LINKING HYDROINFORMATICS TOOLS TOWARDS INTEGRATED WATER RESOURCE SYSTEMS ANALYSIS – Part 1

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Session HS38: ***Hydroinformatics: computational intelligence and technological developments in water science applications***

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1. Introduction

The management of complex water resource systems requires **system-wide** decision-making and control, to fulfil multiple and often contradictory water uses and constraints, maximise benefits and simultaneously minimise risks or negative impacts. The rapidly developing area of hydroinformatics provides a variety of methodologies and tools that are suitable to solve specific computational problems and demands an integrated framework of **model co-operation and linking**. A holistic water resource systems analysis framework is presented, comprising **conceptual** and **stochastic** hydrological models, hydrosystem **simulation** models, and algorithms for both linear and non-linear **optimisation**, employed at various scales. Such an **integrated approach**, in addition to the adaptation of the principle of **parsimony** within all modelling aspects, simultaneously ensures a detailed description of the related processes and computational efficiency.

2. Main concepts on water resource systems analysis

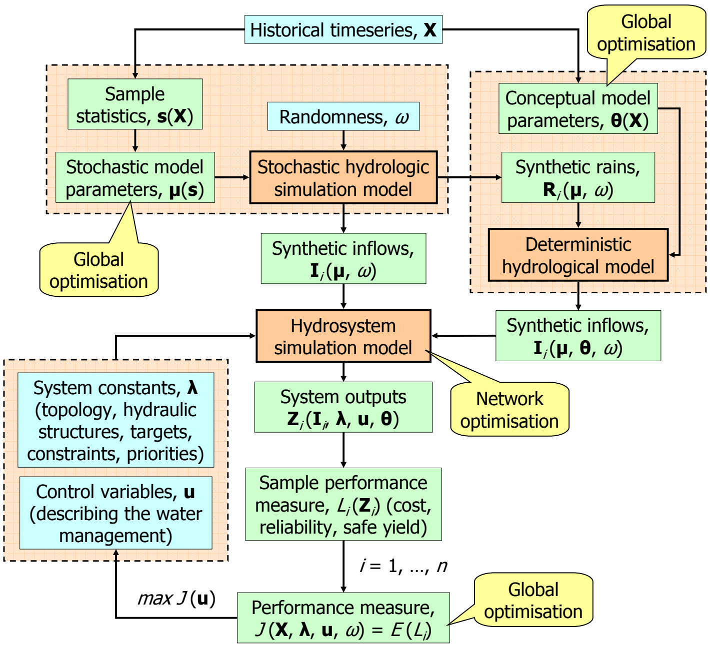
- Schematisation of hydrosystems through a network-type representation of real-world components;
- Parameterisation of processes and controls on the basis of parsimonious structures that are consistent with the available data;
- Conjunctive representation of physical and man-made processes;
- Quantification of uncertainties and risks, employing Monte-Carlo methods;
- Faithful description of system dynamics;
- Use of optimization to provide rational results within multiple modelling scales;
- Effective handling of constraints within simulation;
- Formulation of calibration and optimal control problems on a multicriteria basis.

3. The key role of stochastic simulation

Stochastic simulation is a powerful numerical mathematical technique, appropriate for complex systems, whose study based on analytical methods is laborious or even impossible.

Due to the significant **uncertainties** that are inherent in hydrosystems, among which the major is the uncertainty of future inflows, an estimate of a system's **reliability** is important for its design and operation. This implies to handle hydrological inputs as stochastic processes, thus assuming **synthetic scenarios** (either a unique series or an ensemble of series) of arbitrary length, rather than short-term historical records.

A time series of large length is suitable in **steady-state** simulations, where a low probability value has to be estimated. On the other hand, ensemble time series are used in **terminating simulations** and in **forecast problems**, where initial conditions are known; on the basis of the ensemble series, numerous future trajectories of system's outputs can be generated, thus providing estimations of expected values and confidence zones.



