Hydro-economic optimization under inflow uncertainty using the SDP_GAMS generalized optimization tool

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River Reno close to Bologna
Source: Panoramio

CONTENT

1. Introduction
2. The SDP_GAMS tool
3. Case study: Mijares River Basin (Jucar RBD)
4. Conclusions

The SDP approach

Main advantages:

- Able to handle non-linearities
- Takes into account inflow uncertainty
- Decision-making process treated sequentially

Main disadvantages:

- Requires uncertainty descriptor (Markov Chain)
- The computational burden increases exponentially with the system size: **curse of dimensionality**

The SDP approach

The curse of dimensionality has been worked out by:

- Simplifying the system (decomposition techniques)
- Using interpolation techniques
- Employing alternative approaches (RL, SSDP, SDDP, etc.)

Stochastic dynamic programming developments in multireservoir systems based on *ad-hoc* codes

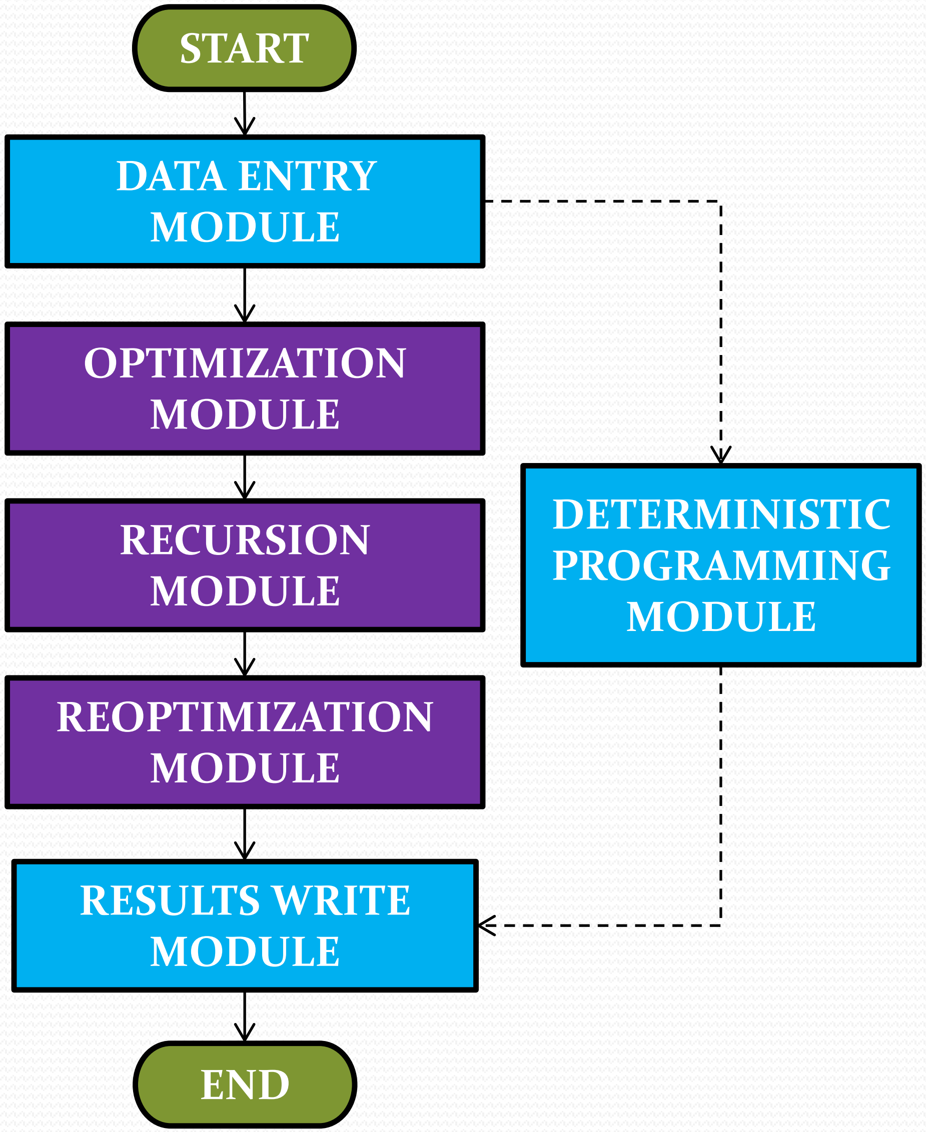
Goal: develop a general-purpose DSS code to solve the SDP algorithm in any multipurpose multireservoir system

