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Models in practice: Experience from the water supply system of Athens

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Presentation outline

- My origins: the university and the research team
- Drinking water for Athens: diagnosis of the management problem
- Some philosophical aspects of water resources modelling
- A methodological framework for the analysis and management of complex water resource systems
- From theory to practice: providing decision support for the water supply system of Athens
- Software demonstration

This presentation is available on-line at:

http://www.itia.ntua.gr/en/docinfo/1095/

National Technical University of Athens (NTUA)

- The oldest (founded in 1832) and most prestigious educational institution of Greece in the field of technology; also closely linked with Greece's resist for independence, democracy and social progress.
- In Greek, is called **Ethnicon Metsovion Polytechneion**, i.e. National Metsovion Polytechnic (to honour several benefactors from Metsovo, a small town in the region of Epirus, who made substantial donations in the 19th century).
- NTUA is now divided into nine academic Schools. Its academic staff includes more than 700 people, while the total number of employees (administrative, technical and research staff) is about 1350. The total number of undergraduate students is about 8500 and postgraduate 1500.

ITIA research team (www.itia.ntua.gr)

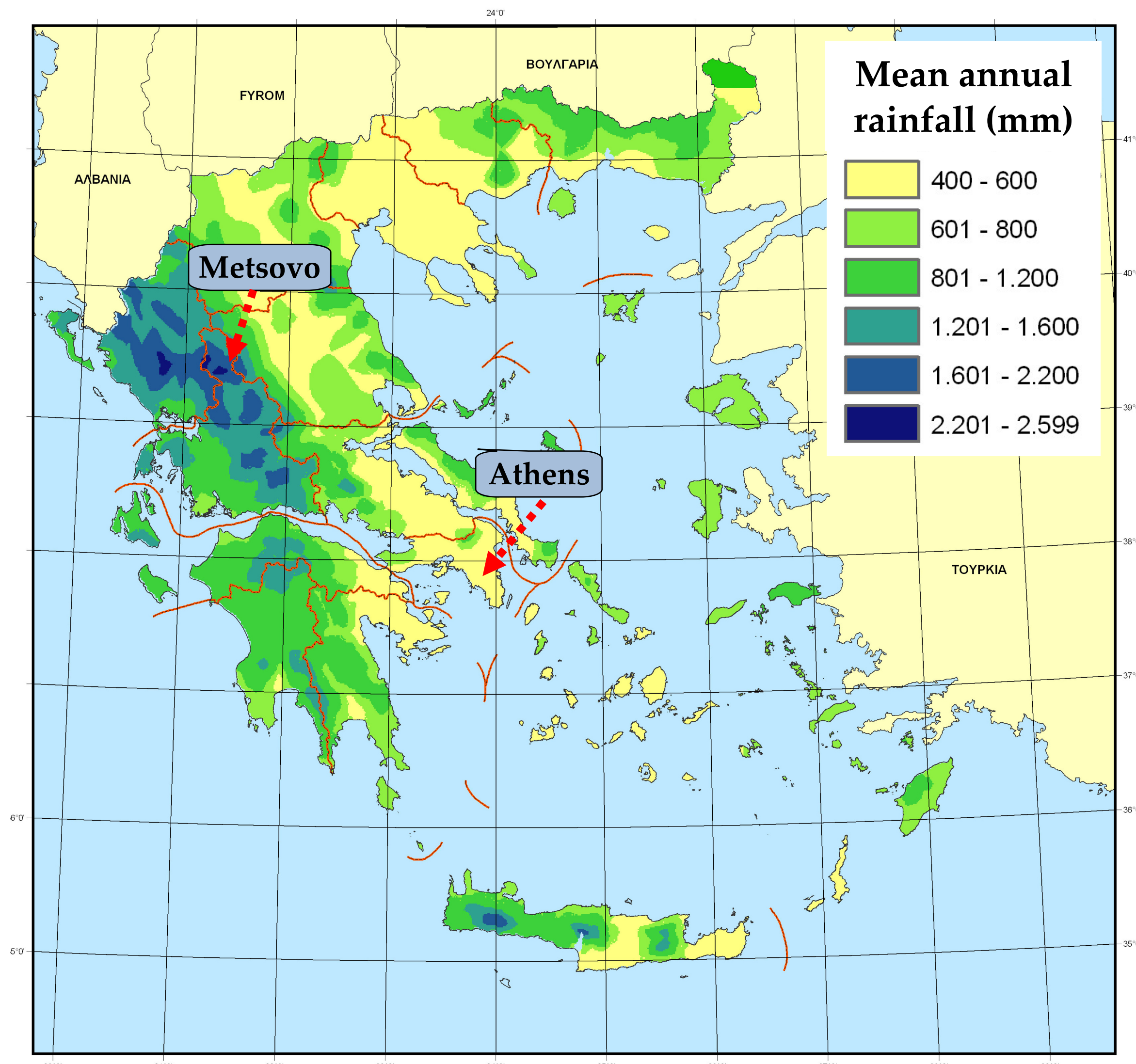
ITIA research team, comprising 24 members (academic staff, research assistants, PhD students), under Prof. D. Koutsoyiannis (from 1986)

ITIA = willow tree (not an acronym)

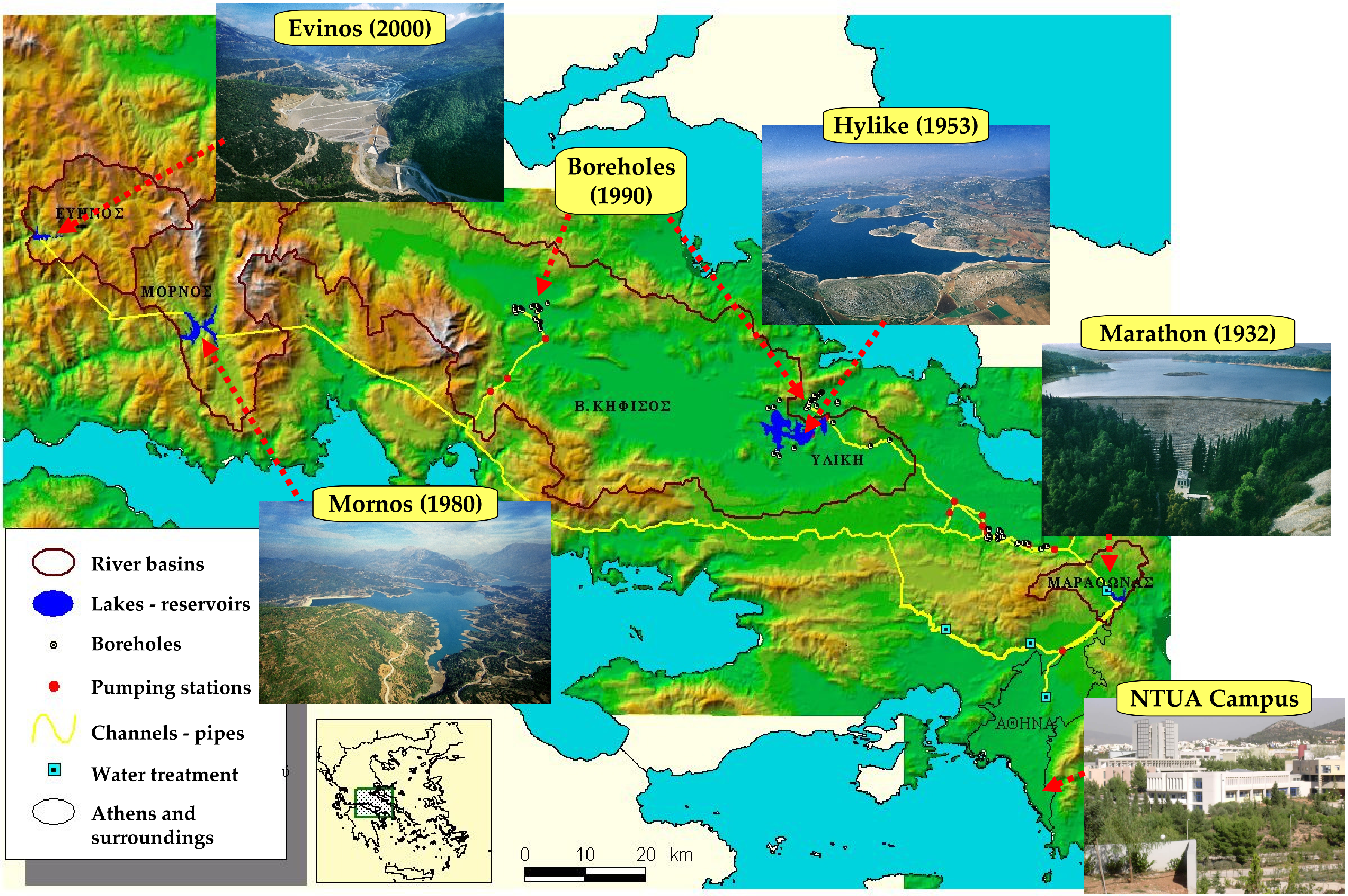
Repository containing 1100 research documents (papers, presentations, project reports, lecture notes, theses, books, engineering studies)

The hydrological "paradox" of Greece

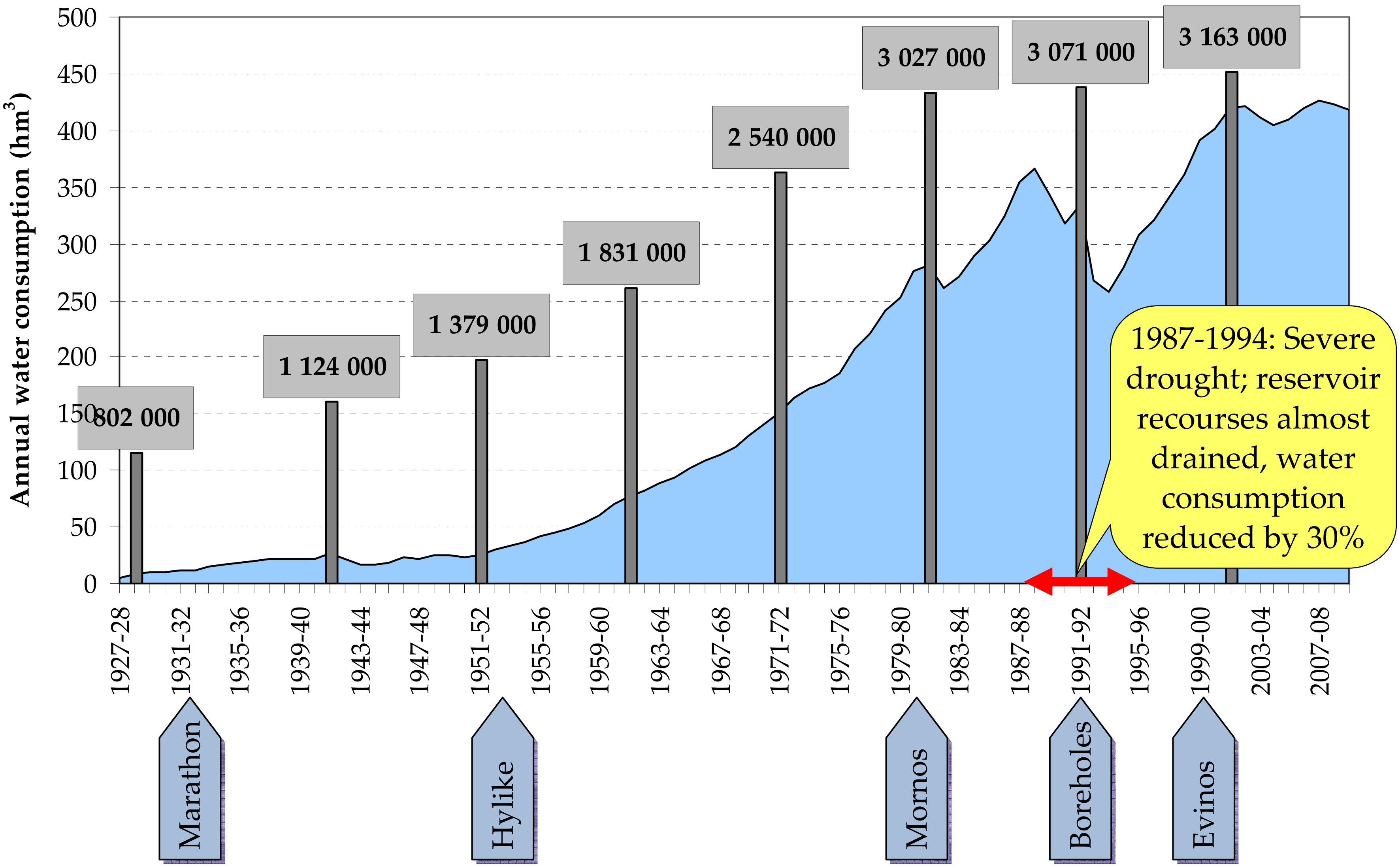
- While Western Greece is very prosperous in water recourses (wet climate, mountainous topography), it is weakly developed.
- Eastern Greece attracts most of the population (~40% in Athens) and the economic activities, but is poor in water, due to its semi-arid hydroclimatic regime.
- Large transfer projects are essential to restore both water and energy "equilibrium".