4. The key role of optimisation

Optimisation is an irreplaceable tool, that is used at various levels within a water resource systems analysis. Specifically, the following problems are handled through optimisation:

1. **Estimation of model parameters**: This involves the optimal parameter estimation of stochastic models for preserving the historical sample statistics, and the calibration of conceptual hydrological models, on the basis of observed responses.
2. **Allocation of hydrosystem fluxes**: At each simulated step, a network optimisation problem is formulated to handle the physical and operational constraints, to preserve priorities and to minimise costs, on the basis of the actual operation policy.
3. **Detection of optimal designs and policies**: It involves the estimation of controls corresponding to a given parameterisation of the system's design or operation and a given global performance measure.

5. Stochastic representation of hydrological processes

A stochastic generating scheme must preserve all essential statistical characteristics as well as the typical peculiarities of hydrological processes, by providing:

- Statistical consistency across multiple **time scales** (annual, monthly);
- Simultaneous representation of all processes at many locations, through **multivariate analysis**;
- Preservation of time dependencies, via appropriate autocorrelation modelling, with emphasis on **long-term persistence** (the "Hurst phenomenon");
- Preservation of **skewness** and **intermittencies**, appearing at finer scales;
- Operation in **simulation** and **forecast** mode.

The above issues have been implemented within the stochastic hydrology package **CASTALIA**, where annual time series of a generalised autocovariance structure, suitable for the description of multi-scale fluctuations, are generated on the basis of a multivariate moving average scheme, and next disaggregated to the lower (i.e. monthly) scale, using an auxiliary multivariate PAR(1) scheme.

6. Deterministic representation of hydrological processes

When past inflow records at the control sites are inadequate or even missing, or when the management practices affect significantly the observed hydrological regime of the hydrosystem, it is necessary to establish a deterministic hydrological model providing rational estimates of inflows, on the basis of precipitation and other meteorological data.

An innovative tool, named **HYDROGEIOS**, was recently developed to represent the hydrological processes and the man-made interventions in complex hydrographic networks, following a semi-distributed approach. Its main advantages are:

- Conjunctive representation of **surface** and **groundwater** processes;
- **Physically-based** approach, but within a **parsimonious structure**;
- Limited requirements regarding **hydrological** and **geographical data**;
- **Network representation** of water management components, thus ensuring full compatibility with the schematisation of the hydrosystem control model;
- Incorporation of parameter estimation tools for **multicriteria calibration**.

LINKING HYDROINFORMATICS TOOLS TOWARDS INTEGRATED WATER RESOURCE SYSTEMS ANALYSIS – Part 2

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7. Representation of hydrosystem structure

The fundamental components of water resource systems include major hydraulic structures for **surface and groundwater abstractions**, and also **conveyance** facilities. They also include the **watershed** as a source of water as well as the physical aquatic **environment** and the associated **ecosystems**. In the proposed framework, recently implemented within the software package **HYDRONOMEAS**, the hydrosystem schematisation is based on a **network-type** representation of real-world components, comprising:

- the hydrographic network;
- water storage components (reservoirs);
- groundwater facilities (represented as groups of boreholes);
- conveyance facilities (pipes, channels, pumps);
- hydropower units;
- demand sites and other control points (nodes).

Apart from the topology, **static input data** for each component includes capacity, cost/benefit and energy information. Dynamic data refers to **inflow forecasts**, either generated directly (through the stochastic hydrological model) or indirectly (through an off-line cooperation of stochastic and deterministic models).

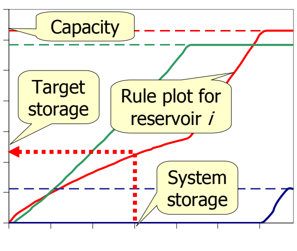
8. Representation of hydrosystem operation

Except in very simple structures, the operation of a typical hydrosystem involves numerous **degrees of freedom**, by means of alternative choices regarding abstractions and water transportation paths. Hence, a mathematical representation of water resources management is required, to specify a consistent allocation of all **hydrosystem fluxes** at each computational step.

