CONTROL OF UNCERTAINTY IN COMPLEX HYDROLOGICAL MODELS VIA APPROPRIATE SCHEMATISATION, PARAMETERISATION AND CALIBRATION – Part 1: Theory

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Session HS4/9: *Hydrological modelling strategies across scales: Model parameterisation, comparison and ensembles*

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1. Introduction

The recent expansion of complex, distributed modelling schemes makes the traditional **parameter estimation** problem via optimisation extremely difficult to handle. Recent advances provide a variety of mathematical techniques to quantify the uncertainty of model predictions. These aim to discover "promising" trajectories of the model outputs that correspond to multiple, "behavioural" parameter sets, rather than a single "global optimal" one. Yet, their application indicates that it is not unusual the case where **model predictive uncertainty** is comparable to the typical statistical uncertainty of the measured outputs, thus making the model validity at least questionable. Uncertainty is due to **multiple sources** that are interacting in a chaotic manner. Some of them are "inherent" and therefore unavoidable, whereas other may be controllable via appropriate **schematisation**, **parameterisation** and **calibration**. The above issues are discussed on the basis of a conjunctive modelling scheme, applied to two complex hydrosystems of Greece.

2. Current trends in hydrological modelling

- Detailed temporal and spatial scale of modelling;
- Physically-based approach (even applicable in ungauged basins);
- Increased requirements regarding distributed geographical data;
- Conjunctive handling of surface and groundwater processes;
- Coupling with climatic, management, water quality and hydrodynamic models;
- Generation of multiple fluxes at multiple watershed sites;
- Real-time operation, for forecasting purposes.

High computational effort + Enormous requirements for data + Huge number of degrees of freedom ⇒ **Estimation of parameters?**

3. Sources of uncertainty

- Bad representation of processes or missing of processes, due to under-parameterisation;
- Formulation of too complex structures that cannot be supported by the existing data (over-parameterisation);
- Change of watershed characteristics (due to urban development, deforestation, etc.);
- Measurement errors;
- Temporal and spatial variability of processes;
- Construction of model inputs on the basis of auxiliary data (e.g. stage → discharge, temperature → evaporation, etc.)
- Model fitting on non-representative data;
- Unknown initial conditions;
- Use of fitting criteria that are inconsistent with the statistical structure of errors;
- Weaknesses of global optimisation algorithms to handle so rough response surfaces, especially in high-dimensions.

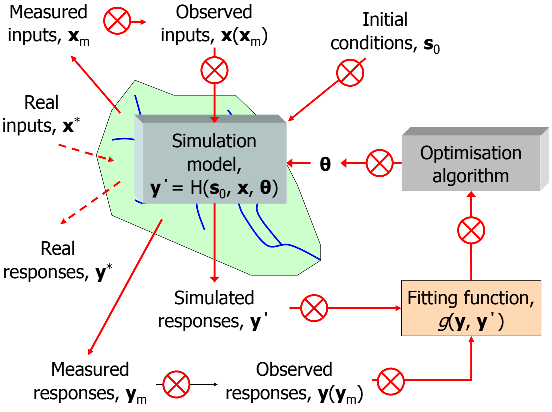

***Figure 1**: The calibration procedure through optimisation as a "mathematical game" of recycling errors and uncertainties.*

4. Uncertainty, equifinality and global optimisation

The **equifinality** concept refers to the generation of alternative optimal parameter sets, on the basis of different model structures, calibration data, single fitting criteria or combinations of them.

The hydrological community recognises that it is impossible to detect a "global" optimal model structure neither a "global" optimal parameter set, which definitely better reproduce the entire hydrological regime of a basin. Hence:

- uncertainty is **unavoidable**;
- the optimisation, as an **automatic** procedure, fails to handle the calibration problem.

The traditional model calibration problem is thus formulated from a new point-of-view, asking to:

- **control uncertainties** though appropriate model schematisation and parameterisation;
- better quantify **model predictive capacity**;
- provide a **best-compromise** parameter set, in order to be used for operational purposes.

