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Hydronomeas 2020: Open-source decision support system for water resources management

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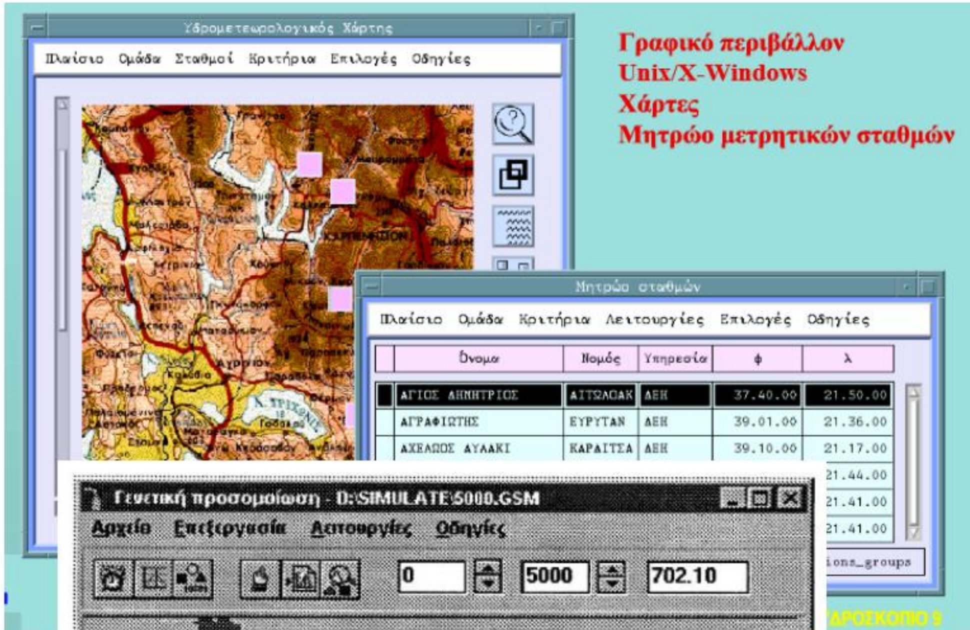
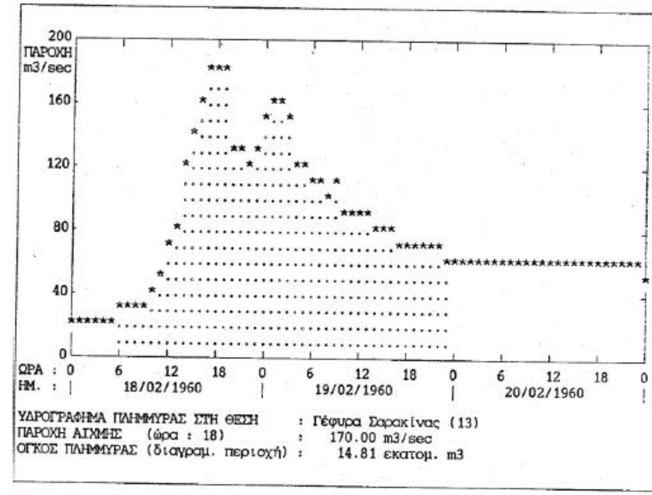
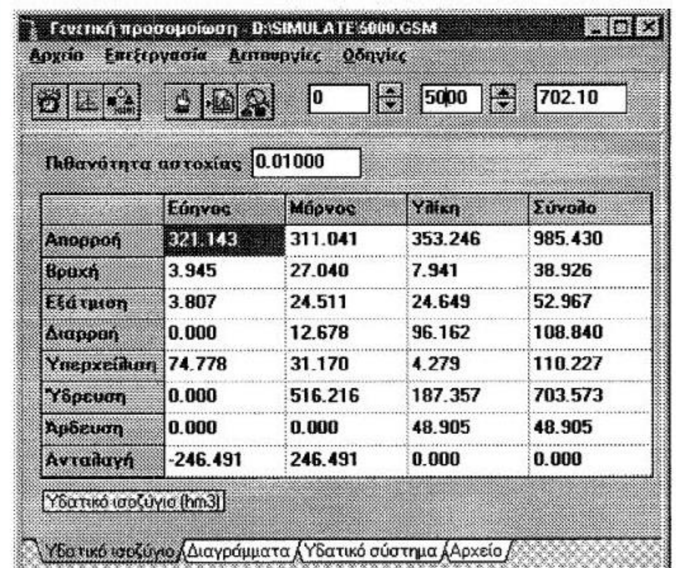
Presentation available online: www.itia.ntua.gr/2020/

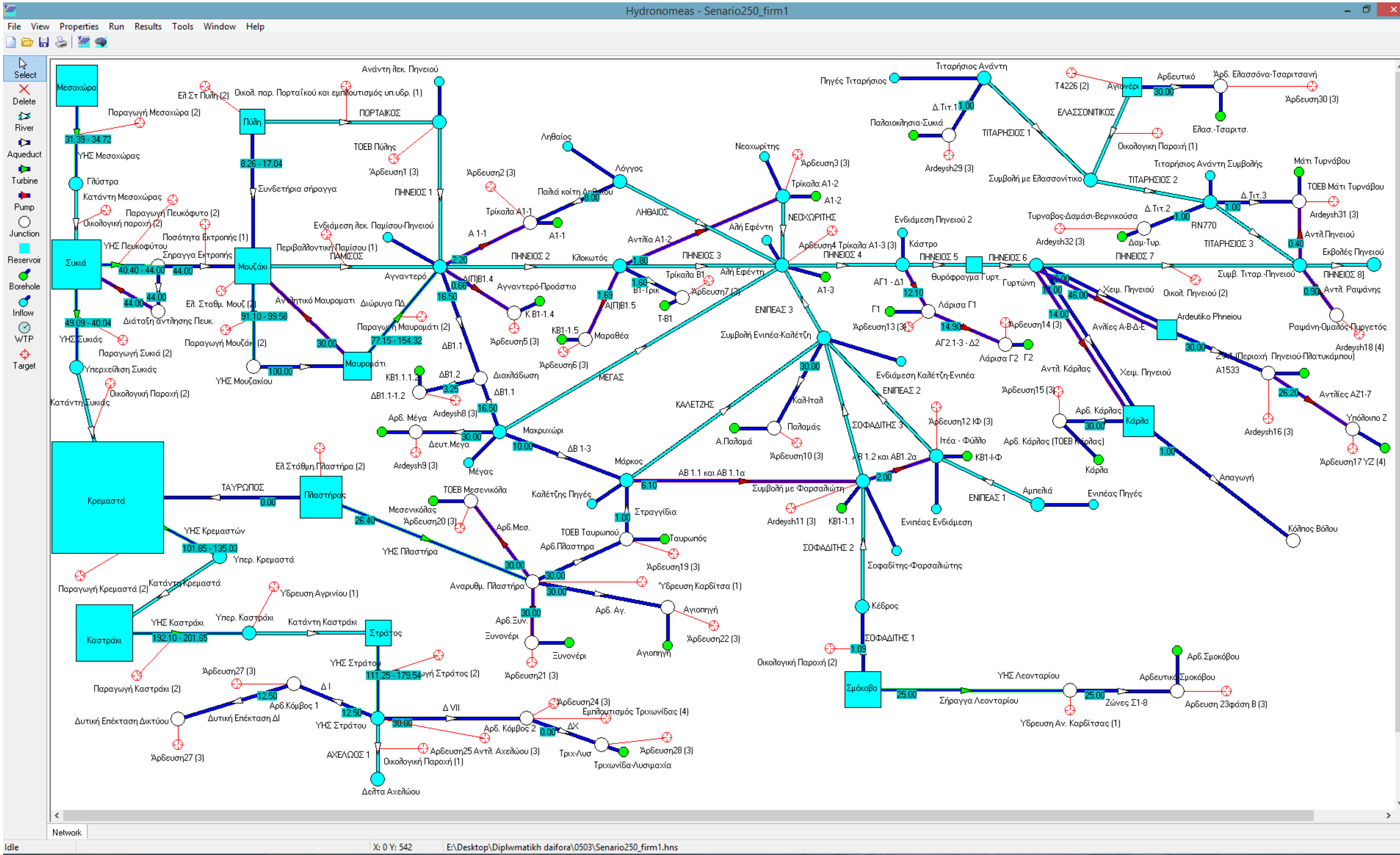
From retro HydroInformatics applications…





