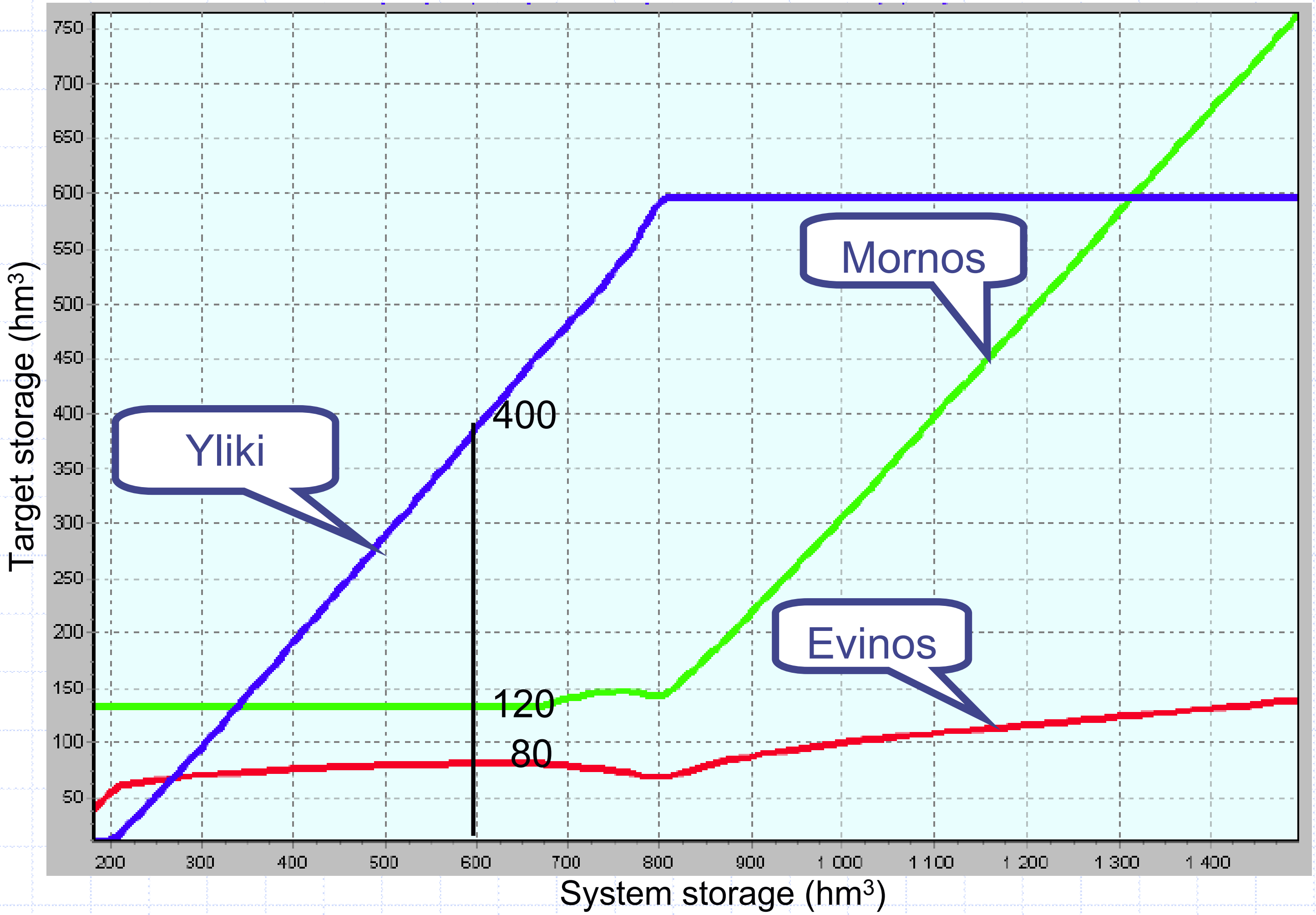
❑Water supply system schematisation

- Digraph representation
- Minimize cost function with Simplex algorithm



Results

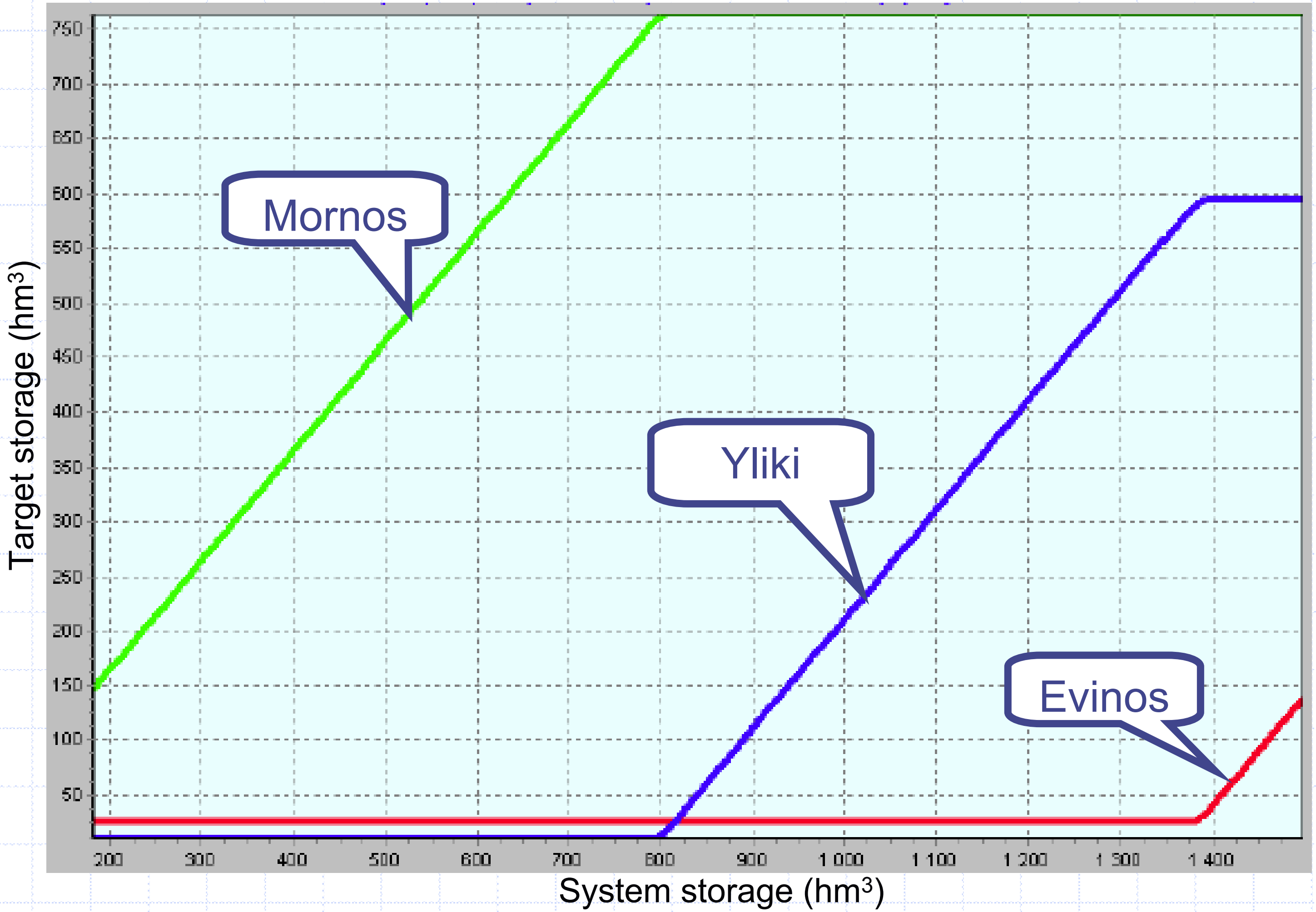
❑Parametric rules for reservoirs system control (scenario 1 – medium demand)



- Water from Yliki is used with low priority to reduce cost

Results

❑Parametric rules for reservoirs system control (scenario 2 – high demand)



- Water from Yliki is used with high priority to reduce losses

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

Efstratiadis, A., G. Karavokiros, S. Kozanis, A. Christofides, A. Koukouvinos, E. Rozos, N. Mamassis, I. Nalbantis, K. Noutsopoulos, E. Romas, L. Kaliakatsos, A. Andreadakis, and D. Koutsoyiannis, The ODUSSEUS project: Developing an advanced software system for the analysis and management of water resource systems, 3nd General Assembly of the European Geosciences Union, Geophysical Research Abstracts, Vol. 8, Vienna, 03910, European Geosciences Union, 2006.

