

The management of the Athens water resource system: Methodology and implementation

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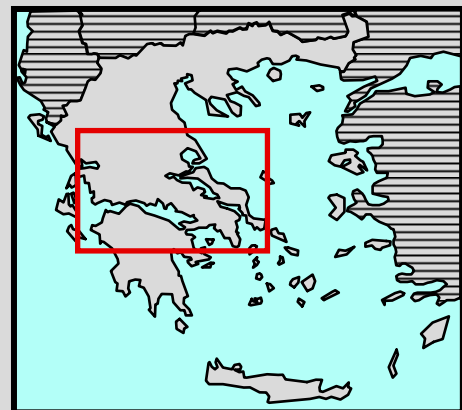
Not in photo: A. Christofides, S. Kozanis, O. Kitsou

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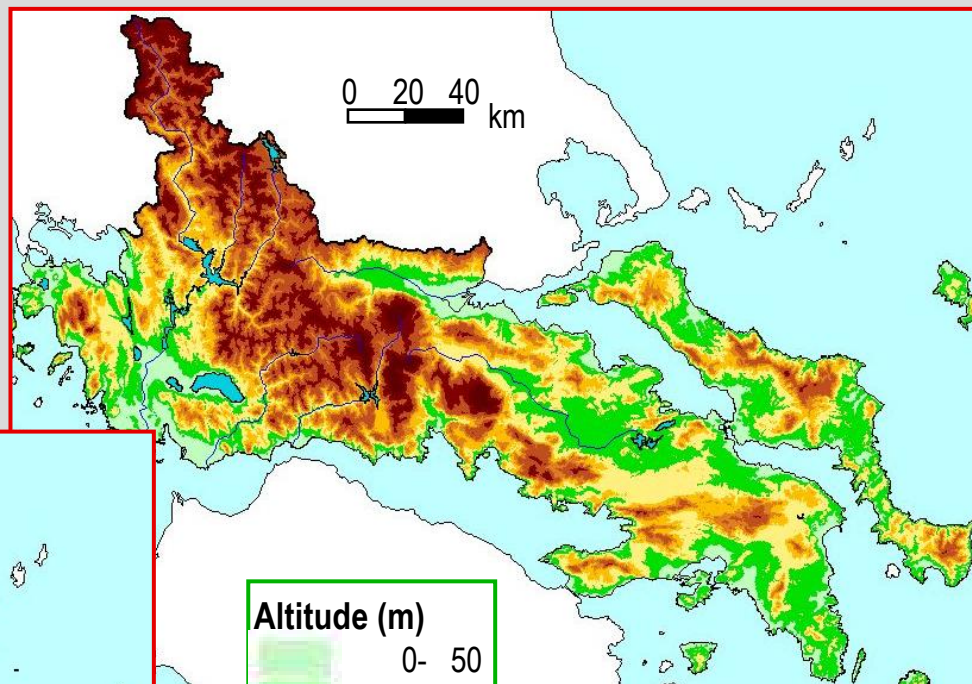
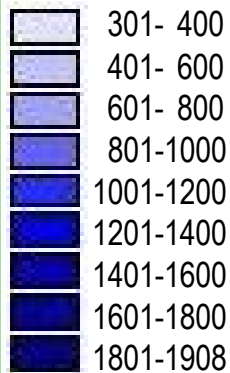


“Υσον, ὕσον Ζεῦ κατὰ τῆς ἀρούρης τῶν Ἀθηναίων

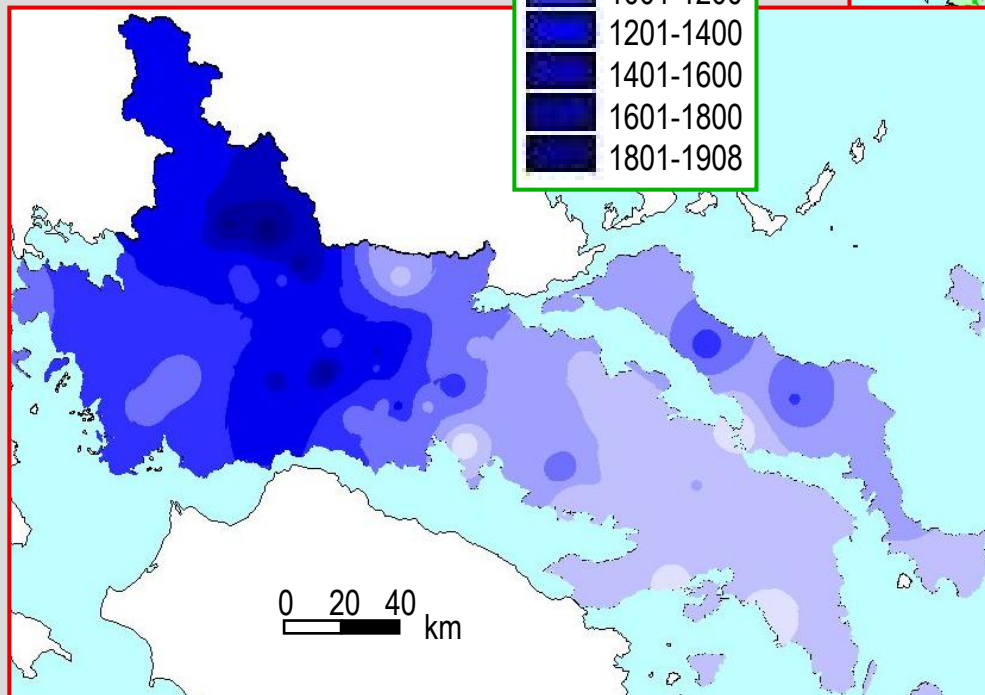
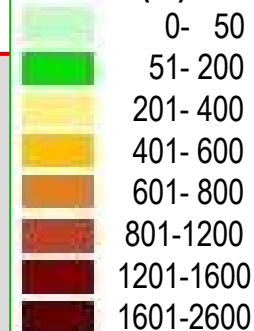
Do rain, do rain Zeus against the earth of Athenians (Ancient Greek prayer)



Mean annual rainfall (mm)



Altitude (m)