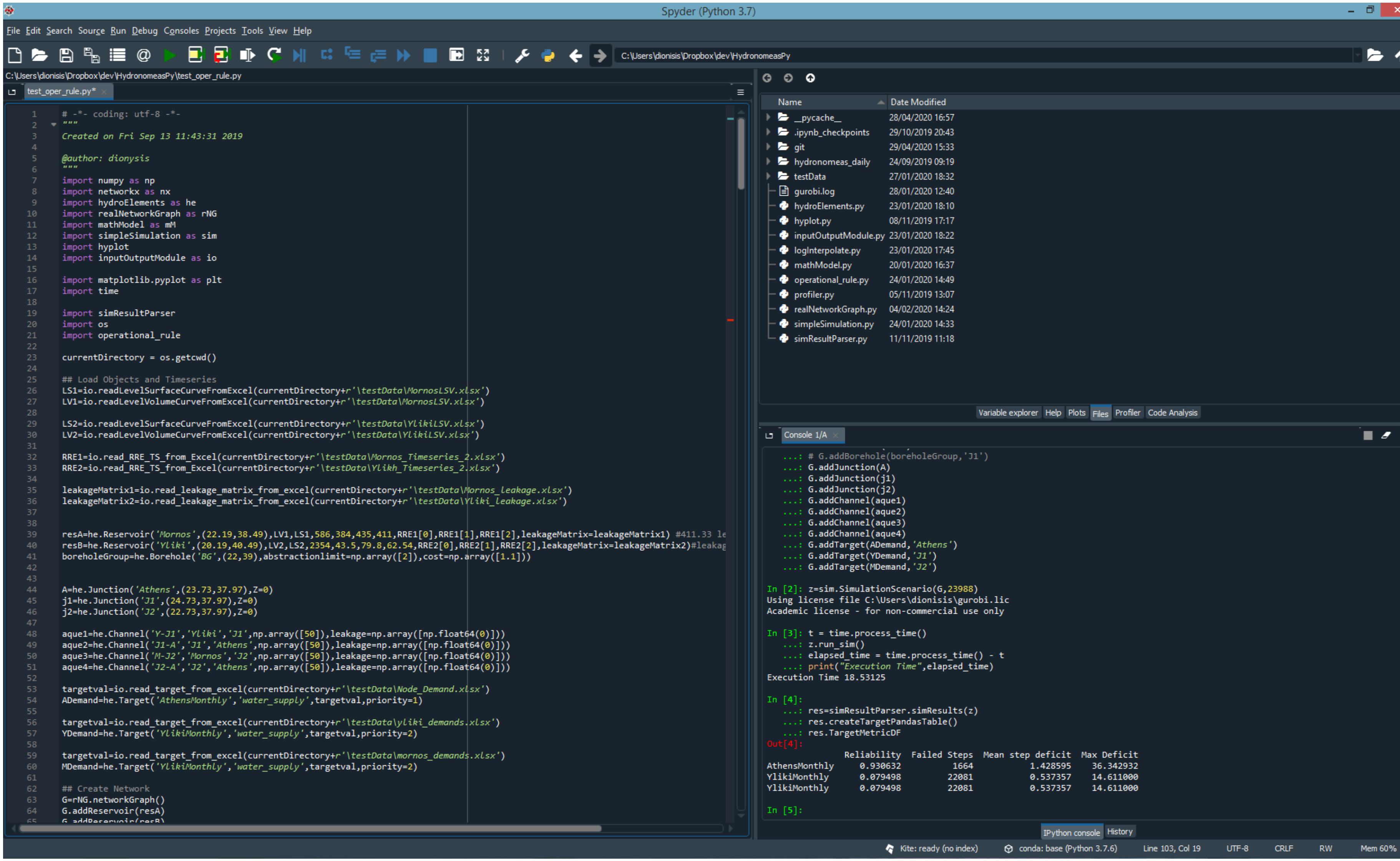


... to a modern DSS...



Source: Koukouvinos *et al.*, 2015

… to a new open source python package (soon)!