Efstratiadis, A., E. Rozos, A. Koukouvinos, I. Nalbantis, G. Karavokiros, and D. Koutsoyiannis, An integrated model for conjunctive simulation of hydrological processes and water resources management in river basins, *2nd General Assembly of the European Geosciences Union, Geophysical Research Abstracts, Vol. 7*, Vienna, 03560, European Geosciences Union, 2005.

Efstratiadis, A., I. Nalbantis, and E. Rozos, Model for simulating the hydrological cycle in Boeoticos Kephisos and Yliki basins, Modernisation of the supervision and management of the water resource system of Athens, Report 21, 196 pages, Department of Water Resources, Hydraulic and Maritime Engineering - National Technical University of Athens, Athens, January 2004.

Karavokiros, G., A. Efstratiadis, and D. Koutsoyiannis, Hydronomeas (version 3.2) - A system to support the management of water resources, Modernisation of the supervision and management of the water resource system of Athens, Report 24, 142 pages, Department of Water Resources, Hydraulic and Maritime Engineering - National Technical University of Athens, Athens, January 2004.

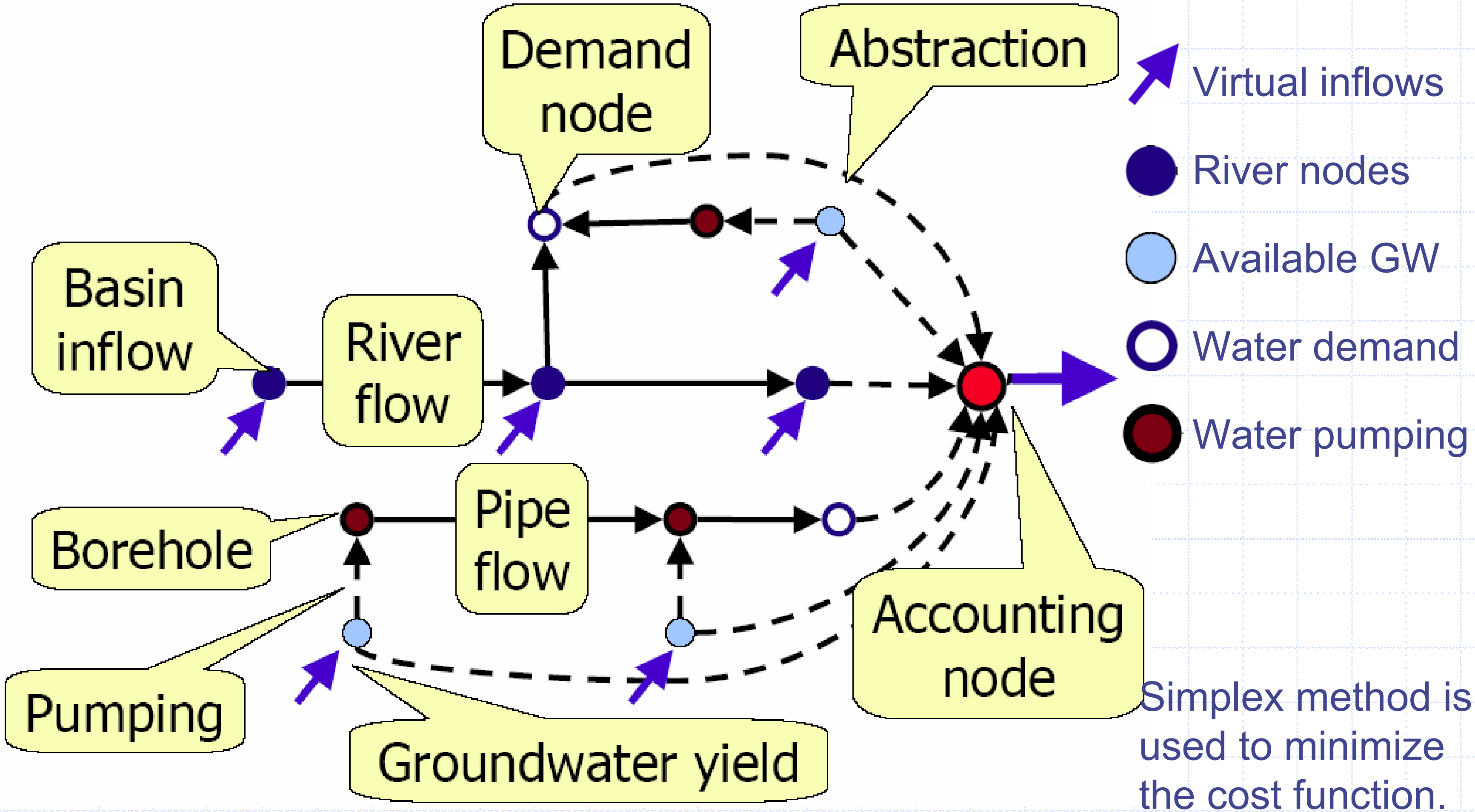
Rozos, E., and D. Koutsoyiannis, Modelling a karstic aquifer with a mixed flow equation, 3nd General Assembly of the European Geosciences Union, Geophysical Research Abstracts, Vol. 8, Vienna, 03970, European Geosciences Union, 2006.

