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Session HS3 - Parameter estimation and uncertainty assessment in hydrological modelling: New approaches and future directions

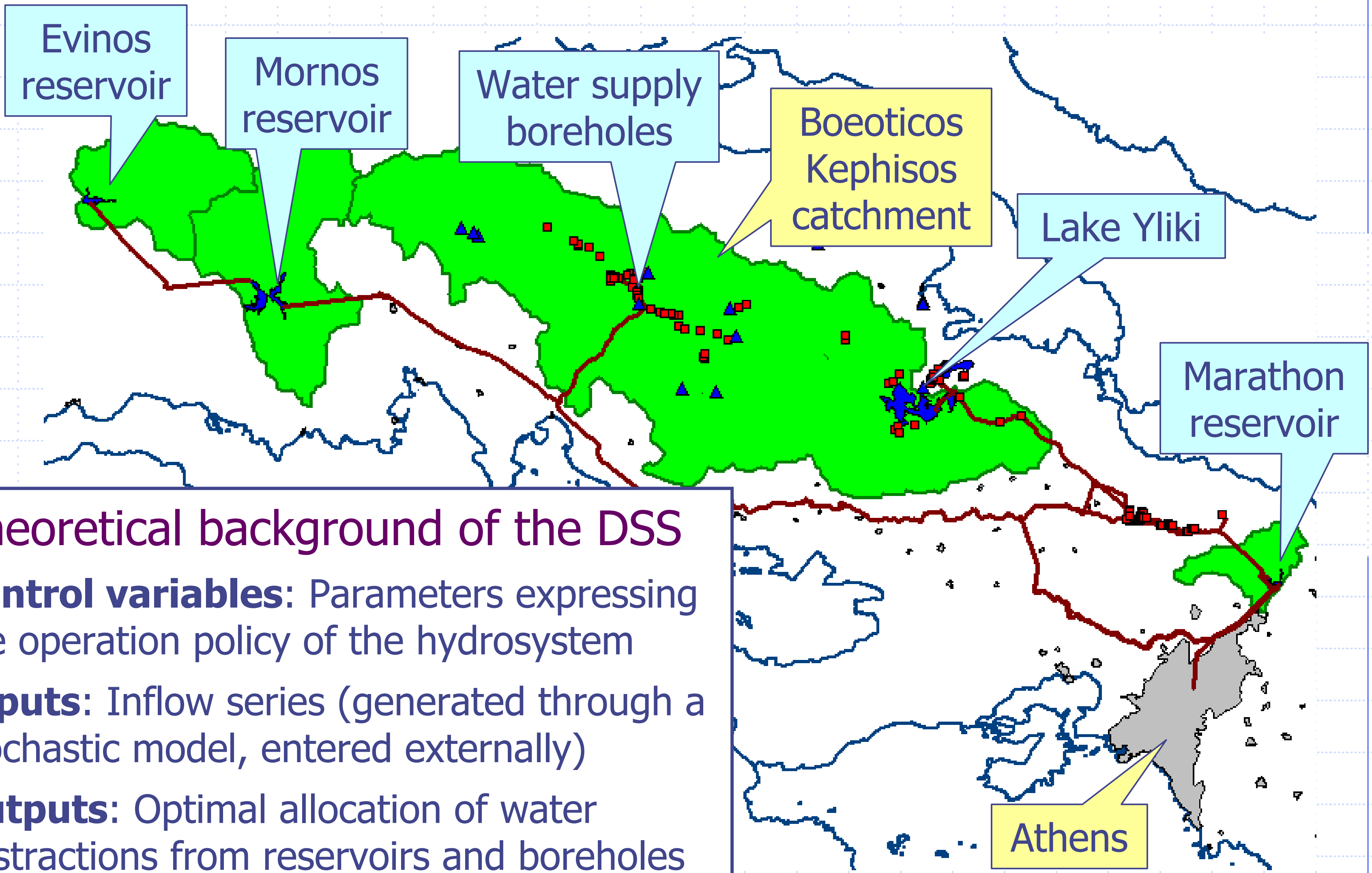
Calibration of a conjunctive surface-groundwater simulation model using multiple responses