Project description

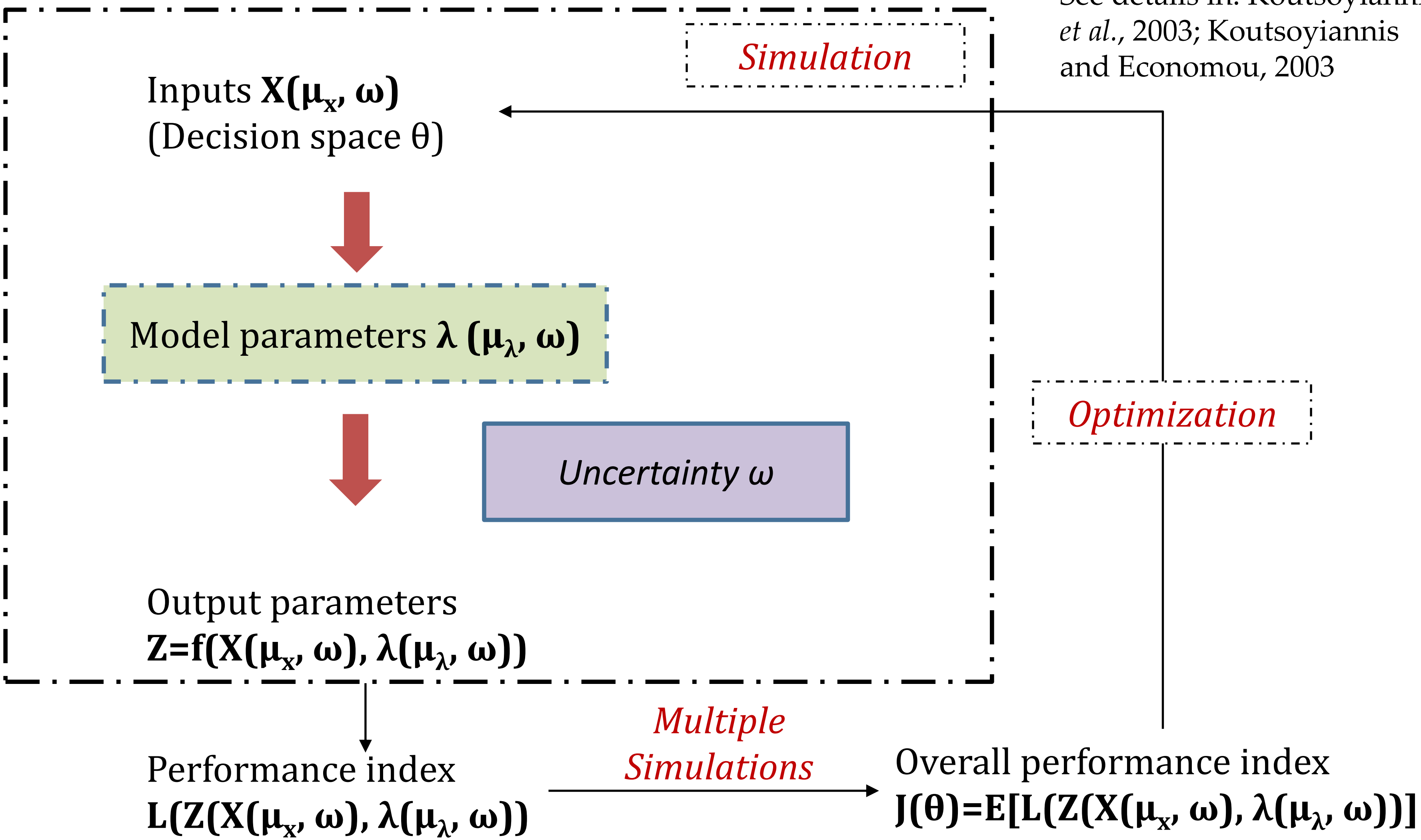
- **Objective**
  - Provide a full featured DSS python module (Hydronomeas 2020) for water systems, providing all the original functionality of Hydronomeas v.4.9 plus many more enhancements. Initially script-based, with a new GUI on its way!
- **Key enhancements**
  - Terminating and end-state water system simulations under uncertainty, operationalization of the water system's resilience (Makropoulos et al., 2018; Nikolopoulos et al., 2019);
  - Arbitrary simulation time scale (e.g. monthly, daily or higher temporal resolution, depending on available input data);
  - Dynamic component attributes through simulation (e.g. can simulate the aging of an aqueduct through time and its replacement) and incorporation of stochastic demand timeseries;
  - New reservoir operational rules with simpler parameters and ability to distribute water deficits across a larger time horizon;
  - Global energy production optimization in systems with complex topology;
  - Two options for solving the water allocation problem in each step of the simulation: i) the very fast commercial solver Gurobi, provided that the user acquires a license and ii) the open source scipy linprog solver, provided with the Anaconda Python distribution;
  - Easy problem formulation and connection to virtually all optimization algorithms available for Python;
  - Dependencies: the user needs only the Anaconda distribution to run the basic program.

Links with Python scientific packages

- **Modularity** and **easy extensibility** is ensured as Hydronomeas 2020 is purely Python based and object-oriented. All of the modules and classes are implemented using as dependencies well known Python scientific packages, namely:
  - *NetworkX,* for the representation of the real water system topology and the mathematical digraph of the system
  - *Numpy,* for all algebraic operations with vectors, matrices and scalars in the mathematical formulation of the water system
  - *Scipy,* for the linear programming solvers for water allocation in the iterations for sparce matrices and the global optimization routines
  - *Matplotlib*, for visualization purposes (results, topology graphs etc.)
  - *Pandas*, for handling input and output data (timeseries, tables, curves, etc.)
- Hydronomeas 2020 currently consists of 4 primary modules:
  - *hydroelements*: classes of the real water system objects implementing their behaviour (reservoirs, pumps, turbines, targets, rivers, boreholes, etc.)
  - *realNetworkGraph*: allows the representation of a system as a network graph of *hydroelements* instances
  - *mathModel*: allows the representation of a system's network graph as a mathematical model of linear programming in each iteration
  - *simulationScenario*: defines and runs a simulation scenario for the water system
  - plus, many other helper modules e.g. for data input, result export, connection to global optimization procedures, visualization etc.