The water supply system of Athens (~ 4000 km²)



Providing drinking water to Athens: Evolution of annual demand, population and water recourses



Management challenges and complexity issues (1)

- Multiple and conflicting performance criteria:
  - Preservation of very high reliability level for Athens (up to 99%);
  - Minimization of energy consumption due to pumping through Hylike and boreholes, thus minimizing the operation cost of the hydrosystem.
- Multiple water uses and constraints:
  - Water supply of local communities and agricultural uses;
  - Environmental constraints (preservation of ecological flow);
  - Minimum and maximum storage controls for reservoirs (Mornos, Evinos, Marathon).
- Multiple sources of uncertainty:
  - Hydro-climatic uncertainty (chaotic thus unpredictable processes);
  - Evolution of demand for the various water uses;
  - Evolution and functionality of critical components of the network.
- Multiple water allocation options:
  - Multiple water recourses (four reservoirs, five borehole groups);
  - Multiple conveyance paths, each with different cost;
  - Multiple connections between the four water treatment plants.

Management challenges and complexity issues (2)

- Multiple cases of water losses:
  - Significant leakage from Hylike, reaching almost half of its storage during a year (karst background);
  - Non-negligible losses due to spill (Evinos) and evaporation (Mornos, Hylike);
  - Significant leakage along both open channels and pressured pipes.
- Multiple environmental impacts:
  - The flow downstream of the Mornos and Marathon dams is interrupted, since there are no facilities for ecological release;
  - The use of the boreholes in the middle course of Boeoticos Kephisos basin for water supply instead for irrigation causes social pressures from farmers;
  - Intensive pumping drastically affects the karst aquifer dynamics and can even interrupt the flow through the neighbouring karst springs, which account for 15% of the runoff to Hylike;
  - Groundwater abstractions around Hylike result to increased leakages.

Non-typical management problem … → … requires sophisticated models … → … to provide optimized results… → … to be implemented **in practice**

Philosophical dilemmas in water resources modelling

1. System-wide vs. empirical management
2. Holistic (integrated) vs. monomeric modelling
3. Top-down (macroscopic) vs. bottom-up overview
4. Conceptual vs. physically-based representation of complex processes
5. Parsimonious vs. high-dimensional mathematical structures
6. Models supported by data vs. data-driven (i.e. black-box) models
7. Accepting and describing uncertainty (stochastic models) vs. ignoring uncertainty (deterministic models)
8. Resolving conflicts vs. seeking for globally optimal solutions
9. Interpreting results on the basis of engineering experience vs. applying results obtained by automatic algorithms
10. Providing decision-support vs. predicting future decisions

Keyword 1: Holistic

- Conjunctive representation of all essential components of the system under study;
- Accounting for main interactions and feedbacks (surface water vs. groundwater, natural systems vs. human-modified systems);
- Maintenance of an analogous level of detail in the mathematical description of the multiple modelling components;
- Exploitation of any kind of knowledge (data and experience);
- Effective combination of different methodological approaches;
- On-line integration of all algorithmic procedures into a unique modelling environment.

Keyword 2: Parsimony

- Reasonable data requirements;
- Reasonable spatial resolutions, given that a perfect description of heterogeneity is rather utopian;
- Simple yet realistic assumptions regarding the mathematical structures, thus avoiding too complicated conceptualizations;
- Use of as few parameters as possible in optimizations;
- Non-parsimony results both in increased **uncertainty** as well as increased (and often impractical) **computational effort** (the curse of dimensionality).

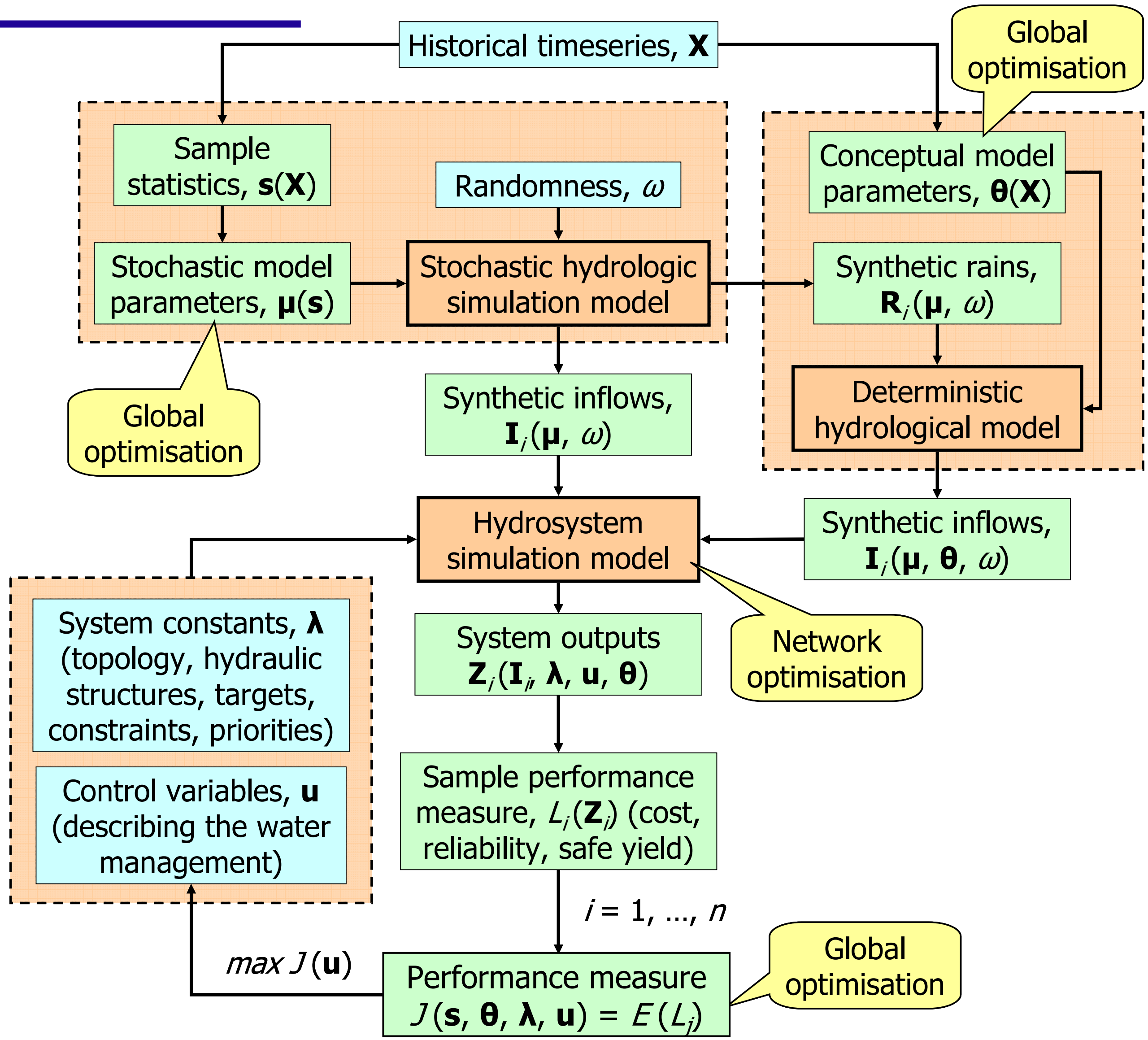
Keyword 3: Stochastic (simulation)

- Uncertainty is inherent in hydroclimatic processes due to their chaotic structure; even if measuring and modelling errors (known as "epistemic" uncertainty) are eliminated, deterministic predictions remain a myth.
- A specific water management policy is linked to a specific risk (i.e. failure probability) – zero risk does not exist.
- In complex systems, the evaluation of risk cannot be obtained through typical statistical approaches, i.e. by assigning probability functions for its responses, since the latter are decision-related.
- Stochastic (Monte Carlo) simulation is a powerful numerical technique, appropriate for complex systems, whose study based on analytical methods is laborious or even impossible.
- In practice, stochastic simulation comprises a three-phase procedure:
  - Generation of synthetic forcing time series, using a stochastic model that reproduces the statistical characteristics of the observed ones;
  - Running a (deterministic) model with synthetic inputs (forcing data) to represent the dynamics of the system under study;
  - Statistical analysis of the model outputs to interpret the system responses in probabilistic terms.

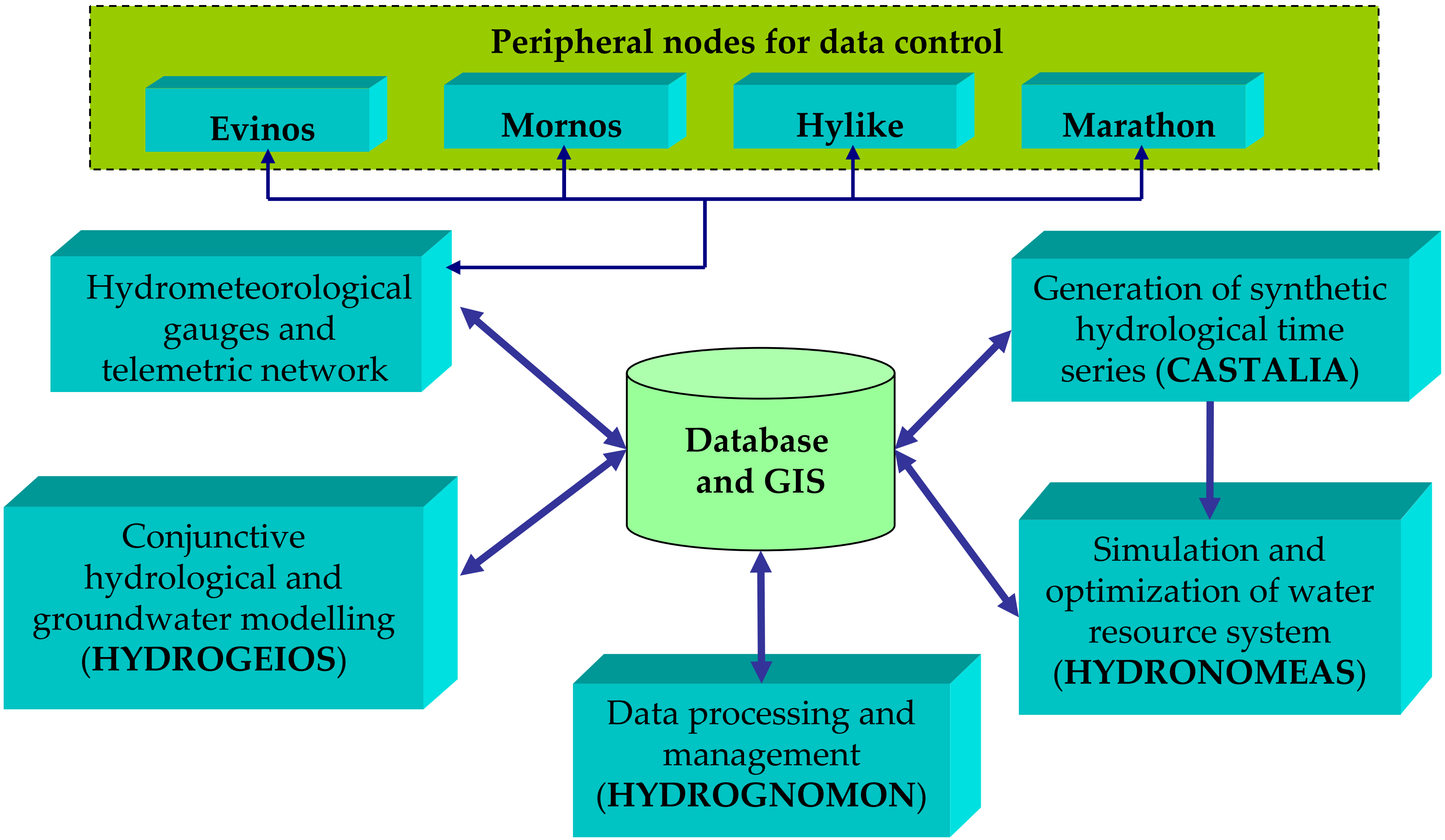
Outline of the parameterization – simulation – optimization framework

The optimized performance of the system depends on:

- the statistical characteristics of the observed hydrological data;
- the parameters describing the rainfall-runoff mechanisms;
- the constant properties of the hydrosystem (e.g. hydraulic data);
- the optimized parameters of the management policy (control variables).

