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Stochastic simulation-optimization framework for energy cost assessment across the water supply system of Athens

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Presentation available online: www.itia.ntua.gr/1783/

How much does the Athens' raw water cost?

- Two companies are involved in Metropolitan Athens' water:
  - a public company (Assets EYDAP) for its production and transportation up to the water treatment plants (external water supply system);
  - a private company (EYDAP S.A.) for the distribution of drinking water to consumers (~ 3.5 million) and wastewater treatment (internal system).
- Why this question?
  - Water cost assessment and retrieval is an obligation by WFD2000/60/EC;
  - The two companies need to assess a fair cost of raw water in order to regulate their legal agreements.
- Breakdown of raw water cost:
  - Existing infrastructure cost;
  - Operational and maintenance cost;
  - Labour and administrative cost;
  - Environmental cost;
  - Resource cost.

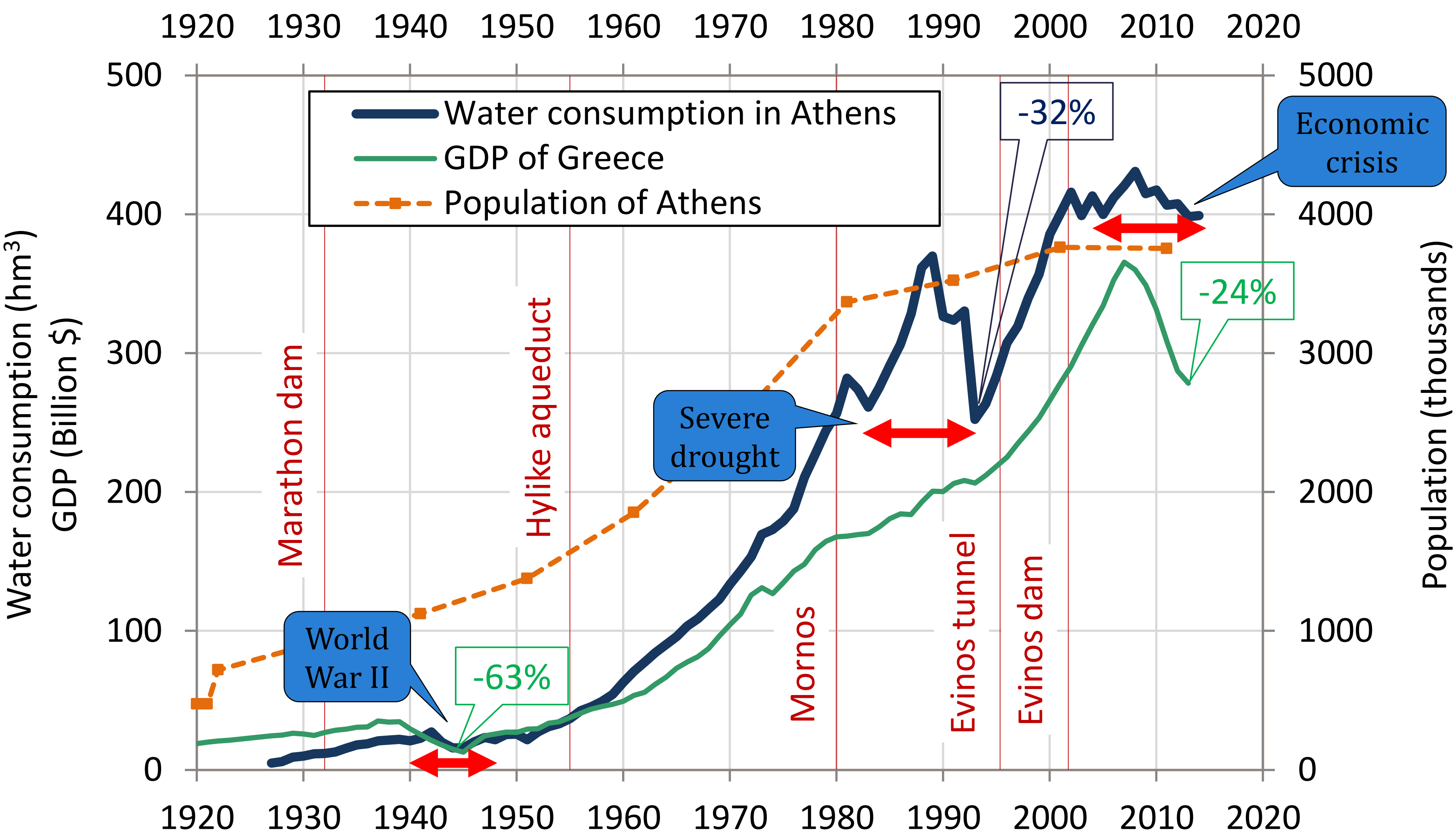
  (Existing infrastructure, operational and maintenance, and labour and administrative costs: Supply cost)
- In the water supply system of Athens, key component of the operational cost is the **energy cost**, due to pumping, which is not a constant quantity but depends on the **time-varying inflows and demands** and the **water management policy**.