5. Key issues on schematisation and parameterisation

The adaptation of the **principle of parsimony** within the schematisation and parameterisation procedure may help to reduce some of the model uncertainties. The former refers to the **spatial discretisation** of the system under study, whereas the latter refers to the correspondence of model free variables to its **physical characteristics**. Usually, the two concepts are confused, thus leading to over-parameterised schemes.The key-points for formulating parsimonious schemes are:

- Keeping the simplest model structure, to emphasise on the representation of the processes required by the study;
- Using as many parameters as they can be explained by the available "knowledge" on the system (regarding data and experience).

The above issues are consistent with the concept of **conceptual semi-distributed** models.

6. Towards a multiobjective approach

It is true that…	**Therefore we demand…**
The increased modelling requirements require too many parameters	Taking into account **multiple criteria**, to be consistent with the model parameterisation
Fully- and semi-distributed schemes generate multiple responses, at multiple sites	**Simultaneous fitting** of all measured fluxes, to describe the heterogeneity of processes
Multiple fitting criteria, when are aggregated into a single measure, introduce significant subjectivity to the optimisation procedure	Separate handling of the contradictory fitting criteria via **vector optimisation**, to avoid numerical scaling problems, due to the arbitrary aggregation
The various uncertainties affect in a complex manner the calibration procedure	The detection of **error sources** and the systematic investigation of their **interactions**
Optimisation algorithms are troubled when handling high-dimensional and highly nonlinear response surfaces	To significantly restrict the parameter bounds, to conduct search towards the **promising areas** of the search space

7. Calibration principles for establishing robust models

A conceptual model is characterised robust when:

- it ensures the reproduction of all possible system behaviours, with satisfactory accuracy;
- its parameters are representative of the "macroscopic" properties of the basin.

A robust calibration involves the exploitation of all **available information** about the system and the incorporation of **hydrological experience** within the optimisation procedure, by means of:

- formulating the fitting criteria;
- selecting the parameter boundaries;
- detecting the best compromise parameter set.

A **multiobjective framework**, involving the generation of representative Pareto-optimal sets, may be an additional tool, regarding:

- the investigation of acceptable trade-offs;
- the "trapping" of the best-compromise parameter set.

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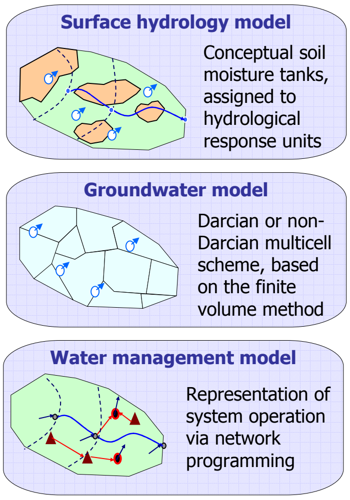
8. Hydrological simulation via the HYDROGEIOS model



Surface hydrology model

Conceptual soil moisture tanks, assigned to hydrological response units

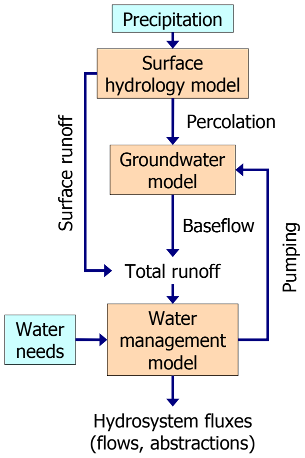
Groundwater model

Darcian or non-Darcian multicell scheme, based on the finite volume method

Water management model

Representation of system operation via network programming

***Figure 1**: Modelling components*



Precipitation

Surface hydrology model

Percolation

Groundwater model

Baseflow

Surface runoff

Total runoff

Pumping

Water needs

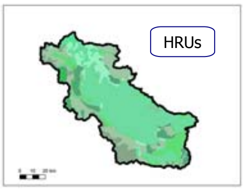
Water management model

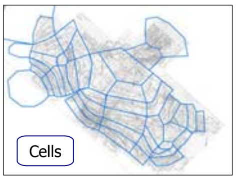
Hydrosystem fluxes (flows, abstractions)