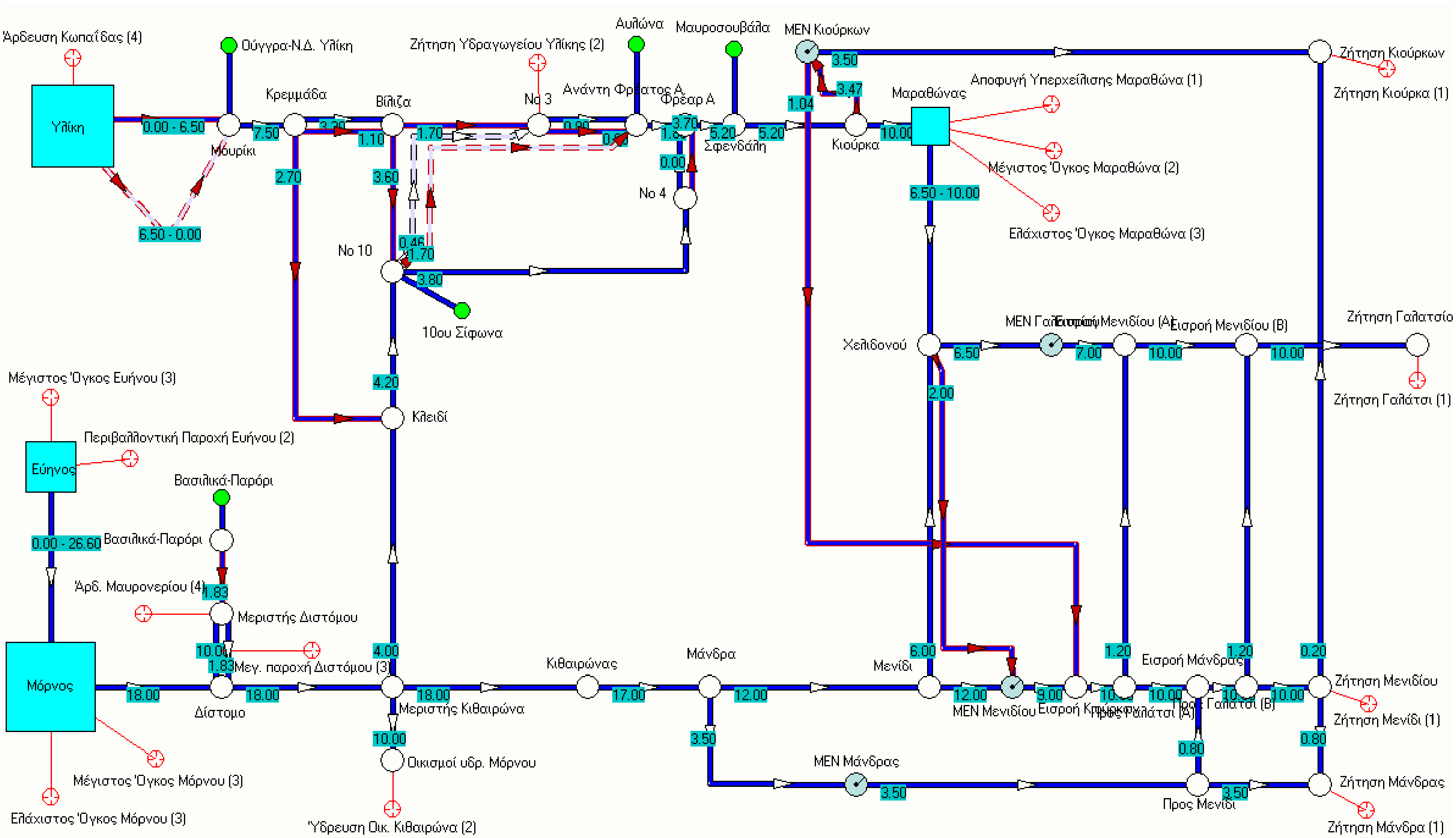


Architecture of the decision support system (DSS) for the management of Athens water supply



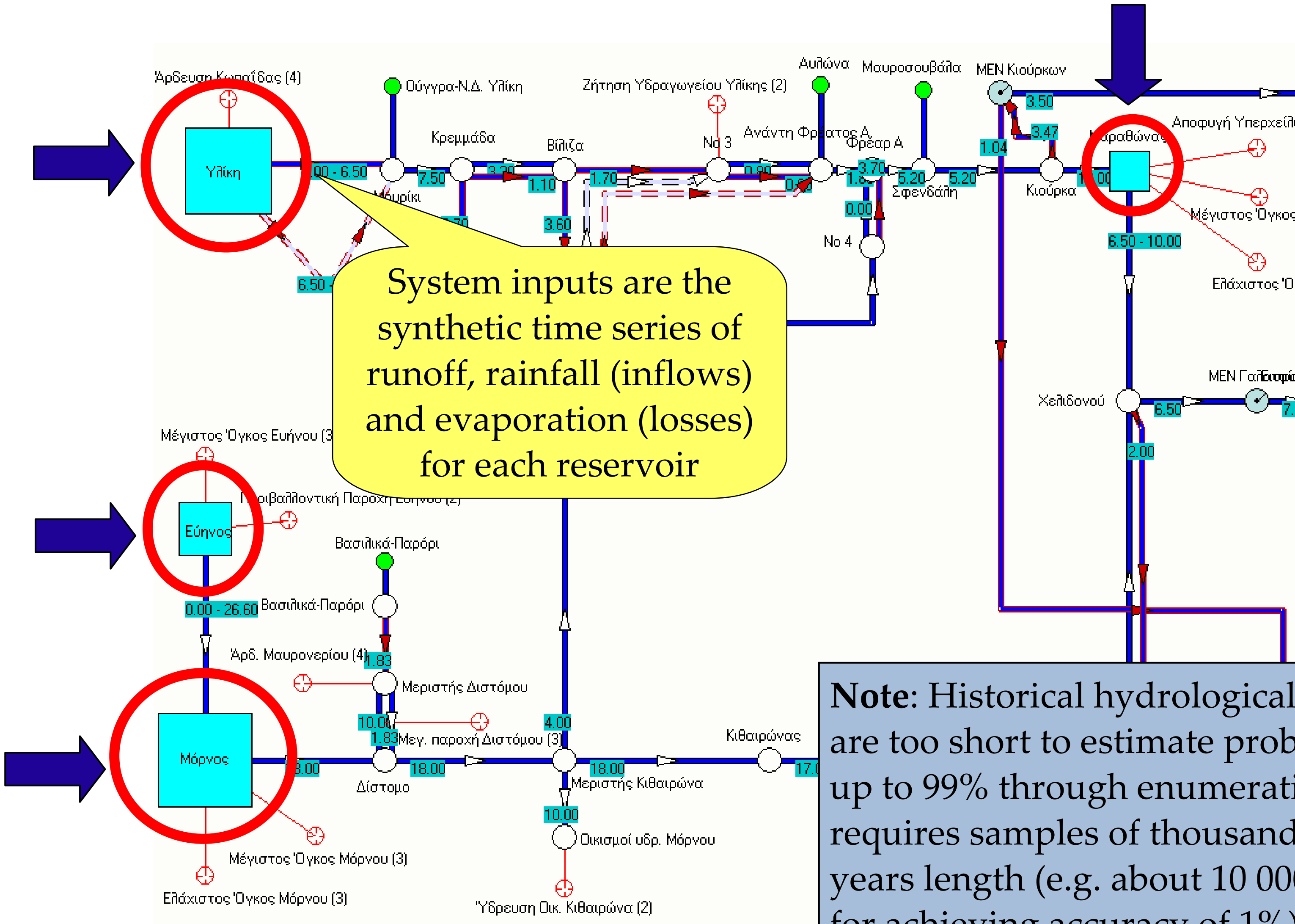
Notice: The DSS was developed during 1999-2003 and upgraded during 2008-2010

Schematization of the water resource system



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

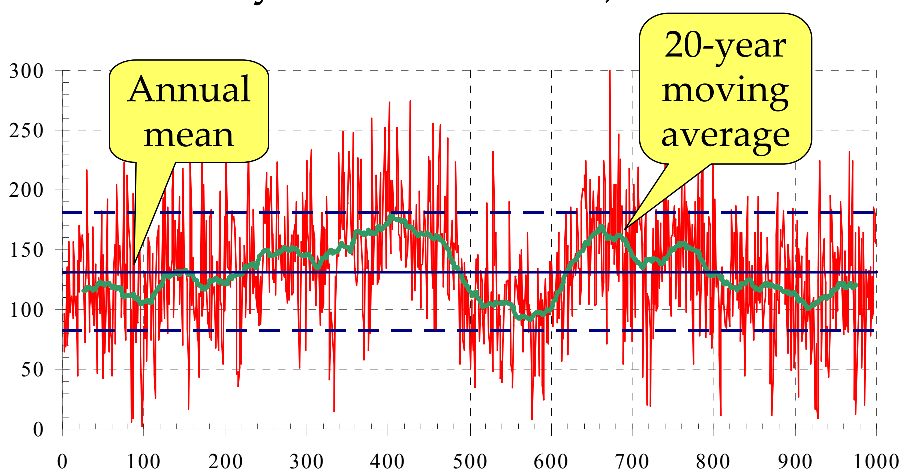
Task 1: Generation of hydrological inputs



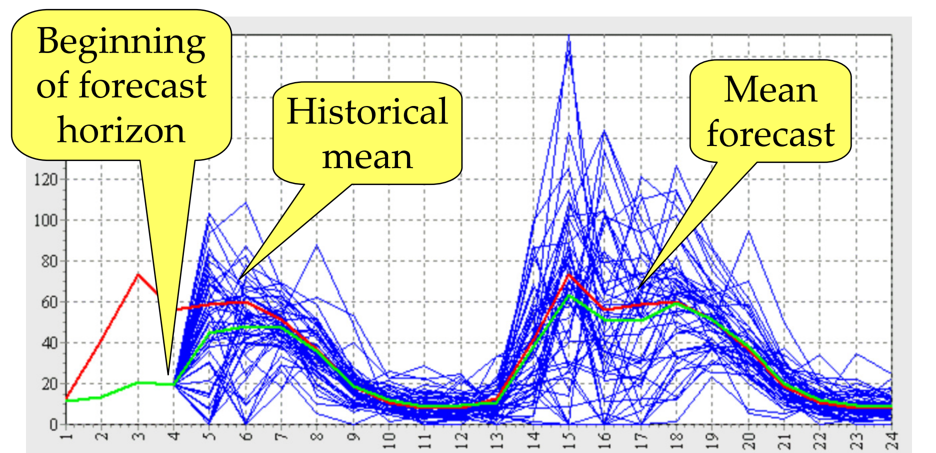
Note: Historical hydrological records are too short to estimate probabilities up to 99% through enumeration; this requires samples of thousands of years length (e.g. about 10 000 years, for achieving accuracy of 1%)

Requirements for the stochastic model (Castalia)

- Multivariate stochastic modelling, to represent multiple processes at multiple locations that are inherently correlated;
- Preservation of marginal statistics up to third order (asymmetry);
- Preservation of temporal and spatial correlations;
- Multiple time scales of preservation, from annual (preservation of over-year scaling, i.e. the Hurst phenomenon) to monthly (preservation of periodicity);
- Operation in steady-state simulation mode (synthetic series of very long horizon) and forecast mode, conditioned to present and past data (terminating simulation; "ensemble" series, representing multiple hydrological scenarios for relatively small horizons).



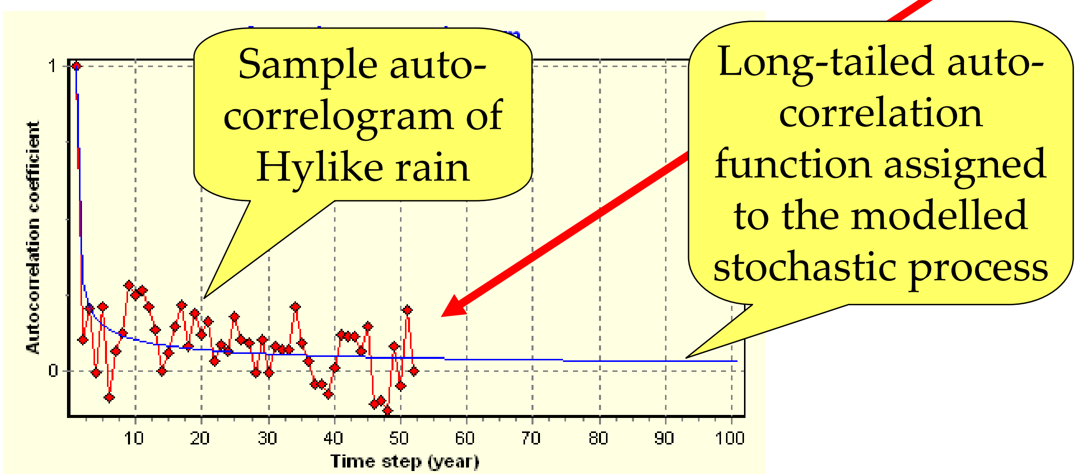
Annual time series for steady-state simulation