A. Efstratiadis, D. Koutsoyiannis, E. Rozos & I. Nalbantis

Department of Water Resources

National Technical University of Athens

The motivation: A DSS for the management of the water supply system of Athens



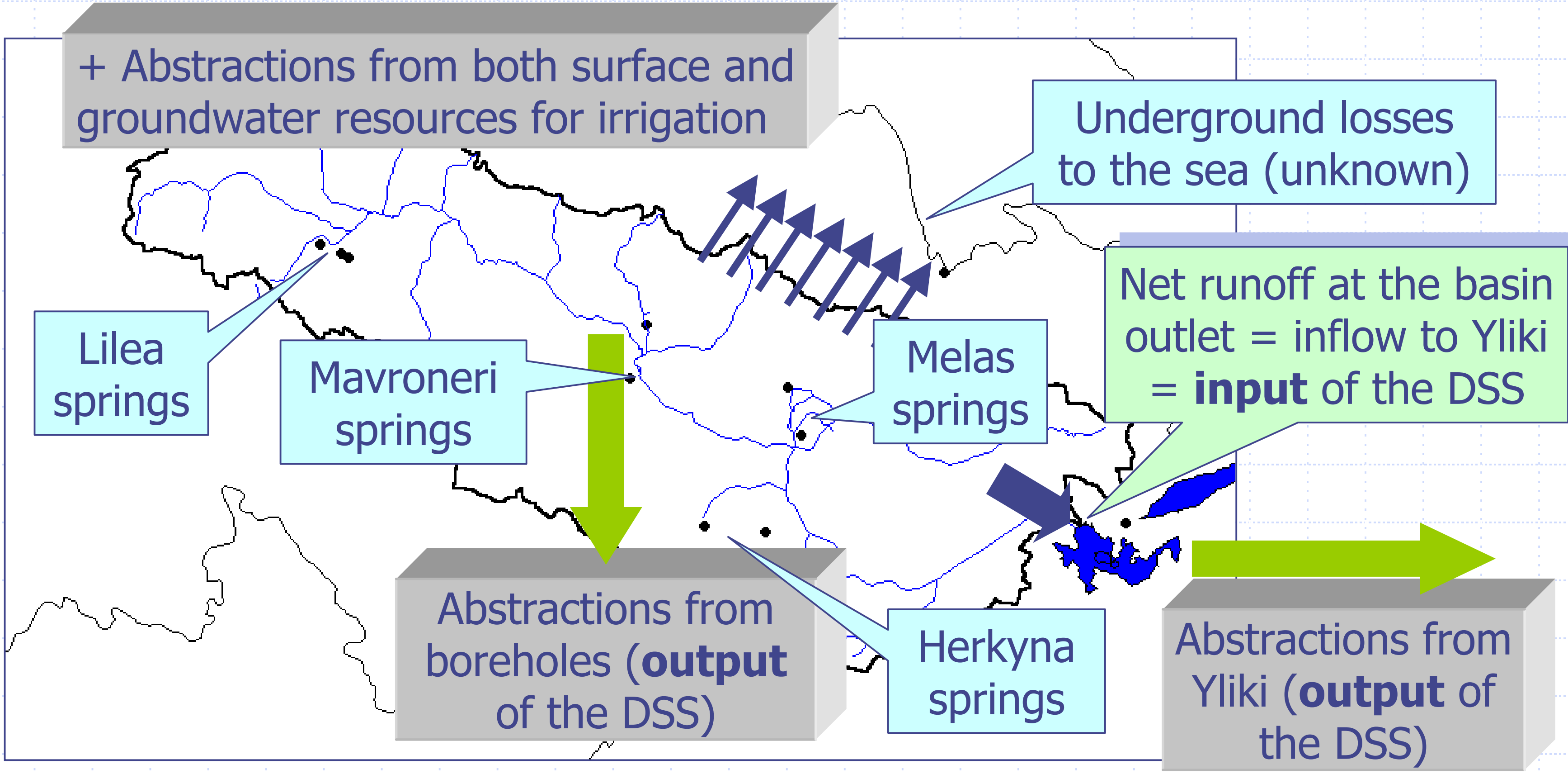
Theoretical background of the DSS

Control variables: Parameters expressing the operation policy of the hydrosystem

Inputs: Inflow series (generated through a stochastic model, entered externally)

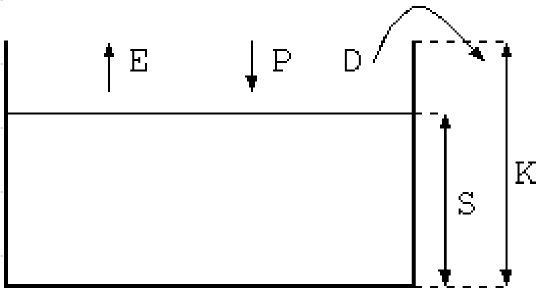
Outputs: Optimal allocation of water abstractions from reservoirs and boreholes

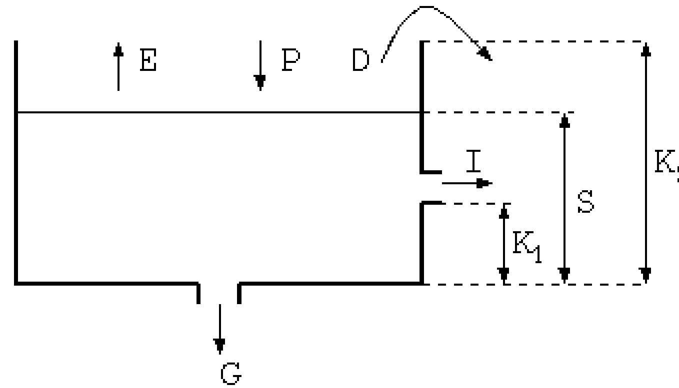
The Boeoticos Kephisos catchment: Why conjunctive simulation?