Contrasting the cost of a water bottle to its content

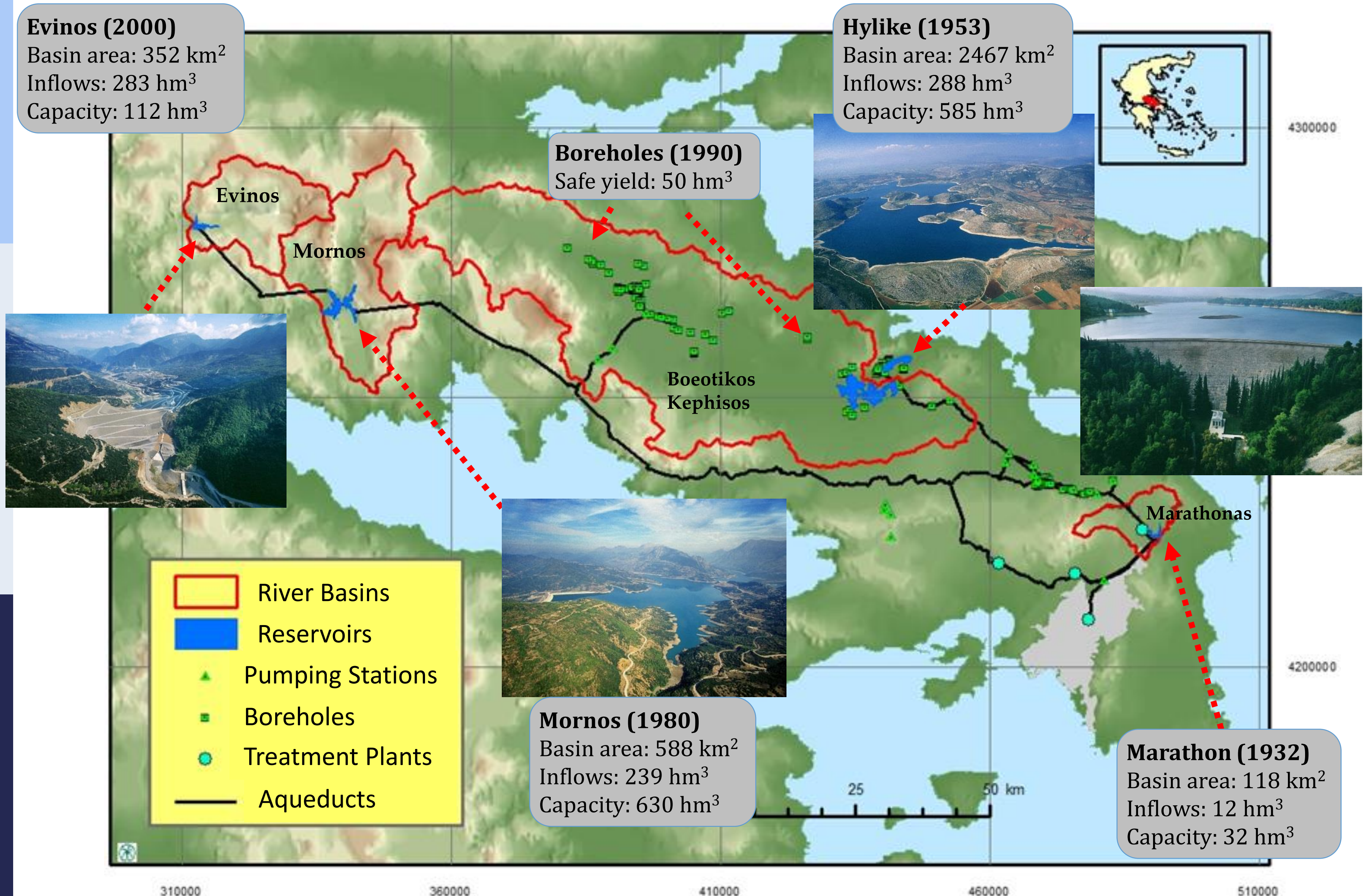
- Raw material: plastic or glass
- Production fully controllable by the industrial power (assuming unlimited raw material)
- Minimal risk of producing faulty products
- Steady production cost for a certain amount of bottles
- Unit cost decreases as the production of bottles increases (economies of scale)
- Unit cost is fully known, at least for a medium-term horizon

- Raw material: rainfall and other meteorological drivers
- Production depends on rainfall and its transformation to runoff, which are subject to major uncertainties at all temporal scales
- Risk of production also depends on complex human drivers, i.e. water uses, constraints and the management policy
- The total production cost is expected to increase with demand, particularly when the water is retrieved and transferred via pumping

Providing water to Athens: Evolution of annual demand, population, GDP and infrastructure



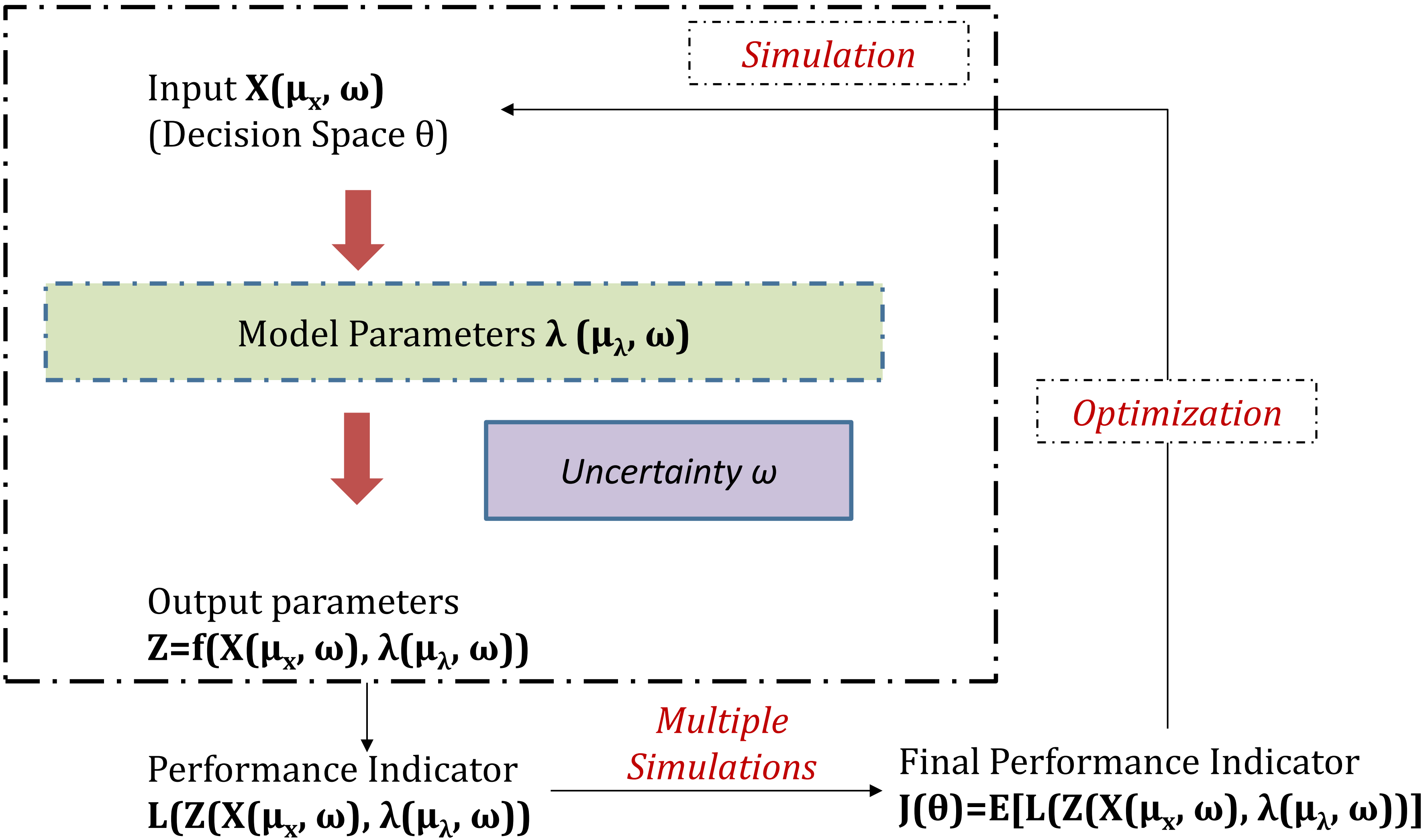
The water supply system of Athens (~4000 km²)