Approach: use GAMS supported by GAMS – MS Excel links

Outline and Flowchart — THE SDP_GAMS TOOL

Main features:

- Regular SDP approach
- GAMS skills not required
- Maximizes benefits
- Discrete storages and inflows
- Lag-1 Markov chain
- Modular approach



Data entry module

THE SDP_GAMS TOOL

Calls from Excel to GAMS to introduce:

- System features (physical, economic and environmental)
- Discrete variables and Markov Chain
- Reoptimization data
- Convergence control parameters

MODEL GENERAL FEATURES

Type of problem	Maximization
Recursion primary convergence limit (Benefits)	0.01
Recursion maximum number of iterations	20
Optimization module previously executed?	Yes
Recursion module previously executed?	Yes
Reoptimization desired?	Yes
Optimization module quick mode	Enabled
Reoptimization interpolation mechanism	Piecewise linear
Reoptimization module reservoir prevalence mode	Enabled
Type of reoptimization desired	Stochastic

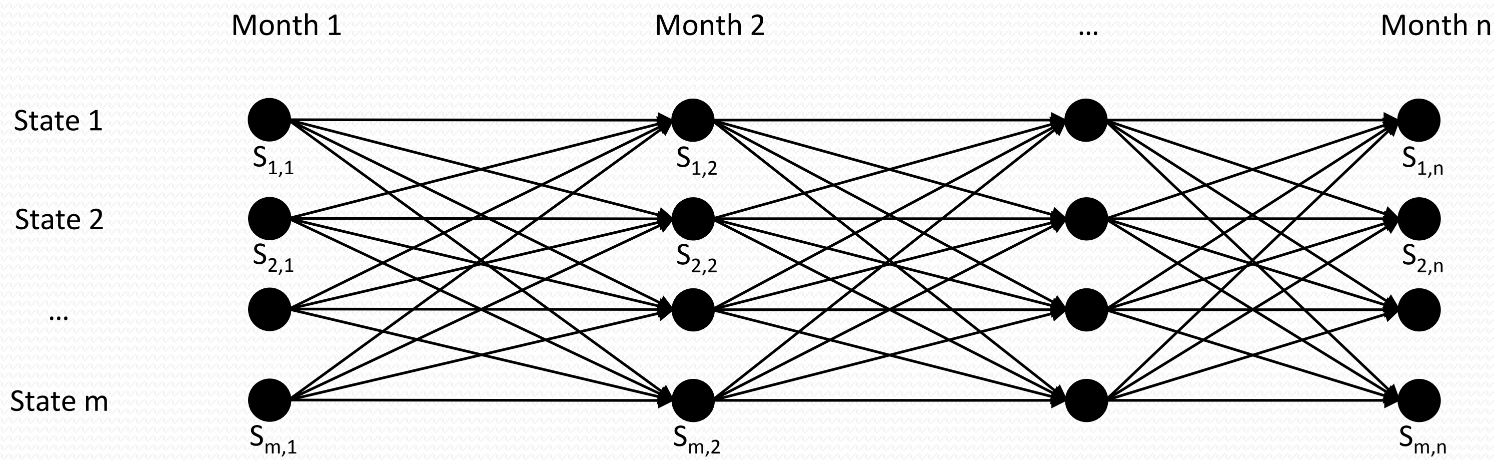
SYSTEM FEATURES

Number of temporal stages per recursive cycle (t)	12
Number of inverted temporal stages per cycle (r)	12
Number of nodes in the system (nod)	7
Number of reservoirs in the system (e)	2
Coefficients of reservoir's volumen-surface curves (g)	3
Number of inflows entry points (p)	2
Maximum number of inflow branches (br)	4
Number of demands (d)	4
Coefficients of demand benefit curves (gd)	4
Number of discrete inflow classes per temporal stage (a)	16
Number of discrete volume classes per temporal stage (v)	91
Number of cycles of the reoptimized series (cycle)	69

Optimization module

THE SDP_GAMS TOOL

GAMS solver (CONOPT, CPLEX) -> optimal immediate benefits associated to each possible combination between discrete state variables