Scope of the study: Establishment of a simulation model to predict the actual inflow to Lake Yliki (compising of flood and spring runoff), for specific water supply and irrigation needs, fulfilled via both surface and groundwater resources

Simulating surface hydrological processes via a modified Thorthwaite model





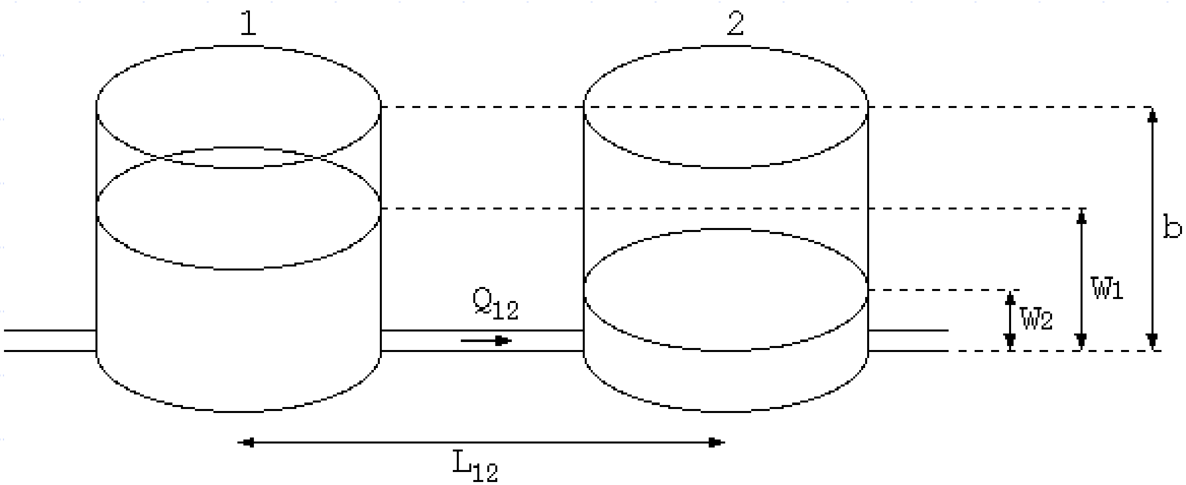
The original model

- Estimates the direct (flood) runoff and the actual evapotranspiration
- Uses a single parameter (soil moisture reservoir capacity)
- Suitable for basins without groundwater
- Allows all rainfall be evaporated within a monthly time step, if it is less than the potential evapotranspiration

The modified model

- Estimates also the interflow (time-lagged runoff) and deep percolation
- Uses three additional parameters (interflow threshold, percolation and interflow retention rates)
- Enables ponding (spill occurs after all processes are implemented)
- Prohibits direct evaporation of all rain falling within a monthly step

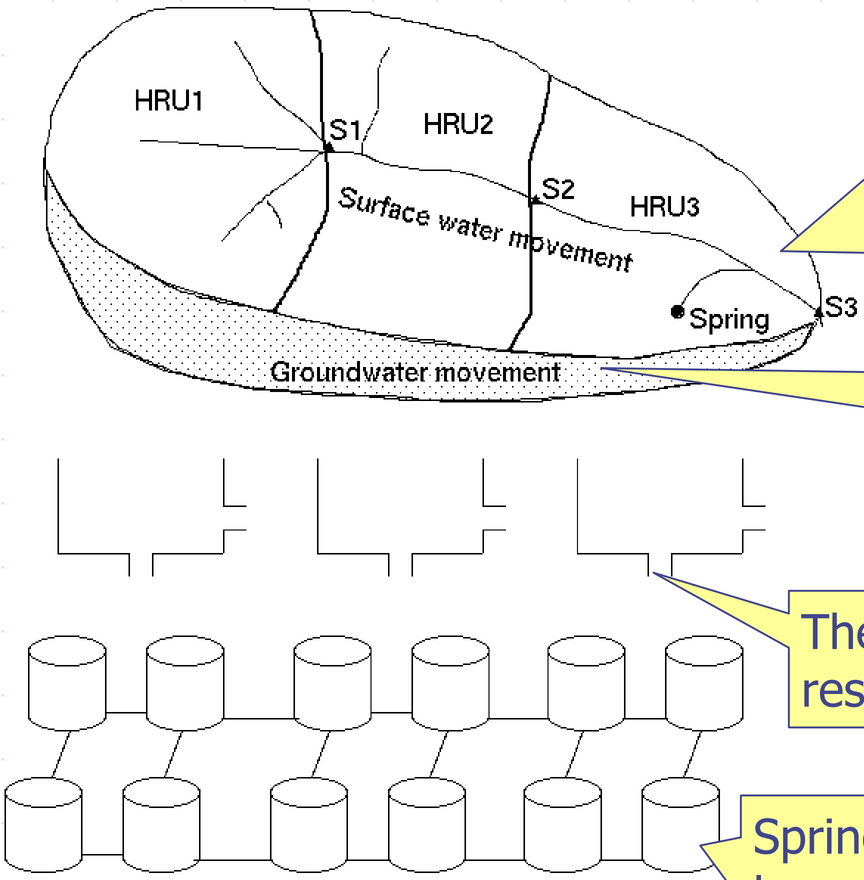
The groundwater simulation model



Main assumptions

- Based on the concept of multi-cell models
- The aquifer is represented as a network of storage elements (tanks) and transportation elements (conduits)
- Discharge between tanks follows Darcy's equation
- The water allocation problem is solved via an explicit numerical scheme, using a small time step that is adapted to achieve the optimum speed and stability
- The stress series (percolation and pumping), usually defined at a higher time level (e.g. monthly), are uniformly distributed in time