Management challenges and complexity issues

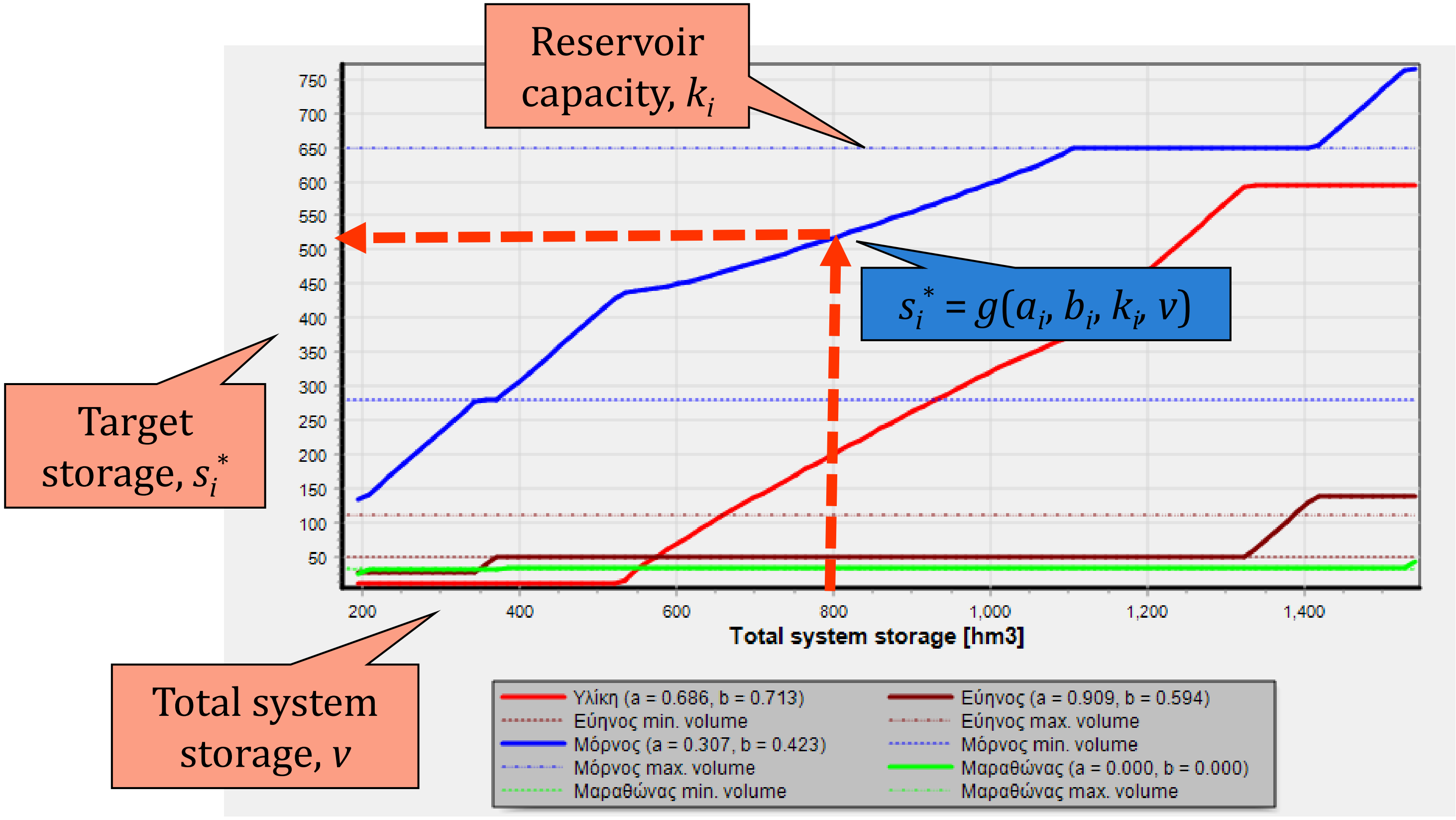
- **Conflicting objectives**
  - Energy cost due to pumping (to be minimized)
  - Long-term reliability (to be maximized)
- **Multiple hydrosystem operation options**
  - Four reservoirs (total useful capacity 1360 hm^3, mean annual inflow 820 hm^3)
  - ~100 boreholes, used as emergency resources (estimated safe yield 50 hm^3)
  - Multiple water conveyance paths, some of them through pumping
- **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**
  - Non-predictable inflows (hydroclimatic uncertainty)
  - Uncertain demands, subject to uncertain socio-economic conditions
  - Uncertain losses due to reservoir (Mornos, Ylike) and conveyance leakages
  - Uncertain technical characteristics of pumps (capacity, efficiency), resulting in approximate estimation of energy consumption

