A Decision Support Tool for the Management of Multi-Reservoir Systems

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Abstract

A decision support tool is developed for the management of water resources, focusing on multipurpose reservoir systems. It is suitable for hydrosystems with multiple and often contradictory water uses and objectives. The mathematical framework is based on the original scheme parameterization-simulation-optimization. This methodology enables the decrease of the number of decision variables, making feasible the location of the optimal management policy, which maximizes the system yield and the overall operational benefit and minimizes the risk of decision-making.

Parametric vs. non-parametric optimization

✓ Owing to the parameterization method, the number of control variables becomes small, thus reducing the computational effort of the optimization process.

✓ Parametric optimization can be combined with stochastic simulation processes, allowing a detailed and faithful representation of hydrosystem's performance.

✓ There are no restrictions on the formulation of the objective function, the state equations and the constraints of the mathematical model.

✓ Control variables do not depend on inflow series but on their statistical properties.

✓ Output of the model is the optimal management policy, in terms of convenient reservoir operation rules.

✓ Once parameters are optimized, the system can be operated even without running the model with updated data.

The parameterization – simulation – optimization methodology

The optimization process

An objective function is formulated, expressing the performance measure of the management. Three different types of problems can be set:

• minimization of the total operational cost

• minimization of the failure probability, for a given set of operational goals (targets)

• maximization of the total annual withdrawal, for a given reliability level

Operational targets are classified to four major categories: a) water consumption, b) firm power generation, c) minimum flow preservation, and d) reservoir storage control. The objective function is evaluated through the simulation process. Given that the optimization problem is strongly nonlinear, advanced techniques are used, particularly the multi-start downhill simplex algorithm (Press el al. 1992) and the shuffled complex evolution method (Duan et al. 1992).

## The parametric rule for multiple reservoirs optimal control

Assuming a system of N reservoirs and a net inflow data set of length T (excluding losses due to evaporation and leakage), system dynamics at each time step t can be expressed as a set of N water balance equations of the form:

$$S_i(t + 1) = S_i(t) + I_i(t) - R_i(t)$$

where $S_i(t)$ is the storage of reservoir i, $I_i(t)$ is the net inflow, and $R_i(t)$ is the controlled release rate. Since the latter is unknown, the system has several degrees of freedom, more precisely $N \times T$. The parameterization reduces drastically this number. The main idea is to distribute the total active storage of the system V at each of the N reservoirs according to the linear rule (Nalbantis and Koutsoyiannis, 1997):