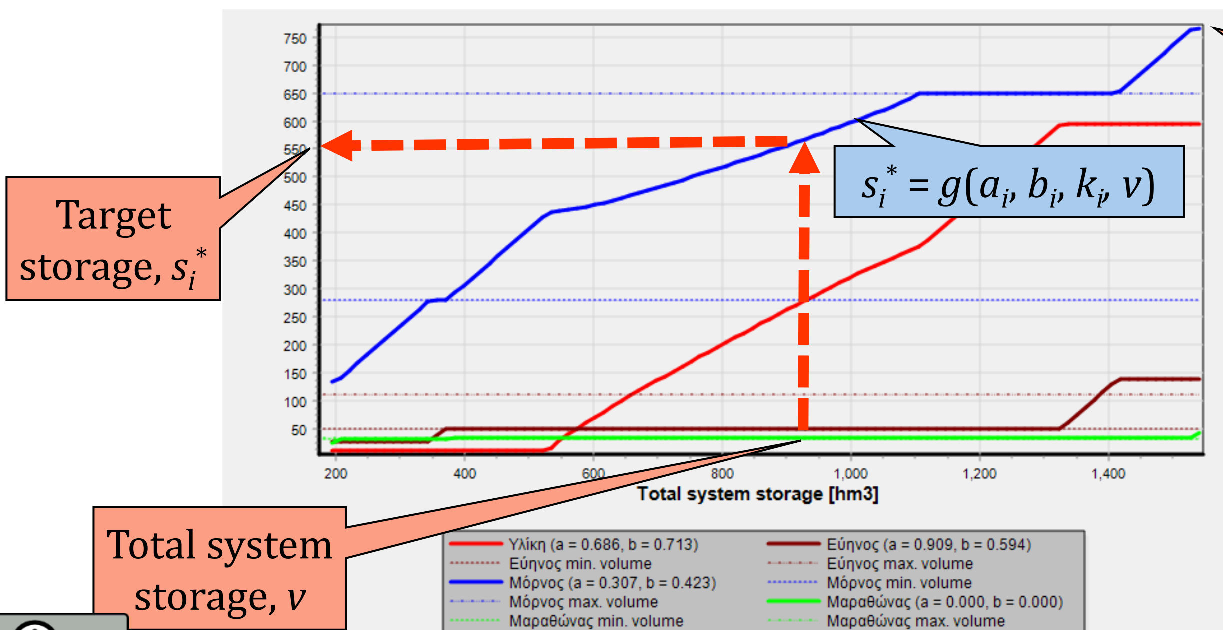
Methodological backbone: Parameterization - stochastic simulation-optimization framework

See details in: Koutsoyiannis *et al.*, 2003; Koutsoyiannis and Economou, 2003



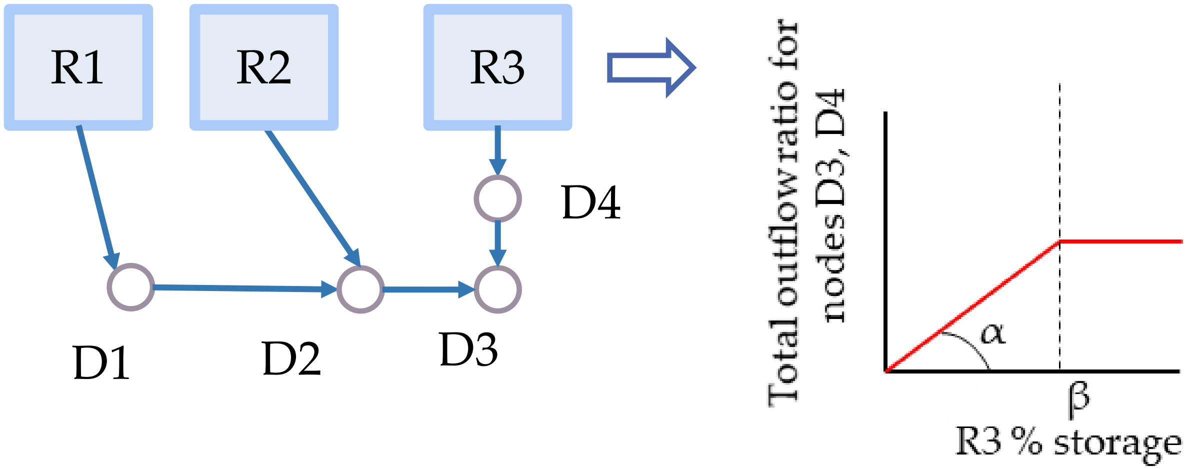
System parameterization

- In previous versions of the DSS, at each time step, and for given inflows and demands, the target releases from reservoirs are estimated on the basis of **parametric operation rules**, using only two control variables per reservoir or groundwater resource (borehole group).
- In Hydronomeas 2020, the rules are also **topology-aware**, which results to more realistic policies, since sources are directly linked with associated demand nodes.
- Another novelty is the **distribution of deficits** across a larger time horizon, based on outflow reduction coefficients according to target priorities and water availability.

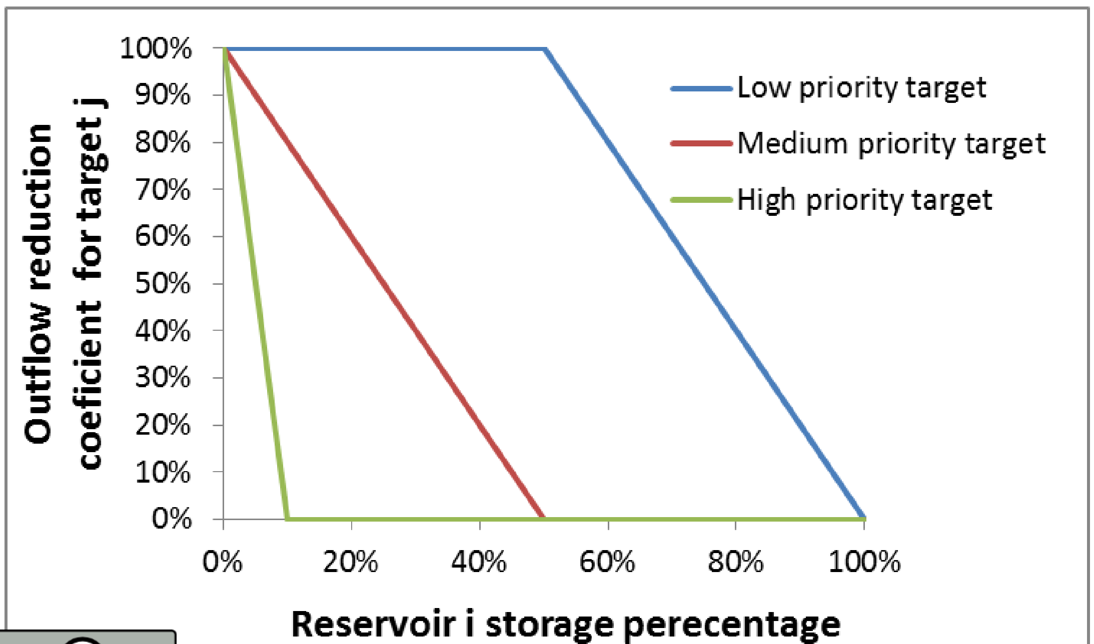


See details in: Nalbantis and Koutsoyiannis, 1997; Koutsoyiannis *et al.*, 2003;