Stochastic simulation-optimization framework for energy cost assessment

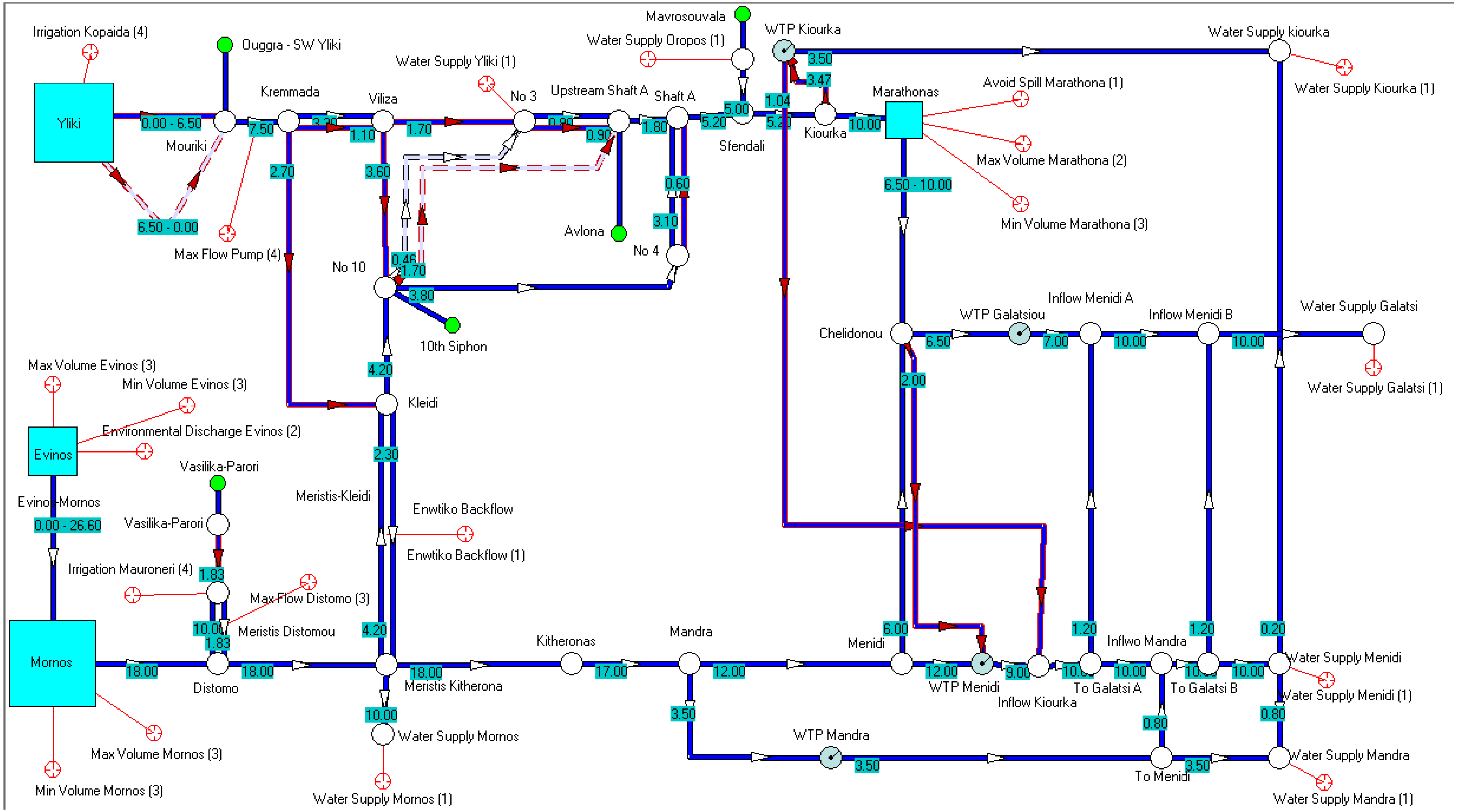


System parameterization

- Since inflows are projected through simulation, the target releases are easily estimated, on the basis on the actual storages and the total water demand.
- The rules are mathematically expressed using two parameters per reservoir, thus ensuring a **parsimonious parameterization** of the related optimization problem, where their values depend on the **statistical** characteristics of inflows.

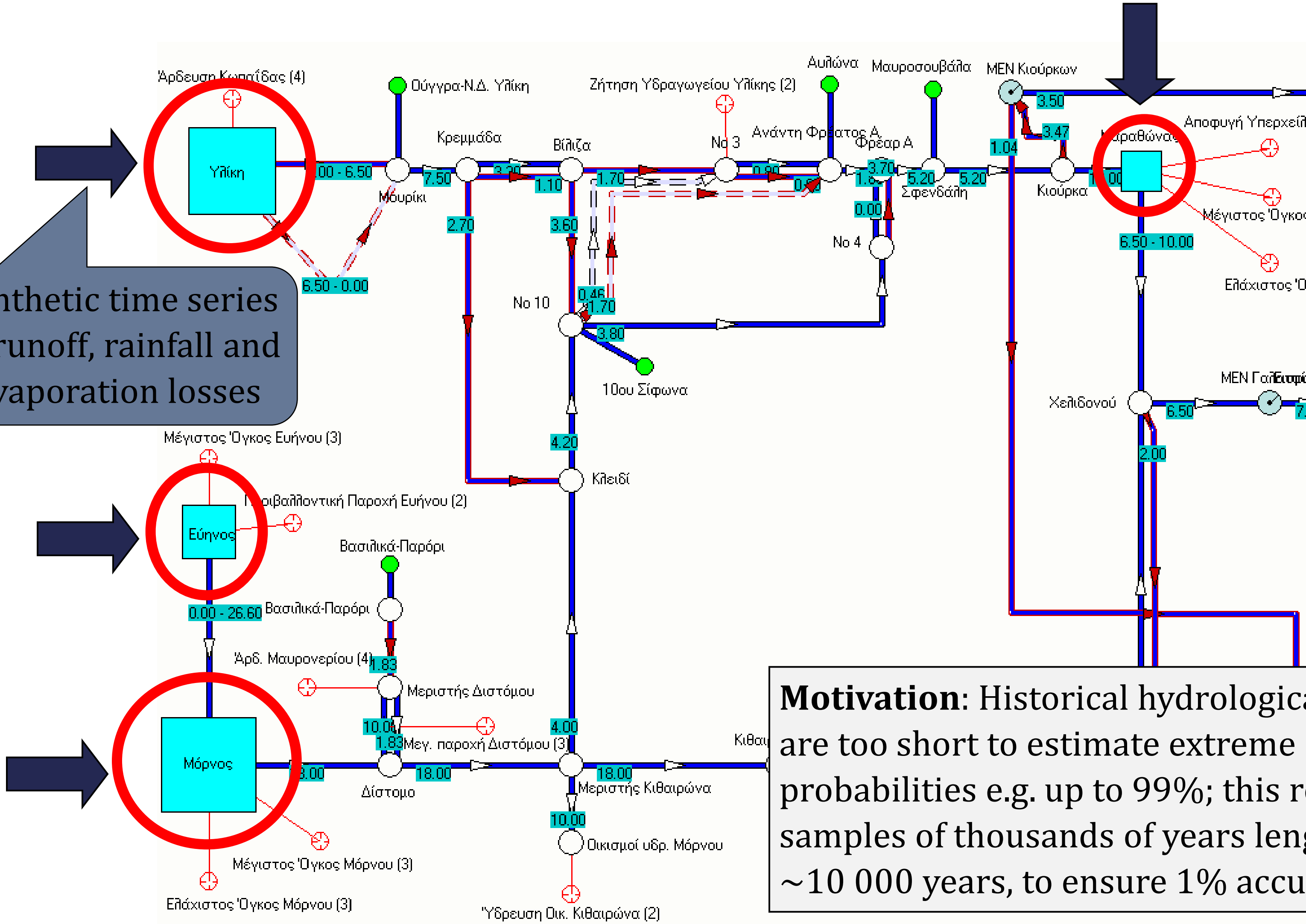


Task 1: Schematization of the hydrosystem



Representation of the water resource system in the graphical environment of **Hydronomeas**