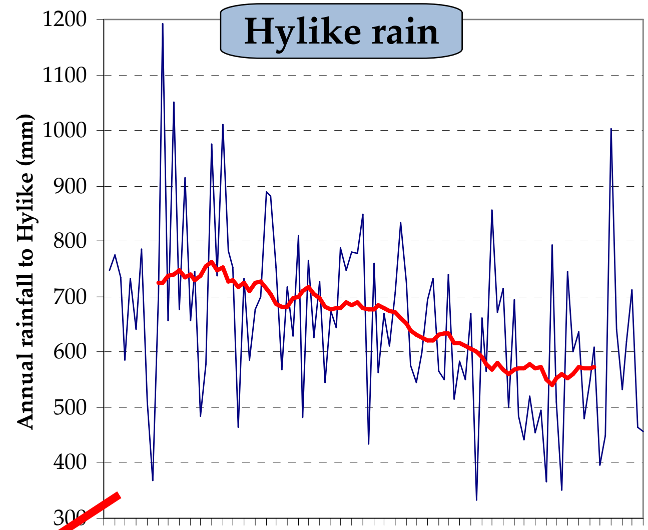


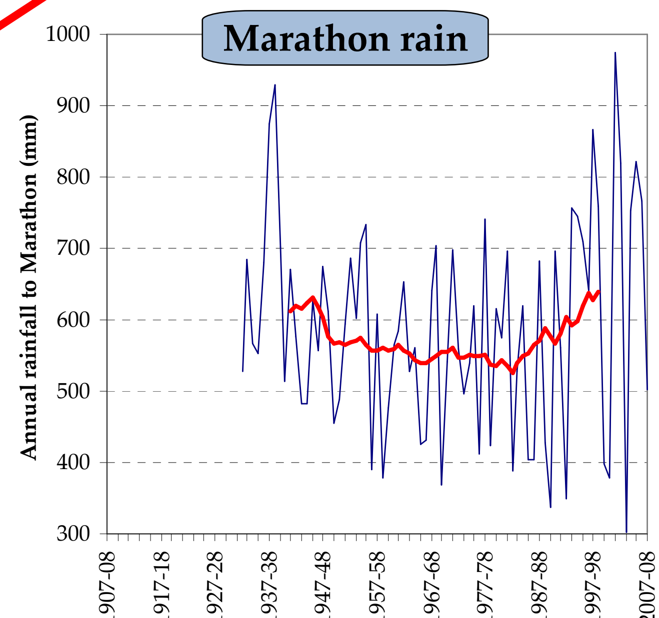
Monthly time series for terminating simulation

Representing the Hurst-Kolmogorov behaviour

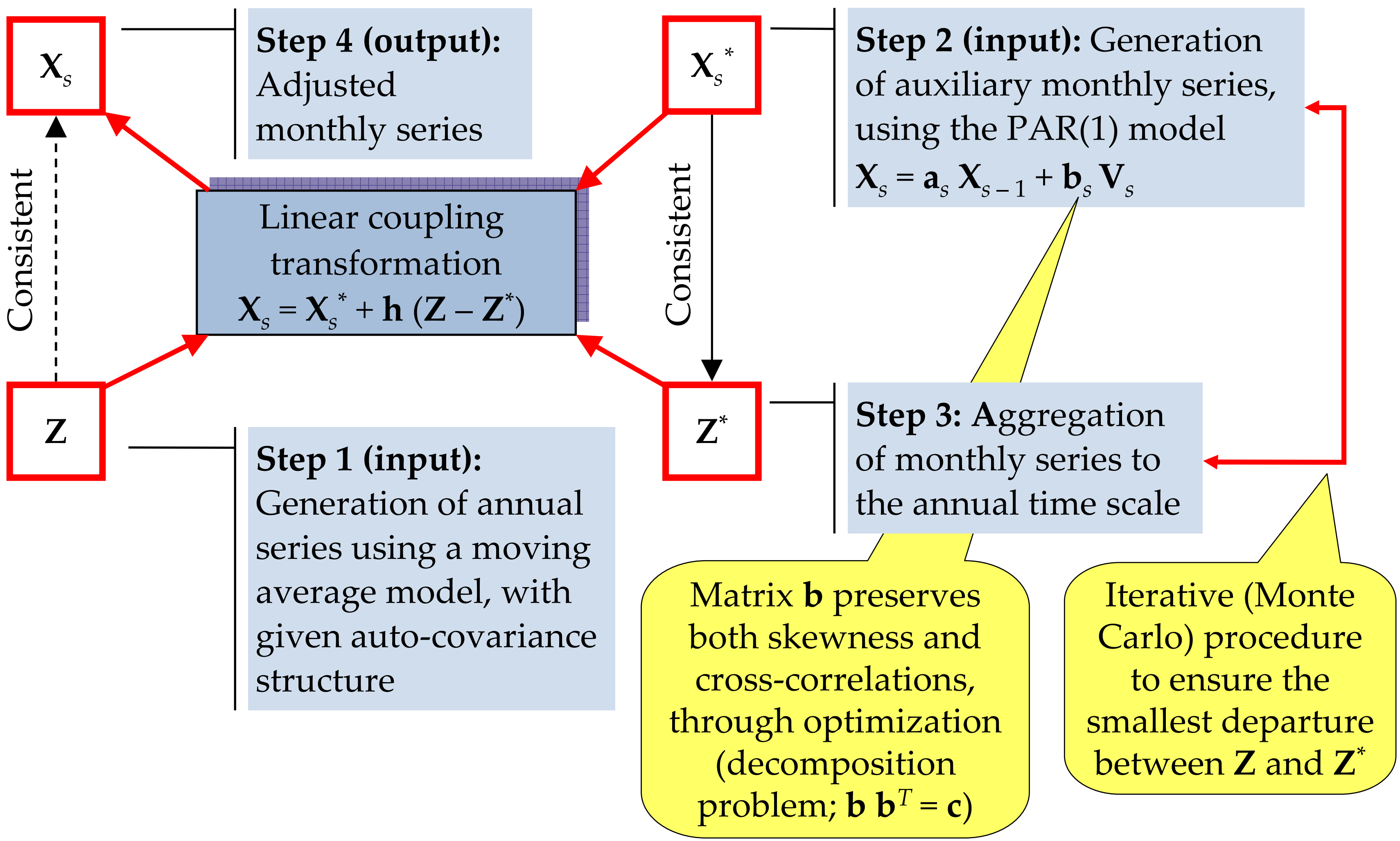
- Historical data exhibit peculiarities, such as fluctuations at multiple scales and trends, which cannot be represented through short-memory schemes, such as ARMA-type models.
- Persistent droughts and changing climate are typical aspects of this behaviour, which is crucial to be represented in water management models.
- The Hurst-Kolmogorov dynamics, explained through the principle of **maximum entropy**, is easily formulated in terms of the variance and autocorrelation of the stochastic process.



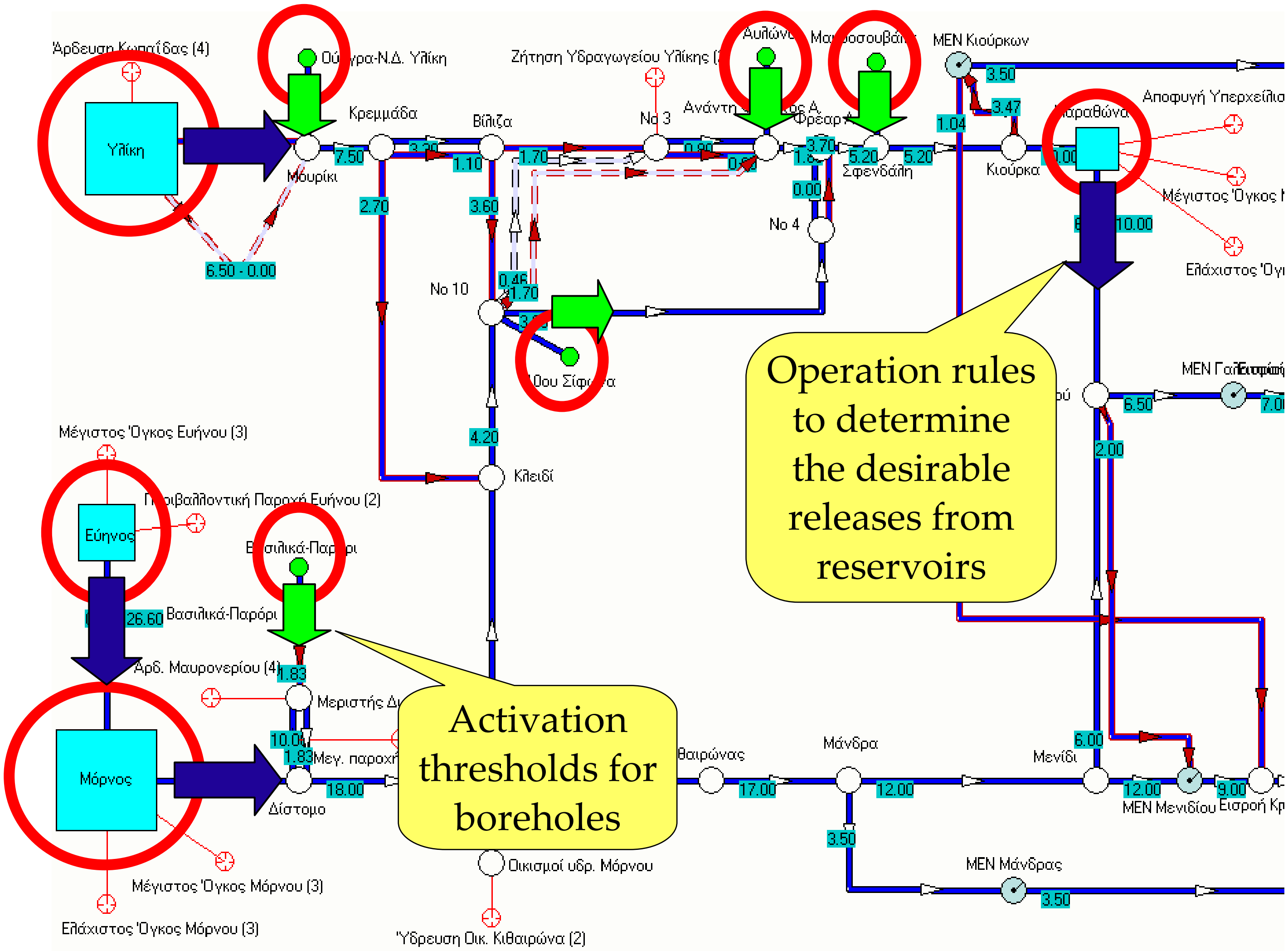




Coupling stochastic models for annual and monthly scales

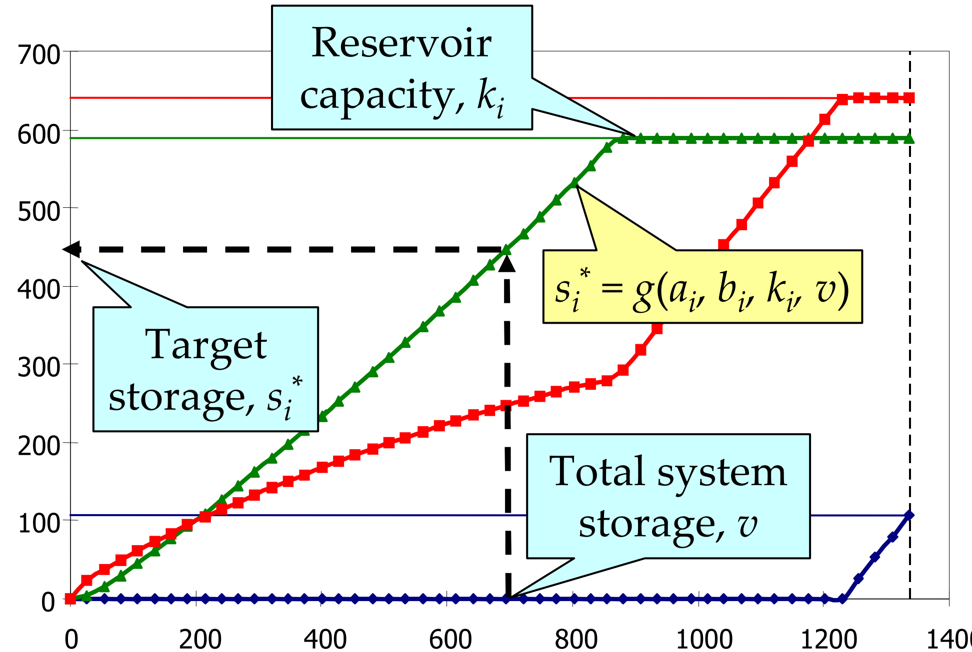


Task 2: Establishment of a systematic control policy for reservoirs and boreholes



Operation rules for multi-reservoir systems

- The rules are nomographs that specify the desirable allocation of reservoir resources and the corresponding releases on a monthly basis, as function of:
  - the estimated total storage of the system at the end of month;
  - the capacities of all reservoirs (physical constraints);
  - any other kind of storage constraints, imposed by the user.