Topology-aware management rules

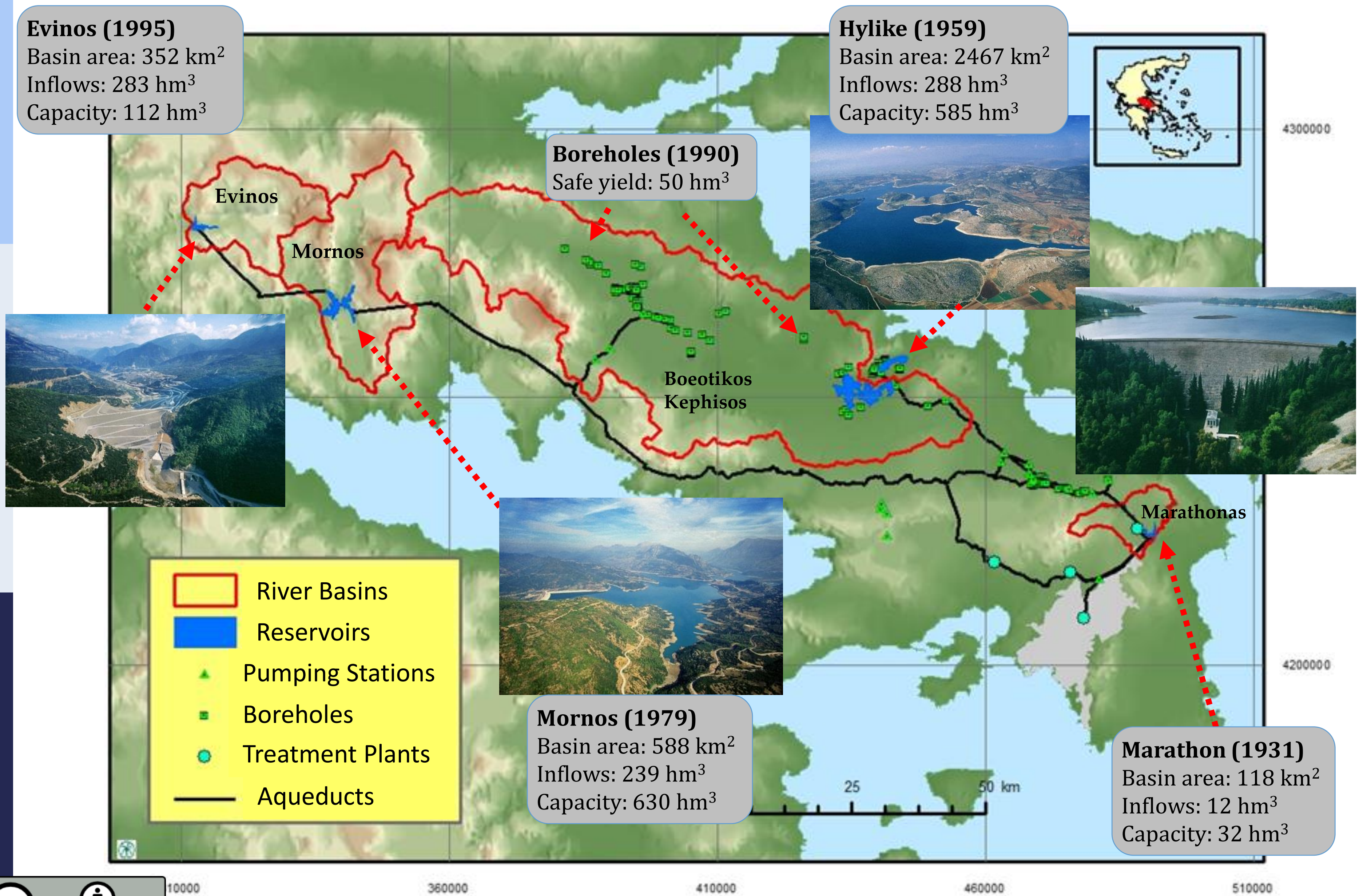


Assignment of target abstractions per source using simple rules, accounting for the sharing of demands



Hierarchical fulfilment of demands and allocation of deficits

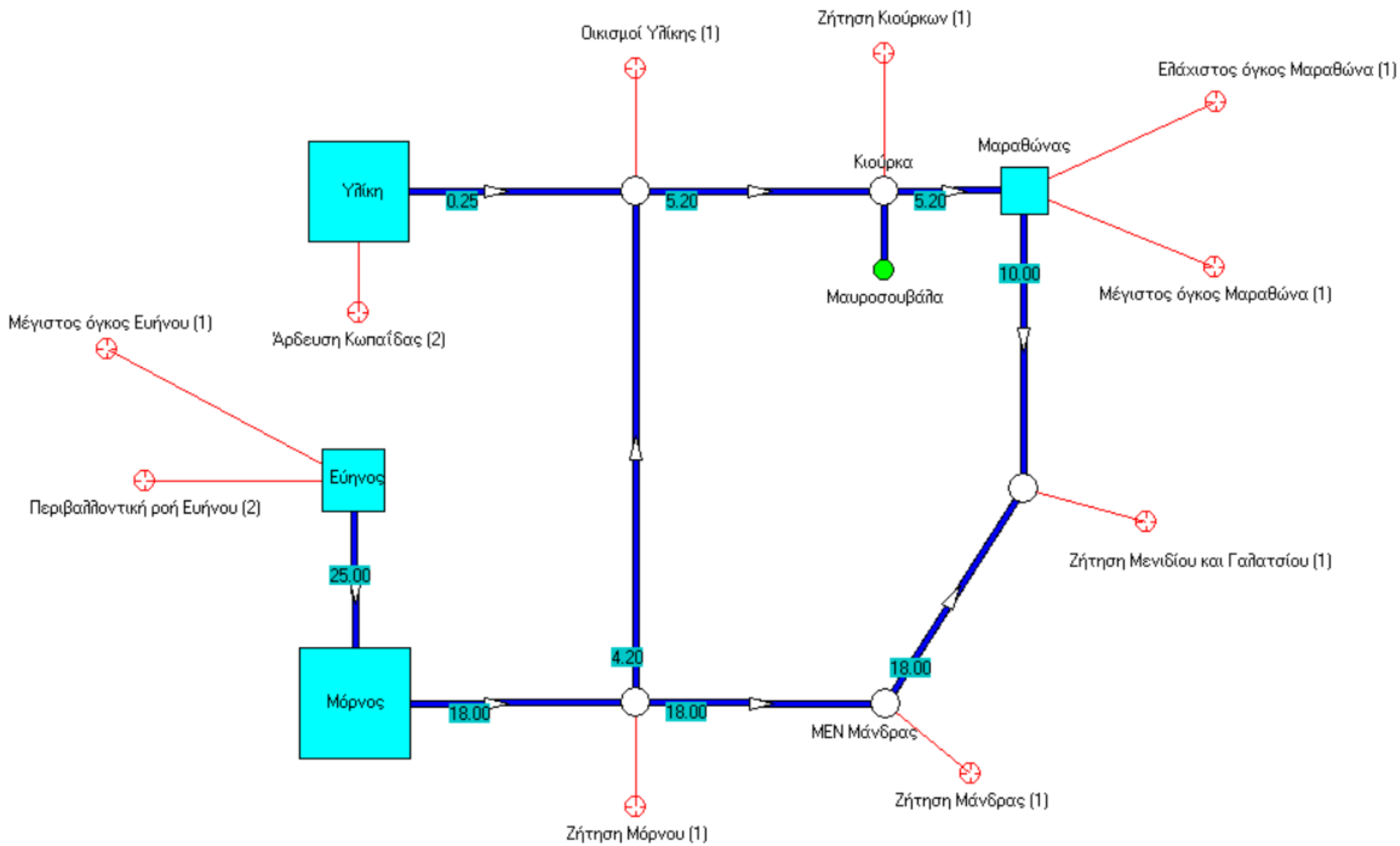
The water supply system of Athens (~4000 km²)