$$S_i^* = K_i - a_i K + b_i V$$

where K_i the capacity of the i reservoir, K is the total capacity of the system, a_i and b_i are unknown parameters and S_i^* stands as the target storage for the i reservoir at the end of each time step. Initial rules are corrected according to an adjusting procedure, in order to satisfy reservoir capacity constraints, and thus they become nonlinear (see figure). The final operating rule is completely determined from the initial values of parameters, irrespectively of all corrections. Therefore, the total number of control variables of the system reduces to $2N$ and becomes independent of the simulation length.
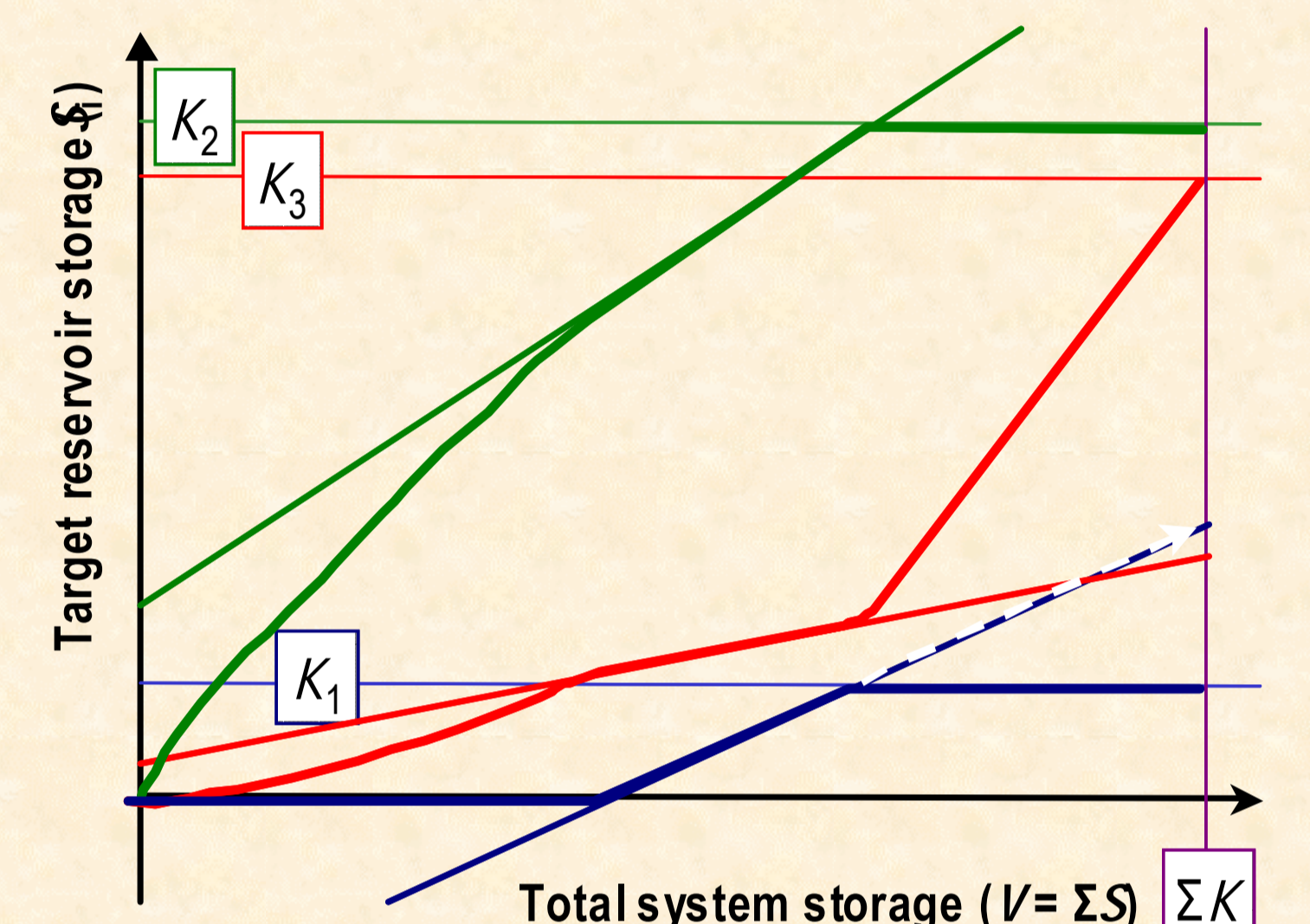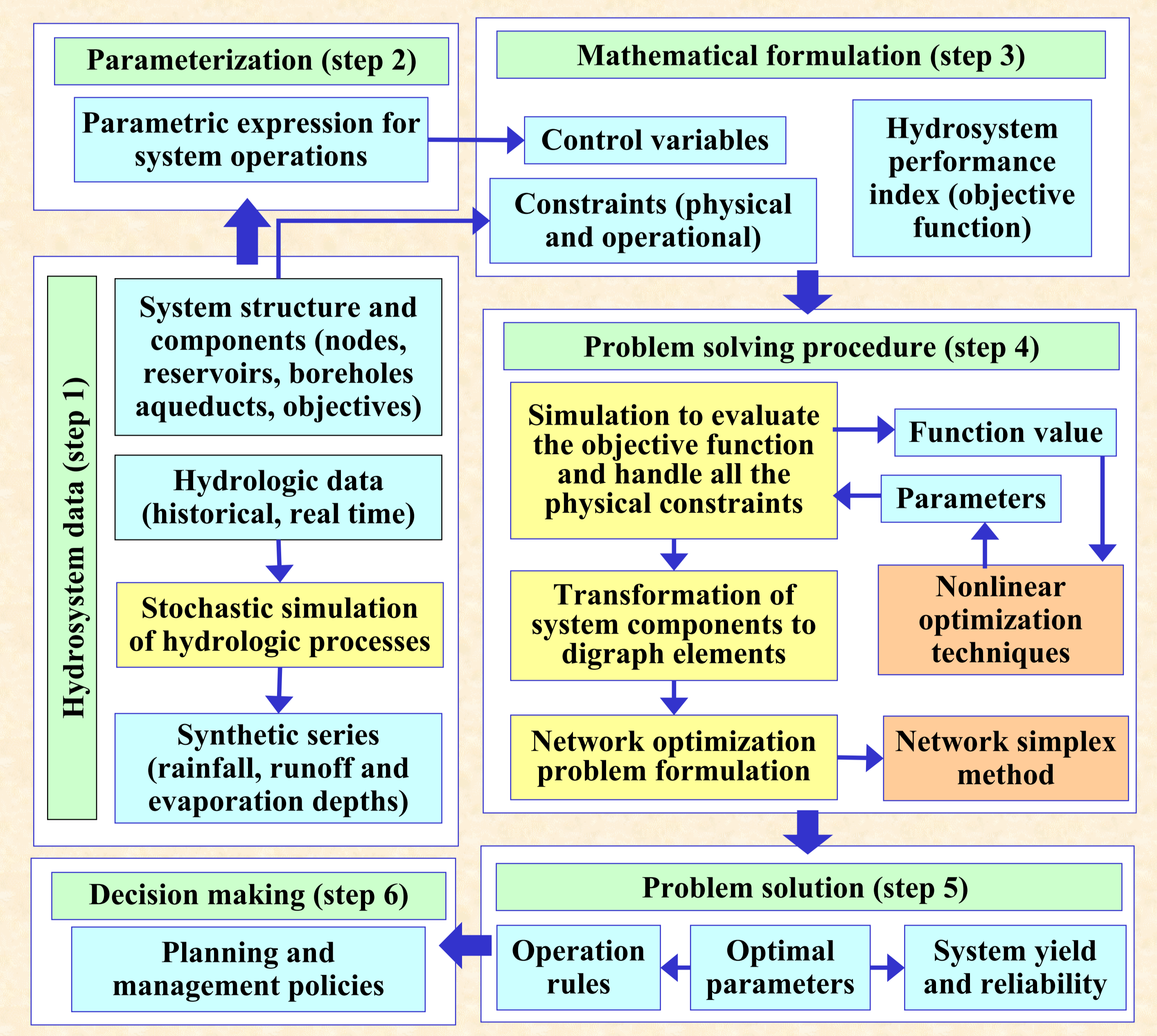
The simulation process: A network optimization approach