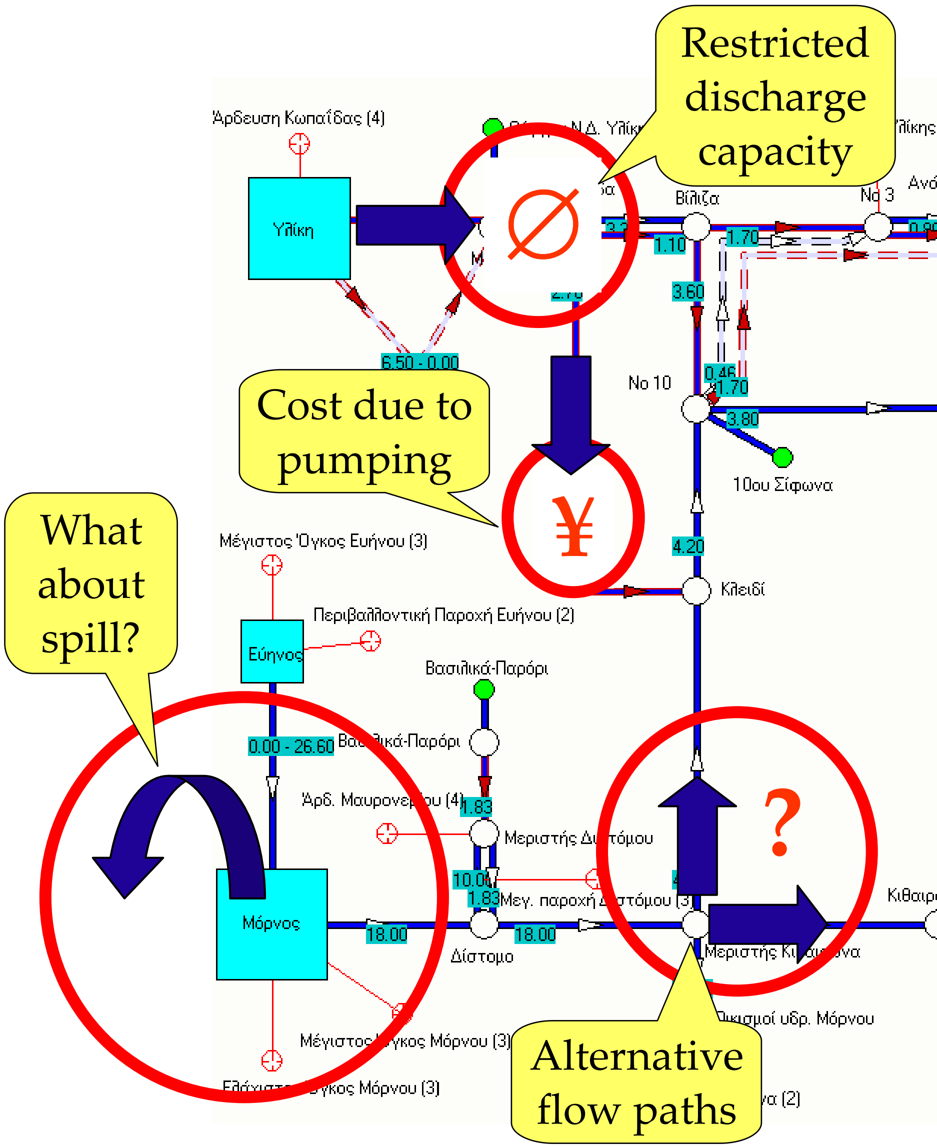


- Since inflows are projected through simulation, the target releases are easily estimated, on the basis on the actual storages and the total water demand.
- The rules are mathematically expressed using two parameters per reservoir, thus ensuring a **parsimonious parameterization** of the related optimization problem, where their values depend on the statistical characteristics of inflows.
- In contrast, linear or dynamic programming approaches would require plethora of decision variables, the number of which depend on the control horizon, while their values depend on the sequence of inflows.

Activation thresholds for groundwater control

- In the water supply system of Athens, groundwater are assumed auxiliary resources, which are typically activated in case of emergency.
- There are more than a hundred boreholes, which are grouped into five clusters to represent combined abstractions from broader aquifer areas.
- The management policy is specified on the basis of two threshold-type parameters per borehole group, i.e. an upper and a lower bound, which express the percentage of total actual reservoir resources to the total capacity. In this context:
  - when the filling ratio of the reservoirs exceeds the upper threshold, the borehole group is not activated;
  - when the filling ratio of the reservoirs is below the lower threshold, the group is activated by priority, without accounting for energy costs;
  - in intermediate states, the group is either activated or not, depending on the minimization of the total energy consumption across the hydrosystem.
- Different threshold values are assigned to the five borehole groups of Athens, thus specifying a desirable hierarchy in their use.

Task 3: Optimal allocation of actual fluxes



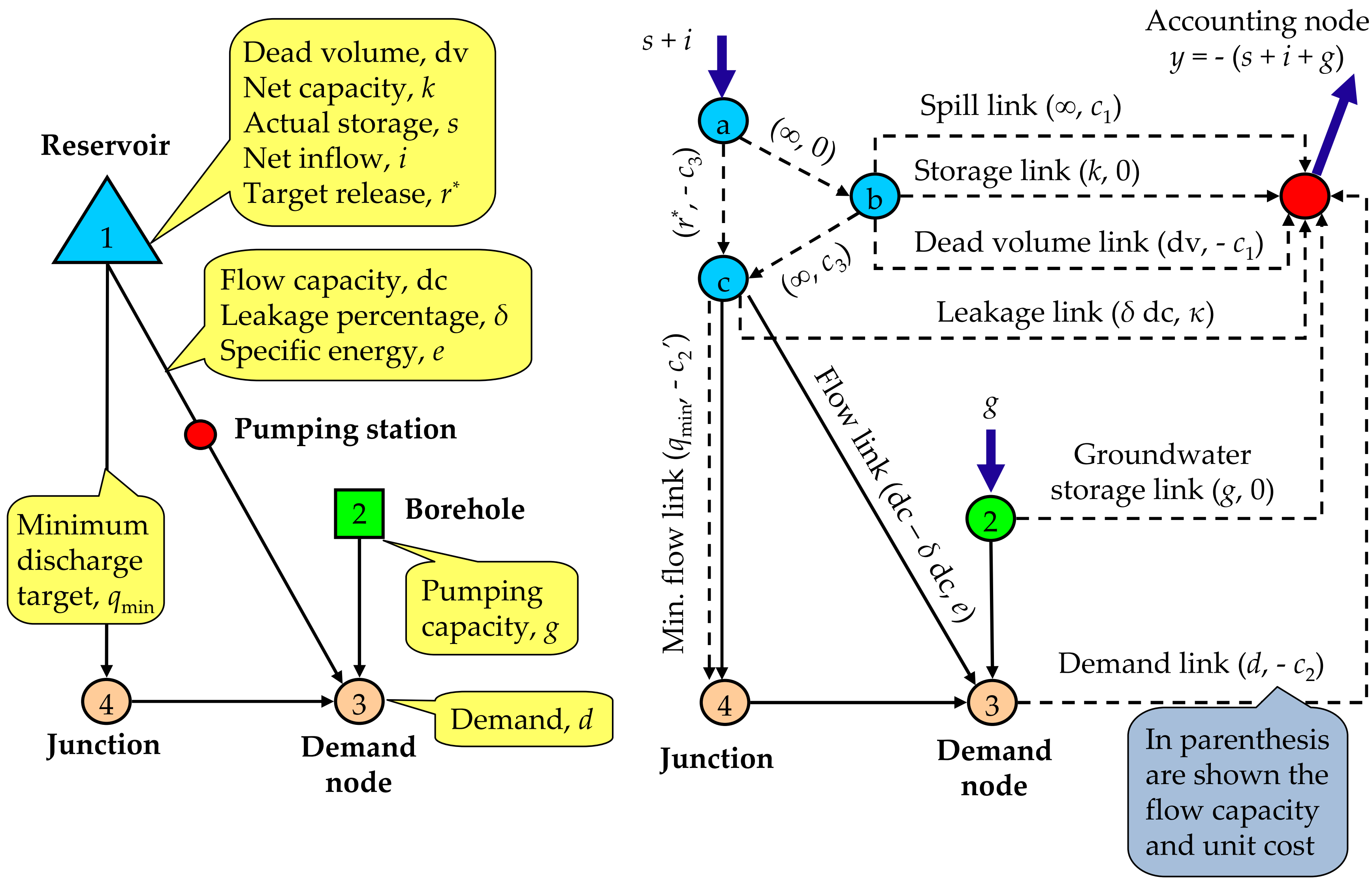
The target releases may differ from the real ones, due to at least one of the following reasons:

- insufficient discharge capacity of the downstream network;
- alternative flow paths;
- multiple and even conflicting uses and constraints to be fulfilled;
- insufficient storage to satisfy all demands or insufficient reservoir capacity to store all flood runoff.

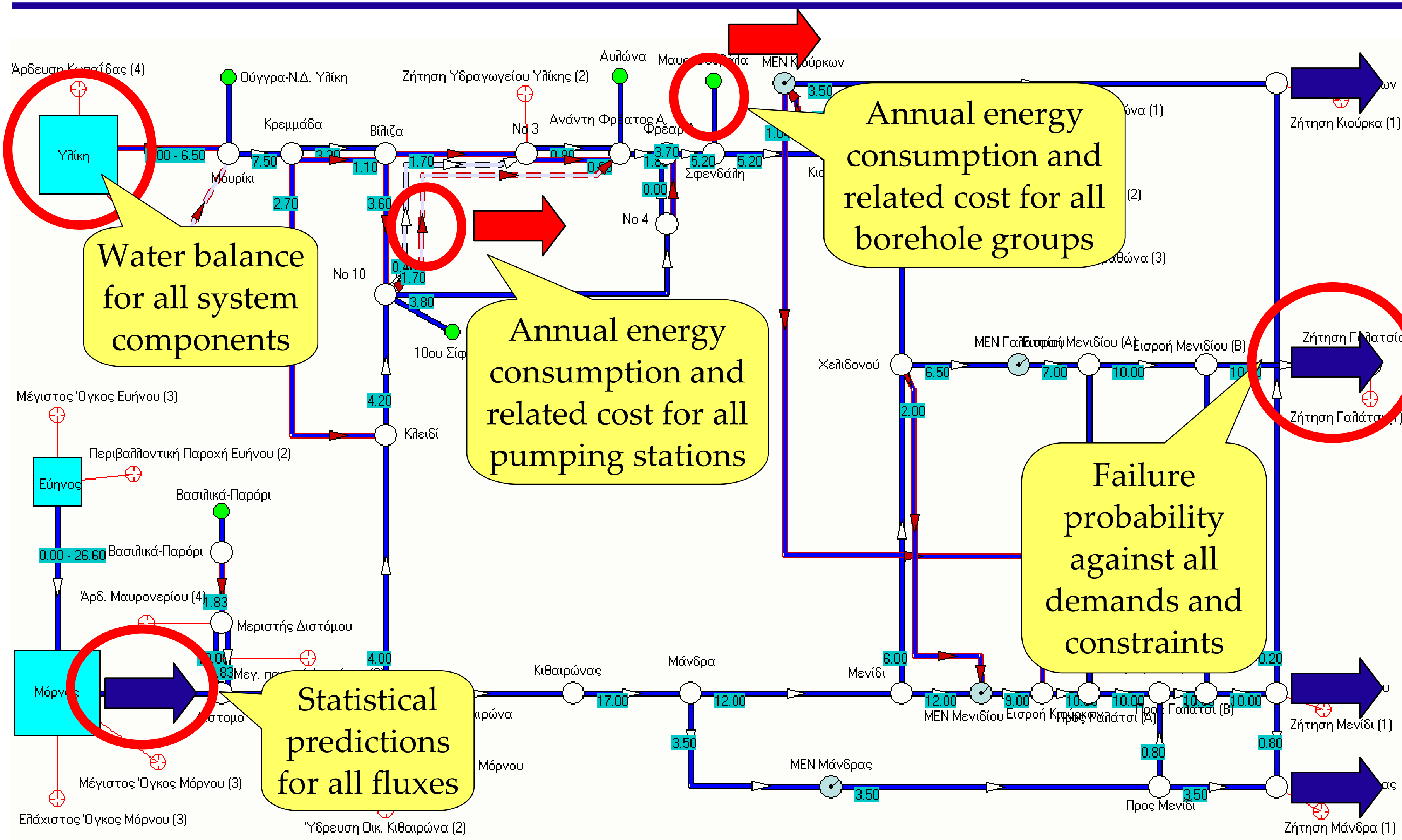
A graph optimization approach to the flow allocation problem

- The real-world system is described through a conceptual graph, whose dummy properties are conveyance capacities and unit costs.
- All hydrosystem fluxes are represented as control variables of a **network linear programming** (NLP) problem, whose objective is the minimization of the total transportation cost through the graph.
- Artificial costs are set either to prohibit undesirable fluxes (positive costs) or to force the model fulfilling water demands for various uses (negative costs).
- Real costs are expressed in energy terms, by means of specific energy (kWh/m^3).
- The assignment of unit costs, real and artificial, is based on a recursive algorithm that implements the following requirements:
  - strict satisfaction of all physical constraints (storage and flow capacities);
  - satisfaction of demands and constraints, preserving their hierarchy;
  - minimization of departures between actual and target abstractions;
  - minimization of total energy consumption.
- The specific mathematical structure of NLP allows for using accurate and exceptionally fast solvers.