Management challenges and complexity issues

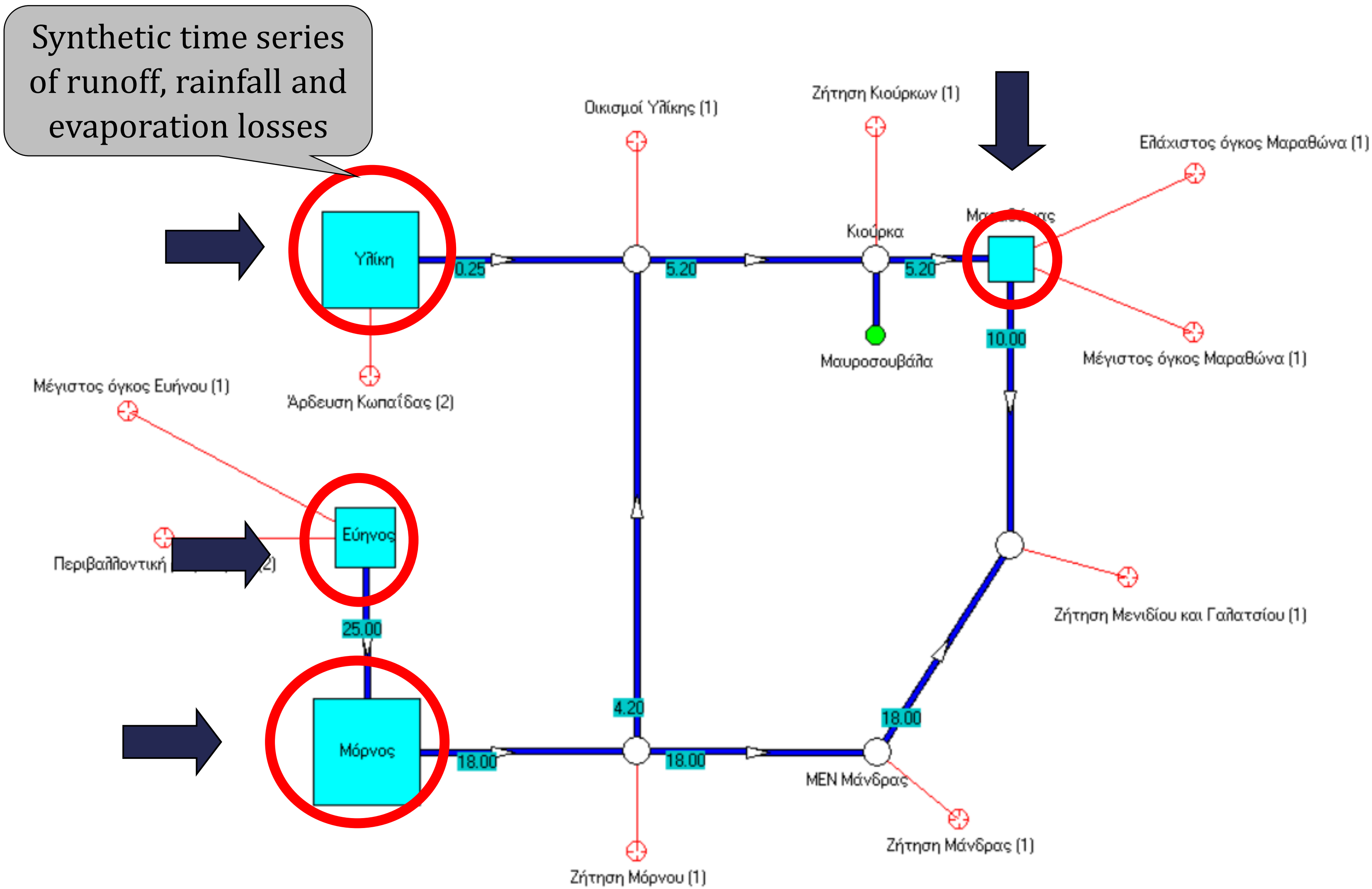
- **Conflicting objectives**
  - Minimization of energy cost
  - Maximization of long-term reliability
- **Multiple water uses**
  - Drinking water to Athens (today ~400 hm^3)
  - Local water uses across the water conveyance network (~70 hm^3)
  - Environmental flows through Evinos dam (30 hm^3)
- **Multiple sources of uncertainty**
  - Hydroclimatic uncertainty leads to *non-predictable inflows*
  - Uncertain socio-economic conditions result to *uncertain demands*
  - *Uncertain losses* through water transportation and conveyance network
  - *Uncertain technical characteristics of pumps* (capacity, efficiency), resulting in approximate estimation of energy consumption
- Hydronomeas v. 4.9 is used operationally by the water utility EYDAP SA, for the management of its raw water supply system.
- This case study demonstrates the compatibility between the older version and the new Hydronomeas 2020 Python package.