Parts of the presentation

1. The Athens water resource system

History – Components – Technical characteristics

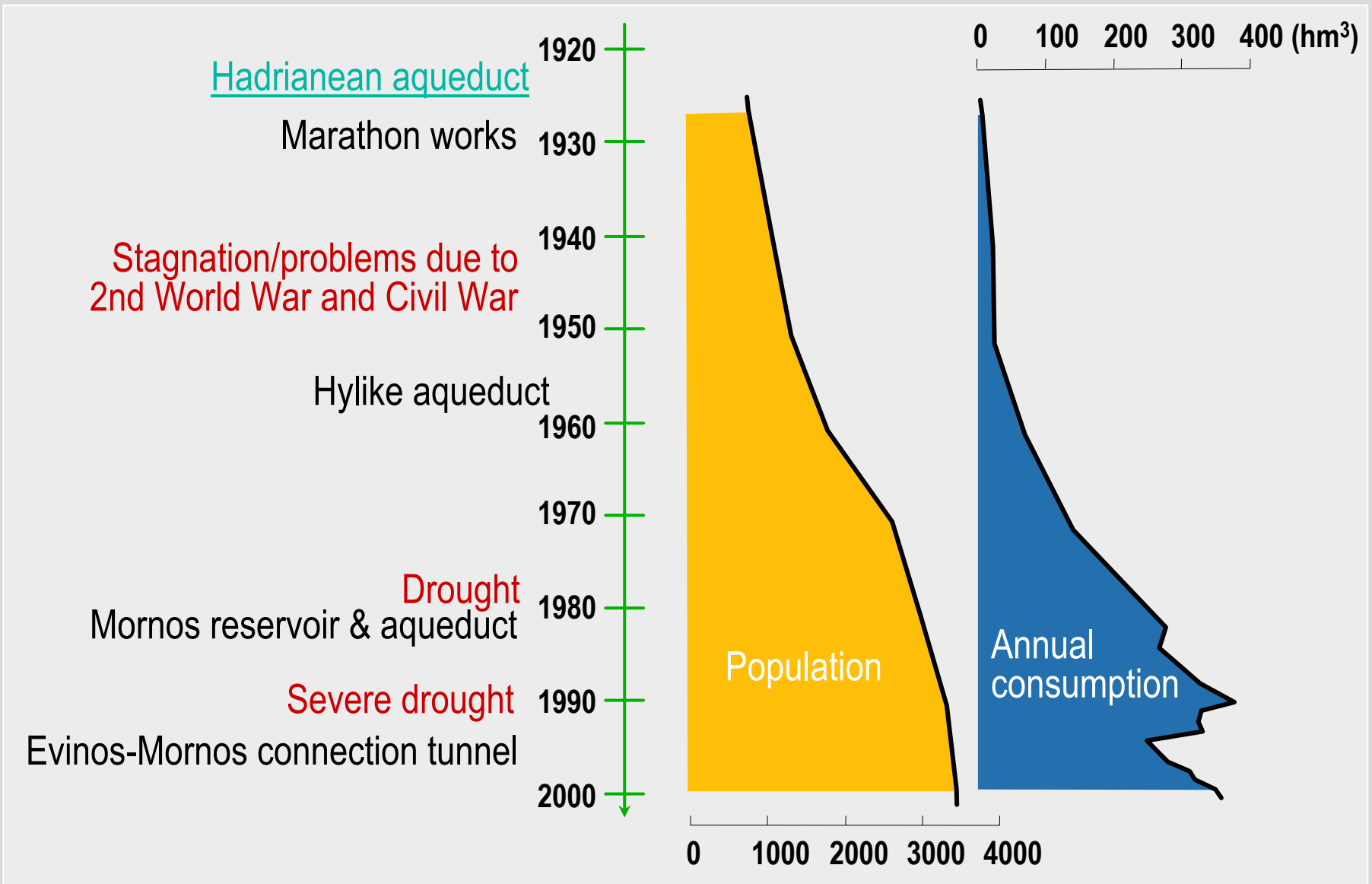
2. Hydrosystem operation issues

Parameterization – Simulation – Optimization

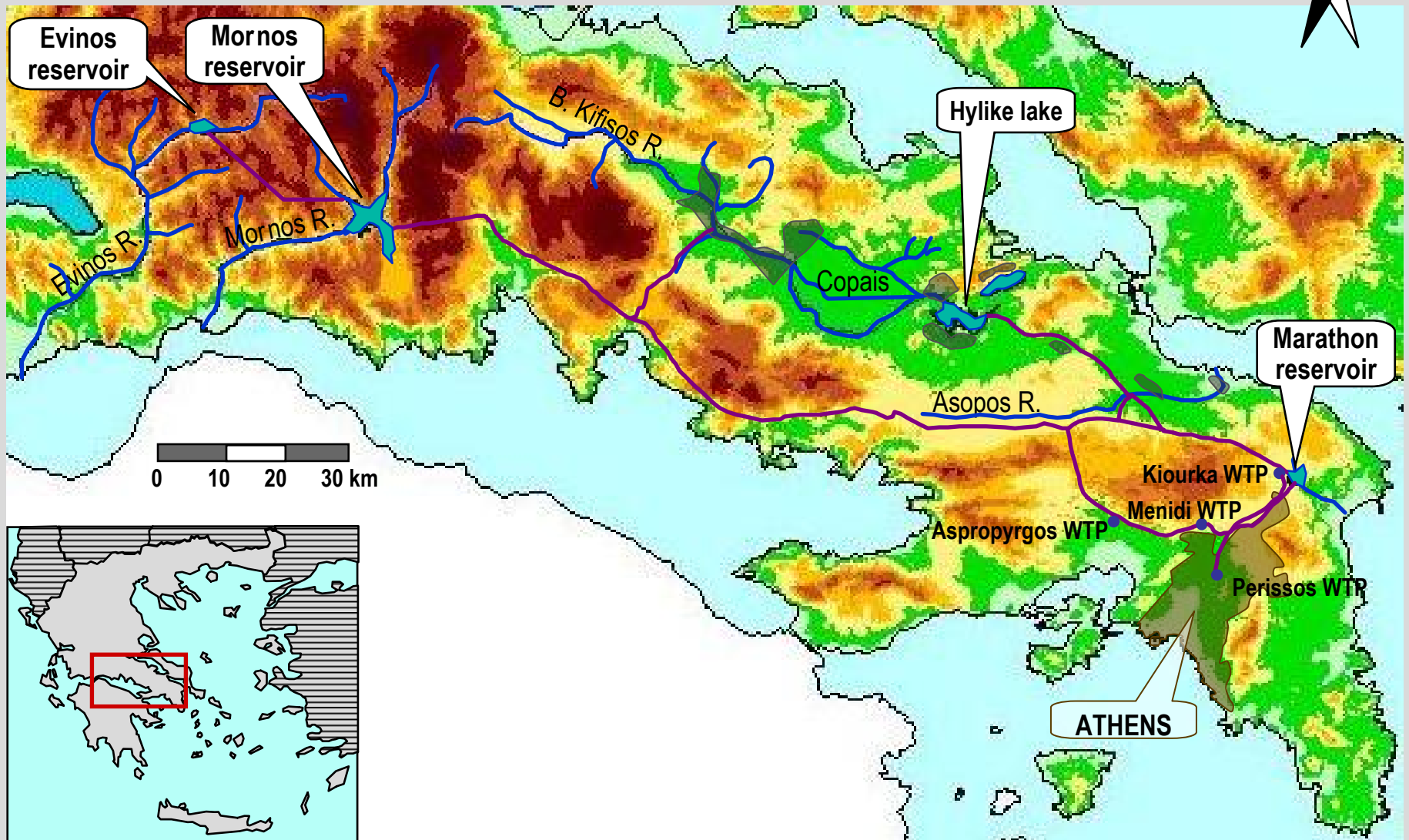
3. Decision support tool integration

Data acquisition – Software systems – Management plans






Evolution of water consumption – Milestones



The hydrosystem: Main components and evolution

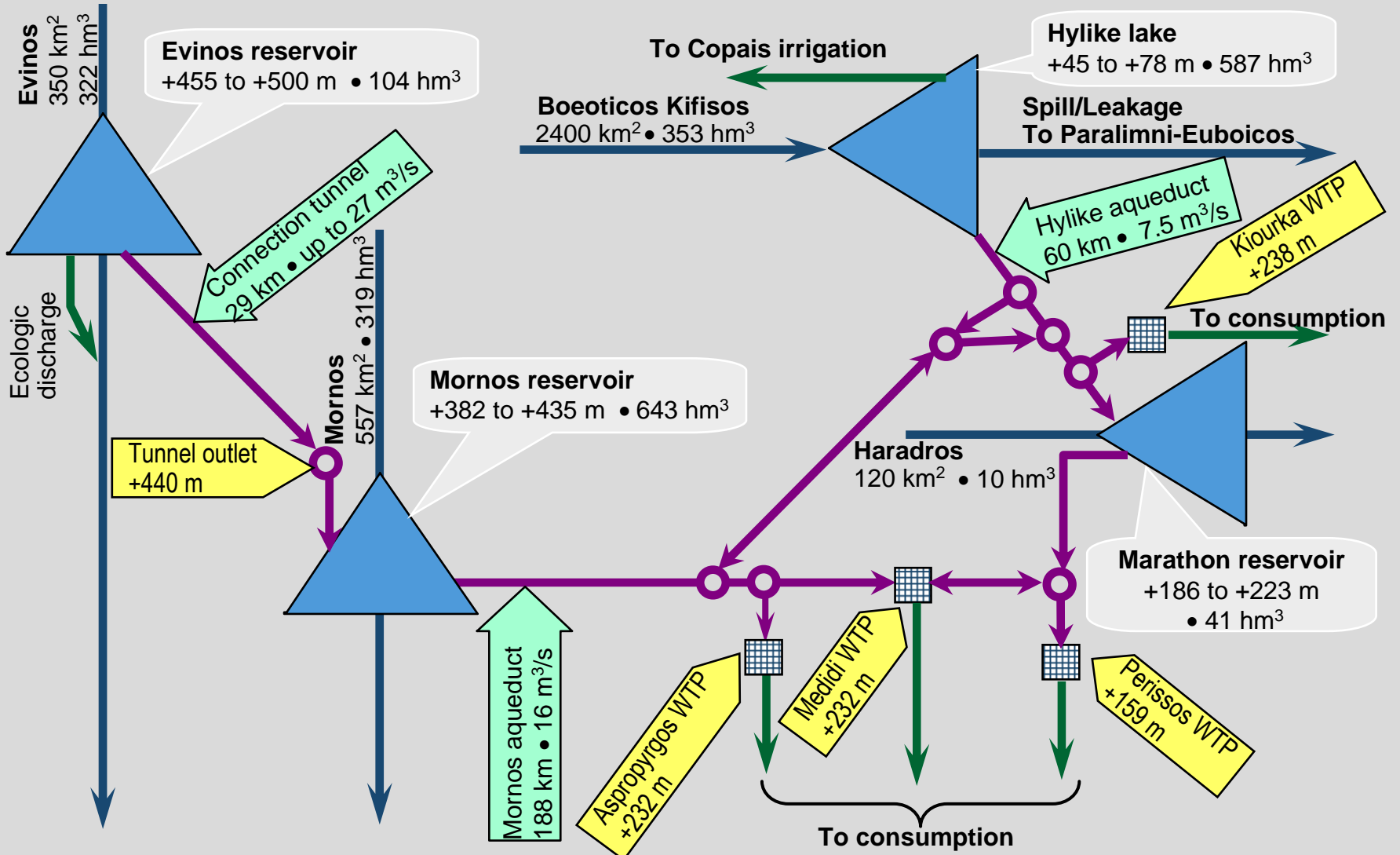


Classification of water resources

Basin	SURFACE WATER		GROUNDWATER
	Primary (Reservoirs)	Secondary (Reservoirs)	Backup (Boreholes)
Evinos 350 km ²	Evinos 322 hm ³ /y 		
Mornos 557 km ²	Mornos 319 hm ³ /y		
Boeoticos Kifisos – Yliki 2400 km ²		Yliki 353 hm ³ /y  	B. Kifisos, middle course 136 hm ³ /y Yliki region 85 hm ³ /y 
Haradros 120 km ²		Marathon 10 hm ³ /y	
North Parnetha			Viliza 26 hm ³ /y  Mavrosouvala 36 hm ³ /y

Area	Inflow	Pumping capacity 	High spill 	High leakage 	Pumping
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Hydrosystem: Current structure



+ Boreholes (with connecting pipes) + Pumping stations + Small hydroelectric power plants

2. Hydrosystem operation issues

Parameterization – Simulation – Optimization

Typical problems to be answered

- ◆ Find the **maximum possible annual release** from the system:
 - for a certain (acceptable) **reliability level** (steady state conditions)
 - for a certain **combination of the system components** (e.g. primary resources)and determine the corresponding:
 - **optimal operation policy** (storage allocation; conveyance allocation; pumping operation)
 - **cost** (in terms of energy; economy; other impacts)
- ◆ Find the **minimum total cost**
 - for a given **water demand** (less than the maximum possible annual release)
 - for a certain (acceptable) **reliability level**and determine the corresponding:
 - **combination of the system components** to be enabled
 - **optimal operation policy** (storage allocation; conveyance allocation; pumping operation)
 - **alternative operation policies** (that can satisfy the demand but with higher cost)

Categories of problems

- ◆ Steady state problems for the current hydrosystem
 - (e.g., previous slide)
- ◆ Problems involving time
 - Availability of water resources in the months to come
 - Impact of a management practice to the future availability of water resources
 - Evolution of the operation policy for a temporally varying demand
- ◆ Investigation of scenarios
 - Hydrosystem structure: Impacts of new components (aqueducts, pumping stations etc.)
 - Demand: Feasibility of expansion of domain
 - Hydroclimatic inputs: Climate change
- ◆ Adequacy/safety under exceptional events – Required measures
 - Damages
 - Special demand occasions (e.g. 2004 Olympic Games)

The methodology: General aspects

Question 1: Simulation **or** optimization?

- Simulation **versus** optimization (water resources literature and practice)
- Simulation methods **for** optimization (more mathematical literature)

Answer: Optimization coupled with simulation

Main advantages

- Determination of optimal policies
- Incorporation of mathematical optimization techniques

Main advantages

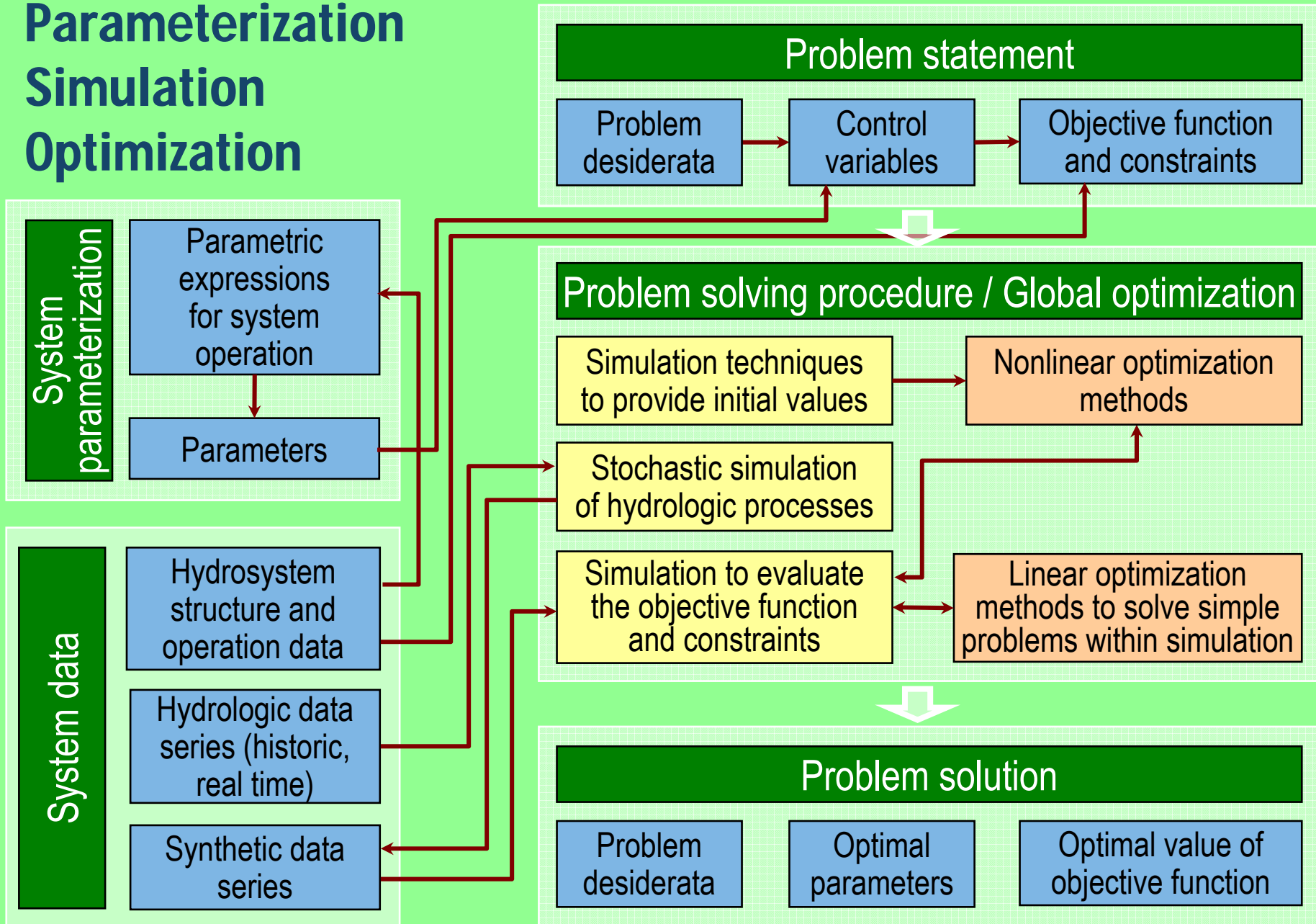
- Detailed and faithful system representation
- Better understanding of the system operation
- Incorporation of stochastic models

Question 2: Which are the control (decision) variables?

- Typically: Releases from system components in each time step

Answer: Introduction of **parametric control rules** with few **parameters** as control variables

Parameterization Simulation Optimization



Introduction to the parametric reservoir operation rule – Some analytical solutions

Maximize release from a simple reservoir system with single water use

◆ Case a: no conveyance restrictions; no leakages

- Solution: Probability of spill equal at all reservoirs (**New York Rule**; Clark, 1950)
- Under certain (rather common) conditions about the distribution of inflows:

Space rule

(Bower et al., 1962)

$$\frac{K_i - S_i}{E[CQ_i]} = \frac{\sum K - V}{\sum E[CQ]}$$

◆ Case b: no conveyance restrictions; significant leakages; insignificant spills

- Solution:

Leakage rule (Nalbantis & Koutsoyiannis, 1997)

$$S_i = \begin{cases} V & \text{for one reservoir} \\ 0 & \text{for all others} \end{cases}$$

◆ Case c: restricted conveyance capacity; insignificant spills; no leakages

- Solution:

Conveyance rule (Nalbantis & Koutsoyiannis, 1997)

$$\frac{S_i}{C_i} = \frac{V}{\sum C}$$

Notation: i = Reservoir index, K = Storage capacity, S = Storage, $V = \sum S$, CQ = Cumulative inflow, $E[\]$ = expectation, C = Conveyance capacity

Formulation of the parametric reservoir operation rule

Initial linear parametric form

$$S_i^* = a_i + b_i V \quad (\text{parameters } a_i, b_i)$$

subject to $\sum a_i = 0, \sum b_i = 1,$

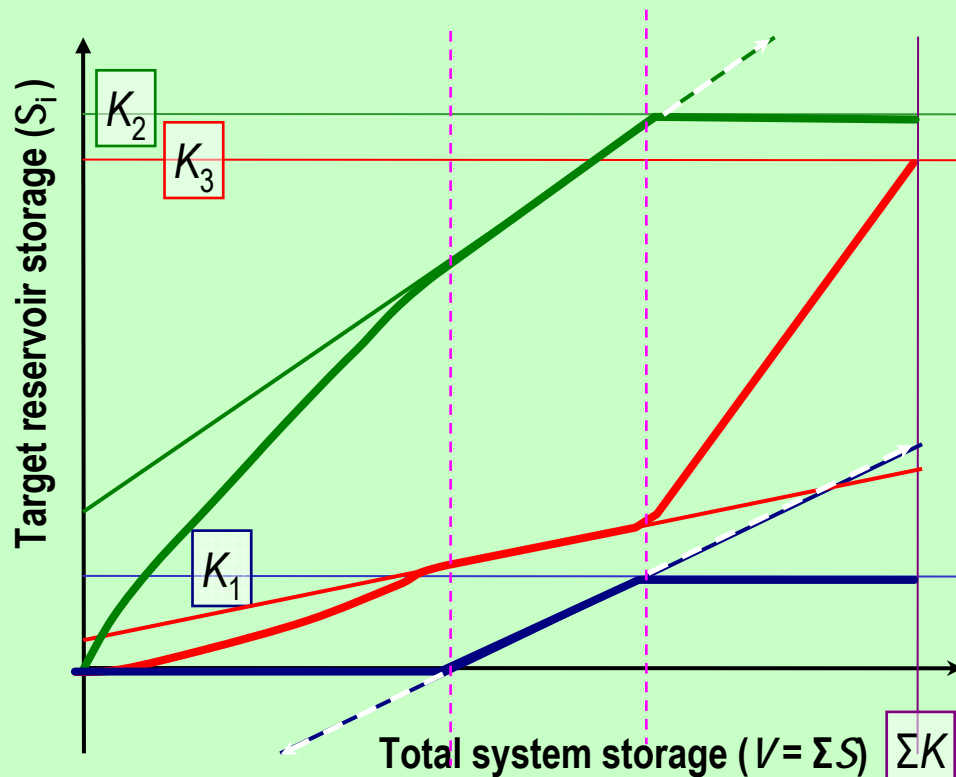
since $\sum S_i^* = V$

Corrected for physical constraints

$$S_i^{**} = \begin{cases} 0 & a_i + b_i V < 0 \\ a_i + b_i V & 0 \leq a_i + b_i V \leq K_i \\ K_i & a_i + b_i V > K_i \end{cases}$$

Adjusted, nonlinear form

$$S_i''' = S_i^{**} + \frac{S_i^{**}(1 - S_i^{**}/K_i)}{\sum S_j^{**}(1 - S_j^{**}/K_j)} (V - \sum S_j^{**})$$



Two parameters per reservoir (a_i, b_i) = **Control variables**

Parameter values **determined by optimization** – depending on the objective function

Parameters may depend also on season (e.g., refilling-emptying period, or months)

$2 \times (\text{reservoirs} - 1) \times \text{seasons}$ total parameters for the reservoir system

A comparison with non-parametric optimization

Problem: Find the maximum release that can be ensured by a system of **3 reservoirs** with **reliability 99%** (probability of failure 1%). Use **1000 years** of simulated data with **monthly time step**. Assume **steady state** conditions.

Non-parametric optimization

Number of control variables:

$$\begin{aligned} & 1000 \times 12 \text{ monthly releases} \\ & \times (3 - 1) \text{ reservoirs} + 1 \text{ (problem target)} \\ & = 24001 \end{aligned}$$

Cannot be combined with simulation

All physical constraints of the system must be entered as problem constraints

Control variables depend on inflow series

Implicit assumption of known inflows (perfect foresight)

The optimization model needs continuous runs with updated data

Parametric rule based optimization

Number of control variables:

$$\begin{aligned} & 2 \text{ parameters/reservoir/ season} \\ & \times (3 - 1) \text{ reservoirs} \times 2 \text{ seasons} \\ & + 1 \text{ (problem target)} \\ & = 9 \text{ (as an order of magnitude)} \end{aligned}$$

Can be combined with simulation

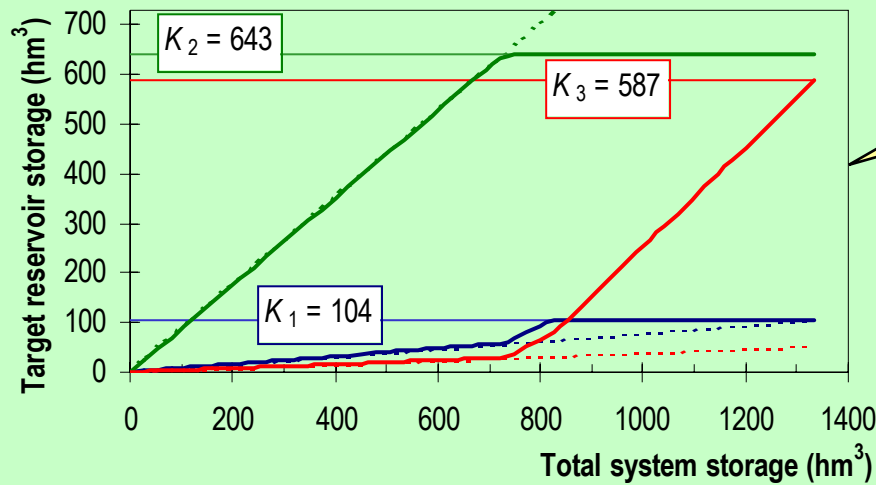
Physical constraints of the system are handled by the simulation model

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

No assumption of known inflows

Once parameters are optimized, the system can be operated without running the model