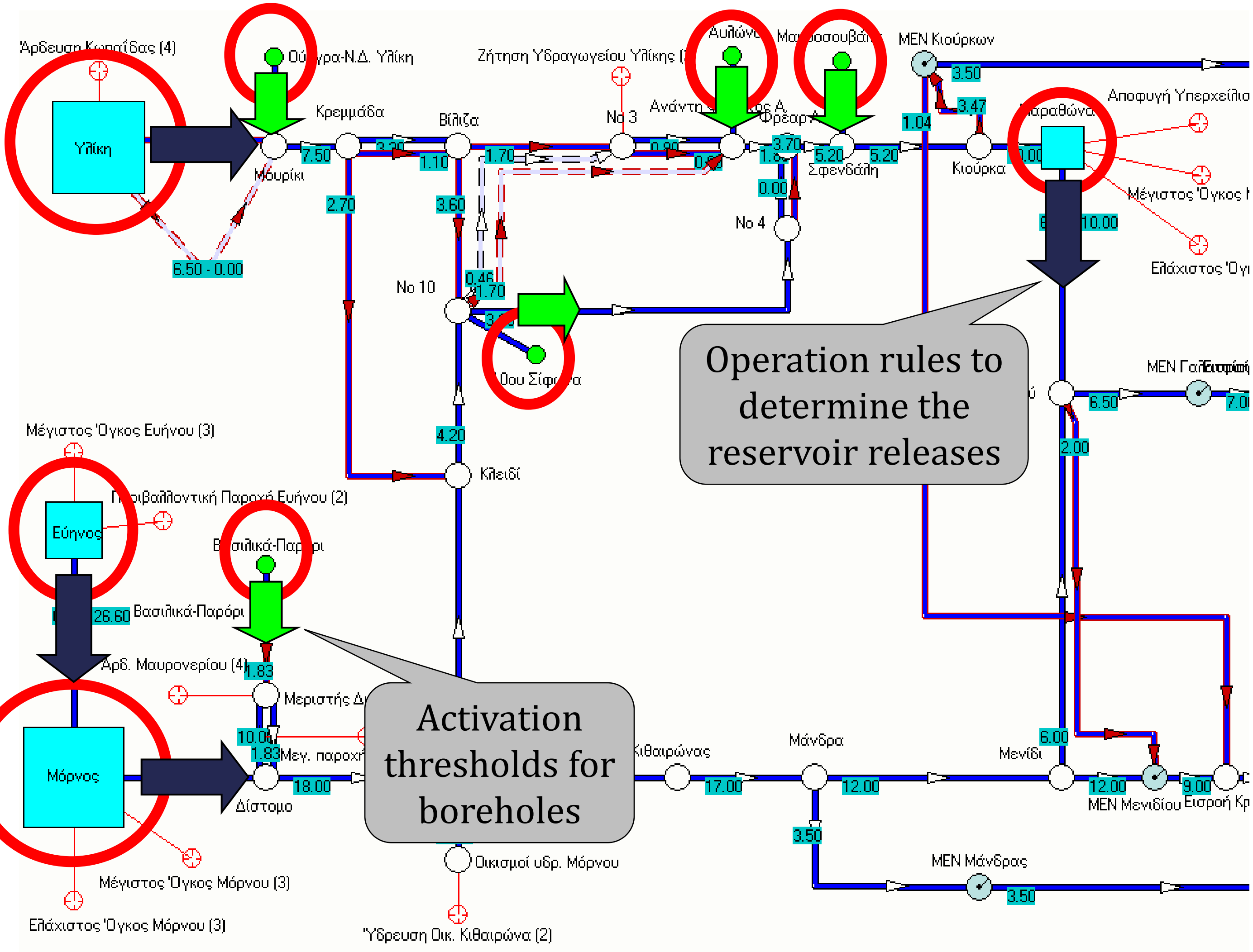
Task 2: Generation of hydrological inputs