Simplified schematization of the hydrosystem



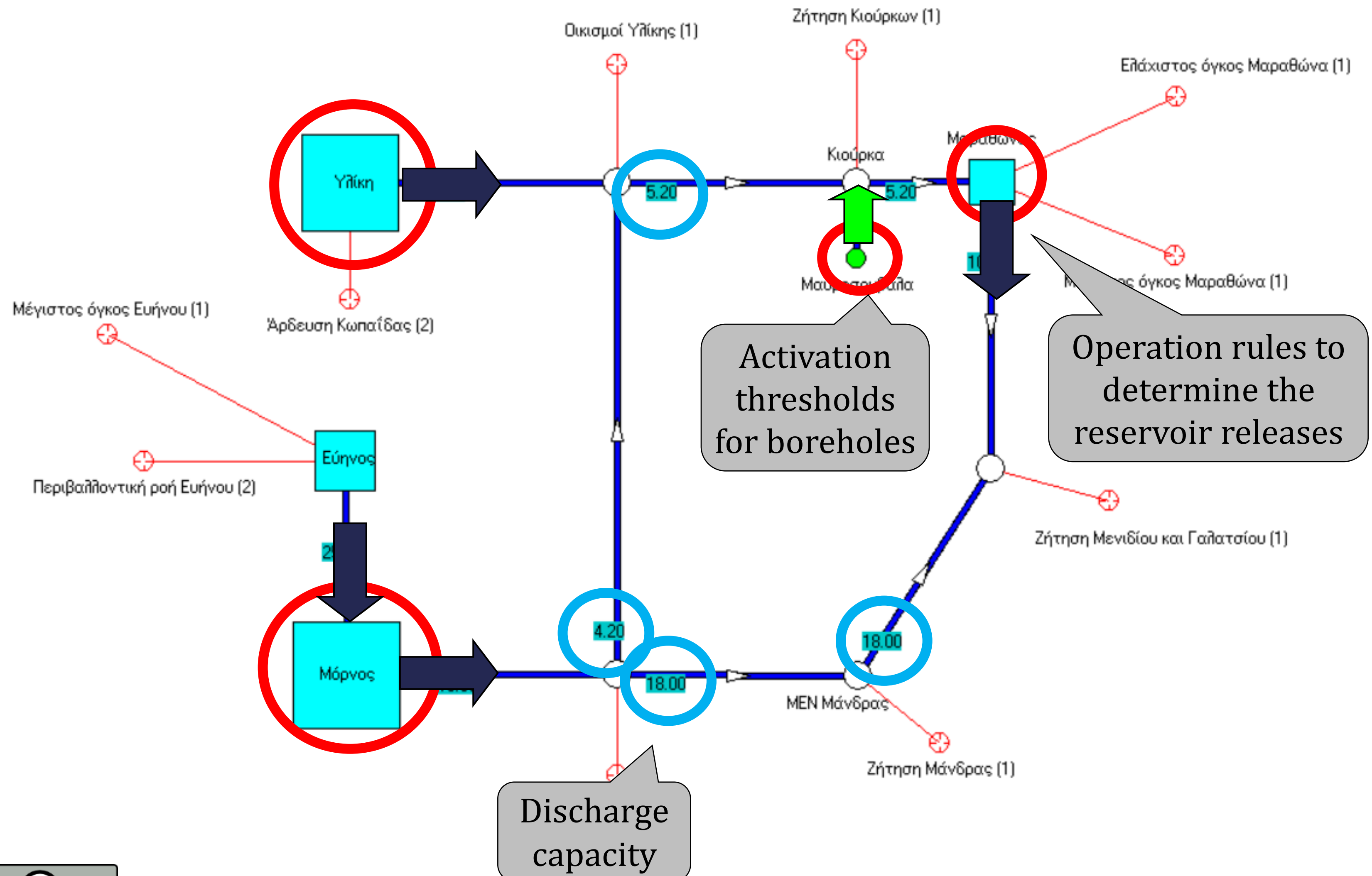
Remark: Representation of the water resource system in the graphical environment of **Hydronomeas v 4.9** here and in the following slides, as currently **Hydronomeas 2020** is **script-based**. Both DSS are used for this case study.