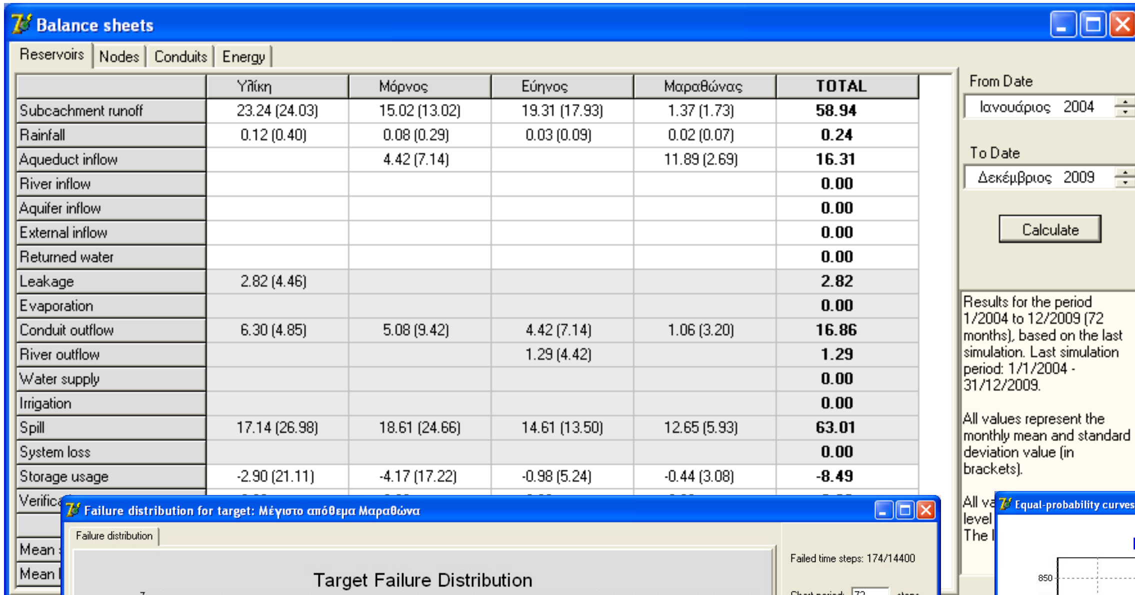
Representation of an elementary water resource system as NLP model



Task 4: Evaluation and optimization of the hydrosystem operation policy

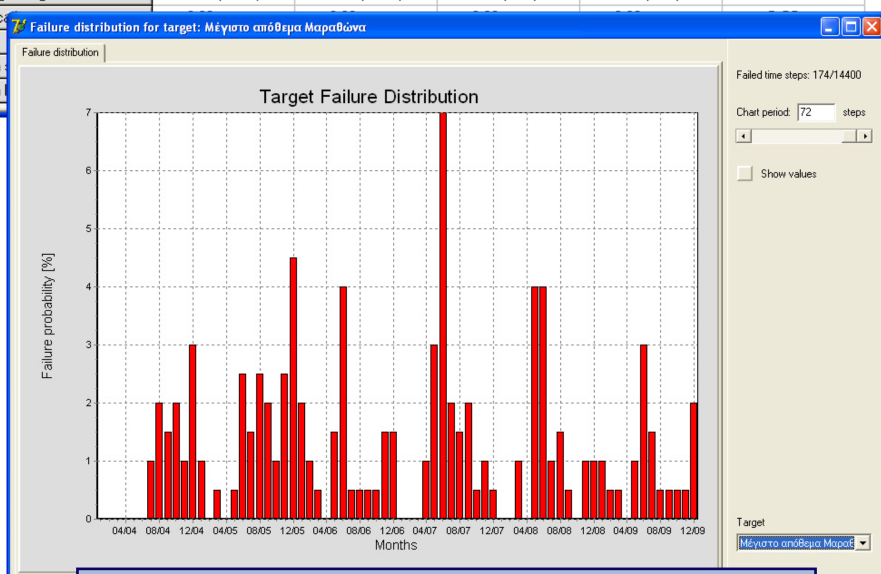


Simulation results

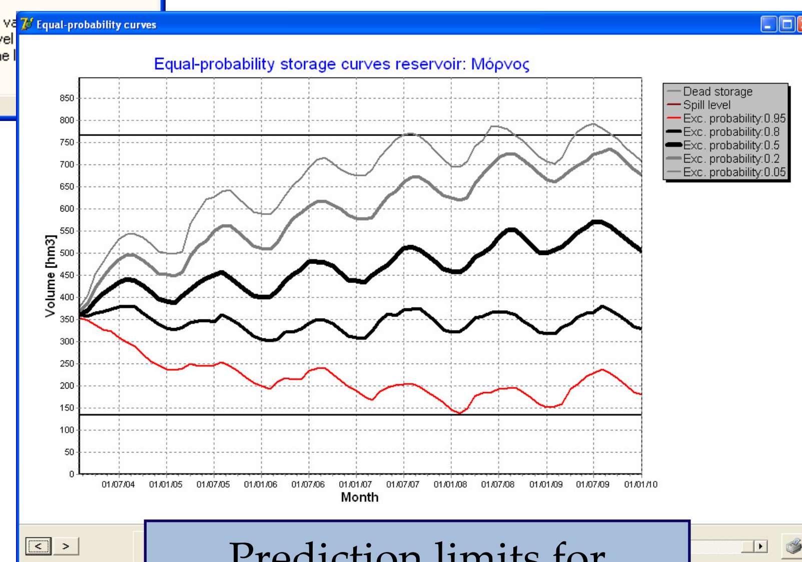


	Υλίκη	Μόρνος	Εύηνος	Μαραθώνας	TOTAL
Subcatchment runoff	23.24 (24.03)	15.02 (13.02)	19.31 (17.93)	1.37 (1.73)	58.94
Rainfall	0.12 (0.40)	0.08 (0.29)	0.03 (0.09)	0.02 (0.07)	0.24
Aqueduct inflow		4.42 (7.14)		11.89 (2.69)	16.31
River inflow					0.00
Aquifer inflow					0.00
External inflow					0.00
Returned water					0.00
Leakage	2.82 (4.46)				2.82
Evaporation					0.00
Conduit outflow	6.30 (4.85)	5.08 (9.42)	4.42 (7.14)	1.06 (3.20)	16.86
River outflow			1.29 (4.42)		1.29
Water supply					0.00
Irrigation					0.00
Spill	17.14 (26.98)	18.61 (24.66)	14.61 (13.50)	12.65 (5.93)	63.01
System loss					0.00
Storage usage	-2.90 (21.11)	-4.17 (17.22)	-0.98 (5.24)	-0.44 (3.08)	-8.49

Water and energy balance for all system components (mean monthly values and standard deviations)



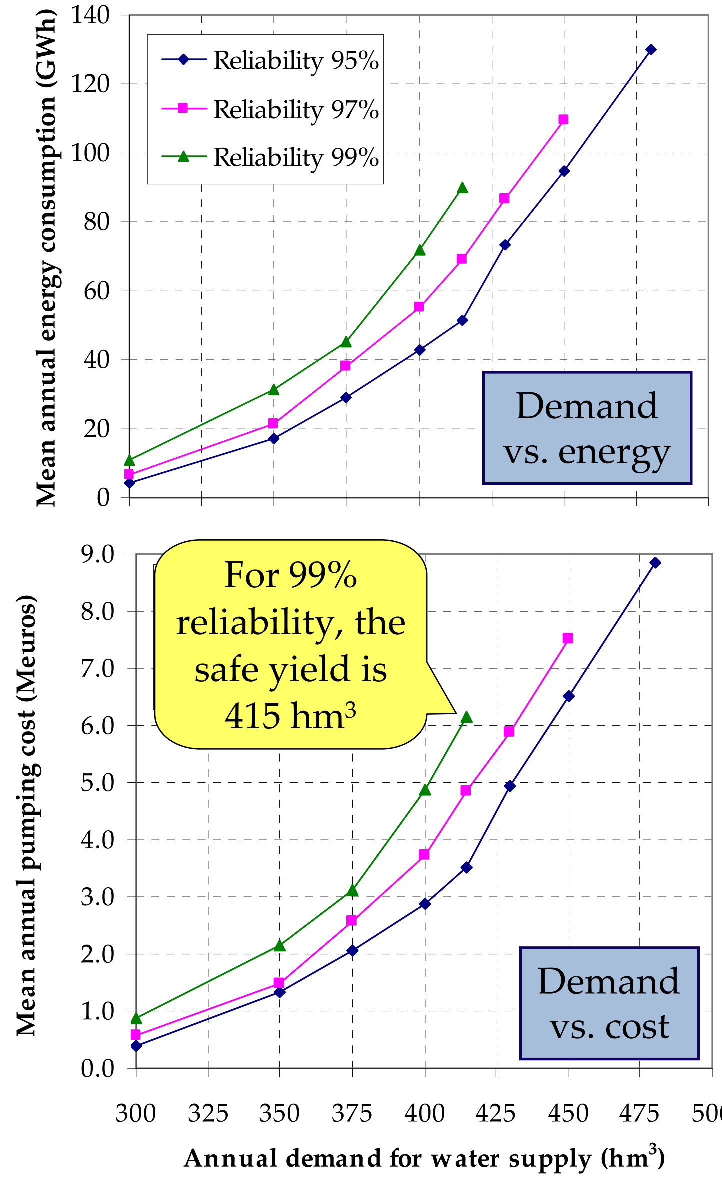
Time-distribution of failure probability (terminating simulation)



Prediction limits for reservoir storage and level (terminating simulation)

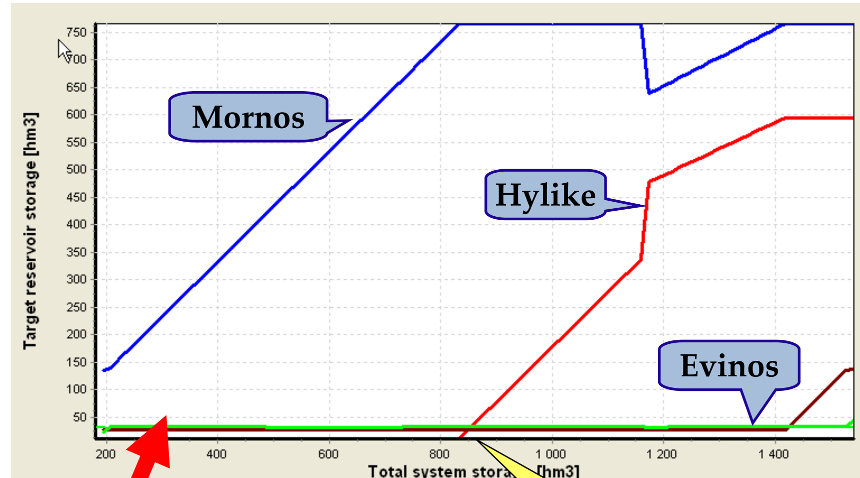
Practical issue 1: Appraisal of energy cost against demand and reliability

- **Problem statement**: estimation of the mean annual energy consumption and the related cost, for a given annual demand and a given reliability level.
- Control variables were the six parameters of the operation rules for Mornos, Evinos and Hylike, while the borehole thresholds were manually specified.
- Formulated as a non-linear (global) optimization problem of two criteria, i.e. minimization of energy and preservation of the desirable reliability level.
- The two criteria were evaluated through steady-state simulation, using 2000 years of synthetic hydrological data.
- **Practical interest**: assessing the full (i.e. financial and environmental) cost of water.



Practical issue 2: Potential of existing resources

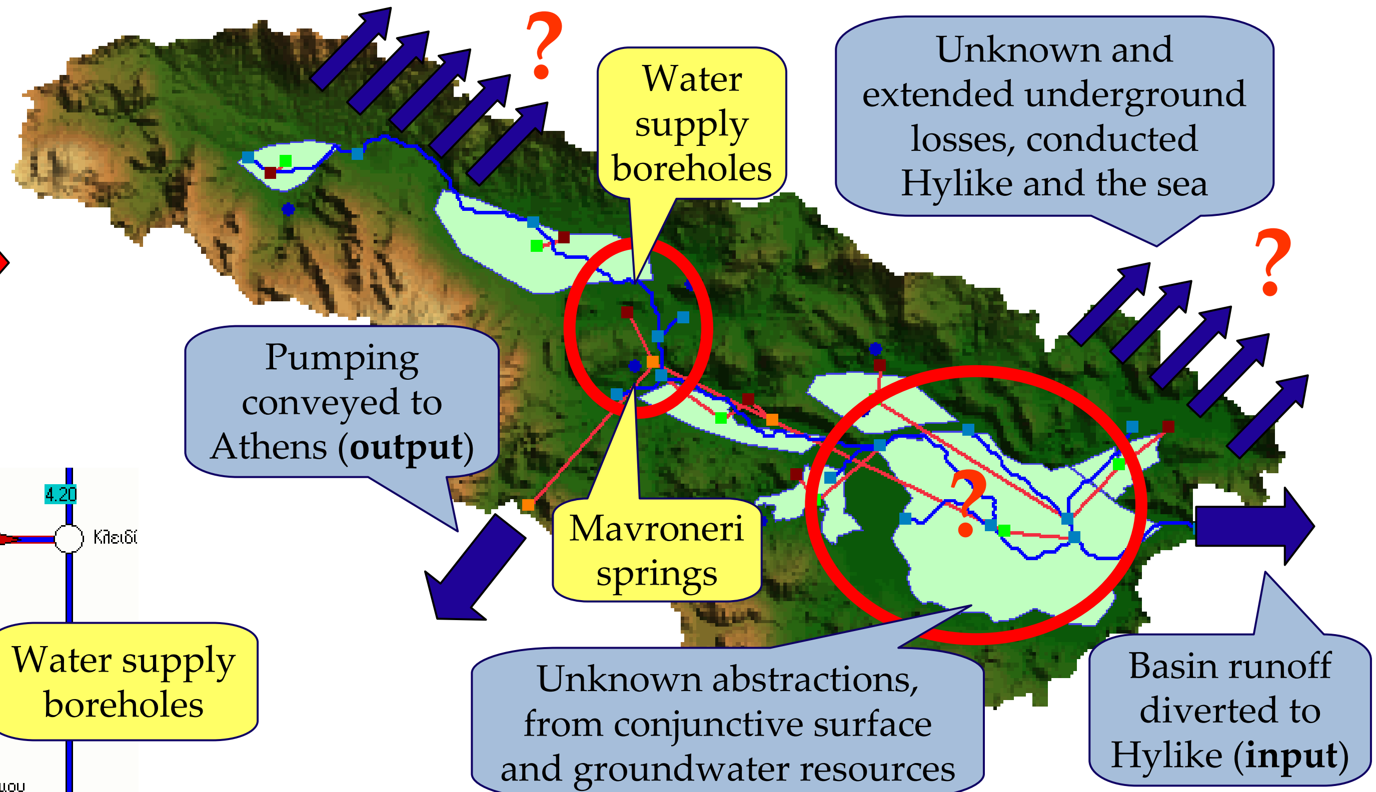
- **Problem statement**: estimation of the theoretical safe abstraction from water resources for 99% reliability, assigning unlimited flow capacity to the network, for various borehole operation policies.
- **Practical interest**: assessing the limits of the actual resources, for the long-term planning of new projects.