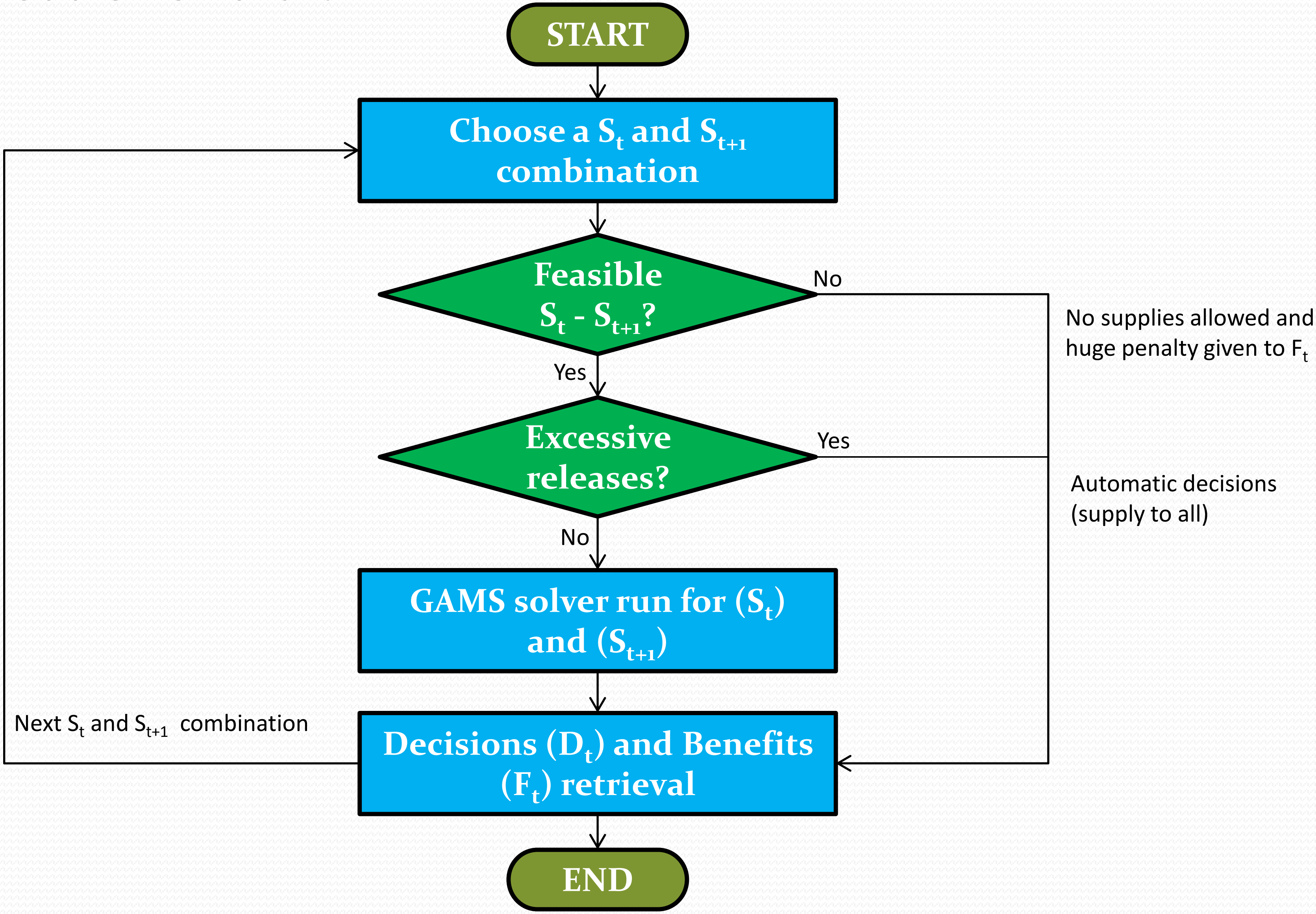


Longest computational time

For reservoirs in series, a “quick mode” can be activated to save computation time

Optimization module

Module flowchart



Recursion module

Solves backwards the Bellman recursive equation using the optimization results

$$F_t(S_t, Q_t) = \max_{D_t} \left[B(S_t, Q_t, D_t) + \sum_q P_{p,q} \cdot F_{t+1}(S_{t+1}, Q_{t+1}) \right]$$