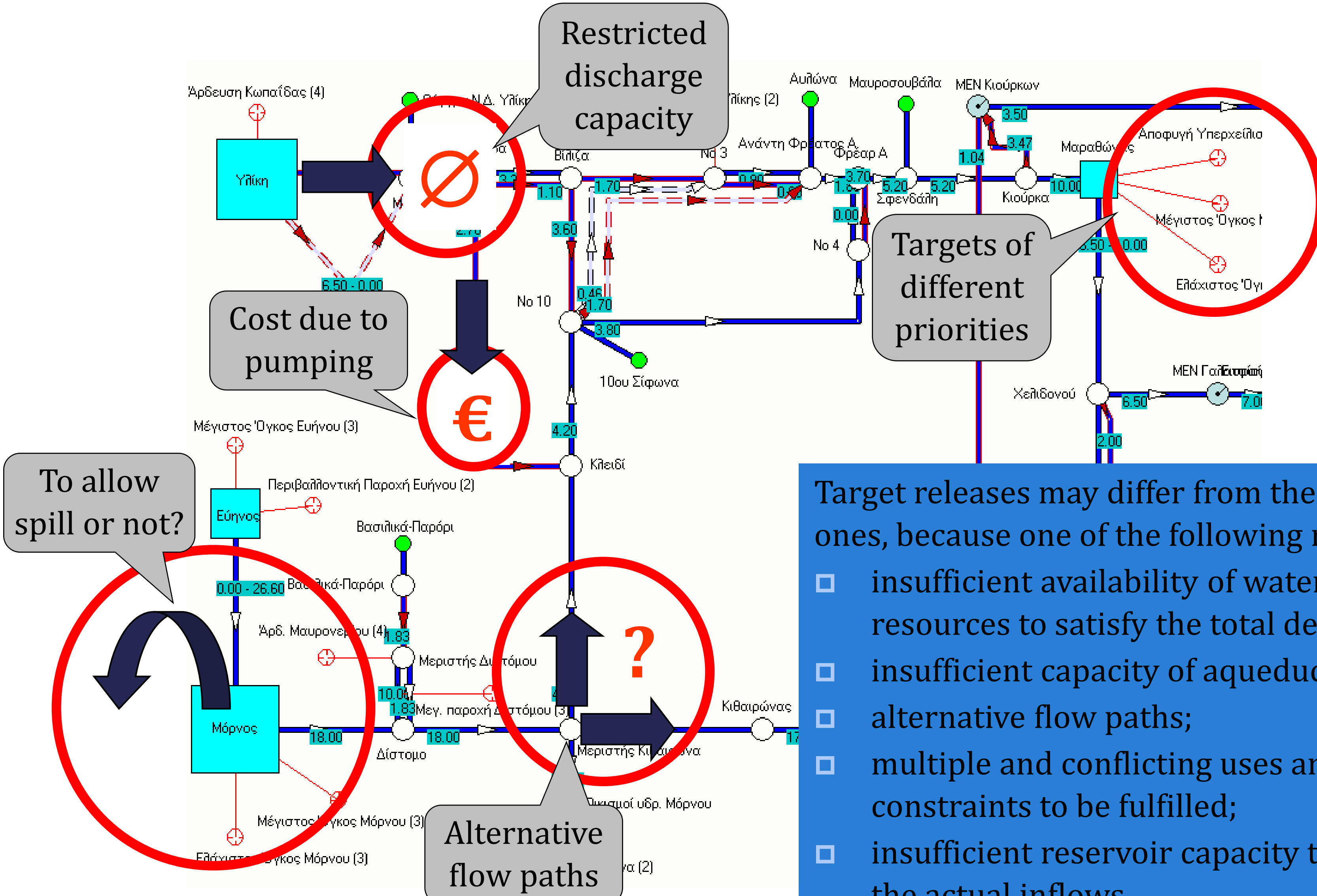
Synthetic time series of runoff, rainfall and evaporation losses

Motivation: Historical hydrological records are too short to estimate extreme probabilities e.g. up to 99%; this requires samples of thousands of years length (e.g., ~10 000 years, to ensure 1% accuracy)

Task 3: Establishment of the long-term control policy for reservoirs and boreholes



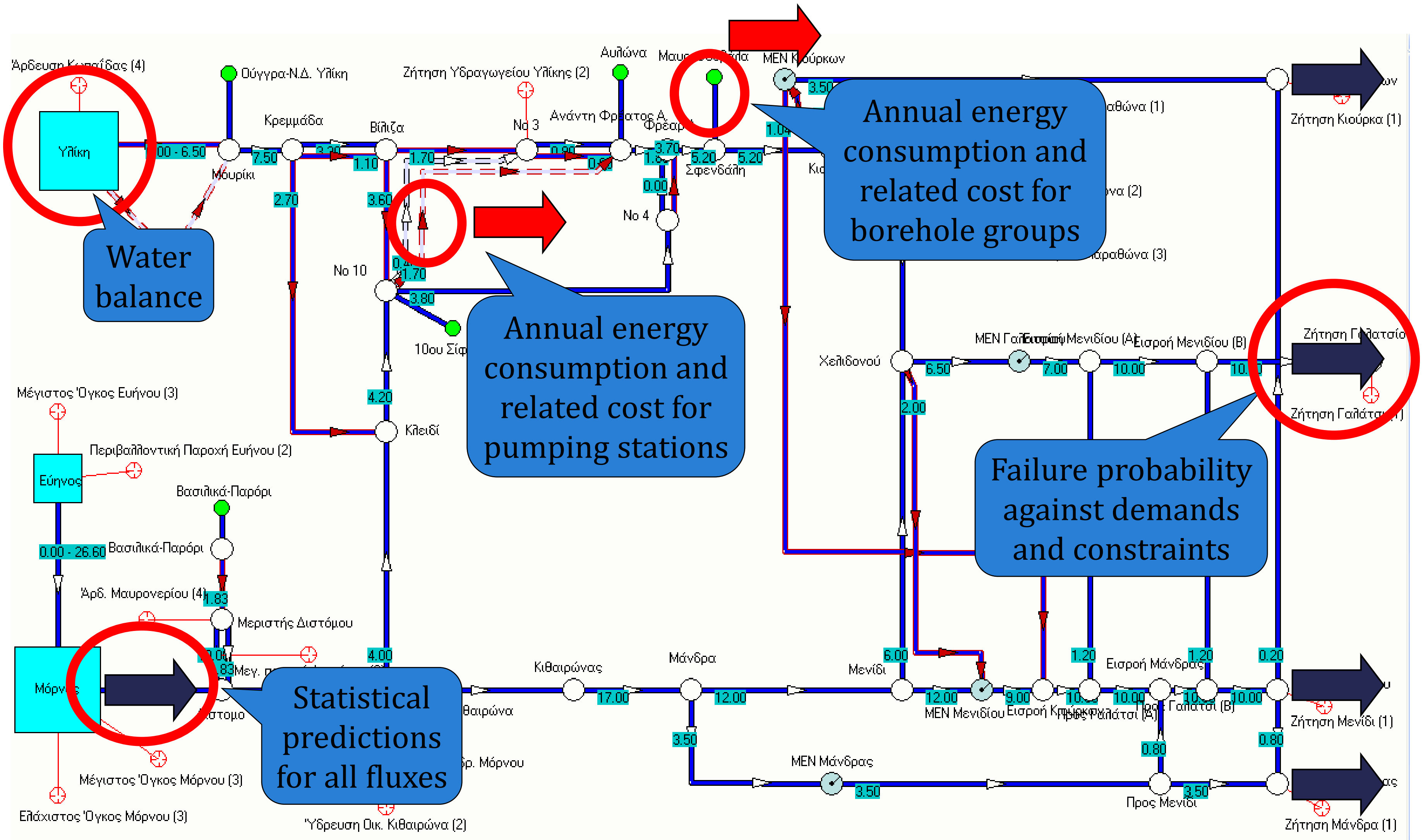
Task 4: Optimal allocation of actual fluxes