Application of the parametric rule – Optimal results



Maximization of system release

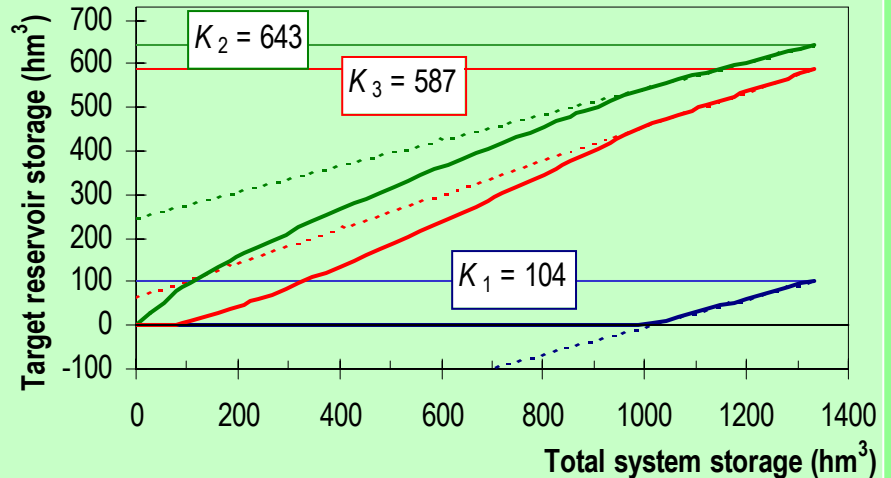
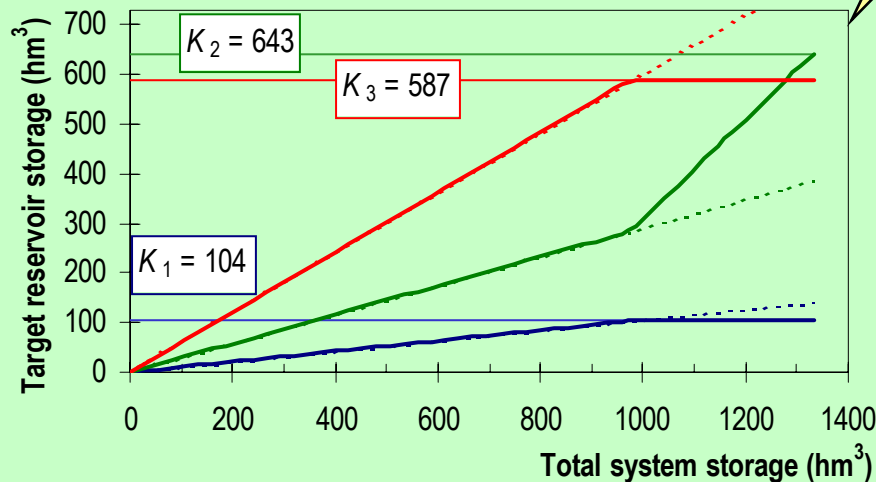
— Evinos

— Mornos

— Hylke

Minimization of cost for system release = 87% of maximum

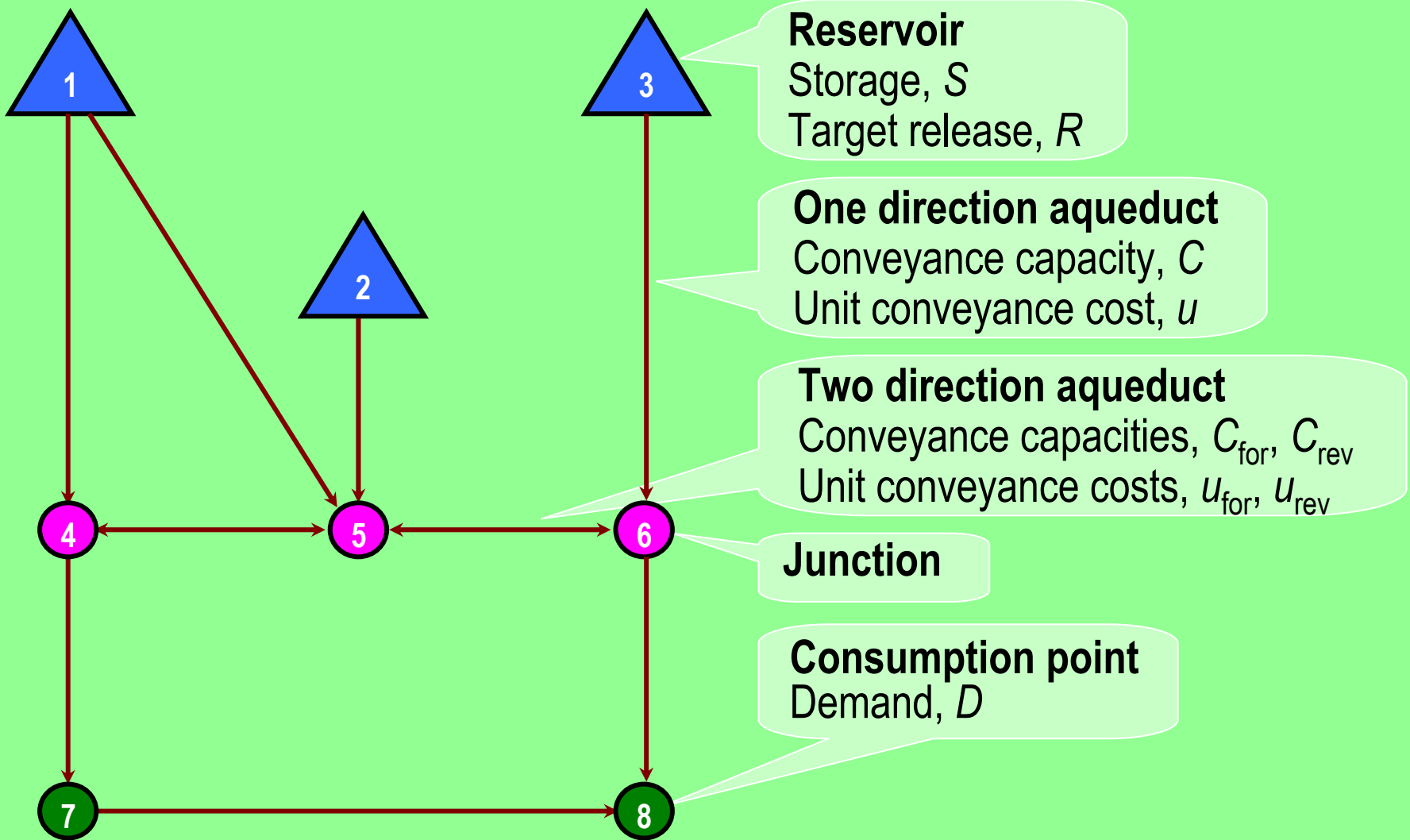
Maximization of system release but with no leakage at Hylke



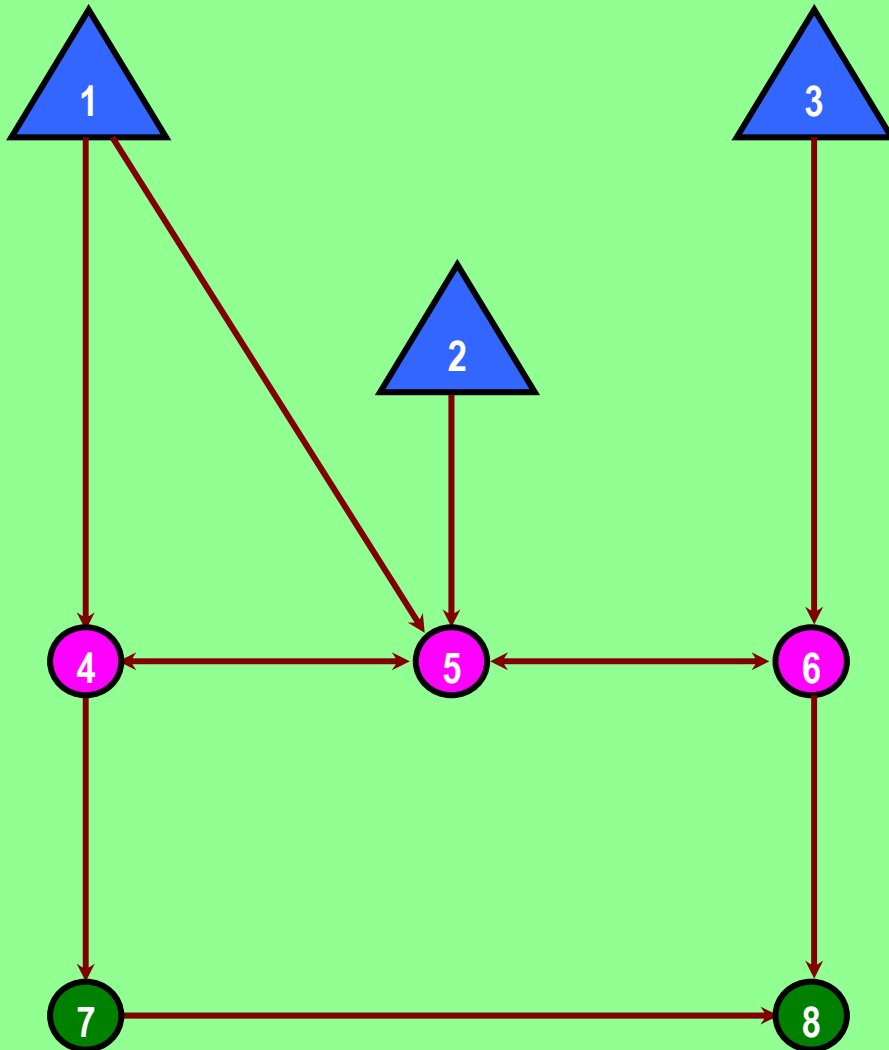
Considering the complete hydrosystem – Simulation

- ◆ Assuming that parameters a_i and b_i are known, the **target releases** from each reservoir will be also known in the beginning of each simulation time step
- ◆ The **actual releases** depend on several attributes of the hydrosystem (physical constraints)
- ◆ Their estimation is done using **simulation**
- ◆ Within simulation, an **internal optimization** procedure may be necessary (typically linear, nonparametric)
- ◆ Because parameters a_i and b_i are not known, but rather are to be optimized, simulation is driven by an **external optimization** procedure (nonlinear)

Hydrosystem components and attributes



Conveyance problem formulation



Given:

- Demands (D)
- Reservoir storages (S),
- Reservoir target releases ($R \leq S$; $\sum R = \sum D$; from parametric rule)

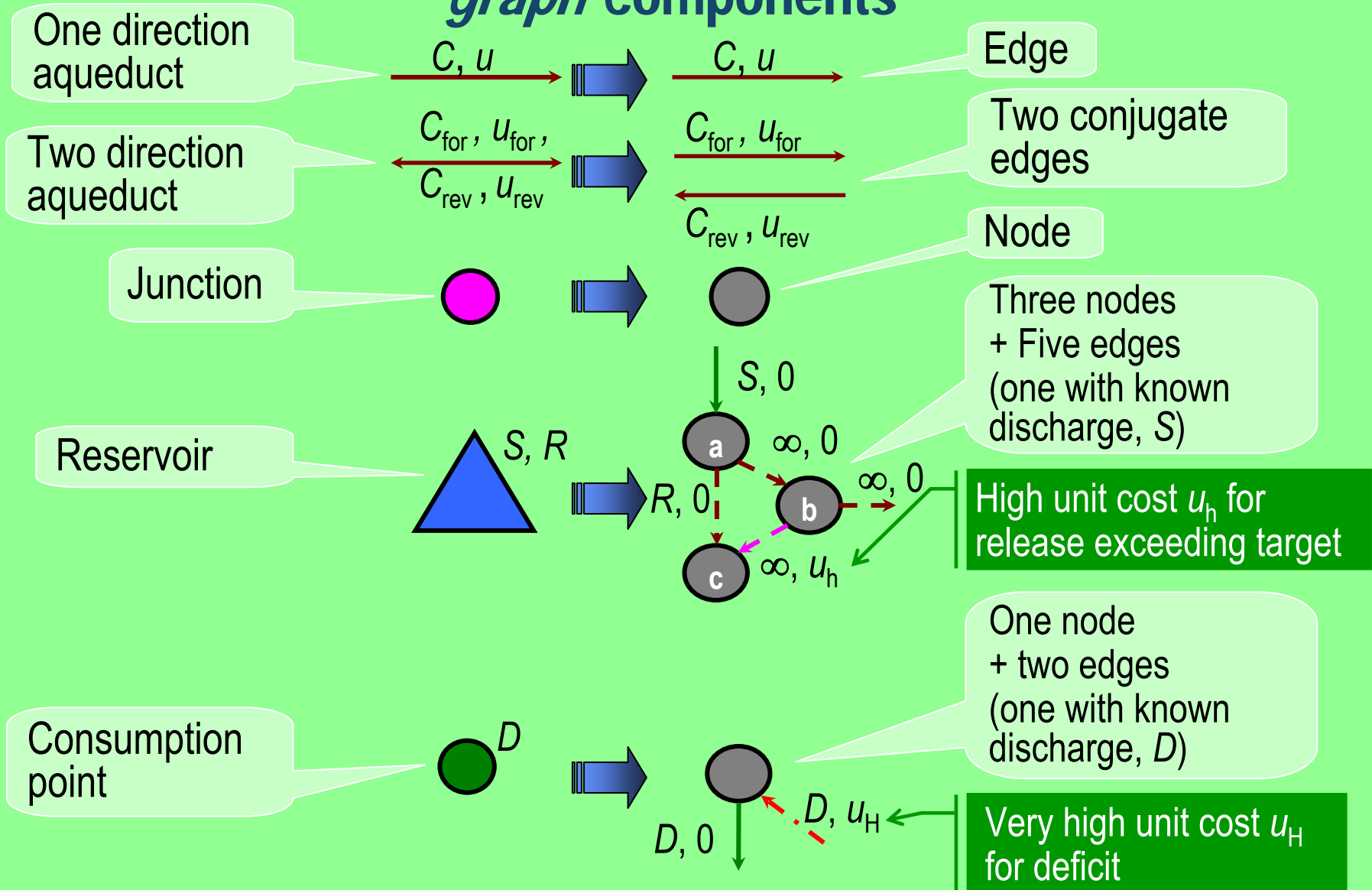
Required:

- Actual (feasible) consumptions (at consumption points)
- Actual (feasible) releases (from reservoirs)
- Aqueduct discharges
- Conveyance cost