Actual system   *Digraph transformation*
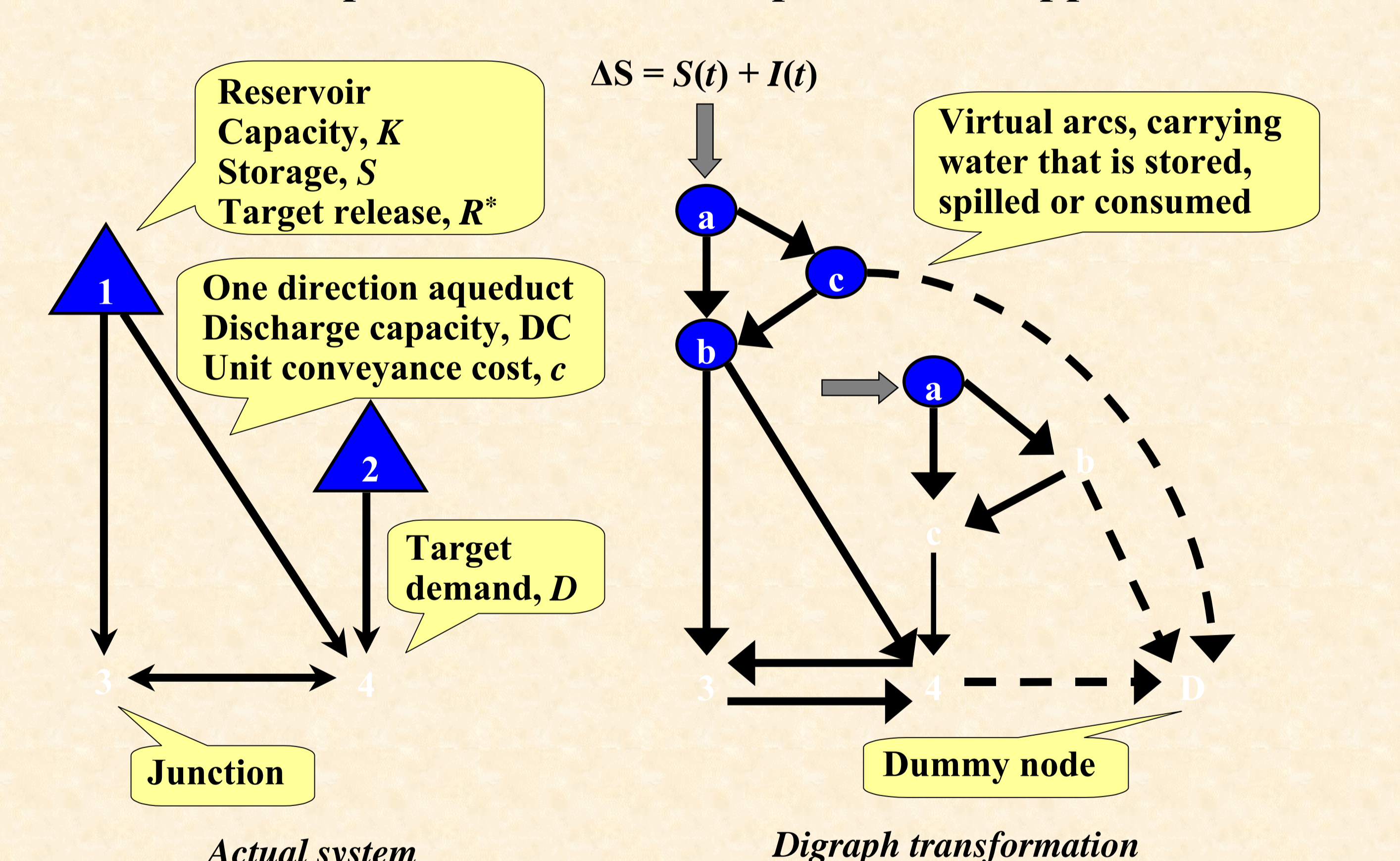
At each time step, target releases may differ from the actual ones, due to physical constraints (e.g., discharge capacity of aqueducts). Moreover, water may be conveyed in the network via multiple paths. A transshipment problem is formulated and solved, assuming that:

▪ system's components and attributes are represented in a digraph form

▪ each reservoir is replaced by three nodes, a "source", a "sink" and a "storage" node

▪ virtual pipes are used to represent each variable of the water balance equation

▪ virtual costs are imposed, in order to penalize non-optimal water transportations

▪ the sum of water that is stored, spilled or consumed is diverted to a dummy node

References

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Press, W. H., S. A. Teukolsky, W. T. Vetterling, and B. P. Flannery, *Numerical Recipes in C*, 2nd edition, Cambridge University Press, Cambridge, U. K., 1992.

# A Decision Support Tool for the Management of Multi-Reservoir Systems

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The decision support system *Hydronomeas*

- It is appropriate for simulating complex multipurpose reservoir systems and for detecting the optimal water resources management policy.

- It is easily applicable to a wide range of hydrosystems, incorporating all natural, operational, environmental and other restrictions.

- A specific characteristic is the visualization of the simulation process.

- It provides a wide range of results, including:
  - The optimal operating rule for each reservoir of the system
  - The probability of failure for each specified target
  - The analytical water and flow balance including the standard deviation value of all results
  - Energy consumption and economic results

- The software has been developed in an Object Pascal – Delphi environment. It uses a relational database and cooperates with a stochastic simulation system for the generation of synthetic hydrological time series.