Optimization module results

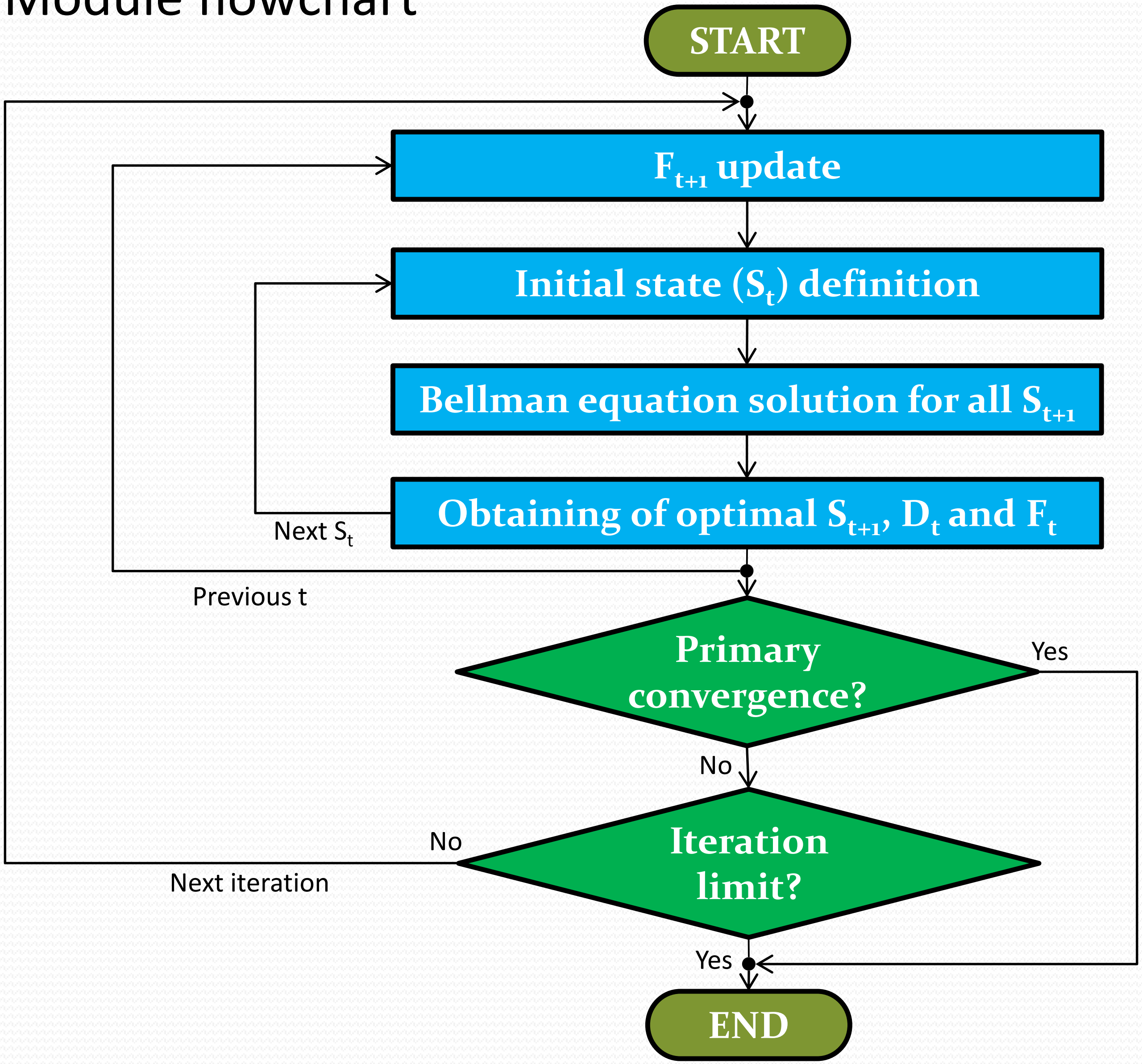
Markov Chain

Features:

- Two convergence criteria: steady benefits (primary) and steady policies (secondary)
- Each iteration corresponds to a year
- Results: steady-state optimal policies (D_t) and steady-state benefit-to-go values (F_{t+1}) for all the discrete states (S_t)

Recursion module

Module flowchart



Reoptimization module

GAMS solver (CONOPT, CPLEX) to solve forward the Bellman recursive equation using the benefit-to-go function values obtained in the recursion module