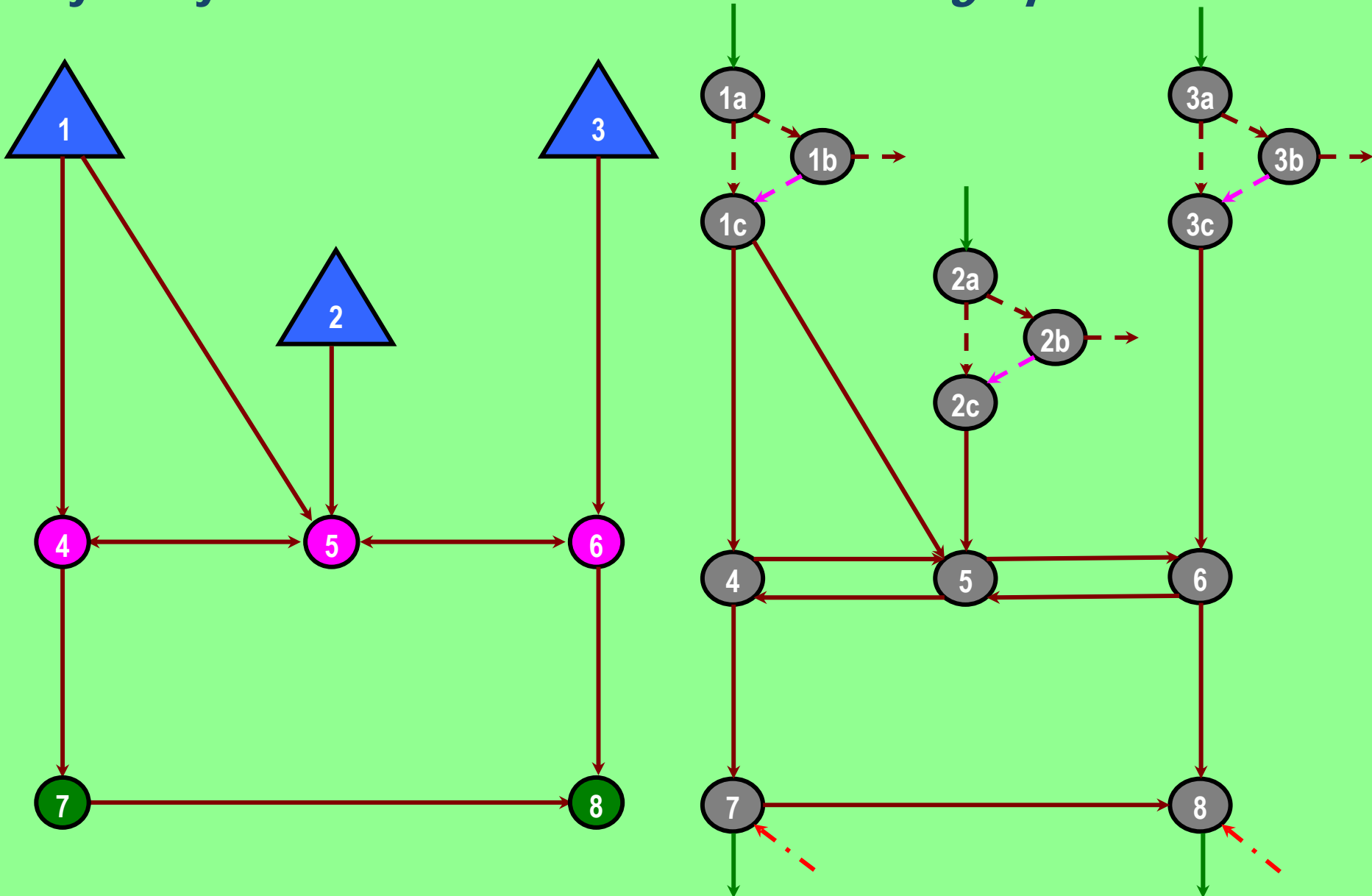
Conditions:

- If possible, no deficits at consumption points
- If possible, releases from reservoirs equal to target releases
- Minimum conveyance cost

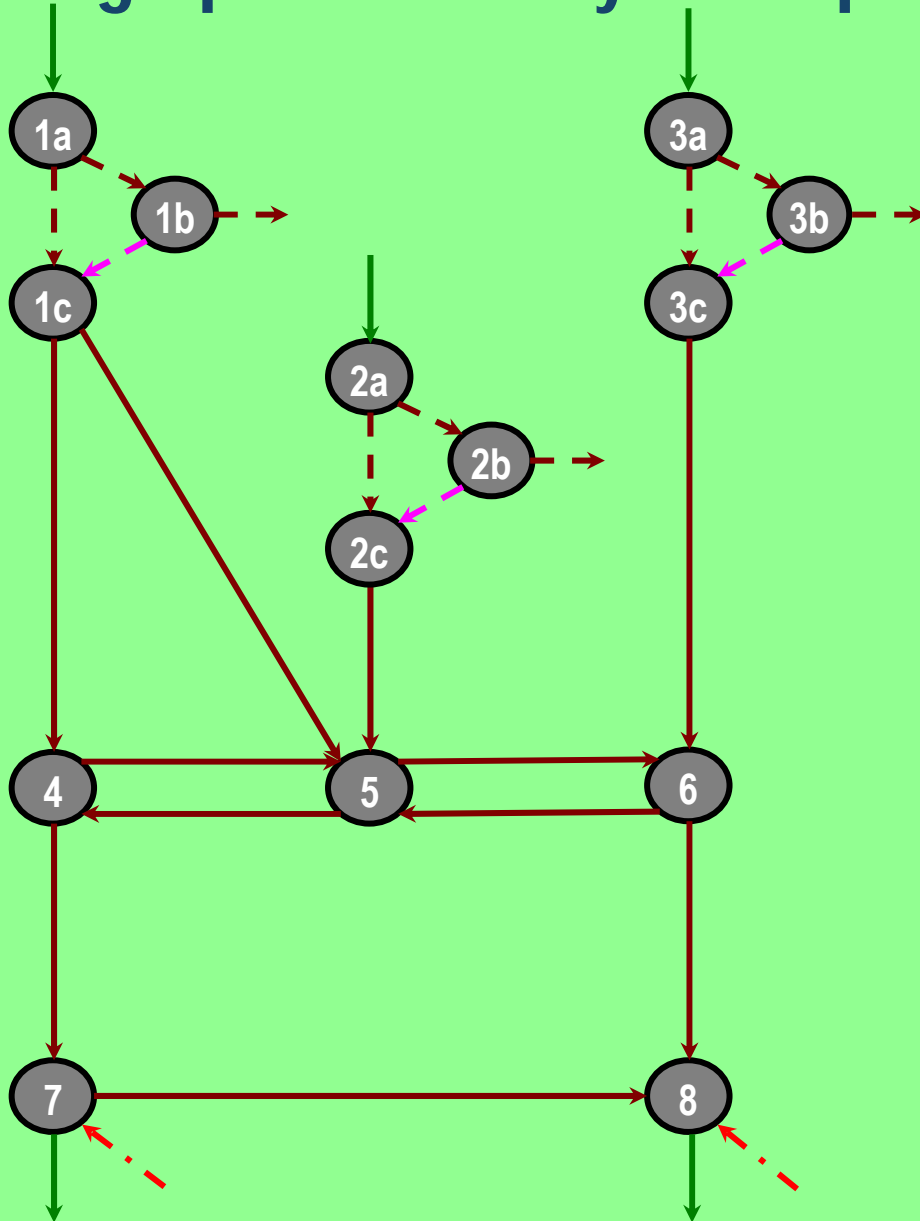
Transformations of hydrosystem components to *graph* components



Hydrosystem and its transformation to *digraph*



Digraph solution by linear programming



Determine all unknown discharges Q_{ij} at edges ij , by **minimizing total cost**

$$TC = \sum_{ij} u_{ij} Q_{ij}$$

subject to equality constraints for each node i

$$\sum_j Q_{ij} - \sum_j Q_{ji} = 0$$

and to **inequality constraints** for each edge ij

$$0 \leq Q_{ij} \leq C_{ij}$$

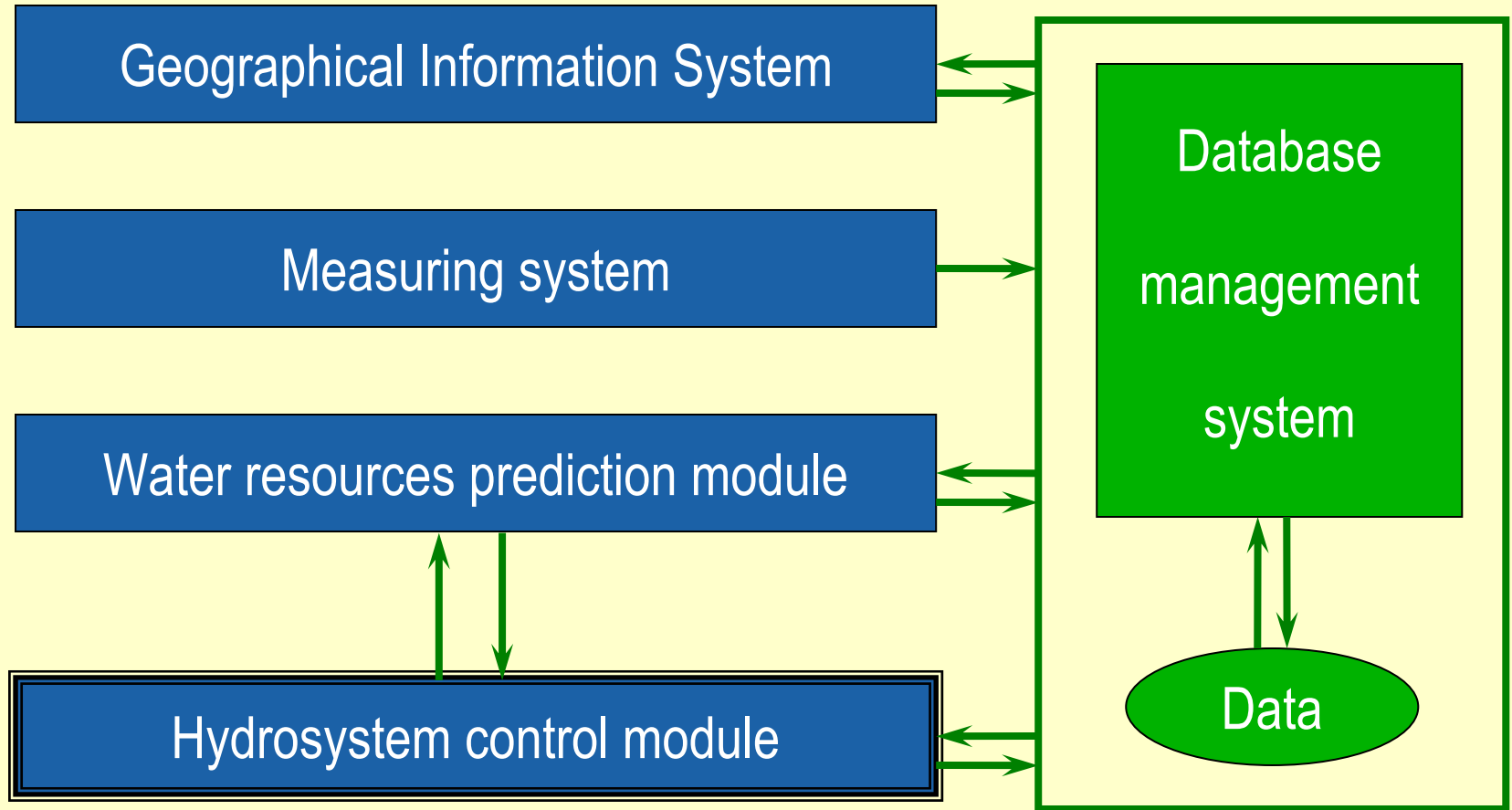
General evaluation and extensions of the parameterization-simulation-optimization method

- ◆ Is parametric rule underparametrized?
 - Nonlinear expressions with three parameters per reservoir did not outperform
 - Homogeneous linear expressions (one parameter per reservoir, $a_i = 0$) result in almost same optimal solutions
 - Considering seasonality (2 seasons) may improve results (slightly)
- ◆ How results of parametric rule based optimization compare to those of nonparametric optimization methods?
 - Generally, they are not inferior
 - In the non realistic case of *perfect foresight*, high dimensional methods may outperform parametric method *with no foresight* (slightly, up to about 2%)
 - In practice, in complex nonlinear problems the parametric method yields better solutions due to more effective locating of global optimum
- ◆ Is the parameterization appropriate for all water uses and hydrosystems?
 - Yes, but different parameterizations may be needed for different components (e.g. aquifers)
 - Successful application to hydropower systems