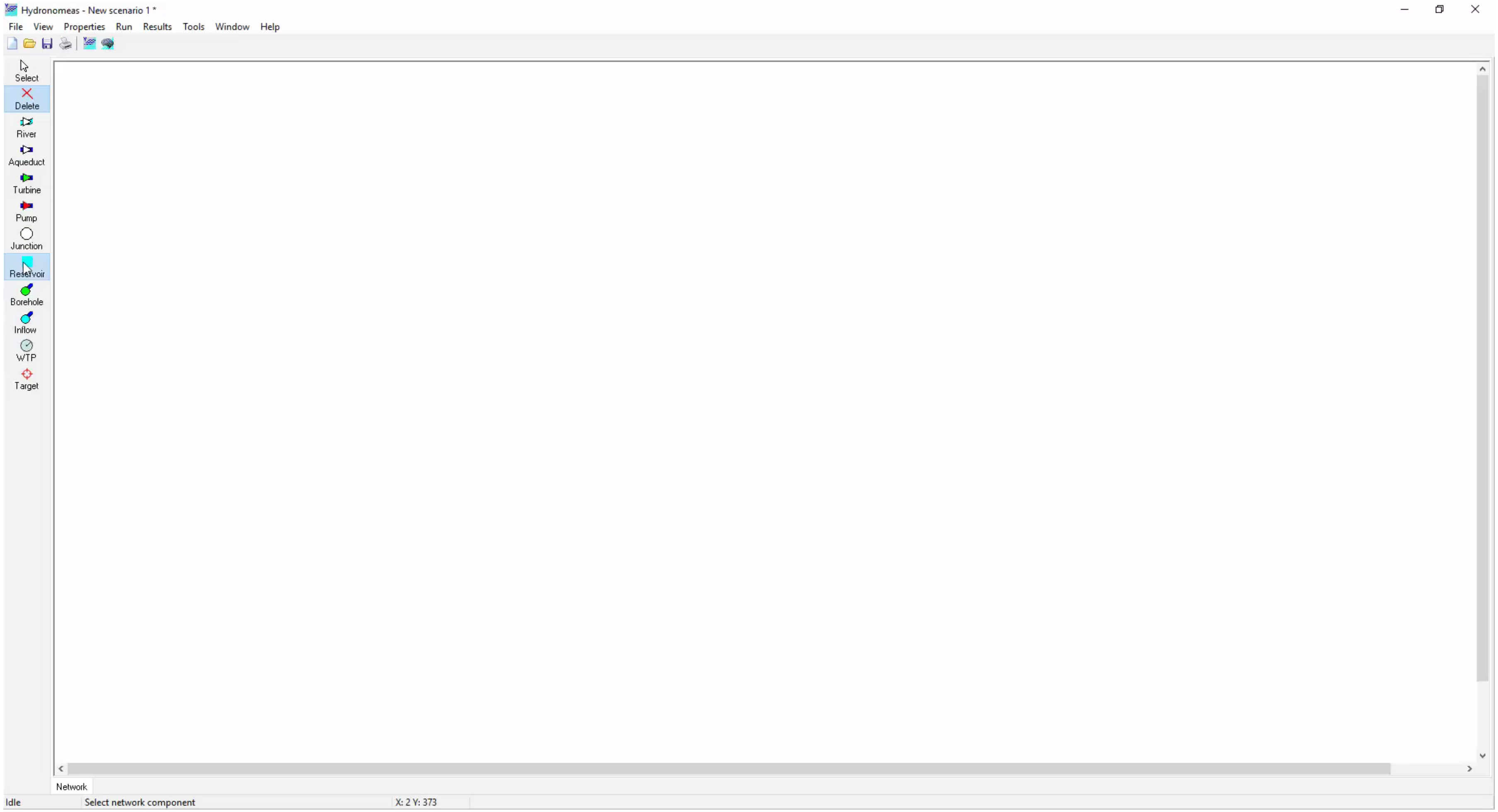
Target releases may differ from the actual ones, because one of the following reasons:

- insufficient availability of water resources to satisfy the total demand;
- insufficient capacity of aqueducts;
- alternative flow paths;
- multiple and conflicting uses and constraints to be fulfilled;
- insufficient reservoir capacity to store the actual inflows.