Model integration within a conjunctive simulation scheme



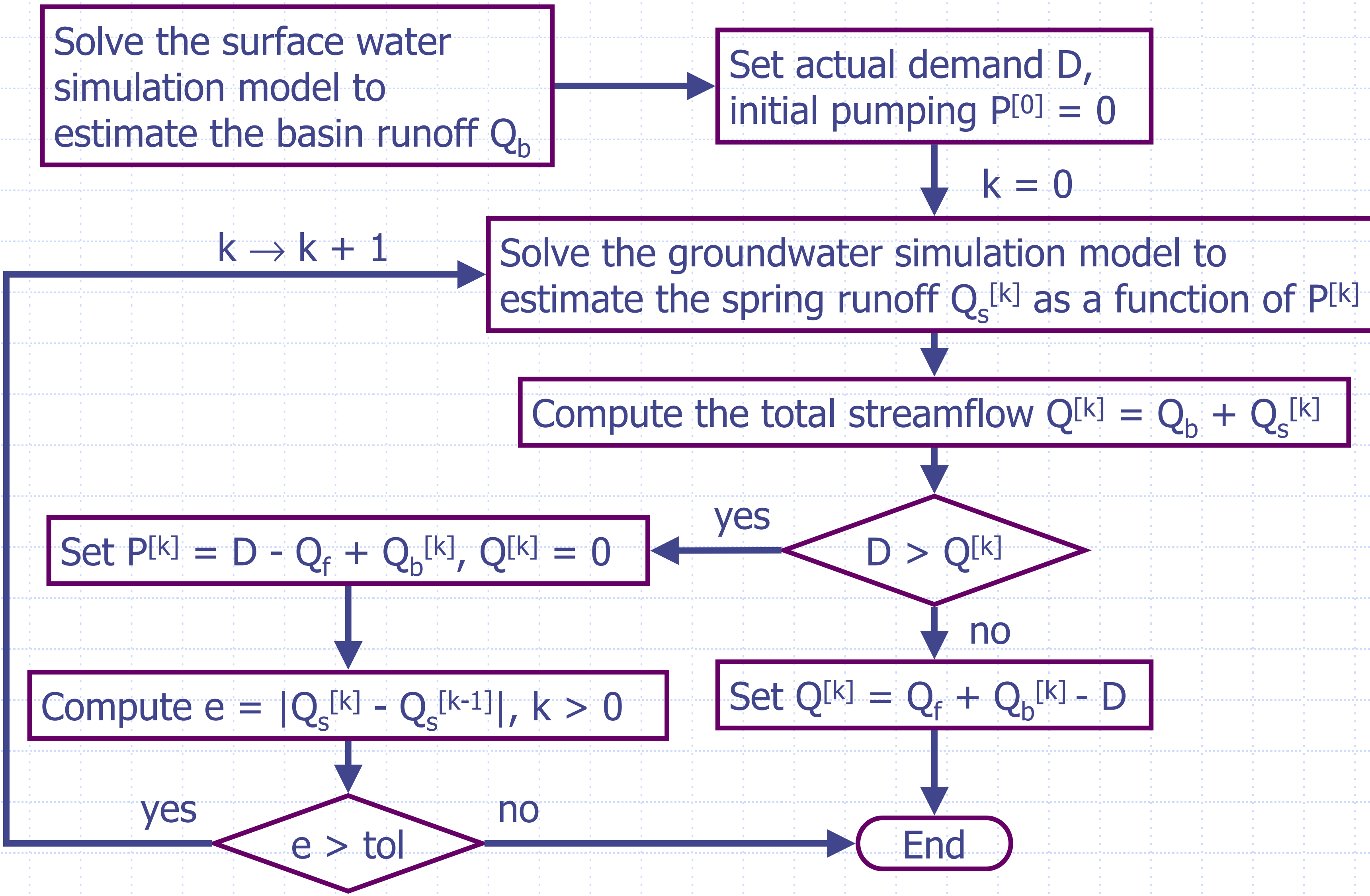
The catchment is divided into spatial subunits with similar morphological and hydrological characteristics (conceptual elements, not necessary sub-basins), called hydrologic response units (HRUs)

The aquifer is formulated as a grid of cells, each one corresponding to a specific groundwater tank

The percolation of each soil moisture reservoir supplies a specific group of tanks

Springs are represented by tanks of very large base, supplied from neighboring tanks; their output is transformed to spring flows that contribute to total streamflow