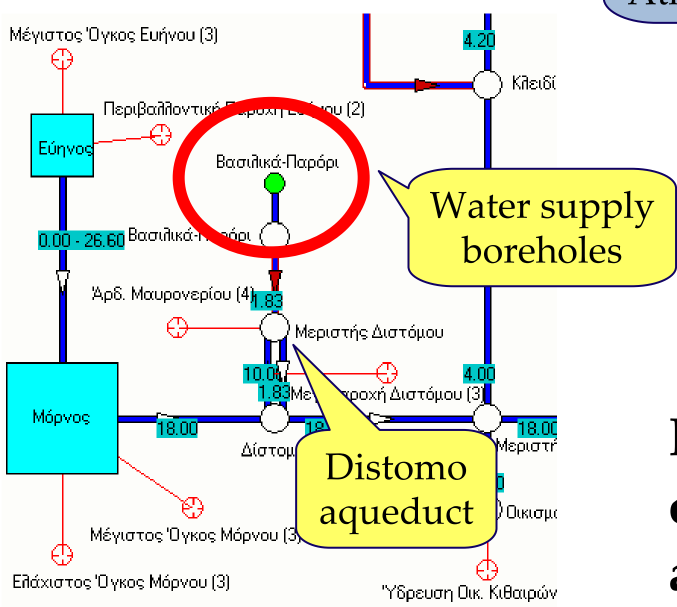


Below this limit, Hylike should be used by priority

Borehole operation policy	**Intensive**	**Normal**	**Limited**	**No pumping**
Upper usage threshold (%)	80	40	20	0
Lower usage threshold (%)	50	25	10	0
Safe abstraction for water supply (hm³)	610.0	560.0	510.0	430.0
Average abstraction from Mornos (hm³)	330.4	400.9	378.1	340.1
Average abstraction from Hylike (hm³)	183.6	140.6	128.8	93.5
Average abstraction from boreholes (hm³)	101.0	23.5	8.0	0.0
Average losses due to leakage (hm³)	82.7	113.8	125.4	143.9
Safe inflow to Athens (hm³)	530.7	487.2	443.7	374.1
Average energy consumption (GWh)	220.7	120.1	98.9	66.1

Task 5: Assessment of the impacts from the operation of Boeoticos Kephisos boreholes





Not just a management problem but a combined hydrological, hydrogeological and water management problem!

The HYDROGEIOS modelling framework

Surface hydrology module

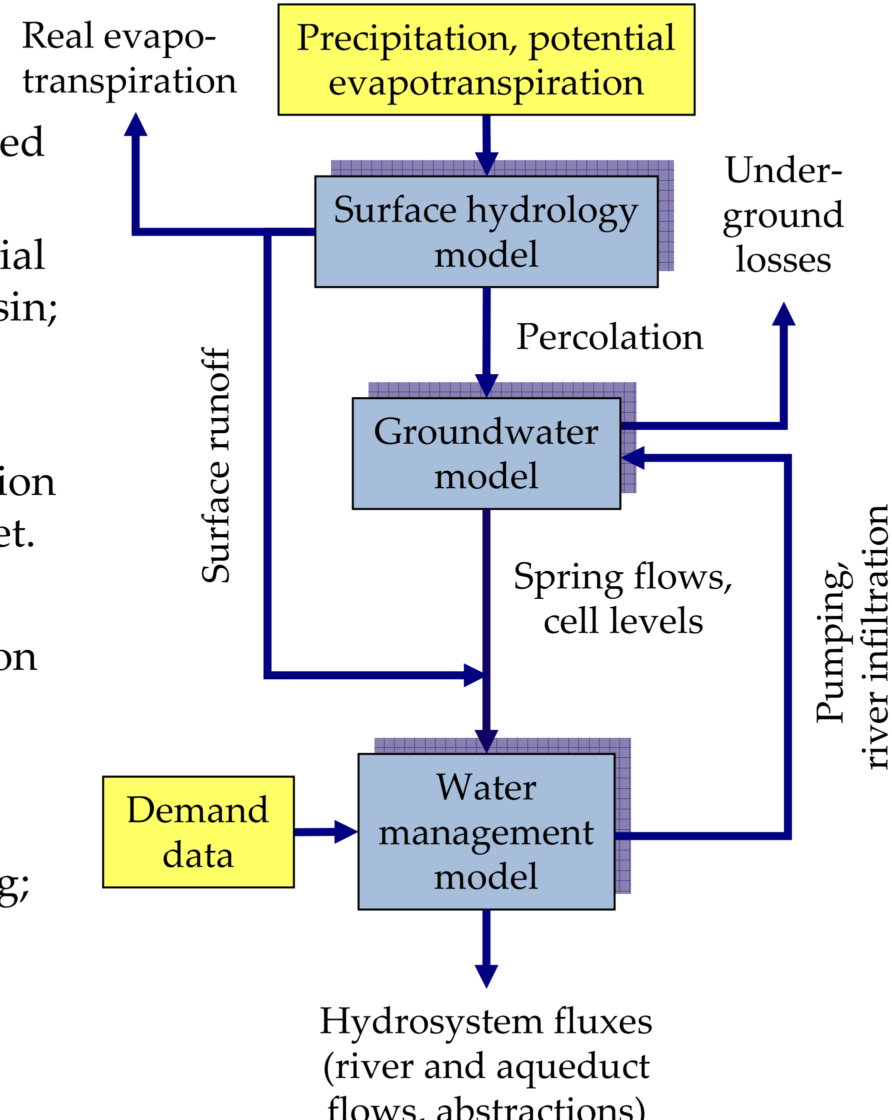
- Semi-distributed schematization;
- Conceptualization through two interconnected tanks, representing the surface processes;
- Model inputs: daily precipitation and potential precipitation (PET) data, varying per sub-basin;
- Parameterization through the hydrological response unit (HRU) concept;
- Model outputs: evapotranspiration, percolation and runoff, transferred to the sub-basin outlet.

Groundwater module

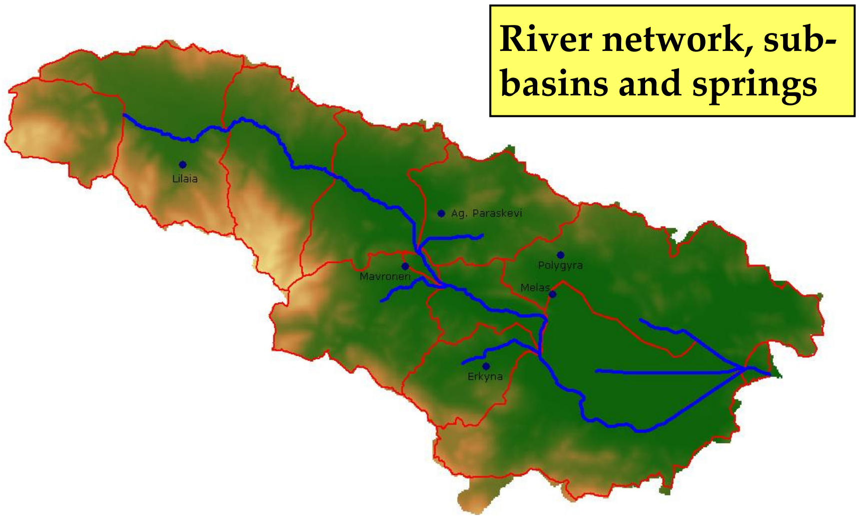
- Finite-volume approach, aquifer discretization to a limited number of polygonal cells of flexible shape;
- Darcian representation of the flow field;
- Stress data: percolation, infiltration, pumping;
- Model outputs: cell levels, spring runoff;

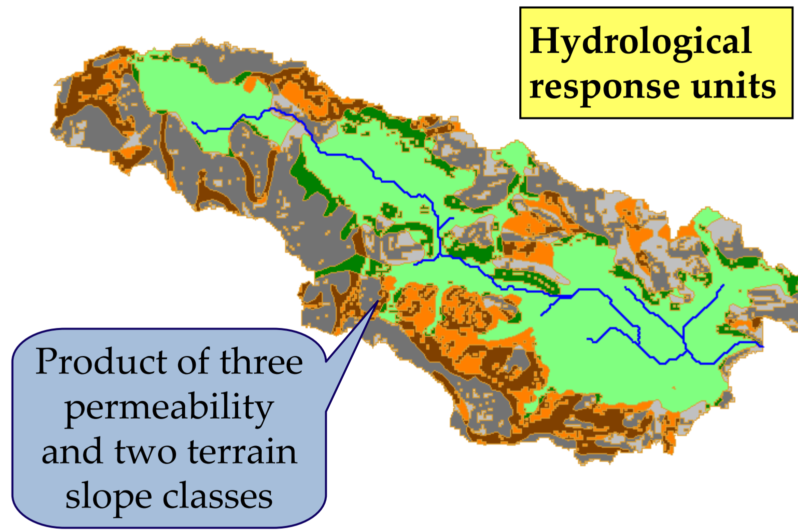
Water allocation module

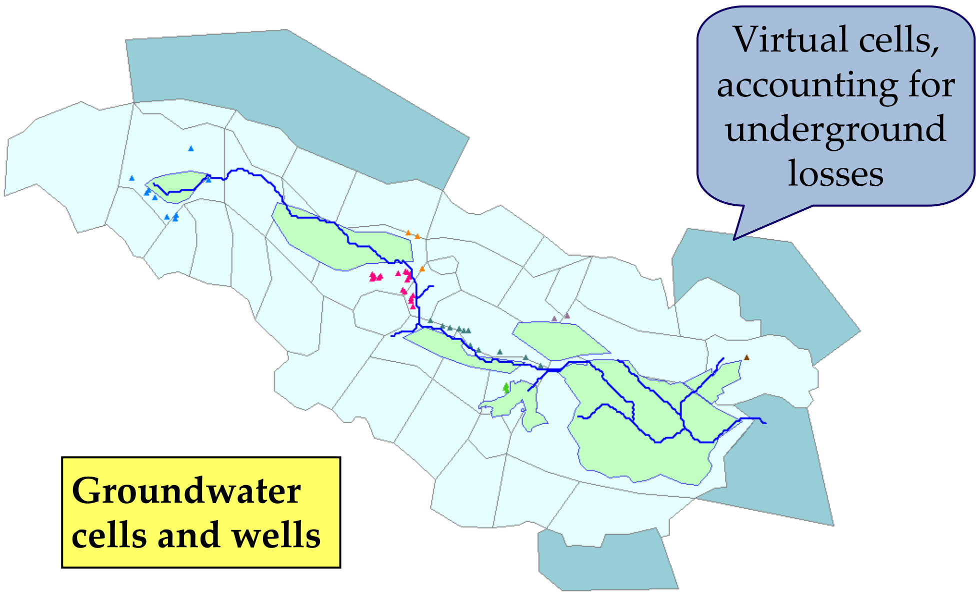
- Extension of the NLP approach, to also embrace the river network components.