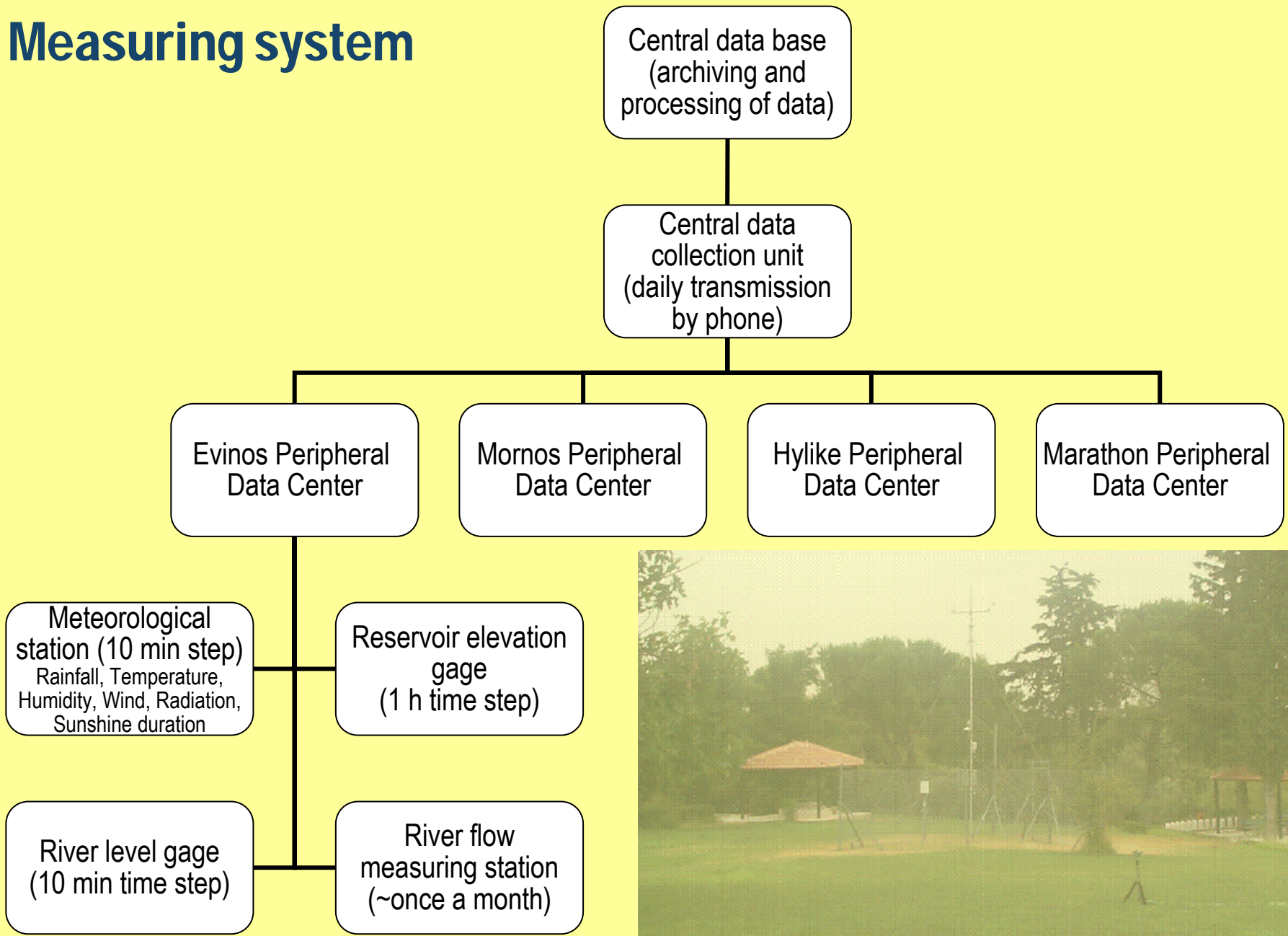
3. Decision support tool integration

Data acquisition – Software systems – Management plans

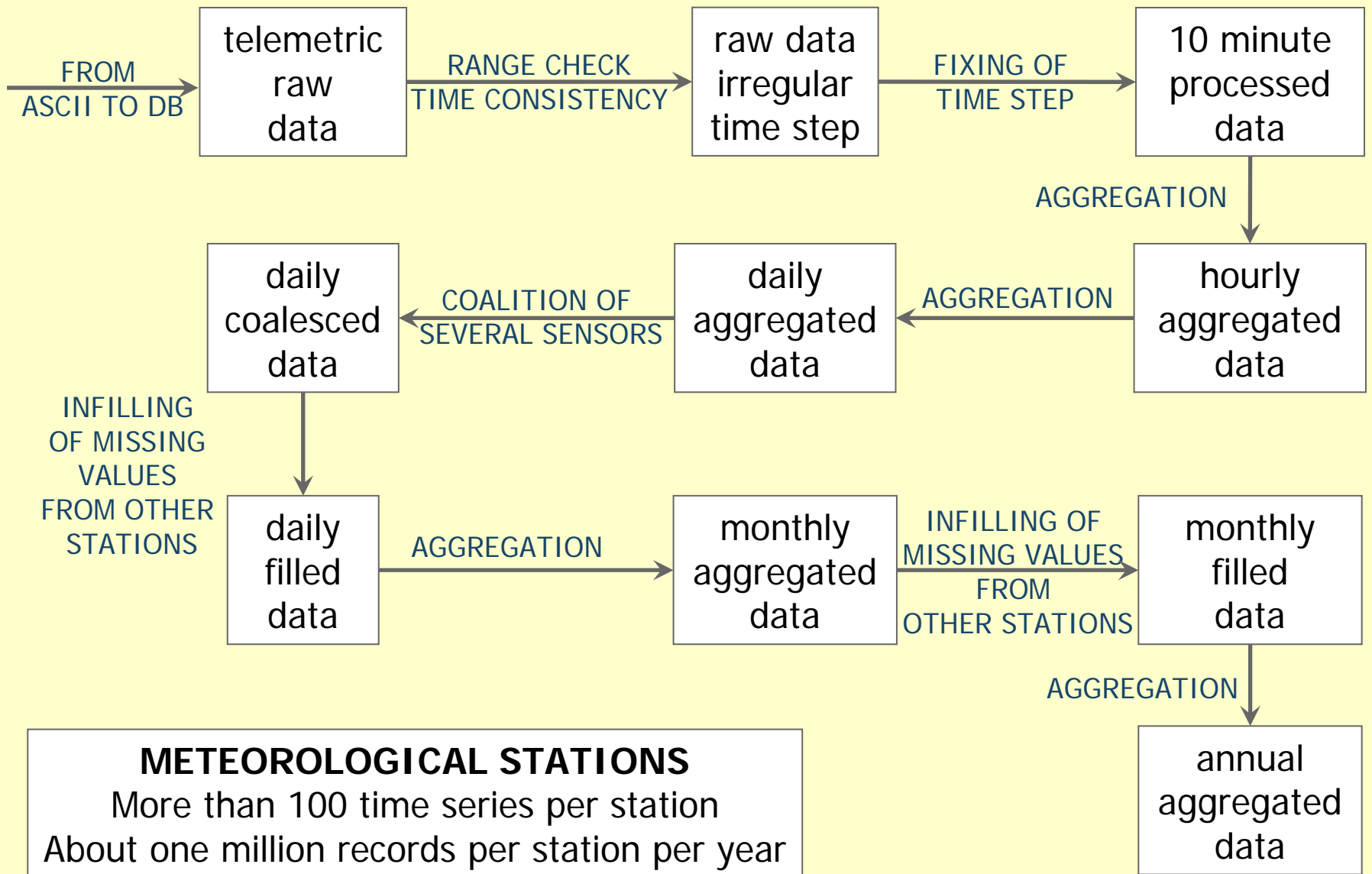
Decision support tool structure



Measuring system



Data management and processing: Time series manipulation



Software system characteristics

- ◆ All models written from scratch
- ◆ Basic development tool: **Delphi** (Object Pascal)
- ◆ Database: **Oracle** (more recently: **PostgreSQL**)
- ◆ Geographic system: **ArcView**
- ◆ Basic software units
 - **Hydrognomon**: Database management, processing of hydrologic data
 - **Castalia**: Stochastic hydrologic simulator
 - **Hydrogeios**: Simulation of surface and ground water processes
 - **Hydronomeas**: Hydrosystem control

Hydrognomon: Processing of hydrologic time series

The screenshot displays the Hydrognomon software interface. The main window shows a time series graph of Stage (m) versus time, with data points and fitted curves. The 'Interpolations (Stage-Discharge)' window is open, showing options for 'Type of Calculations' (Stage-Discharge selected), 'Load Curves' (from File, from DB), and 'Save Curves' (to File, to DB). The 'Required Time Series' list includes 'Dense Stage TS (Required)', 'Sparse Stage TS (Accurate)', 'H-Q measurements, Stage TS', and 'H-Q measurements, Discharge'. The 'Assign to:' field shows '61 ()' and '60 ()'. The 'Options' section includes 'Make H1 Correction', 'Merge Sparse + Dense Stage Data', 'Make H2 Correction', 'Make Stout Correction', and 'Calculate Discharge' (checked). The 'Statistics' window is also open, showing a 'Probability function (%) - scale: Normal distribution' plot with 'Discharge (m³/s)' on the x-axis and 'Probability function (%)' on the y-axis. The plot shows data points and fitted curves for various distributions: Weibull, Gamma, and Confidence interval limits 95%. The 'Distribution curves' window is also open, showing a list of distribution methods: Normal (Gauss), Log Normal, Galton (Log 3p), Exponential, Gamma (2p), Pearson III (G 3p), Log Pearson III, EV-1Max (Gumbel), EV-2Max, EV-1Min (Gumbel), EV-3Max (Gumbel), GEV-Max, GEV-Min, Pareto, GEV-Max (K spc.), and GEV-Min (K spc.). The 'Calculate' button is visible in the bottom right of the 'Statistics' window.

Time series data

Year	14.50	19.70		
1969/09	14.50	19.70		
1969/10	1.50	5.00	35.10	
1969/11	40.60	78.10	64.80	36.00
1969/12	192.60	314.10	144.80	130.80
1970/01	43.10	129.20	75.80	49.80
1970/02	41.50	131.40	62.60	70.10
1970/03	84.80	80.60	42.80	80.40

Hydrognomon: Automatic lumped hydrologic modeling

The image displays the Hydrognomon software interface for Basin Simulation. The main window is titled "Basin Simulation" and includes a menu bar (File, Edit) and tabs for Simulation, Calibration, and Dates. The interface is divided into several sections:

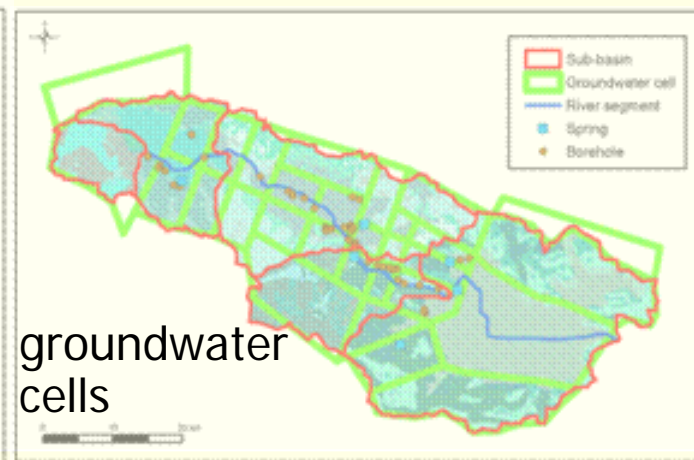
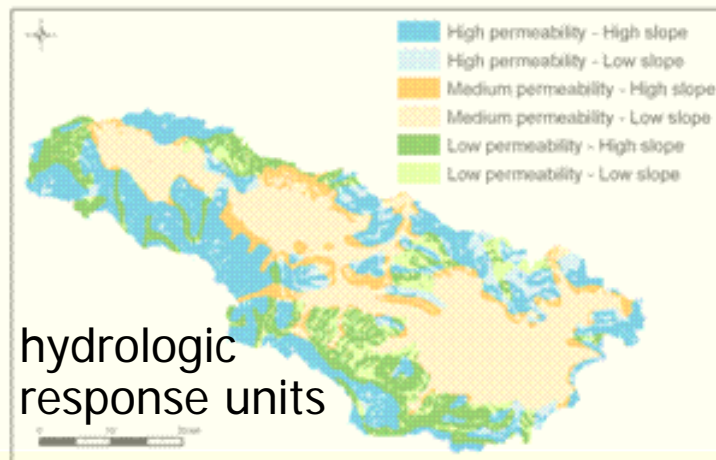
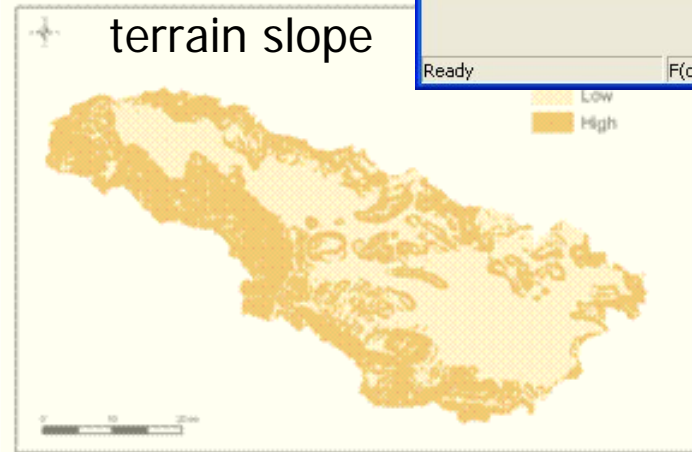
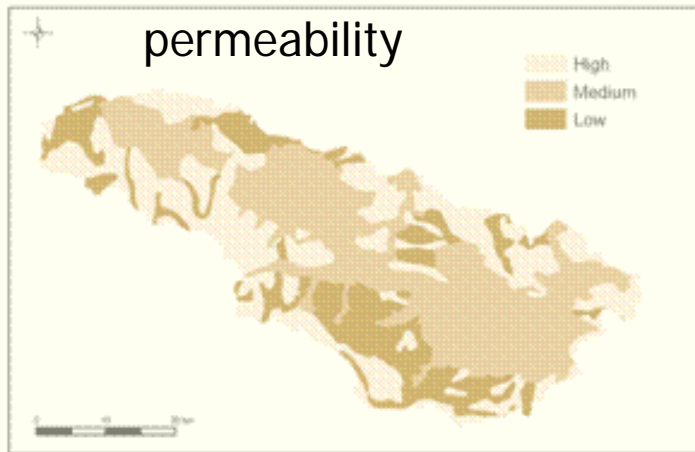
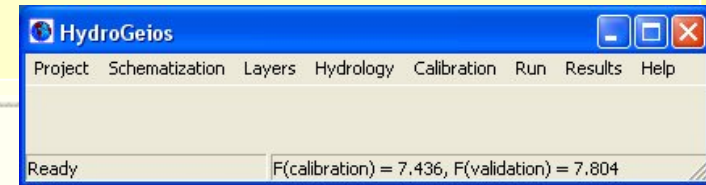
- Simulation Settings:** Includes checkboxes for "Potential Evapotranspiration" and "Pumping". Below these are lists for "0: Βροχόπτωση", "1: Εξάτμ.", "2: Αντίληση", and "3: Απορροή". A "K: Soil Storage Capacity (mm)" field is set to 500.
- Soil Tank:** Features an "Initial Soil Storage (S0, mm)" field set to 0. A "Percolation" parameter μ is set to 0.50. A "Graphical Representation" section shows a diagram of the soil tank with parameters λ (0.50) and $H1$ (100).
- Ground Tank:** Features an "Initial Ground Storage (Y0, mm)" field set to 0. A "Calibrate" section includes checkboxes for κ , "Base flow", and ξ . A "Preset / Calibrated Values" table is shown below.
- Output Timeseries:** A list of output variables including "Runoff", "Evapotranspiration", "Percolation", "Soil storage", "Ground storage", and "Erosion".
- Objective Function and Iterations:** The "Objective Function" is 0.848, and the "Number of Iterations" is 8000. A "Calibrate" button is present.
- Graph:** A line graph showing "Actual Runoff" (red line) and "Calcu. Runoff" (green line) from 1985 to 1993. The y-axis represents runoff in mm, ranging from 0 to 120.

The "Preset / Calibrated Values" table is as follows:

Parameter	Preset Value	Calibrated Value
κ	0.129	0.000
Base flow	0.000	0.047
λ	0.50	0.116
ξ	0.054	0.010
Runoff	215.90	0.000
Evapotranspiration	224.72	0.000
Percolation	0.000	250.96
Soil storage	0.000	0.000
Ground storage	0.000	0.000
Erosion	0.000	0.000

Hydrogeios: Detailed geo-hydrologic modeling

Hydrogeios is a hydrologic model of the entire hydrologic cycle, designed to describe both surface and subsurface processes, and especially karstic processes, as well as local withdrawals for irrigation



Hydrogeios calibration: vector nonlinear optimization

Groundwater cells

General information

Name:

Description:

Properties

Type: Groundwater tank Bottom (m): 280.000

X - centroid (m): 372089 Porosity: 0.269

Water balance timeseries (level in m, else in m3)

Date	Storage	Percolation	Infiltration	Pumping	Sim. level	Real level
Οκτ-84	122461	25493	229360	0	280.010	0.000
Νοε-84	1036255	1748228	324905	0	280.084	0.000
Δεκ-84	1514703	2364798	348420	0	280.122	0.000
Ιαν-85	4888994	6175260	3418377	0	280.394	0.000
Φεβ-85	4460661	4424469	1879408	0	280.359	0.000
Μαρ-85	3583788	3570247	1908831	0	280.289	0.000
Απρ-85	2604403	2297939	1622415	273386		
Μαϊ-85	1233929	1422955	610134	637346		
Ιουν-85	321721	827474	293403	1045847		
Ιουλ-85	274	464671	217745	1354580		

Basins

General information

Name: Λεκάνη ανάντη άνω που

Description:

Properties

Area (km2): 106.200

Mean elevation (m): 957.900

Length of main tributary (km): 0.000

Average slope (%): 0.000

Downstream node: Γραβιά

Parent river section: No river assigned

Water balance timeseries (mm)

Date	Precipitation	Pot. evapor.	Real evapo	Percolation	Infiltration	Runoff	Soil storage	Evap. storag
Οκτ-84	6.3	63.0	5.9	0.1	0.0	0.1	0.3	0.0
Νοε-84	209.8	27.1	27.0	46.2	0.0	2.5	133.6	0.0
Δεκ-84	116.9	21.0	20.9	54.6	0.0	6.3	169.7	0.0
Ιαν-85	475.2	35.3	35.2	132.2	0.0	174.8	366.4	0.0
Φεβ-85	101.9	28.4	28.3	93.3	0.0	74.1	298.1	0.0
Μαρ-85	156.1	43.3	43.1	85.9	0.0	68.0	282.4	0.0
Απρ-85	109.9	91.4	91.1	60.3	0.0	44.6	217.6	0.0
Μαϊ-85	67.3	117.7	81.3	40.1	0.0	39.8	153.5	0.0
Ιουν-85	21.9	160.5	52.5	24.5	0.0	0.7	97.6	0.0
Ιουλ-85	17.7	173.5	39.1	14.4	0.0	0.2	61.6	0.0
Αυγ-85	0.0	168.2	15.0	8.4	0.0	0.0	38.2	0.0
Σεπ-85	24.9	102.5	27.9	5.7	0.0	0.3	29.1	0.0
Οκτ-85	143.9	49.2	49.0	28.1	0.0	1.7	93.6	0.0
Νοε-85	297.5	31.7	31.6	82.1	0.0	54.2	243.9	0.0
Δεκ-85	111.2	21.4	21.3	73.8	0.0	46.6	234.7	0.0
Ιαν-86	178.1	32.6	32.5	82.2	0.0	57.4	261.7	0.0
Φεβ-86	305.5	37.4	37.3	112.0	0.0	147.9	334.4	0.0
Μαρ-86	133.9	49.9	49.7	87.6	0.0	69.4	286.8	0.0

Precipitation

Calibrated model responses

Properties

Process type: River discharge

Model component: Σίραγγα Καρδίτσας (4)

Discharge series (m3/s)