Data management

Aqueduct Data

Target Data

Reservoir Data
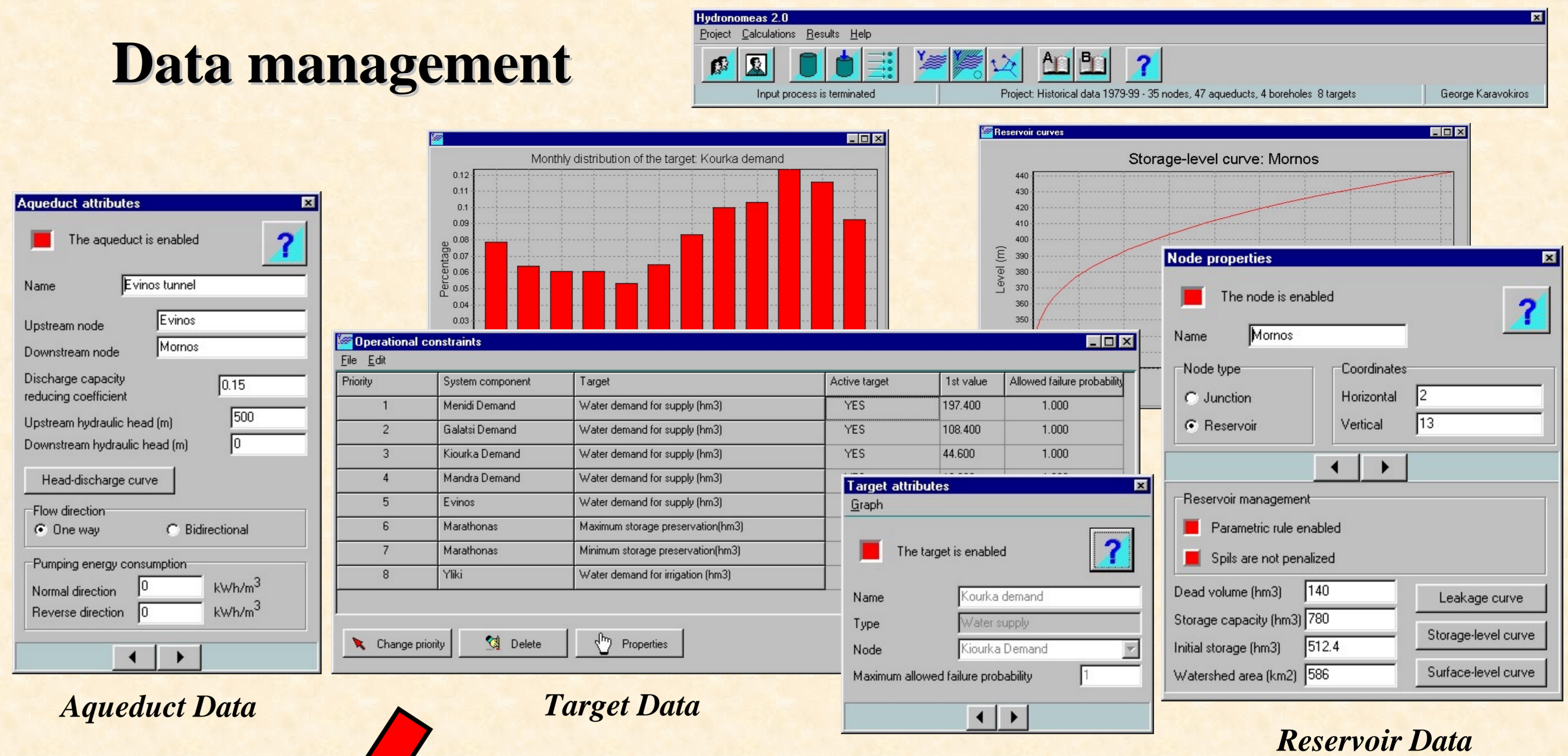
Simulation – Optimization
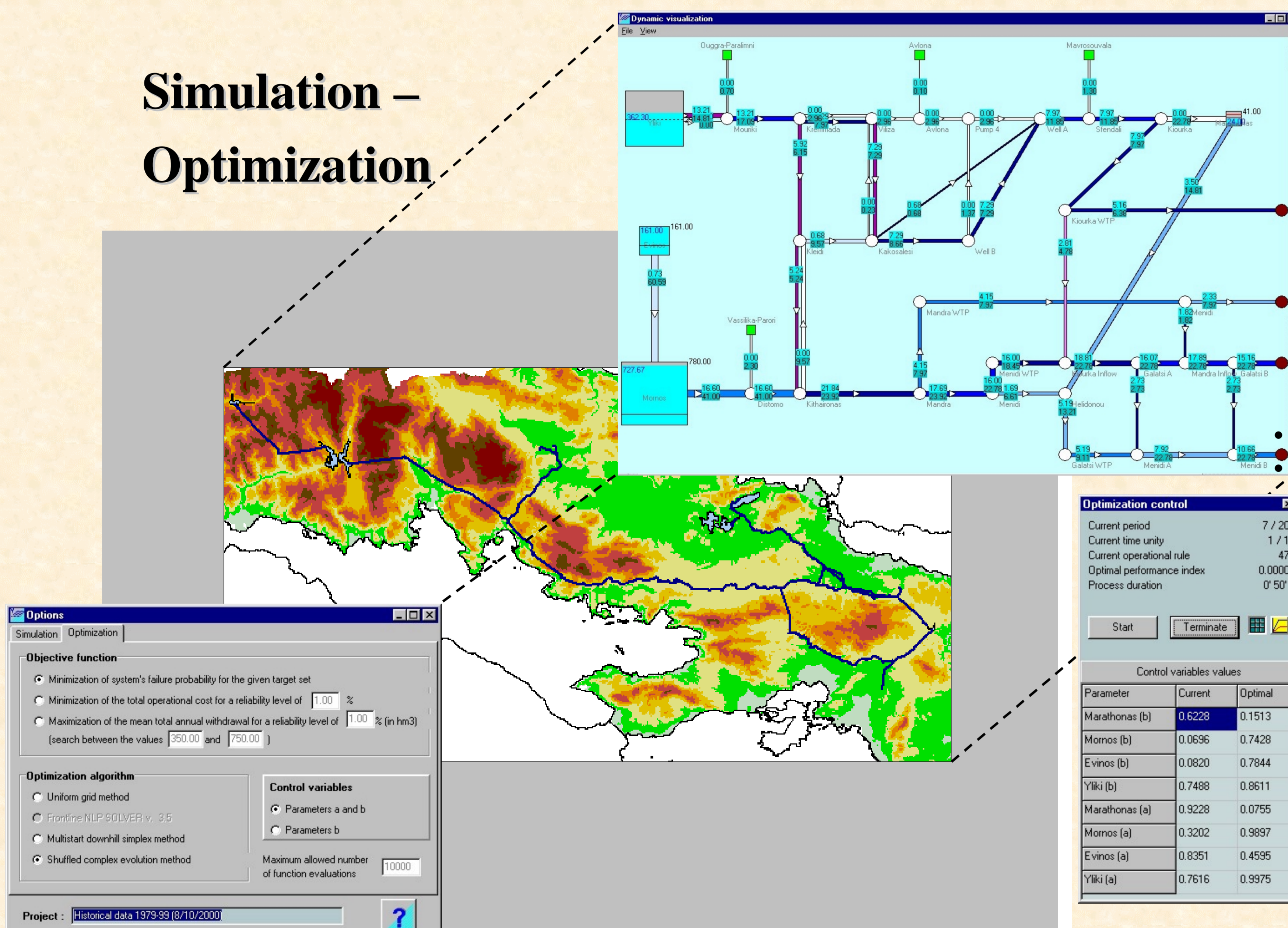
Case study: The Athens water supply system