Modelling the Boeoticos Kephisos basin







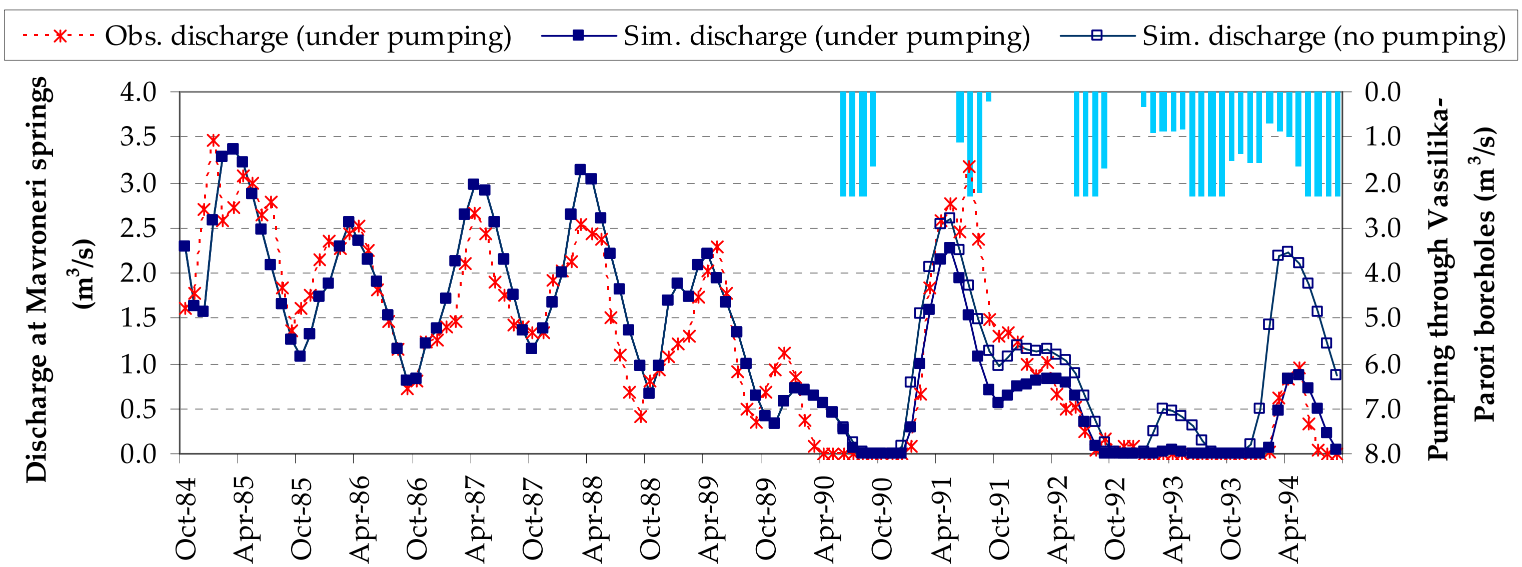
Basin area: 1956 km^2
Mean altitude: 481 m
Main course length: 102 km
Mean annual rainfall: 875 mm
Mean annual runoff: 146 mm (after abstractions; 50% is the baseflow)
Major geological formation: limestone, at most karstified (40%)

Estimation of model parameters on the basis of multiple fitting criteria

- Since the total number of parameters is 52 (36 for the surface model and 16 for the groundwater model), it is crucial to introduce **multiple criteria**, in order to respect the **principle of parsimony** thus reducing uncertainty.
- Criteria used in calibration (control period 1984-1994):
  - Efficiency of observed runoff at the basin outlet and downstream of six karst springs;
  - Additional criteria for reproducing spring flow intermittency (easily observable information of major interest in water management);
  - Penalty functions to prohibit unrealistic water level “trends”, indicating systematic evacuation or filling of groundwater tanks (piezometric data has no sense at such scales; yet these empirical criteria prohibit from illogical fluctuations of the model internal variables, i.e. groundwater storages).
- Hybrid calibration (weighted objective function)
  - Step-by-step optimization of relatively small groups of parameters;
  - Manual rejection of solutions performing poorly against even one criterion (either in calibration or in validation) or providing unreasonable parameter values;
  - Very effective while particularly time-consuming strategy, primarily driven by the hydrological experience.

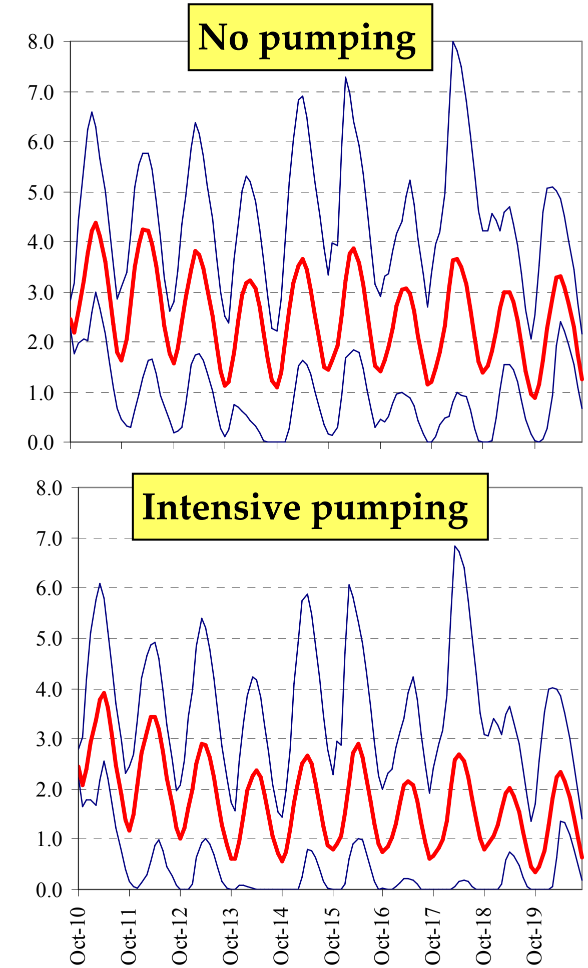
Practical issue 3: How sustainable is the exhaustive use of boreholes?

- Most of the water supply boreholes of Athens were drilled within the frame of emergent measures taken during the persistent drought from 1988 to 1994.
- The most important were drilled in the middle course of Boeoticos Kephisos basin, close to the karst springs of Mavroneri, accounting for 15% of the basin runoff, which is turn is diverted to Hylike.
- Due to the considerable reduction of rainfall and the intense pumping, the flow of Mavroneri springs was twice interrupted during 1990 and 1993, thus resulting to severe social and environmental problems.



Stochastic simulation of the basin under alternative water supply policies

- Terminating simulation; generation of 100 synthetic rainfall scenarios, of 10-year length.
- Two extreme management scenarios are examined, with regard to the operation of the water supply boreholes at the middle course of the basin, assuming (a) zero pumping, and (b) intensive pumping, during the 10-year control period.
- Regarding irrigation, the actual demand was assigned to the seven agricultural areas.
- Under the intensive abstraction policy, there is a progressive decrease of the spring outflow, which indicates that, in a long-term perspective, the intensive use of the boreholes for the water supply of Athens is not sustainable.
- **Practical interest**: evaluation of safe groundwater yield; estimation of environmental impacts and related costs, under specific pumping policies.



Simulated discharge at Mavroneri springs (mean and 80% prediction limits)

Task 6: Global optimization through the evolutionary annealing-simplex algorithm

- **Motivation**
  - Heuristic algorithm that joins ideas from different approaches (genetic algorithms, simulated annealing, downhill simplex), in order to both ensure effectiveness (i.e. accuracy in locating the optimum) and efficiency (i.e. algorithmic speed);
- **Main concepts**
  - An random population of points is generated within the search space;
  - The search space comprises internal boundaries, corresponding to user-defined limits (prior uncertainty), and external boundaries, corresponding strict mathematical limits of the control variables;
  - The population is evolved through both local and global transition rules;
  - A simplex searching pattern implements local search, while global search is implemented through mutation;
  - All transition rules embed randomness, since they contain a stochastic component;
  - Both downhill and uphill moves can be accepted according to a modified objective function $g(\mathbf{x}) = f(\mathbf{x}) + r\,T$, where $f(\mathbf{x})$ is the original function to minimize, r is a unit random number and T a "temperature" term;
  - An adaptive annealing "cooling" schedule regulates the "temperature" of the system, which determines the degree of randomness through evolution.

Synopsis of the modelling framework

- Model schematisation through a network-type representation of the hydrosystem components;
- Parameterisation of processes and controls on the basis of parsimonious structures, which are consistent with the available data;
- Conjunctive representation of hydrological and anthropogenic processes;
- Recognition of uncertainty and quantification of system risks through stochastic simulation;
- Representation of the Hurst-Kolmogorov behaviour in the modelled hydroclimatic processes;
- Faithful description of system operation and handling of all constraints through a network linear optimization approach;
- Use of effective and efficient optimization techniques to provide rational results, with reasonable computational effort;
- Formulation of calibration and optimal control problems within a multi-criteria framework.
- Interpretation of model results to provide pragmatic solutions in real-world problems.

Bibliography

- Efstratiadis, A., and D. Koutsoyiannis, An evolutionary annealing-simplex algorithm for global optimisation of water resource systems, *Proceedings of the Fifth International Conference on Hydroinformatics*, Cardiff, UK, 1423–1428, International Water Association, 2002.
- Efstratiadis, A., and D. Koutsoyiannis, One decade of multiobjective calibration approaches in hydrological modelling: a review, *Hydrological Sciences Journal*, 55(1), 58–78, 2010.
- Efstratiadis, A., D. Koutsoyiannis, and D. Xenos, Minimising water cost in the water resource management of Athens, *Urban Water Journal*, 1(1), 3-15, 2004.
- Efstratiadis, A., I. Nalbantis, A. Koukouvinos, E. Rozos, and D. Koutsoyiannis, HYDROGEIOS: A semi-distributed GIS-based hydrological model for modified river basins, *Hydrology and Earth System Sciences*, 12, 989–1006, 2008.
- Koutsoyiannis, D., A generalized mathematical framework for stochastic simulation and forecast of hydrologic time series, *Water Resources Research*, 36(6), 1519-1533, 2000.
- Koutsoyiannis, D., A. Efstratiadis, and G. Karavokiros, A decision support tool for the management of multi-reservoir systems, *Journal of the American Water Resources Association*, 38(4), 945-958, 2002.
- Koutsoyiannis, D., A. Efstratiadis, and K. Georgakakos, Uncertainty assessment of future hydroclimatic predictions: A comparison of probabilistic and scenario-based approaches, *Journal of Hydrometeorology*, 8 (3), 261–281, 2007.
- Koutsoyiannis, D., and A. Economou, Evaluation of the parameterization-simulation-optimization approach for the control of reservoir systems, *Water Resources Research*, 39(6), 1170, 1-17, 2003.
- Koutsoyiannis, D., and A. Manetas, Simple disaggregation by accurate adjusting procedures, *Water Resources Research*, 32(7), 2105-2117, 1996.
- Koutsoyiannis, D., C. Makropoulos, A. Langousis, S. Baki, A. Efstratiadis, A. Christofides, G. Karavokiros, and N. Mamassis, Climate, hydrology, energy, water: recognizing uncertainty and seeking sustainability, *Hydrology and Earth System Sciences*, 13, 247–257, 2009.
- Koutsoyiannis, D., Climate change, the Hurst phenomenon, and hydrological statistics, *Hydrological Sciences Journal*, 48(1), 3–24, 2003.
- Koutsoyiannis, D., Coupling stochastic models of different time scales, *Water Resources Research*, 37(2), 379-392, 2001.
- 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.
- Koutsoyiannis, D., Optimal decomposition of covariance matrices for multivariate stochastic models in hydrology, *Water Resources Research*, 35(4), 1219-1229, 1999.
- Nalbantis, I., A. Efstratiadis, E. Rozos, M. Kopsiafti, and D. Koutsoyiannis, Holistic versus monomeric strategies for hydrological modelling of modified hydrosystems, *Hydrology and Earth System Sciences Discussions*, 7, 8265–8308, 2010.
- Nalbantis, I., and D. Koutsoyiannis, A parametric rule for planning and management of multiple reservoir systems, *Water Resources Research*, 33(9), 2165-2177, 1997.
- Rozos, E., A. Efstratiadis, I. Nalbantis, and D. Koutsoyiannis, Calibration of a semi-distributed model for conjunctive simulation of surface and groundwater flows, *Hydrological Sciences Journal*, 49(5), 819–842, 2004.
- Rozos, E., and D. Koutsoyiannis, A multicell karstic aquifer model with alternative flow equations, *Journal of Hydrology*, 325(1-4), 340–355, 2006.
- Rozos, E., and D. Koutsoyiannis, Error analysis of a multi-cell groundwater model, *Journal of Hydrology*, 392(1-2), 22–30, 2010.

Greek glossary used

- Academic
- Acronym
- Agriculture
- Analogous
- Analysis
- Anthropogenic
- Architecture
- Arithmetic
- Atmosphere
- Automatic
- Asymmetry
- Basis
- Bibliography
- Chaos
- Characteristic
- Climate
- Code
- Cost
- Crisis
- Criterion
- Critical
- Critique
- Cycle
- Democracy
- Diachronic
- Diagnosis
- Diagram
- Dilemma
- Dramatic
- Drastic
- Dynamic
- Economy
- Ecology
- Electricity
- Emphasis
- Empirical
- Energy
- Entropy
- Ephemeral
- Epistemic
- General
- Genetic
- Generation
- Geography
- Geology
- Geometry
- Glossary
- Graph
- Graphical
- Heterogeneity
- Heuristic
- Hierarchy
- Historical
- Holistic
- Horizon
- Hybrid
- Hydrology
- Hydraulics
- Hydrometric
- Hydrograph
- Hypothesis
- Logical
- Macroscopic
- Mathematics
- Matrix
- Mechanism
- Meteorology
- Meter
- Method
- Metrics
- Metropolitan
- Monomeric
- Morphological
- Myth
- Neural
- Nomograph
- Paradigm
- Paradox
- Parallel
- Parameter
- Parenthesis
- Peripheral
- Periodicity
- Phase
- Phenomenon
- Philosophy
- Piezometric
- Plethora
- Policy
- Polygonal
- Polytechnic
- Practice
- Pragmatic
- Problem
- Programming
- Physical
- Physiographic
- Schematization
- Scheme
- Series
- Sophisticated
- Static
- Statistics
- Stochastic
- Strategy
- Symbol
- Synthetic
- Synoptic
- System
- Systematic
- Technique
- Technology
- Telemetric
- Theory
- Thesis
- Topography
- Topology
- Type
- Typical
- Utopian

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ありがとう

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