Date	Simulated	Observed
Οκτ-84	5.425	4.400
Νοε-84	7.145	7.700
Δεκ-84	6.938	10.200
Ιαν-85	33.719	38.600
Φεβ-85	24.190	18.500
Μαρ-85	22.341	24.500
Απρ-85	15.115	19.800
Μαϊ-85	4.261	6.600
Ιουν-85	0.000	2.800
Ιουλ-85	0.000	0.000
Αυγ-85	0.000	0.200
Σεπ-85	1.677	2.400
Οκτ-85	7.505	6.700
Νοε-85	9.371	10.200
Δεκ-85	12.012	11.600
Ιαν-86	12.889	10.300
Φεβ-86	19.231	16.700
Μαρ-86	14.858	15.700
Απρ-86	6.202	7.300
Μαϊ-86	2.678	3.800
Ιουν-86	0.000	0.800
Ιουλ-86	0.000	0.000

Statistics

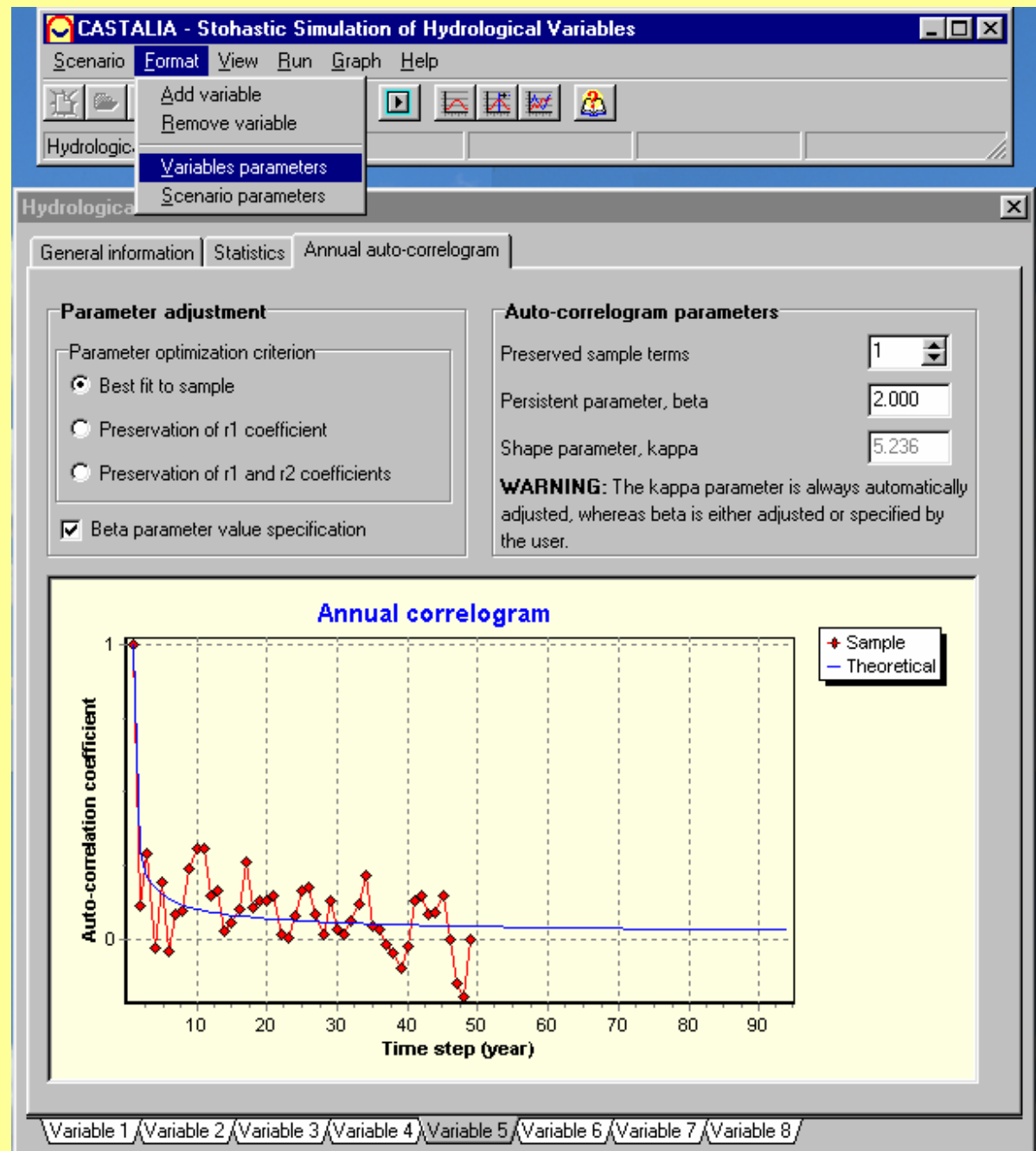
Statistical measure	Calibration	Validation
Average of observed series	7.438	5.502
Average of simulated series	7.524	6.537
St. deviation of observed series	8.360	6.683
St. deviation of simulated series	7.961	8.076
Coef. of variation of observed series	1.124	1.215
Coef. of variation of simulated series	1.058	1.235

Performance measures

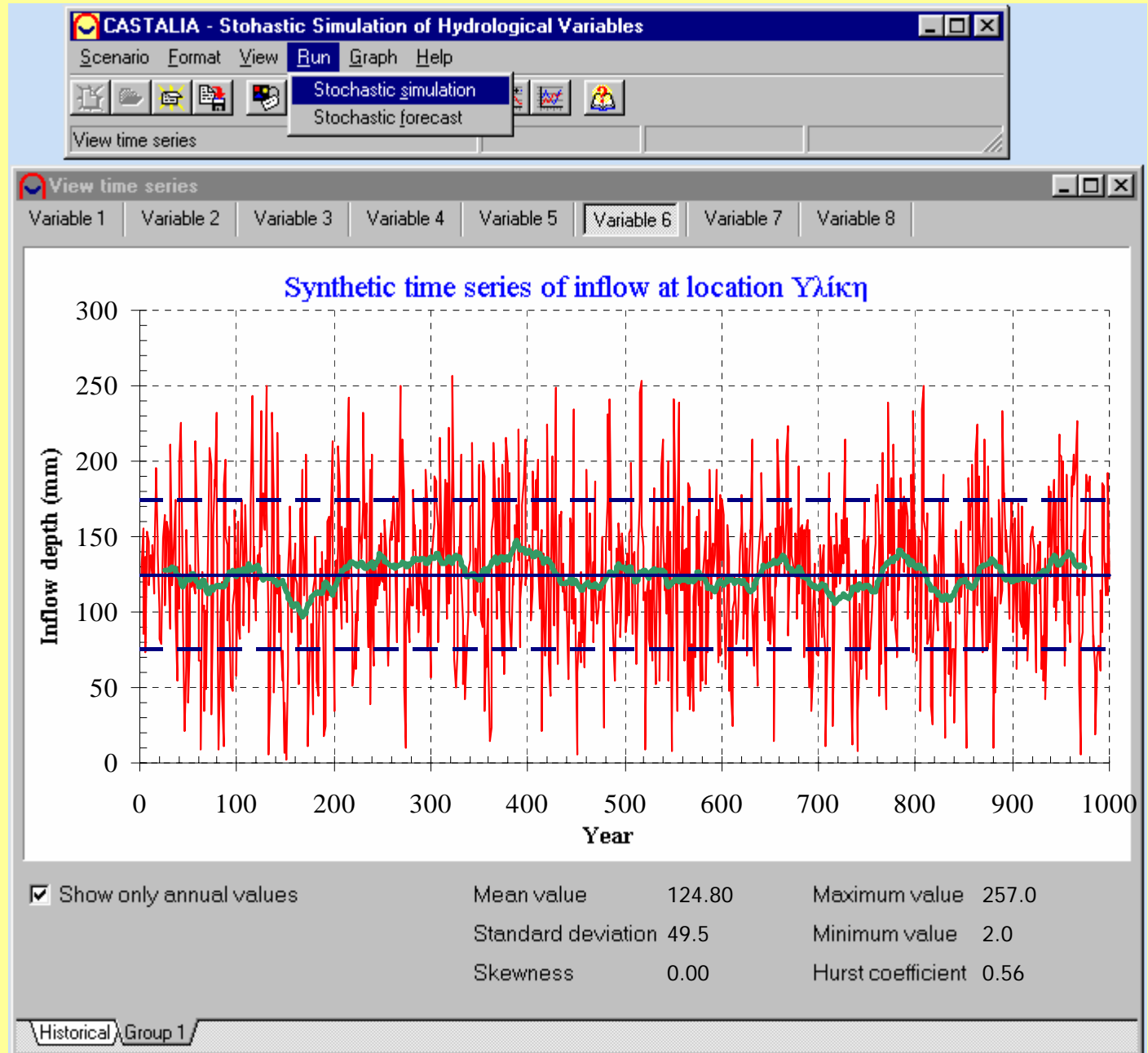
Performance measure	Calibration	Validation	Weight
Nash-Sutcliffe measure	0.887	0.751	8.000
Average bias	-0.012	-0.188	0.100
St. deviation bias	0.048	-0.208	0.100
Coef. of variation bias	0.059	-0.017	0.000
Intermittence flow error	1.066	0.999	1.000
Kendall variable	0.115	0.064	0.000
Value in obj. function	1.978	3.034	

Discharge (m3/s)

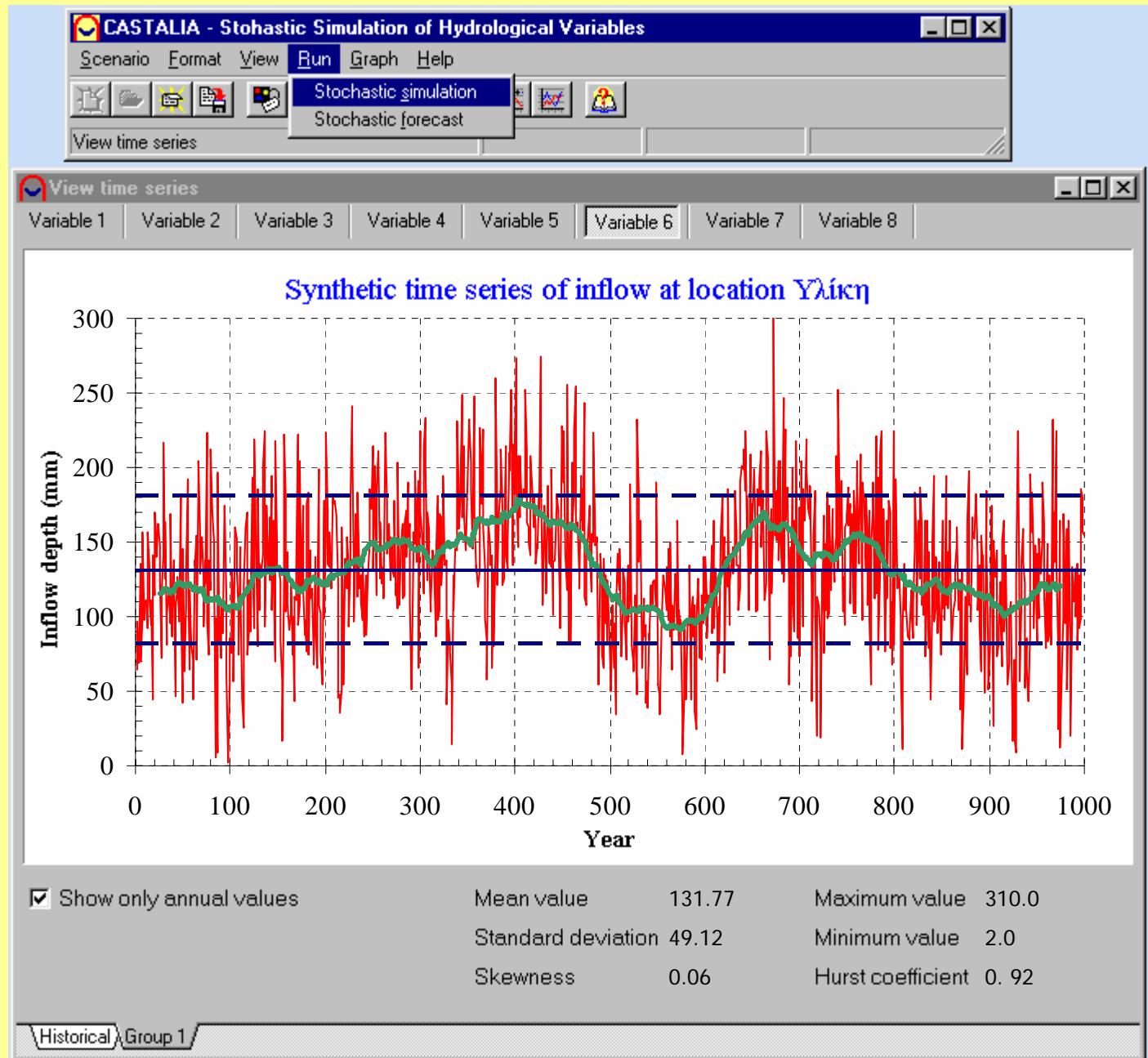
Castalia: Parameter estimation- Parameters of autocorrelation and persistence



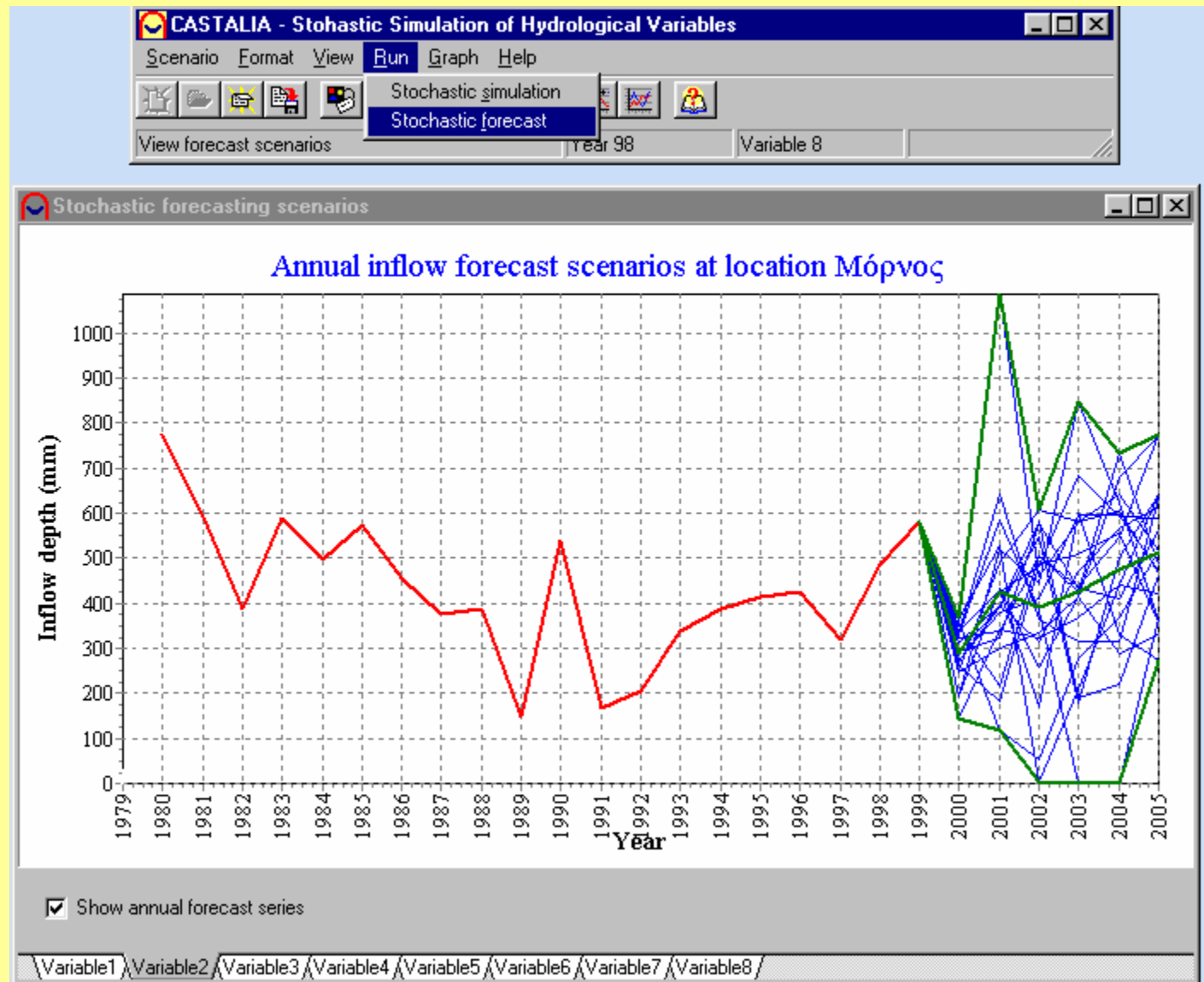
Castalia: Stochastic simulation without long term persistence