Rozos, E., and D. Koutsoyiannis, A multicell karstic aquifer model with alternative flow equations, Journal of Hydrology, 2006.

Rozos, E., and D. Koutsoyiannis, Application of the Integrated Finite Difference Method in groundwater flow, 2nd General Assembly of the European Geosciences Union, Geophysical Research Abstracts, Vol. 7, Vienna, 00579, European Geosciences Union, 2005.

Water basin model

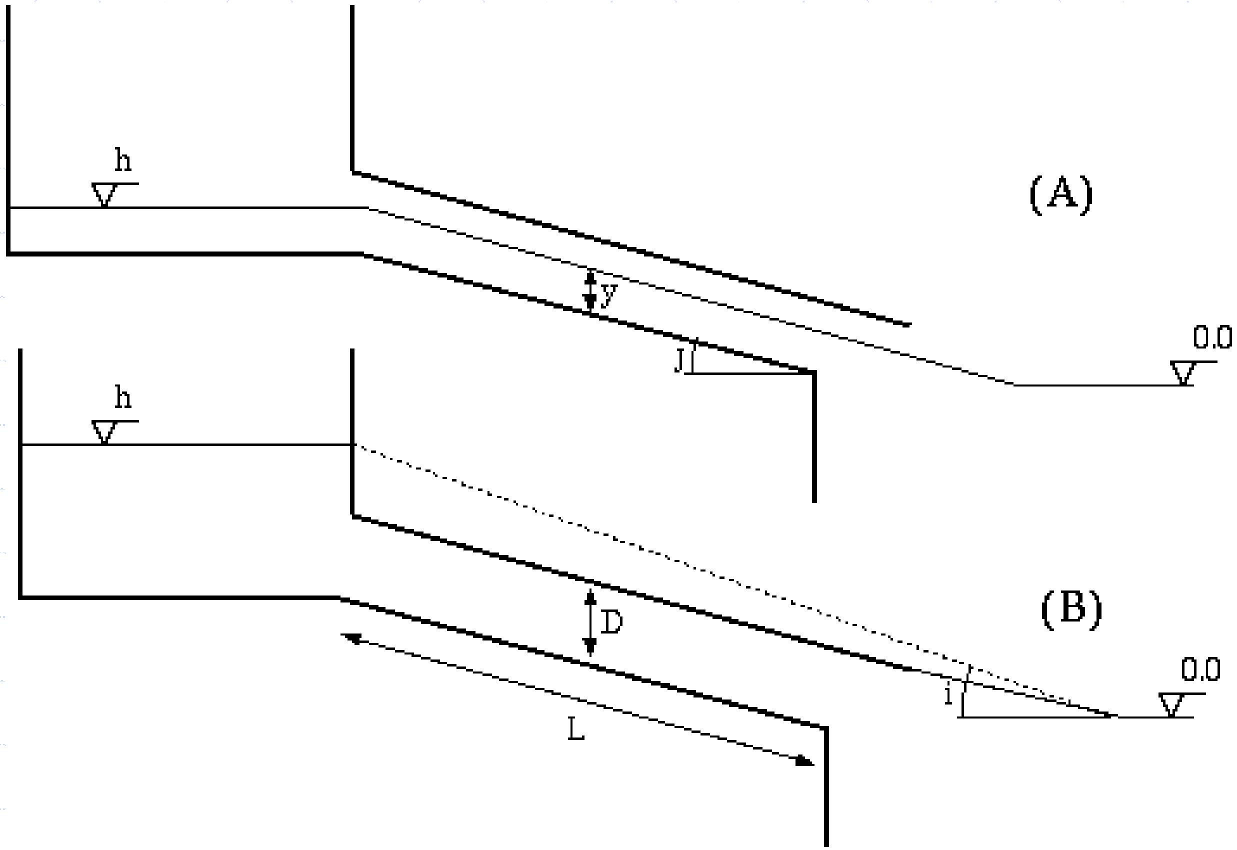
- Digraph representation



Simplex method is used to minimize the cost function.

Modelling the hydrosystem

❑Groundwater model

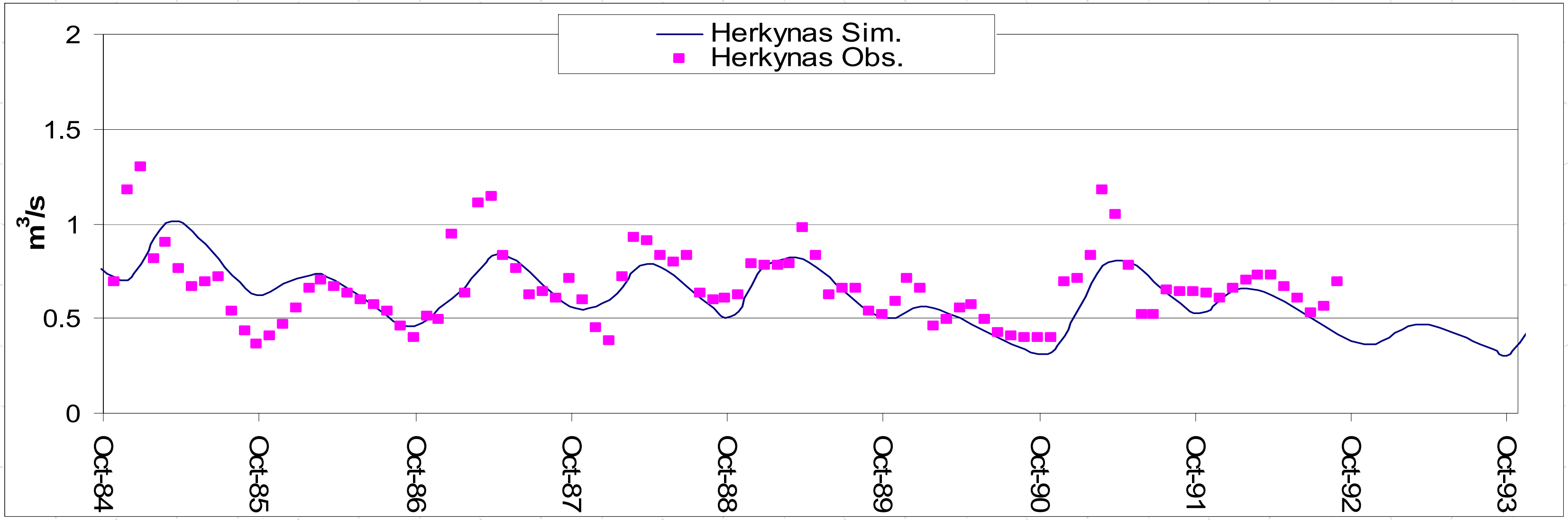


Use of an alternative flow equation was proved advantageous in simulation of water level fluctuation but the accuracy in calculations of fluxes was not improved.