- The system supplies water for domestic and industrial use to the metropolitan area of Athens, serving a population of 4 million people. It also provides water for irrigation and environmental protection. The total withdrawal is 370 hm^3 (year 2000).

- Surface as well as underground resources are used, although the latter are considered only as auxiliary.

- The system consists of three main reservoirs, having a total net storage capacity of 1350 hm^3 and a mean annual inflow of 850 hm^3. A fourth reservoir with capacity 40 hm^3, which is located near Athens, is used as an emergency storage.

- The reservoir system is characterized by significant losses, due to leakage and spill.

- There are two major conveyance works, a 200 km long gravity aqueduct and a 50 km long pumping pipe system.

- The persistent drought of recent years as well as the significant increase of water consumption (as high as 6% per year) shows the importance of a rational management policy, which can increase the system yield and reliability and minimize the operating cost.

- *Hydronomeas* is currently used as the main decision support tool of the water resource system of Athens.

Hydronomeas gives answers to questions such as:

- What is the maximum total withdrawal from the hydrosystem, for a given hydrologic regime and a given reliability level?

- What is the minimum failure probability in achieving a given set of operational goals, for a given hydrologic regime?

- What is the minimum cost to achieve a given set of operational goals, for a given hydrologic regime and a given reliability level?

- What are the consequences of modifications in the hydrosystem (e.g., construction of new projects), and the impacts of different management policies or hydroclimatic scenarios?

- Which will be the water availability for a short-term time horizon?

- How could the system respond to special occasions such as channel damages or an intense increase of water demand for a specific period (e.g., during the 2004 Olympic Games)?

Results

Acknowledgments

Hydronomeas was developed within the framework of the project "*Modernization of the Supervision and Management of the Water Resources System of Athens*", funded by the Athens Water Supply and Sewage Company.