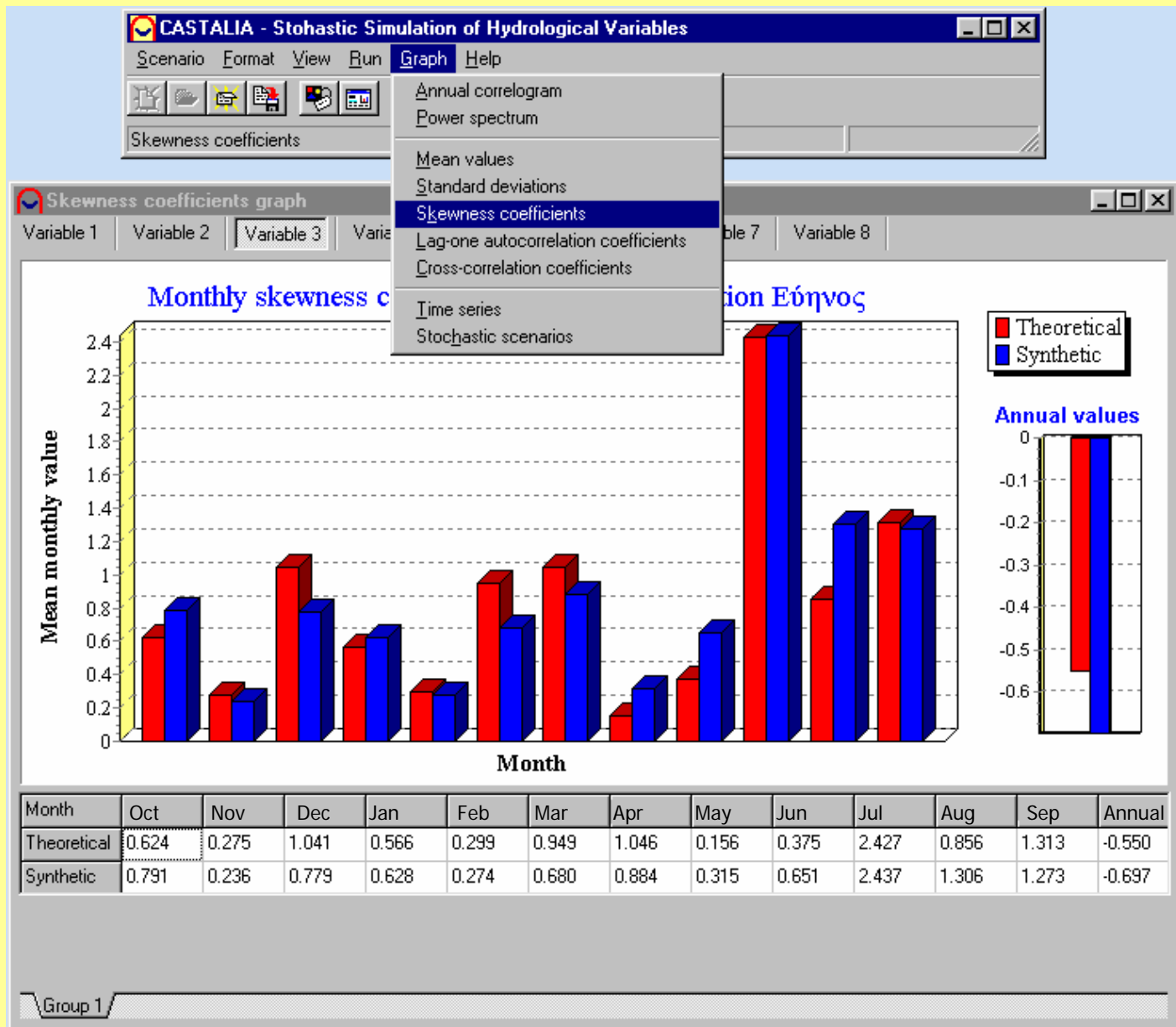
Castalia: Stochastic simulation with long term persistence



Castalia: Stochastic forecasting with long term persistence



Castalia: Preservation of marginal statistics – Skewness



Hydronomeas: Hydrosystem data management

Φόρμα Κόμβου/Ταμιευτήρα

Ο κόμβος είναι ενεργός

Όνομασία:

Είδος κόμβου

Απλός κόμβος

Ταμιευτήρας

Συντεταγμένες

Τετημένη:

Τετανυμένη:

Διαχείριση ταμιευτήρα

Διαχείριση ενεργή

0 Σταθερός όγκος

Νεκρός όγκος:

Χωρητικότητα:

Αρχικός όγκος:

Έκταση υπολεκάνης:

Φόρμα Προτεραιότητας Στόχων και Φόρμα Στόχοι

Συνιστώσα δικτύου	Κατανάλωση νερού - Ύδρευση (hm3)	NAI	53.300	1.000
1 Μουρίκι-Κρεμμάδα - 14/3/01				
2 Ζήτηση Μενιδίου				
3 Ζήτηση Γαλατσίου				
4 Ζήτηση Κιούρκων	Κατανάλωση νερού - Ύδρευση (hm3)	NAI	53.300	1.000
5 Ζήτηση Μάνδρας	Κατανάλωση νερού - Ύδρευση (hm3)	NAI	23.600	1.000
6 Μόρνος	Μέγιστος όγκος (hm3)	NAI	600.000	1.000
7 Εύηνος	Κατανάλωση νερού - Ύδρευση (hm3)	NAI	2.600	1.000

Προτεραιότητα Διαγραφή Στοιχεία

Φόρμα Υδραγωγείου

Το υδραγωγείο είναι ενεργό

Όνομασία:

Ανάντη κόμβος:

Κατάντη κόμβος:

Κατεύθυνση ροής

Μονοσήμαντη

Αμφίδρομη

Φόρμα Γεώτρησης

Η γεώτρηση είναι ενεργή

Όνομασία:

Κόμβος:

Κατανάλωση ενέργειας kWh/m³:

Άνω κατώφλι:

Κάτω κατώφλι:

Μέγιστη παροχή

Μηνιαία διακύμανση στόχου: Ζήτηση Γαλάτσι - 14/3/01

Μήνας	Τιμή στόχου
1	0.105
2	0.09
3	0.068
4	0.063
5	0.055
6	0.06
7	0.058
8	0.082
9	0.1
10	0.105
11	0.098
12	0.11

Φόρμα Ιδιοτήτων Στόχου

Γράφημα

Ο στόχος είναι ενεργός

Όνομασία:

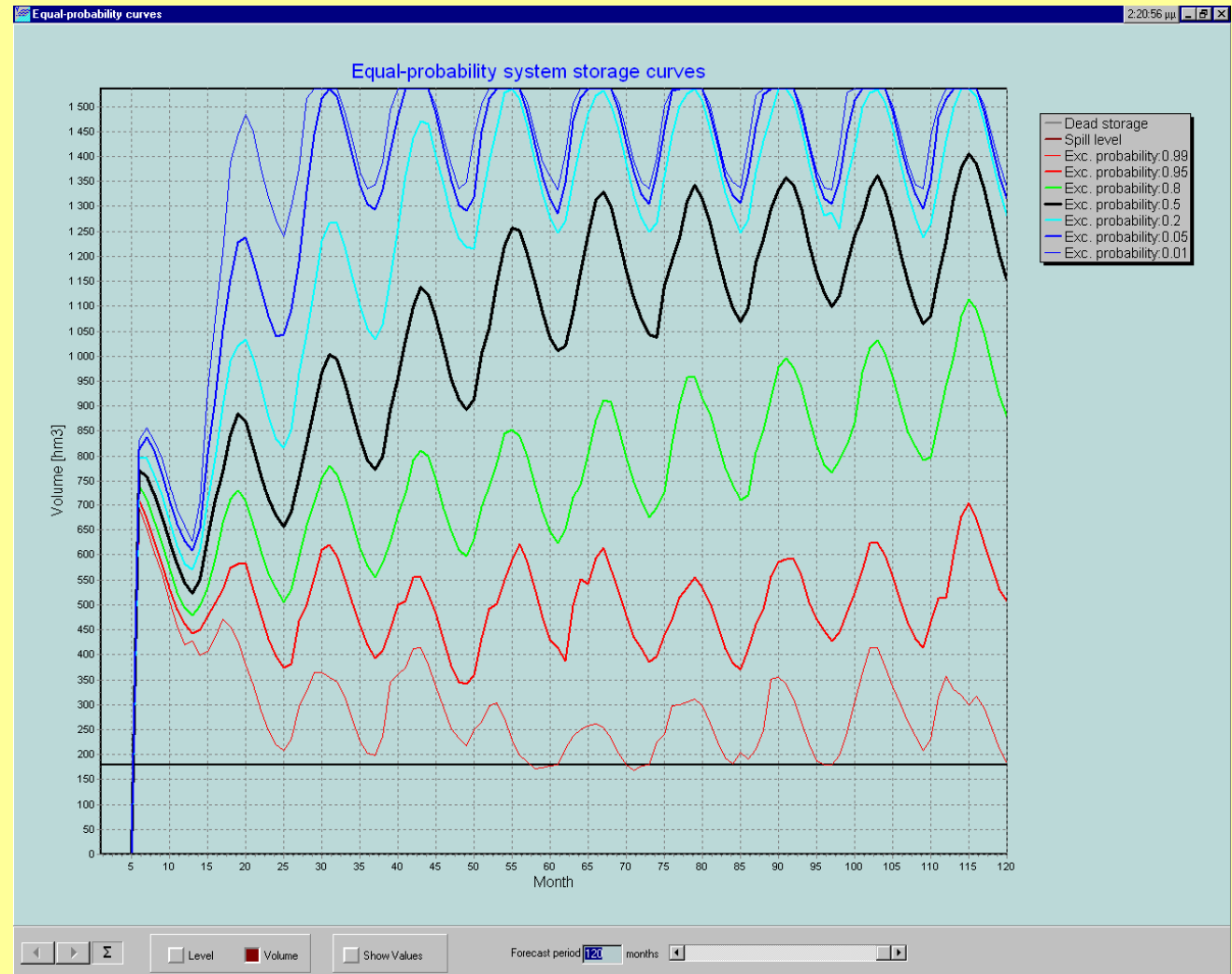
Είδος:

Αγωγός:

Μέγιστη αστοχία:

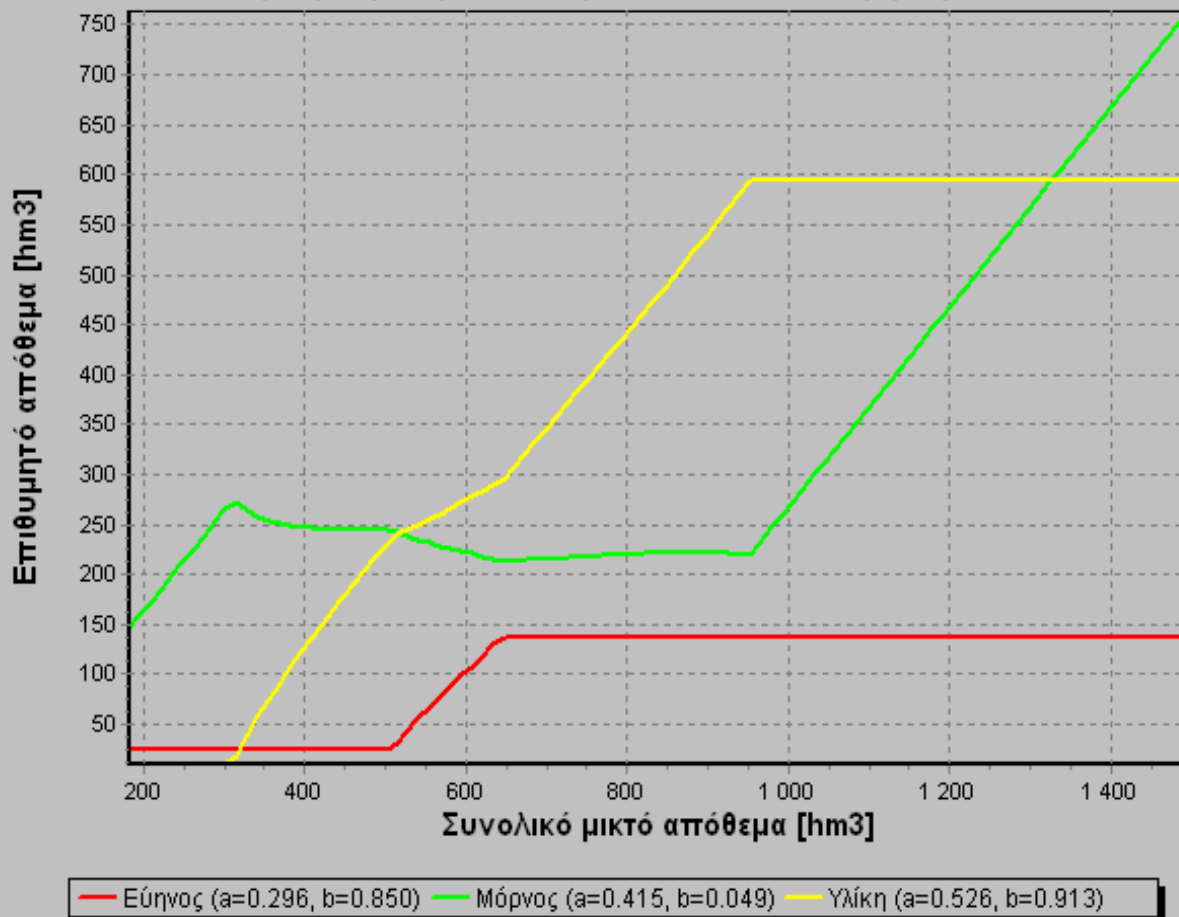
Hydroneas: Stochastic forecast of hydrosystem storage

Evolution of quantiles of system storage (for several levels of probability of exceedance) for the next 10 years as a result of 200 terminating simulations with long-term persistence