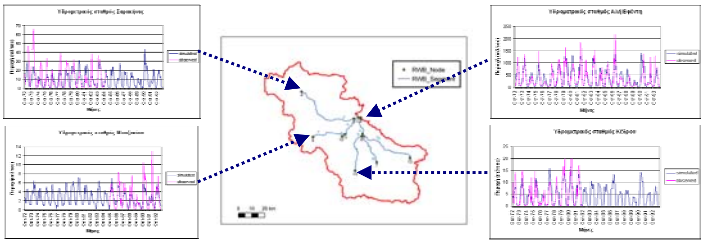
***Figure 2**: Simulation flowchart*

9. Application to the Western Thessaly hydrosystem

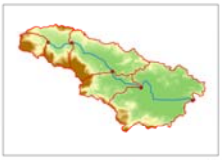
- Watershed area of 6087.5 km^2, lying on 3 prefectures.
- Extended irrigated areas supplied by both surface and groundwater resources, as well as by water diverted from the neighbouring Plastiras reservoir.
- Relatively poor infrastructures but many authorities, with different interests, involved in water management.
- Main modelling issues:
  - 12 sub-basins, 12 river segments;
  - 9 hydrological response units (HRUs), by combining permeability and land cover maps;
  - 48 groundwater cells, formulated on the basis of the average piezometric map;
- Control period: 1973-93 (half for calibration)
- Model parameters (100 in total) were estimated using a weighted function, comprised of:
  - the determination coefficients of 5 hydrographs and 11 water table series;
  - the bias of the average spring flow;
  - trend penalties for the rest of groundwater tanks;

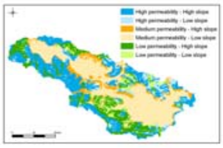

HRUs


Cells

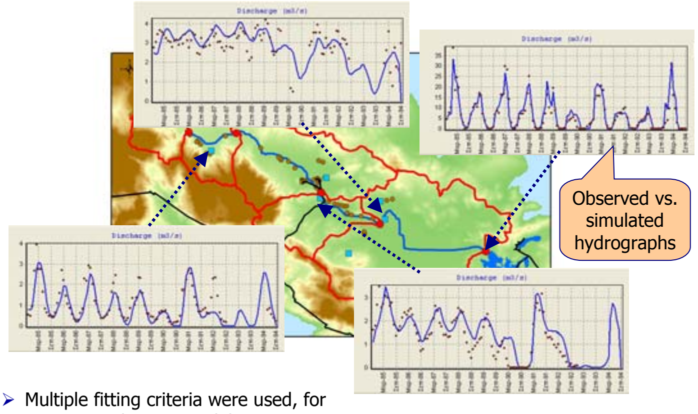


10. Application to the Boeoticos Kephissos river basin



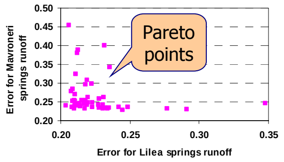


- Watershed area of 1950 km^2, with:
  - highly non-linear interactions between surface and groundwater processes and man-made interventions;
  - conjunctive water uses, affecting drastically the hydrological regime of rivers and springs;
  - extended sea losses due to the karstic background.
- Main modelling issues:
  - semi-distributed schematisation of the river network, divided to 5 sub-basins;
  - 6 hydrological response units, by combining soil permeability and terrain slope maps;
  - aquifer discretisation in 30 cells;
  - representation of water management issues (costs, demands, borehole capacities), on a network basis.
- Observed series: daily discharge measurements at the basin outlet (Karditsa tunnel), sparse (1-2 per month) discharge measurements at six main karstic springs
- Control period: 1984-94 (first 6 years for calibration)

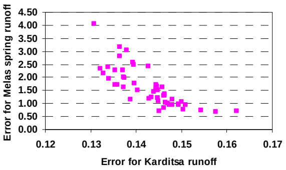


Observed vs. simulated hydrographs

- Multiple fitting criteria were used, for estimating the 105 model parameters:
  - determination coefficients and bias for the 7 hydrographs (outlet + springs);
  - penalties for not preserving intermittencies;
  - trend penalties for all groundwater levels.
- A hybrid strategy was carried out, using both single- and multiobjective optimisation tools, to locate a best compromise parameter set that ensures: (a) satisfactory fitting to all measured responses, (b) realistic reproduction of non-measured responses, and (c) parameter values that are consistent with the "macroscopic" physical characteristics of the basin.



Pareto points



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