Handling of combined abstractions



Model calibration via an evolutionary annealing-simplex algorithm

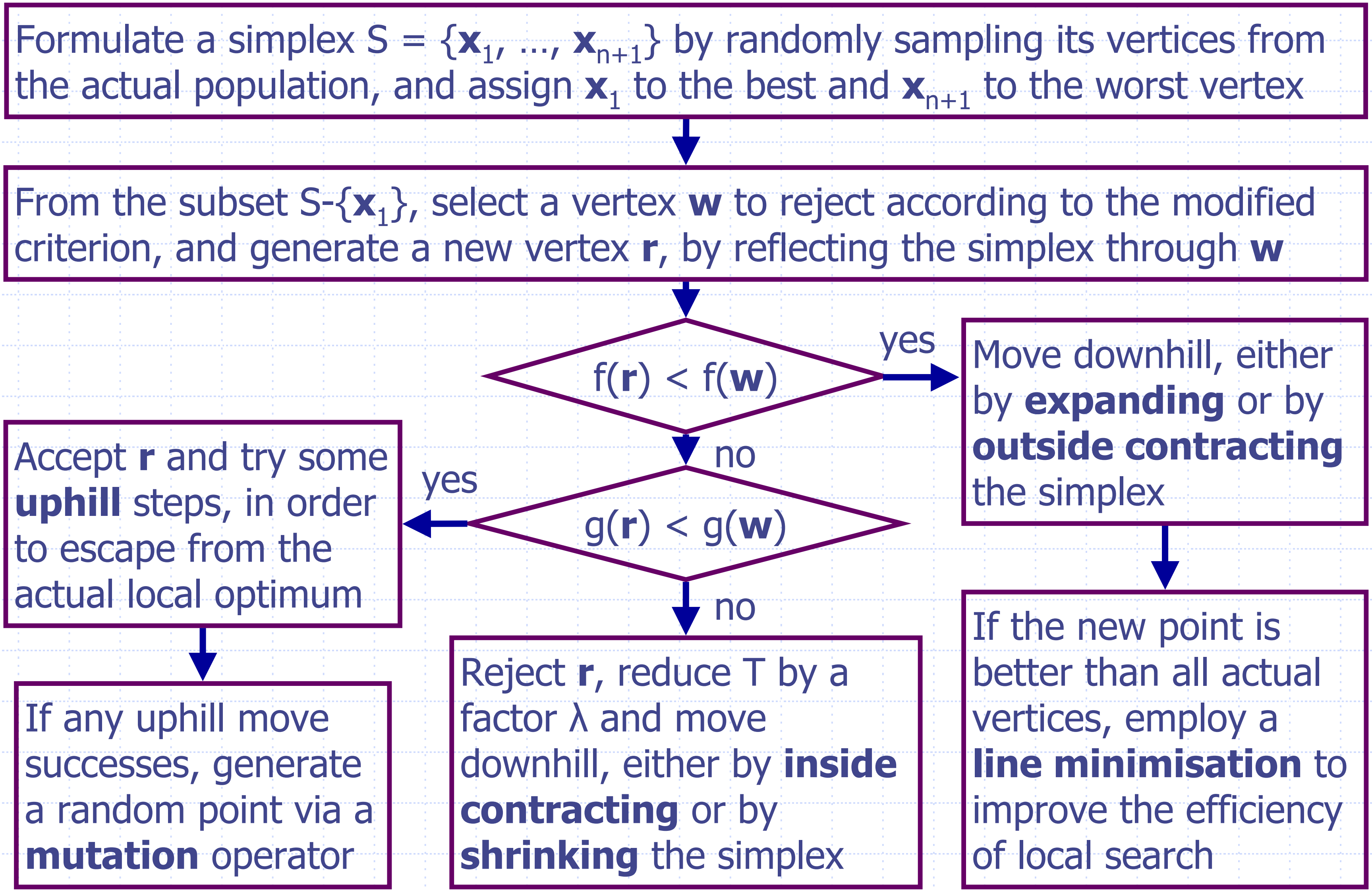
The motivation

Formulation of a heuristic algorithm that joins ideas from different methodological approaches, in order to both ensure **effectiveness** (i.e. accuracy in locating the optimum) and **efficiency** (i.e. algorithmic speed)

Main concepts

- An **evolutionary** scheme is introduced
- The evolution is employed through transition rules that are mainly based an a **simplex** searching pattern
- All transition rules contain a stochastic component
- Both downhill and uphill moves can be accepted according to the modified objective function g(**x**) = f(**x**) + r T, where r is a unit random number and T a "temperature" term
- An adaptive **annealing** "cooling" schedule regulates the system's "temperature", which determines the degree of randomness through the evolution procedure

Flowchart of a typical iteration step



The Boeoticos Kephisos basin case study: Objectives and restrictions

Objectives

1. Representation of all essential hydrological processes, including groundwater dynamics, in order to assess the impacts of upstream water abstractions to the watershed yield
2. Accurate prediction of the main watershed response (i.e., runoff series at the basin outlet = inflows to Lake Yliki)
3. Adequate prediction of spring flows, especially of those of Mavroneri that are directly affected by water supply abstractions

Restrictions

1. Model parameterisation consistent with the **principle of parsimony** (use as many parameters as can be supported by available data)
2. Formulation of a **computationally efficient** simulation scheme
3. Reduction of **uncertainties** due to the complexity of the physical processes and the lack of reliable spatially distibuted data

Model reliability = F(structural complexity, available information, predictive uncertainty remaining after the calibration) => a multiobjective problem

The Boeoticos Kephisos basin case study:
Model parameterisation and structure

Surface water model (9 parameters)

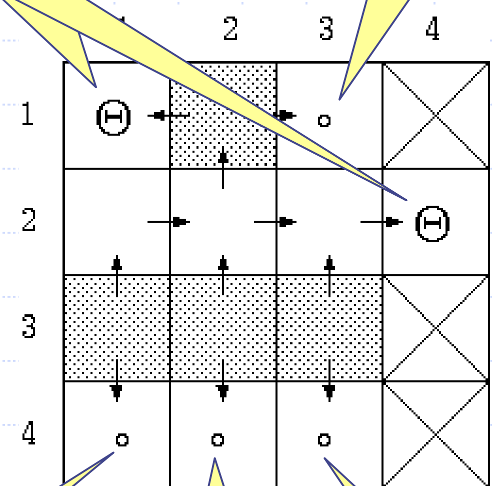
HRU 1: Mountainous, karstic regions (649 km^2)