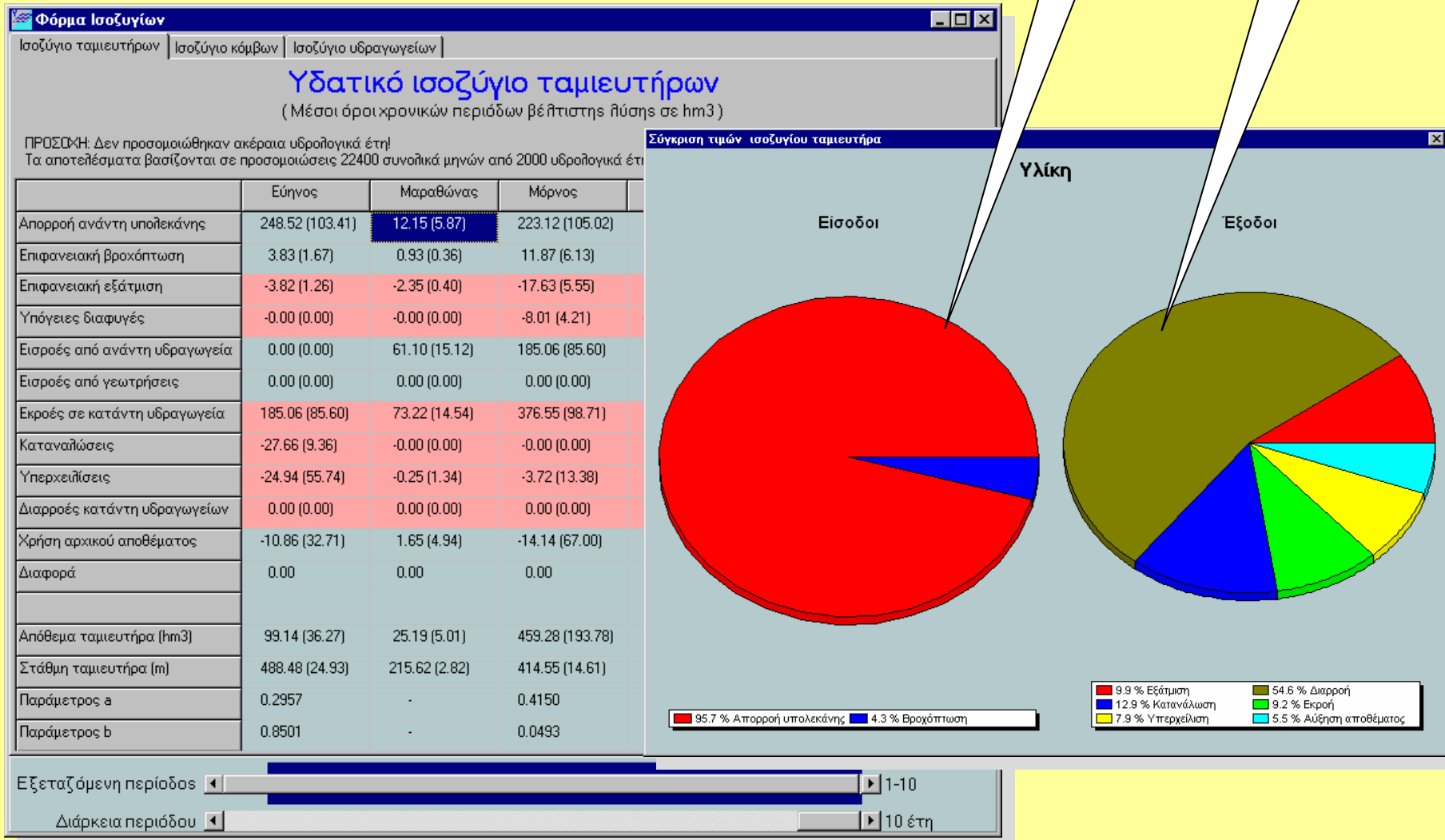
Hydronomeas: Optimal hydrosystem control rules

Γραφική παράσταση κανόνων λειτουργίας



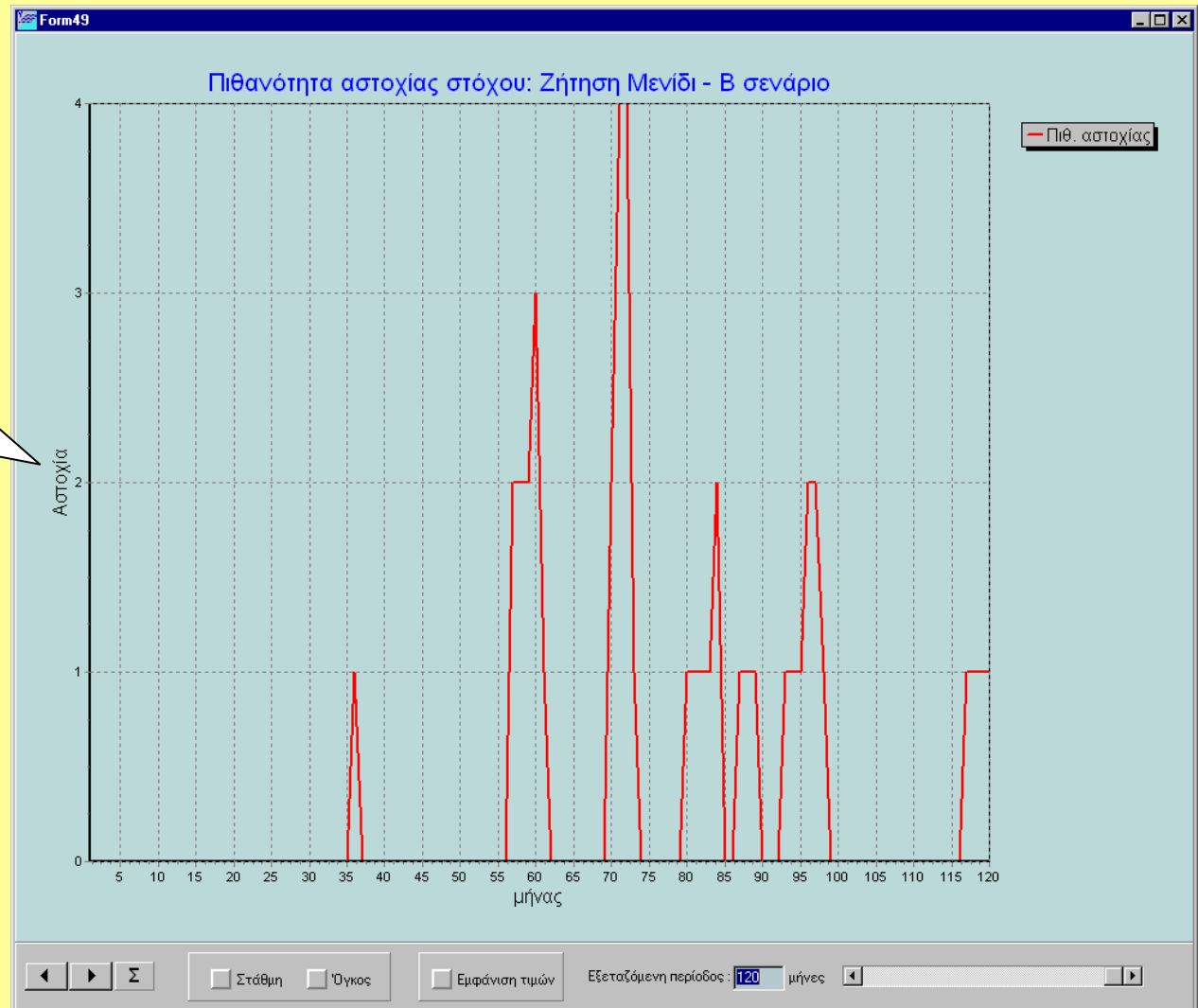
Target allocation
of total reservoir
storage per each
reservoir

Hydronomeas: Reservoir balance



Hydronomeas: Time profile of failure probabilities

Number of failures in a total of 200 stochastic scenarios



Hydronomeas: Reporting

Print Preview

Υ
Υδρονόμος 2.1 - Εθνικό Μετσόβιο Πολυτεχνείο

ΑΣΤΟΧΙΑ ΕΝΕΡΓΩΝ ΣΤΟΧΩΝ (με σειρά προτεραιότητας)

Όνομασία στόχου	Περιγραφή	Αστοχία υδρολογικών περιόδων	Ανώτατη αποδεκτή αστοχία	Αστοχία μηνών	Αστοχία όγκου
Ελάχιστη ροή υδραγ. Υλίκης	Ελάχιστη ροή υδραγωγείου Υλίκης τους πρώτους μήνες προσαρμογής για υλοποίηση υποχρεωτικής απόληξης	0 / 2000	1.00	0 / 24000	0.00 / 0.00
Ζήτηση Μενίδι - 14/3/01	Επιθερμός σε ετήσια βάση και εποχικά κυμαινόμενος στόχος ζήτησης νερού για ύδρευση (Σύνολο Αθήνας 440 hntθ)	17 / 2000	1.00	48 / 24000	0.17 / 224.27
Ζήτηση Γαλάτσι - 14/3/01	Επιθερμός σε ετήσια βάση και εποχικά κυμαινόμενος στόχος ζήτησης νερού για ύδρευση (Σύνολο Αθήνας 440 hntθ)	23 / 2000	1.00	50 / 24000	0.23 / 124.36
Ζήτηση Κιόρκια - 14/3/01	Επιθερμός σε ετήσια βάση και εποχικά κυμαινόμενος στόχος ζήτησης νερού για ύδρευση (Σύνολο Αθήνας 440 hntθ)	23 / 2000	1.00	56 / 24000	0.13 / 51.61
Ζήτηση Μάνδρα - 14/3/01	Επιθερμός σε ετήσια βάση και εποχικά κυμαινόμενος στόχος ζήτησης νερού για ύδρευση (Σύνολο Αθήνας 440 hntθ)	25 / 2000	1.00	63 / 24000	0.07 / 22.77
Μέγιστος Όγκος Μόρνου Περροχή Ευήνου	Επιθερμός μέγιστος όγκος για αποφυγή υπερχειλίσεων Επιθερμή τετραβελονική ή τριτοροχή 2,6 hntθ, εισάγεται ως κοπανάκωση	894 / 2000 999 / 2000	1.00 1.00	7304 / 24000 2918 / 24000	0.00 / 0.00 2.77 / 29.90
Μέγιστος όγκος Μαραθώνα	Στόχος μέγιστου όγκου για αποφυγή υπερχειλίσεων	862 / 2000	1.00	4653 / 24000	0.00 / 0.00
Ελάχιστος όγκος Μαραθώνα	Εποχικά κυμαινόμενος στόχος ελάχιστου όγκου για τη διατήρηση οπθόμενου ασφαλείας	1415 / 2000	1.00	2820 / 24000	0.11 / 17.07
Άρδευση Κωπαΐδας	Ζήτηση νερού για άρδευση της Κωπαΐδας. Παρουσιάζει έντονη εποχική διακύμανση.	16 / 2000	1.00	46 / 24000	0.15 / 35.00

*Μόνο οι ενεργοί στόχοι χρησιμοποιούνται κατά την προσαρμοσμένη βέλτιστη ποσότητα.
 Η πηγή αστοχίας υδρολογικής περιόδου (Έτος) ορίζεται από το λόγο των υδρολογικών περιόδων με αστοχία προς το σύνολο των προσαρμοσμένων υδρολογικών περιόδων.
 Αστοχία που αναφέρεται ως προς τη υδρολογική περίοδο διαπιστώνεται κατά την αστοχία ενός τουλάχιστον χρονικού βήματος (μήνας) της περιόδου.
 Η προτεινόμενη λύση τηρεί τον περιορισμό της ανώτατης αποδεκτής πιθανότητας αστοχίας για κάθε στόχο.*

16/3/2001 5:31:54 μμ 33

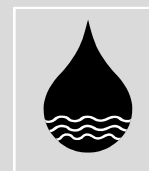
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Management plans and every day operation of the hydrosystem

- ◆ Every five years a master plan of the water supply of Athens is elaborated (the first was issued in 2000)
- ◆ Every year the master plan is revised based on current data and model runs
- ◆ Every three months the annual plan is reassessed and, if necessary, updated by new model runs
- ◆ Meanwhile, the every day management is based on optimal parametric operation rules
- ◆ Models are run for a 10-year lead time to account for long-term effects of today's decisions
- ◆ The general management targets are:
 - Adequacy of water resources
 - Adequacy of conveyance system
 - Cost effectiveness
- ◆ All management is based on a probabilistic approach of forecasts/risk/reliability assuming:
 - Acceptable reliability 99% on an annual basis
 - Potential for further increase of reliability taking into account elasticity of demand and emergency measures in case of impending failure
- ◆ So far, the decision support tool and its modules (thoroughly tested for the Olympics 2004) exhibited good performance

References

1. 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.
2. 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.
3. 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.
4. 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.
5. Nalbantis, I., and D. Koutsoyiannis, A parametric rule for planning and management of multiple reservoir systems, *Water Resources Research*, 33(9), 2165-2177, 1997.



Early stage



← The Hadrianean aqueduct



Supplementary water collection and distribution in Athens (early 20th century until 1930s) →

Marathon dam



Construction of dam, 1928



Today

Construction of spillway, 1928



Hydrosystem

More pictures

Marathon dam (2)



Devastating flood, 1926



Inauguration of Boyati tunnel, 1928



Marathon spillway in action, 1941

Hydrosystem

Previous pictures

Hylike lake and pumping stations



Hylike lake



Hylike, floating pumping stations



Hylike, main pumping station



Kiourka pumping station



Mornos reservoir and aqueduct



Mornos canal at Delphi



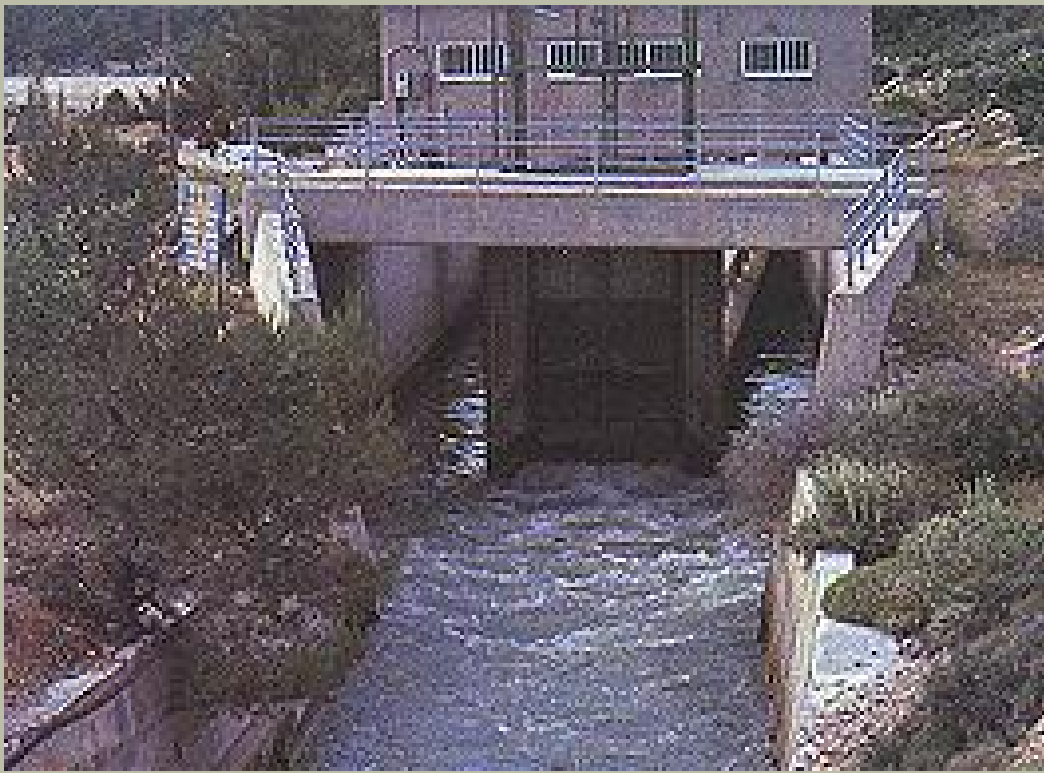
Mornos reservoir

Mornos canal at Thebes plain

Siphon at Distomo



Control of Mornos aqueduct



Canal flow control construction



Aqueduct supervizing & control centre



Hydrosystem

Evinos dam and tunnel



Evinos dam during construction



Construction of the Evinos-Mornos connection tunnel

Treatment plants



Perissos water treatment plant



Aspropyrgos water treatment plant