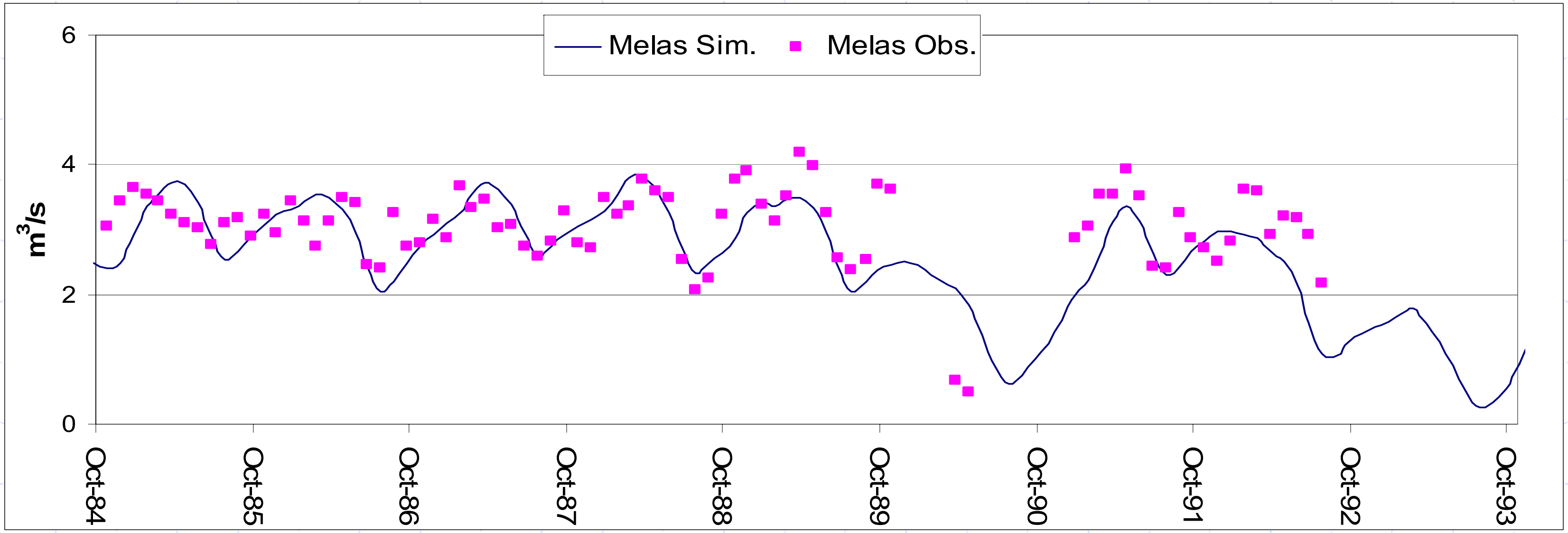
$$Q = C\left(\frac{y}{D}\right)^{\alpha} \; i^{0.5}$$

C: generalised conductivity [L3 T-1].
α: constant between 1 and 2.
i: hydraulic gradient when *y>D*, slope when *y≤D*.

Results



Herkynas Sim.
Herkynas Obs.
m3/s
2
1.5
1
0.5
0
Oct-84
Oct-85
Oct-86
Oct-87
Oct-88
Oct-89
Oct-90
Oct-91
Oct-92
Oct-93



Melas Sim.
Melas Obs.
m3/s
6
4
2
0
Oct-84
Oct-85
Oct-86
Oct-87
Oct-88
Oct-89
Oct-90
Oct-91
Oct-92
Oct-93