The hydrosystem operation is expressed on the basis of **targets** and **controls**, both referring to consumptive (e.g., water supply, irrigation, etc.) and non-consumptive (e.g., firm power generation, etc.) water uses, as well as storage and discharge constraints, assigned a specific **priority hierarchy**. However, target values are **a priori** specified, whereas control values are unknown and are derived **a posteriori**, through the optimisation of a global performance measure of the system. Therefore, control components express a **parameterisation** of the operation policy, given that the related constraint values are parameters of a global optimisation problem.

9. Parameterisation for multi-reservoir systems control

Apart from the storage control constraints, HYDRONOMEAS provides additional flexibility regarding reservoir management, by means of **parametric operation rules**. The latter specify the desirable allocation of storages as a function of the total water availability (the actual state of the system) and the reservoir properties. This scheme is consistent with the **parsimonious** approach in the formulation of the global optimisation problem, since only two parameters per reservoir are assigned.



10. Evaluating water control policies

A set of **numerical criteria** are specified to evaluate the performance of a specific operation policy. HYDRONOMEAS provides a variety of criteria, regarding:

- reliability measures, for steady state and terminating simulations;
- economical issues;
- hydropower generation, distinguishing firm and secondary energy;
- safe yield, for given reliability levels.

The above criteria can be combined within either a scalar or a vector objective function expressing a **global performance measure** against the model controls.

11. Optimising hydrosystem fluxes within simulation

For a **given operation policy** (known values of control variables), the allocation of system fluxes may be still undefined, due to one or more of the following reasons:

- insufficient discharge capacity of the downstream aqueduct network, to convey the desirable abstractions;
- existence of alternative flow paths, with different costs and/or benefits (due to the existence of pumping and/or to hydropower components);
- existence of multiple and contradictory water uses and constraints;
- insufficient inflows to fulfil demands or insufficient capacity to store inflows.

The above problem is formulated as a **transhipment model**, through a **digraph representation** of water balance components within each simulation step. This schematisation preserves the hydrosystem topology, where **artificial components** (nodes and arcs) are also assigned to represent various water management issues. Consistency is ensured through the assignment of **virtual capacities** and **unit costs**. Costs may be either positive or negative, in order to penalise or favour, respectively, specific water allocations. HYDRONOMEAS implements an automatic procedure for evaluating unit costs, which provides:

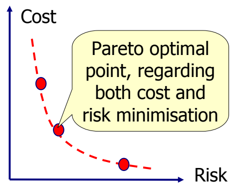
- strict preservation of physical constraints;
- preservation of targets and controls, according to the specified priority order;
- optimisation of real economical issues (pumping costs, hydropower benefits).

The network-type formulation of the problem, in addition to the sparse format of constraint matrices (i.e., continuity equations), enables the use of **very fast linear optimisation algorithms**. Thus, the proposed approach ensures both **accuracy** regarding the representation of processes and computational **efficiency**.

12. Locating the optimal management policy

The optimal water management policy derives from the maximisation of the performance measure, i.e. by solving a **nonlinear optimisation** problem.

If the system's performance is expressed on a multiobjective basis, alternative policies are detected, lying on the **Pareto front** of the corresponding vector objective function. From a mathematical point-of-view, these policies are equivalently acceptable.



13. Effective handling of global optimisation problems

Hydrological calibration and hydrosystem control are of the most challenging global optimisation problems, both involving irregular response surfaces and relatively high-dimensional spaces. In the proposed framework, these are handled through the **evolutionary annealing-simplex** method, whose the main concepts are:

- an evolutionary searching strategy;
- a set of combined (both deterministic and stochastic) transition rules, either downhill or uphill, mainly implemented within a simplex-based evolving pattern;
- an adaptive annealing cooling schedule that regulates the "temperature" of the system, thus controlling the degree of randomness through the evolution.

The algorithm was generalised to handle **multicriteria** problems. Its main issue is the incorporation of an evaluation procedure, based on a ranking scheme and a "feasibility" concept, to guide the search towards desirable areas of the Pareto front. The evolution scheme is quite similar to the original annealing-simplex procedure, albeit some transitions are prohibited to ensure diversity within population.

Acknowledgments – Contact info

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