Generation of hydrological inputs

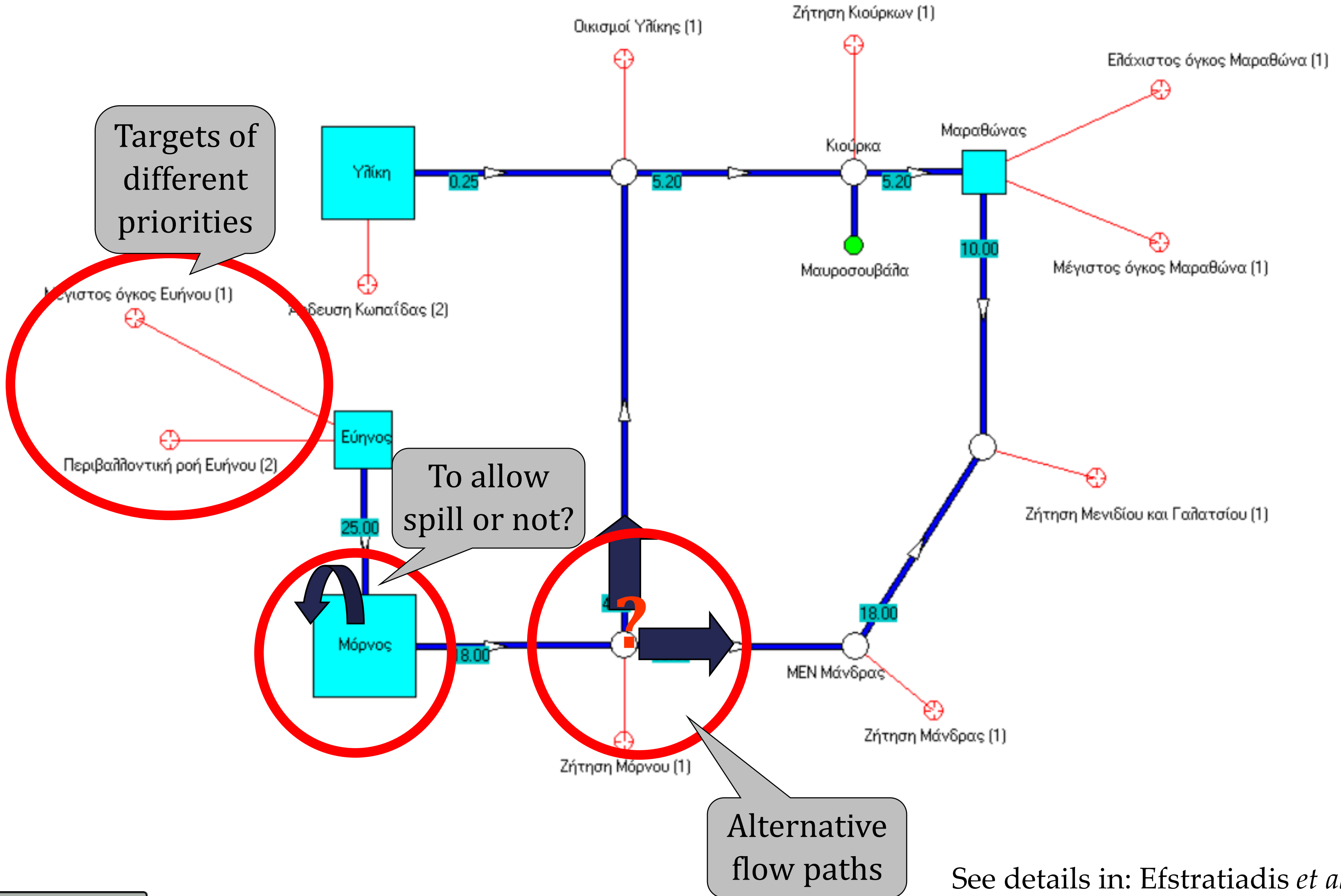


See details in: Efstratiadis *et al.*, 2014

Establishment of the long-term control policy for reservoirs and boreholes



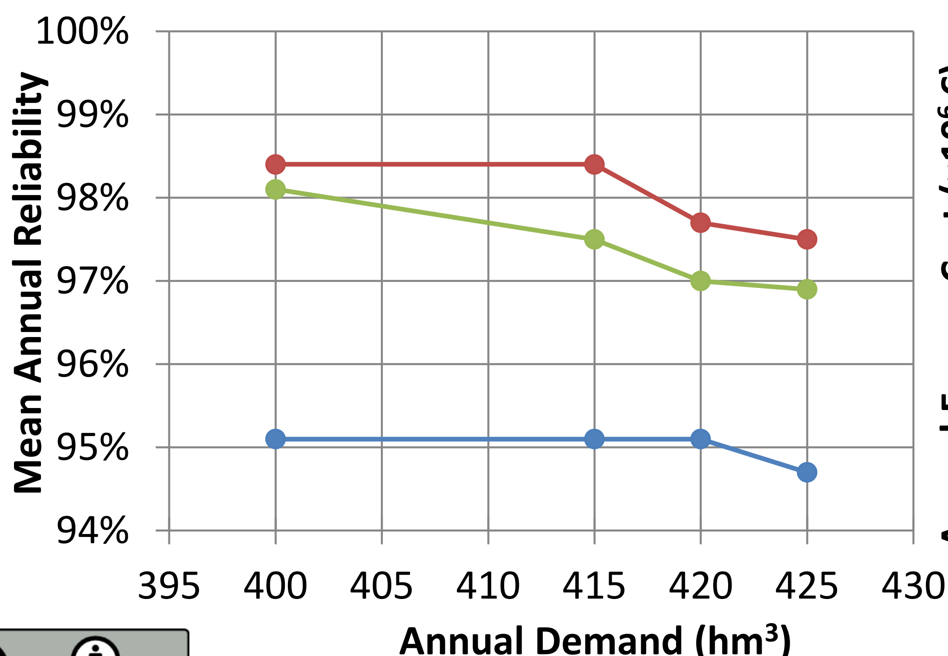
Optimal allocation of actual fluxes

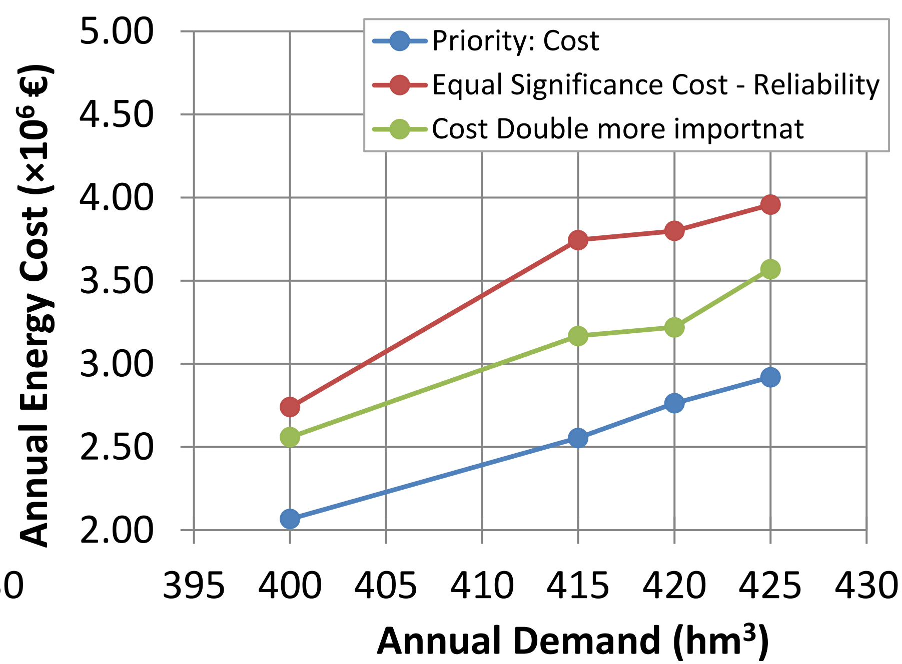


See details in: Efstratiadis *et al.*, 2004

Scenarios & results

- Four annual demand scenarios for broader Athens area: current state (400 hm^3) & three future projections (415, 420, 425 hm^3).
- Three sets of optimization weights (management policy): Prioritization of cost, equal importance of cost and reliability and cost double more important than reliability.
- Results from the use of the new Hydronomeas 2020 seem robust and aligned with results stemming from the same case study implemented with Hydronomeas v 4.9 (Nikolopoulos *et al.*, 2018).





Roadmap & conclusions

- **Roadmap**
  - Late 2020: Estimated release of the Python package Hydronomeas 2020
  - Late 2021: Estimated release of a new Python-based GUI framework for the package for easier data handling (import/export), network and result visualization, simplified optimization procedures etc.
- **Conclusions**
  - Hydronomeas 2020 aims to be a full featured open source DSS, provided as a FOSS Python package to the water recourse management community
  - Built with well known tools in the scientific community ensures flexibility and future extensibility by other water experts
  - Hydronomeas 2020 incorporates state-of-the art methodologies that have been employed in numerous water resources planning and management studies in Greece and operationalized by EYDAP SA in the management of the water supply system of Athens.
  - Testing shows full compatibility between the older stand-alone version and the new Python package. Subsequent testing and publications will focus on showcasing the improvements and additional functionality.

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