HRU 2: Plain, alluvial regions (1339 km^2)

Groundwater model (13 parameters)

Underground losses to sea

Melas springs



Lilea springs

Mavroneri springs

Erkina springs

The Boeoticos Kephisos basin case study: Formulation of the objective function

Available data

1. Daily discharge record at the basin outlet, based on daily stage observations (from 1907, the oldest in Greece)
2. Semi-monthly discharge measurements at the main spring sites, systematic during 1984-1990 (calibration period), less systematic during 1990-1994 (validation period)
3. Non-systematic water table observations at a limited number of wells, indicating non significant overyear trends during calibration

Components of the objective function

1. The weighted sum of **determination coefficients** of the hydrographs at the basin outlet and the four springs (5 goodness-of-fit measures)
2. The square difference between the initial and final water level at all groundwater tanks (to prohibit the appearance of **overyear trends** in simulated tank-level series)
3. The average square error of **spring intermittency** (to prohibit both the generation of spring runoff in case of flow interruption and the unjustifiable interruption of spring flows)

The Boeoticos Kephisos basin case study: Outline of the calibration procedure

Phase 1: Identification of regions of attraction

Implementation of a large number of calibrations via the evolutionary annealing simplex algorithm, by modifying the boundaries of the feasible parameter space and the weighting coefficients of the objective function

Phase 2: Location of the global optimum

Further investigation, by restricting the feasible space; implementation of separate calibrations for the surface and groundwater simulation model, to ensure (a) a good fitting of the hydrograph at the basin outlet and (b) an acceptable fitting of the spring hydrographs

Intermediate (manual) phase: Criteria for rejecting solutions

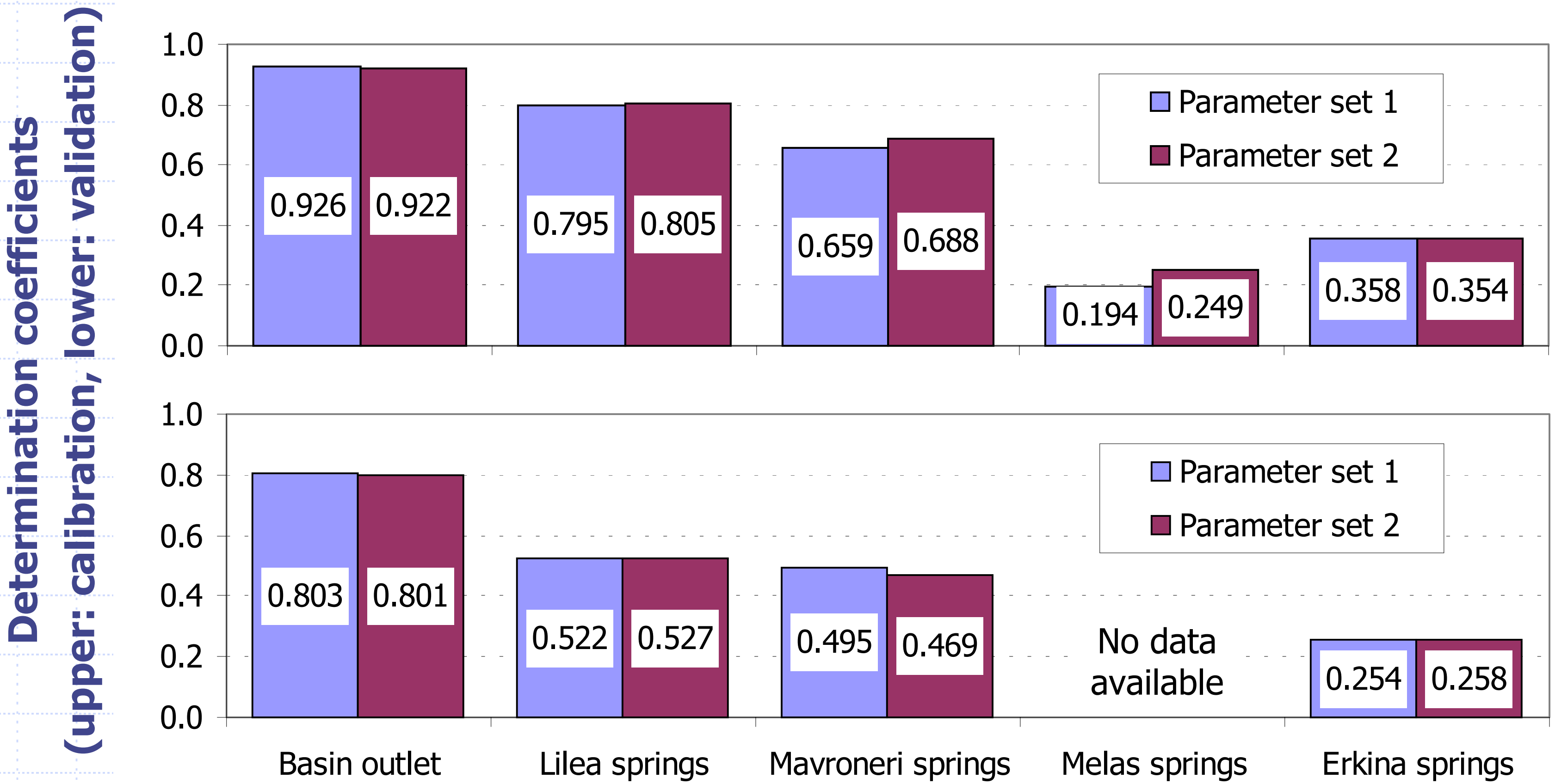
At the end of each calibration phase, all parameter sets providing at least one of the following characteristics were rejected:

(a) parameters with no physical sense

(b) bad performance for some of the goodness-of-fit criteria (i.e., solutions lying on the boundaries of the Pareto set)

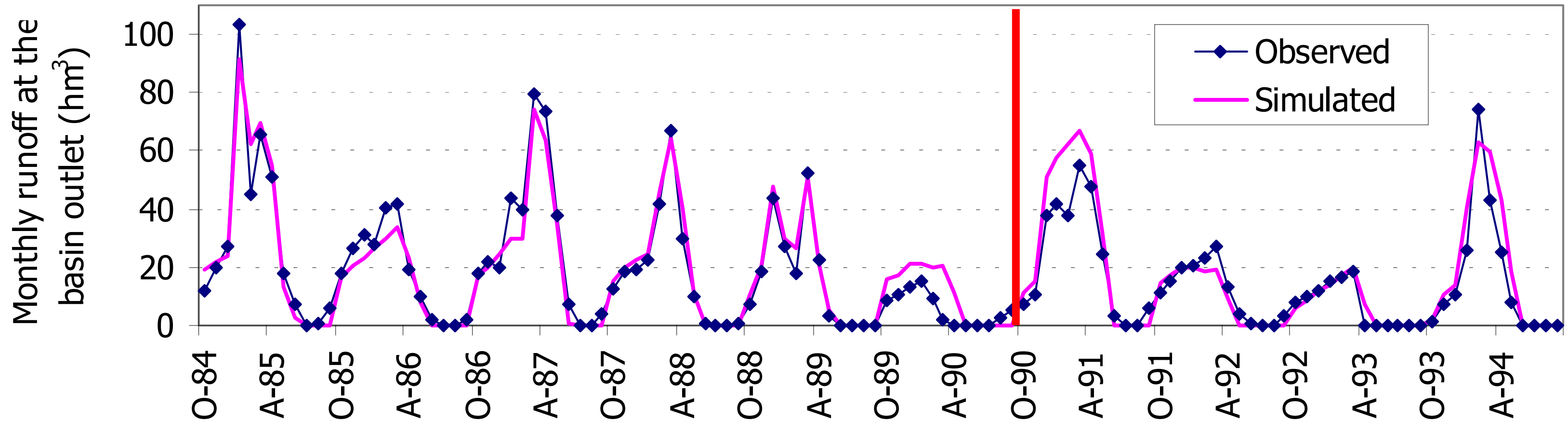
(c) unrealistic hydrologic balance / bad reproduction of output statistics

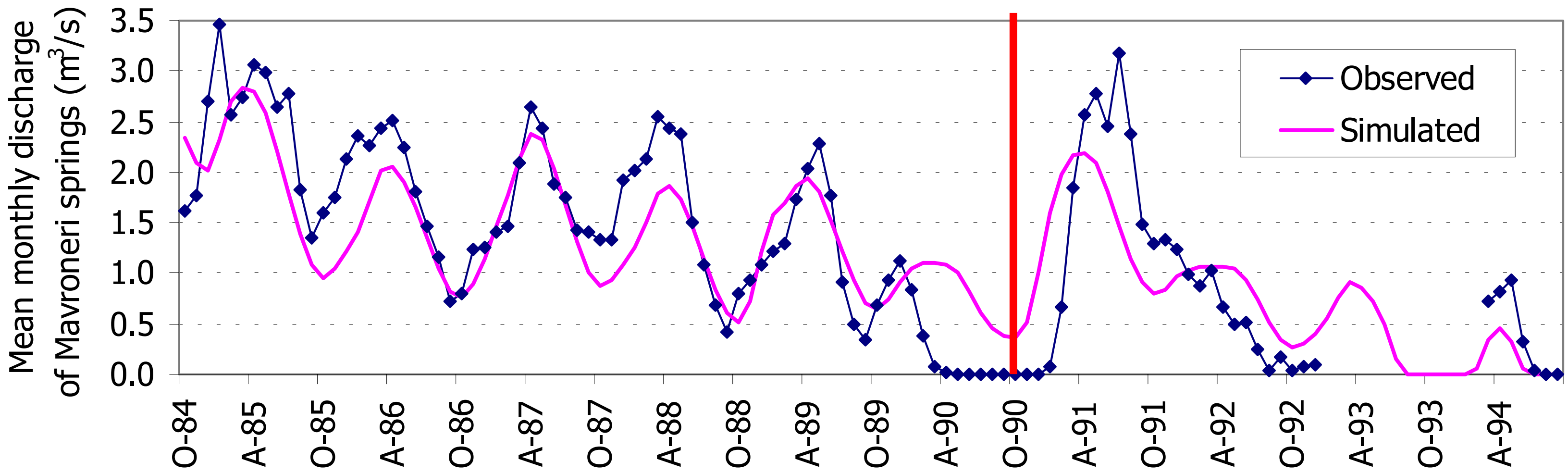
The Boeoticos Kephisos basin case study: Model performance criteria