Task 5: Evaluation and optimization of the hydrosystem operation policy

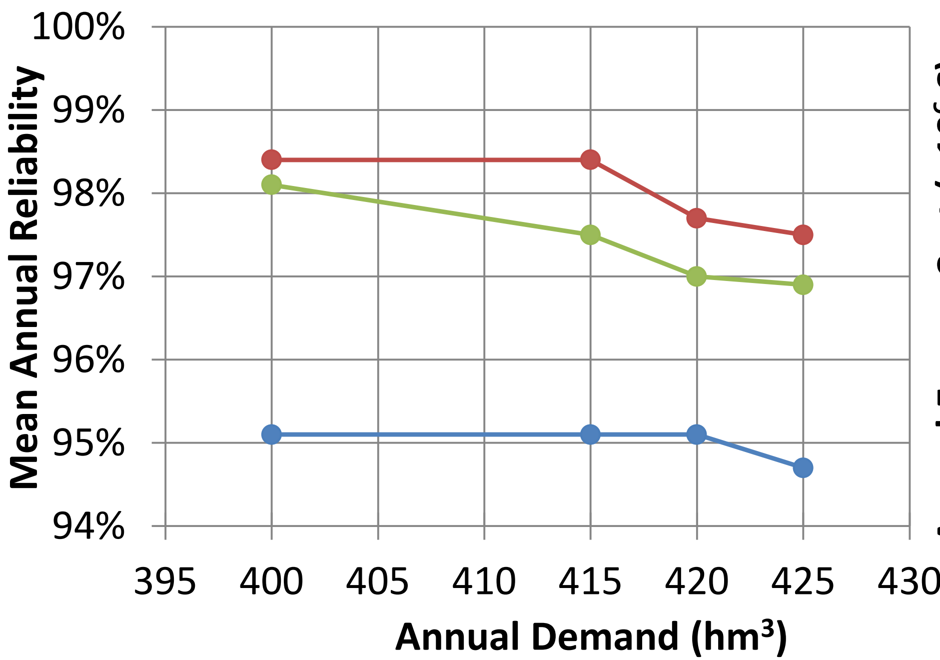


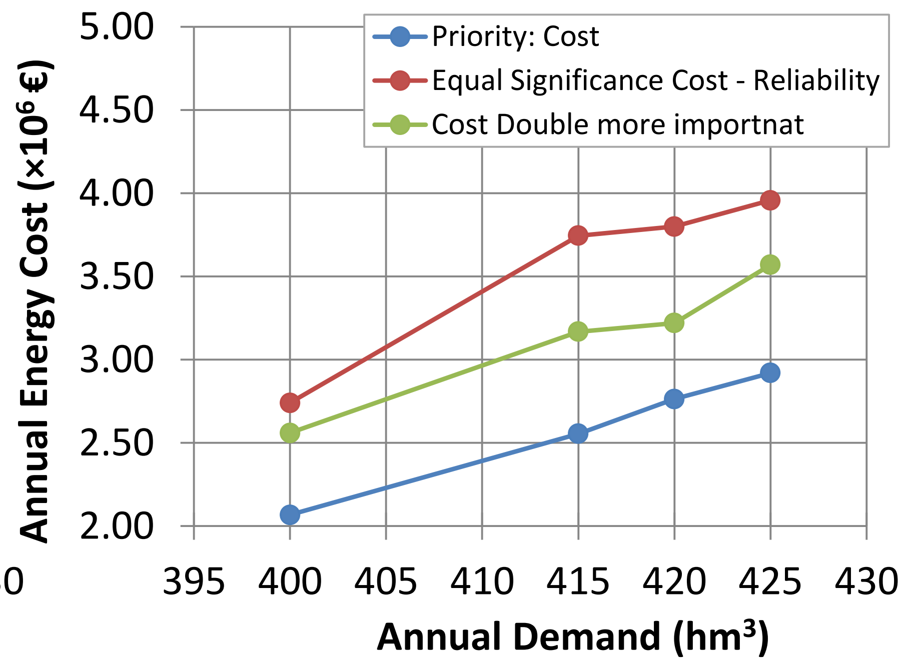
Hydronomeas Workflow



Scenarios & Results

- Four annual demand scenarios: Current state (400 hm^3/year) & three future projections (415, 420, 425 hm^3/y)
- Three sets of optimization weights (management policy): Prioritization of cost, equal importance of cost and reliability and cost double more important than reliability
- Results confirm the great effect of management policy to annual reliability and energy cost
- As demand increases it is more expensive to provide the same reliability level, thus unit cost of raw water increases too





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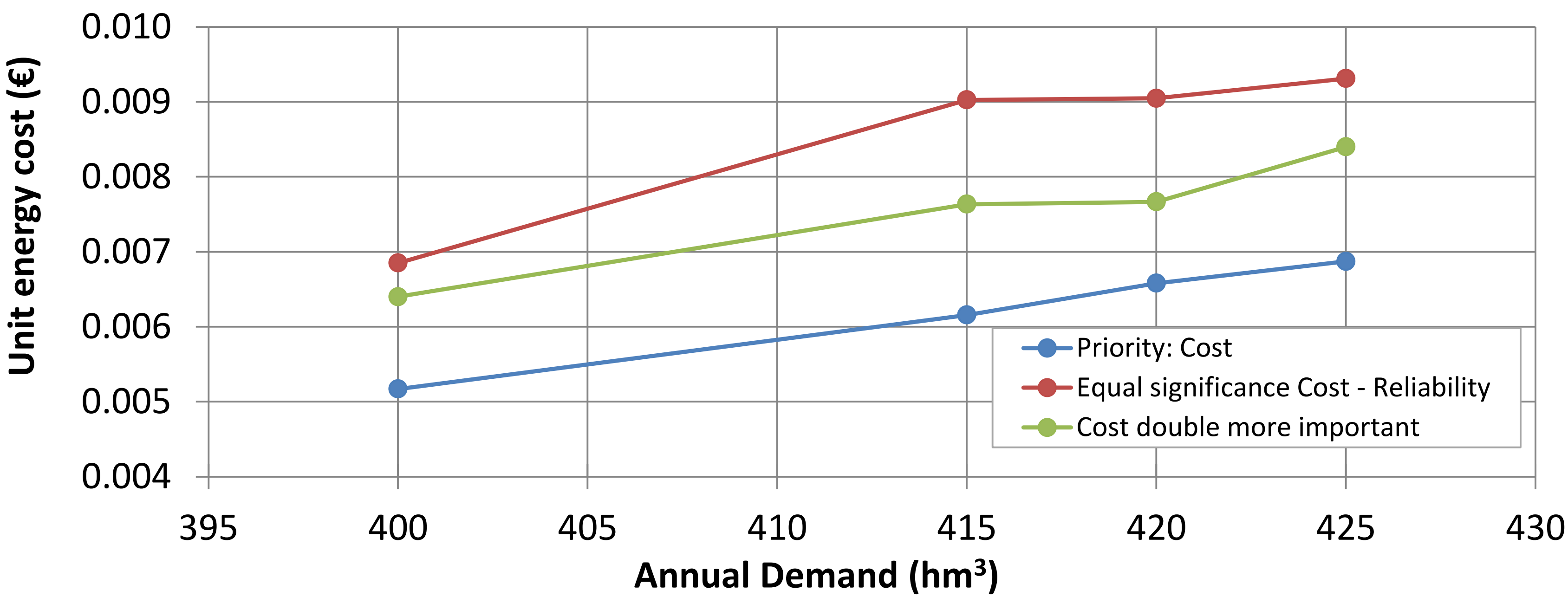

Conclusions

- Economic evaluations and energy assessments are essential elements in the design and management of water resource systems.
- Similarly to water and energy fluxes, economic quantities across hydrosystems should also be handled as random variables, since they are driven by uncertain hydrometeorological processes as well as uncertain human-induced demands and constraints.
- The cost of raw water of Athens is subject to multiple complexities and uncertainties, and its varies significantly according to the water abstraction and water transfer policy.
- In contrast to classical economics, the unit cost of Athens's water does not decrease with the increase of production, since in that case it is essential to activate auxiliary resources requiring pumping, in order to maintain an acceptable reliability level.
- The stochastic simulation-optimization framework implemented within the Hydronomeas software allows providing long-term management practices that ensure the minimal energy cost, for a given demand and a given reliability level.

Related publications

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- Koutsoyiannis, D., G. Karavokiros, A. Efstratiadis, N. Mamassis, A. Koukouvinos, and A. Christofides, A decision support system for the management of the water resource system of Athens, *Physics and Chemistry of the Earth*, 28(14-15), 599-609, 2003.
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- Tsoukalas, I., P. Kossieris, A. Efstratiadis, and C. Makropoulos, Surrogate-enhanced evolutionary annealing simplex algorithm for effective and efficient optimization of water resources problems on a budget, *Environmental Modelling & Software*, 77, 122–142, 2016.