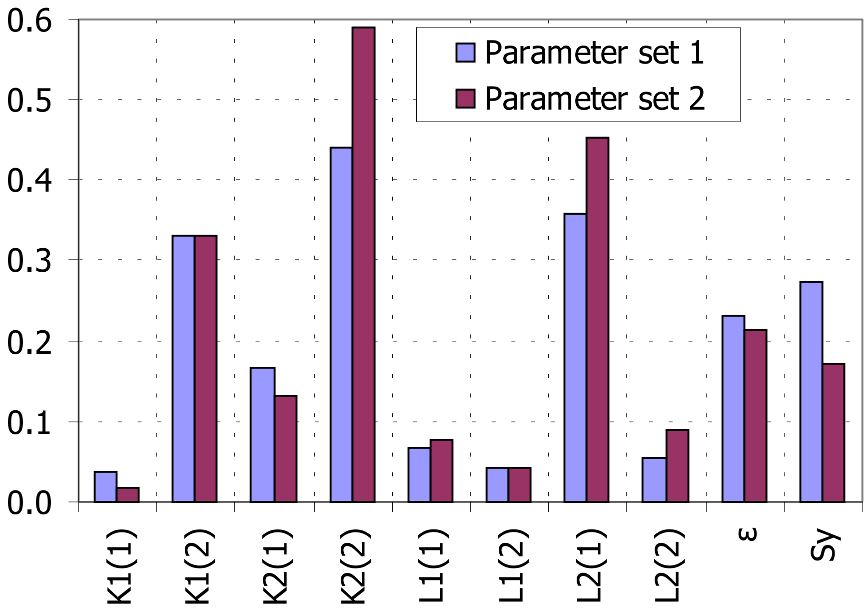
According to both numerical and empirical performance criteria, two optimal parameter sets were finally obtained, which are equivalent

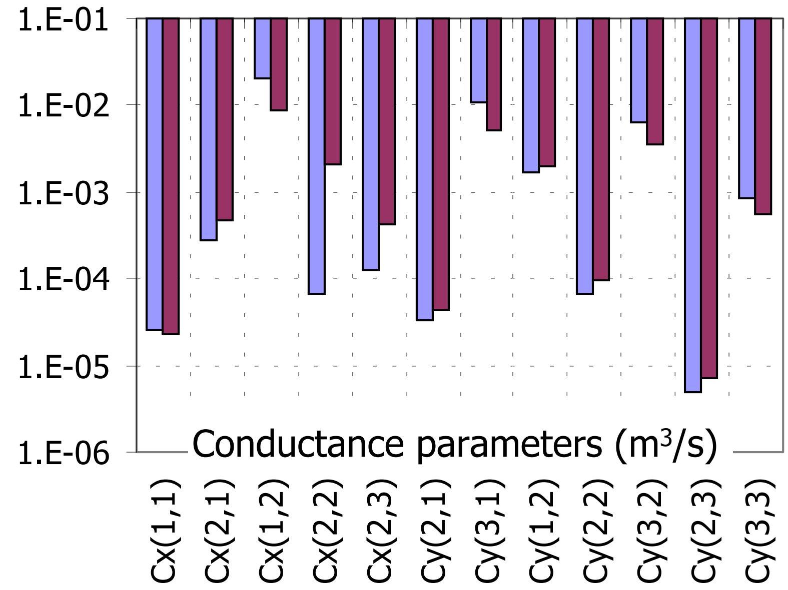
The Boeoticos Kephisos basin case study:
Comparison of hydrographs





The Boeoticos Kephisos basin case study:
Investigation of uncertainties





The uncertainties remaining after the calibration concern the allocation of hydrological losses, i.e. evapotranspiration and outflows to the sea. Set 1 provides the lowest sea outflows (61 hm^3/y) and the highest evapotranspiration (835 hm^3/y or 64.7% of the mean precipitation), whereas set 2 provides the highest sea outflows (182 hm^3/y) and the lowest evapotranspiration (727 hm^3/y or 56.4% of the mean precipitation). In the absence of extended spatial data or direct measurements, it is impossible to distinguish the most reliable set!

Conclusions

- The **conjunctive simulation** scheme, albeit using relatively few parameters and a coarse spatial analysis, managed to represent with reliability the main hydrological processes of an extremely complicated physical system, being computationally efficient
- The **evolutionary annealing simplex** algorithm proved both effective and efficient in handling a calibration problem of significant irregularities
- The formulation of parsimonious structures that are consistent and take advantage of all available information, and the careful examination of all simulated responses (not only the calibrated ones), can reduce the various **uncertainties** regarding the estimation of hydrologic parameters
- The **hydrologist's experience** through the calibration procedure plays a very important role, especially in case of complex problems with several control variables and multiple criteria; this role refers to:
  (a) the formulation of the objective function
  (b) the guidance of the search procedure towards realistic parameter sets
  (c) the selection of the best compromise solution

This presentation is available on-line at:

http://itia.ntua.gr/e/docinfo/567

Contact info:

andreas@itia.ntua.gr

dk@itia.ntua.gr