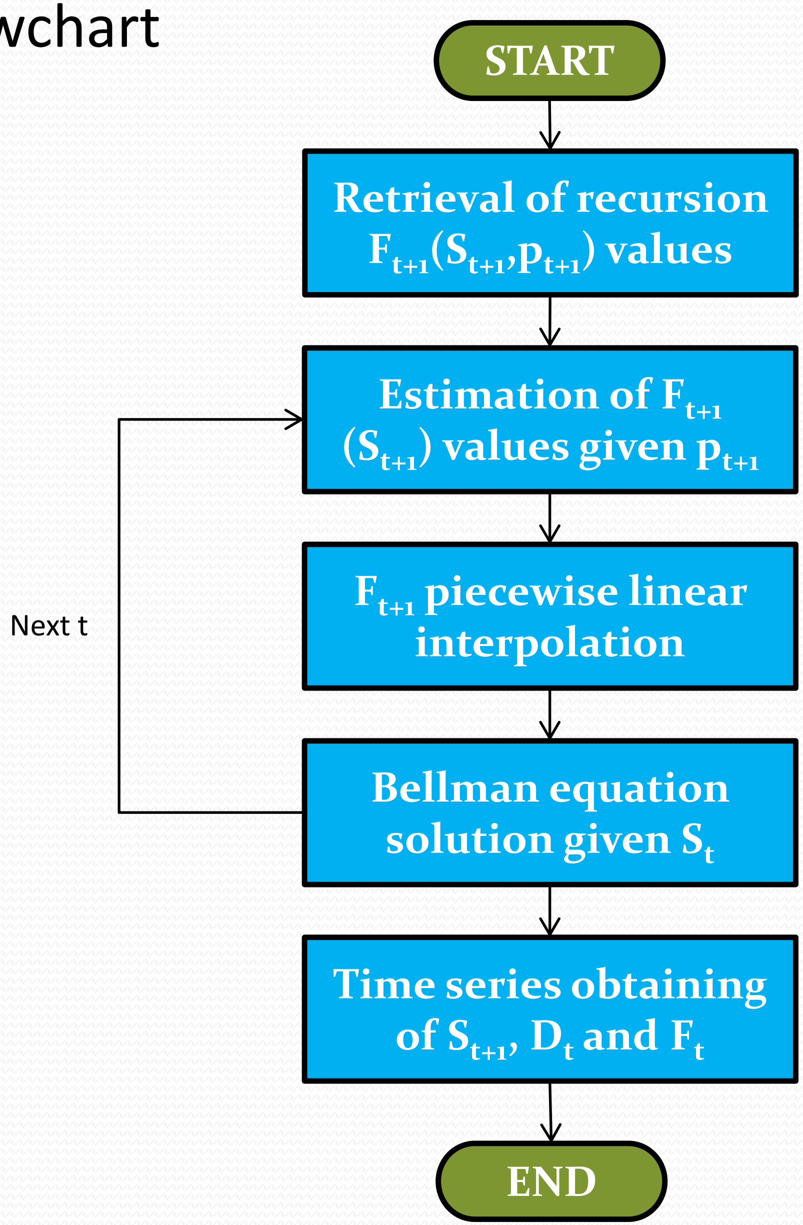
$$F_t(S_t, Q_t) = \max_{D_t} \left[B(S_t, Q_t, D_t) + \sum_q P_{p,q} \cdot F_{t+1}(S_{t+1}, Q_{t+1}) \right]$$

Recursion module results

- Results: time series of
  - Storages
  - Demand deliveries
  - Flows in the system
  - Benefits obtained
  - Marginal water values

Reoptimization module

Module flowchart



Results retrieval module

THE SDP_GAMS TOOL

Call-back from GAMS to Excel to show:

- Recursion module results
- Reoptimization module results

Recursion status report

FIRST CONVERGENCE CRITERIA STATUS	ACHIEVED
SECOND CONVERGENCE CRITERIA STATUS	ACHIEVED
NUMBER OF ITERATIONS DONE	20
ITERATION IN WHICH SECOND CONVERGENCE ACHIEVED	12
FIRST CONVERGENCE ERROR	0.0100
EXPECTED VALUE	63.8000
NUMBER OF NON-NORMAL SOLVER TERMINATIONS	0

Recursion optimal benefits

Stage	Reservoir_1	Reservoir_2	Inflow_1	Inflow_2	Short_Benefits	Long_Benefits	Total_Benefits
t1	2.00	3.00	5.09	0.00	1.51	44.5	46.01
t1	2.00	3.00	5.09	1.00	2.02	44.74	46.75
t1	2.00	3.00	5.09	2.70	2.93	46.57	49.5
t1	2.00	3.00	5.09	29.88	6.74	56.07	62.82
t1	2.00	3.00	7.66	0.00	2.86	47.33	50.19
[illegible]	[illegible]	[illegible]	[illegible]	1.00	[illegible]	[illegible]	49.38
[illegible]	[illegible]	[illegible]	[illegible]	2.70	[illegible]	[illegible]	52.69
t1	2.00	3.00	7.66	29.88	[illegible]	57.29	63.67
t1	2.00	3.00	9.60	0.00	3.93	54.22	58.15

Time stage

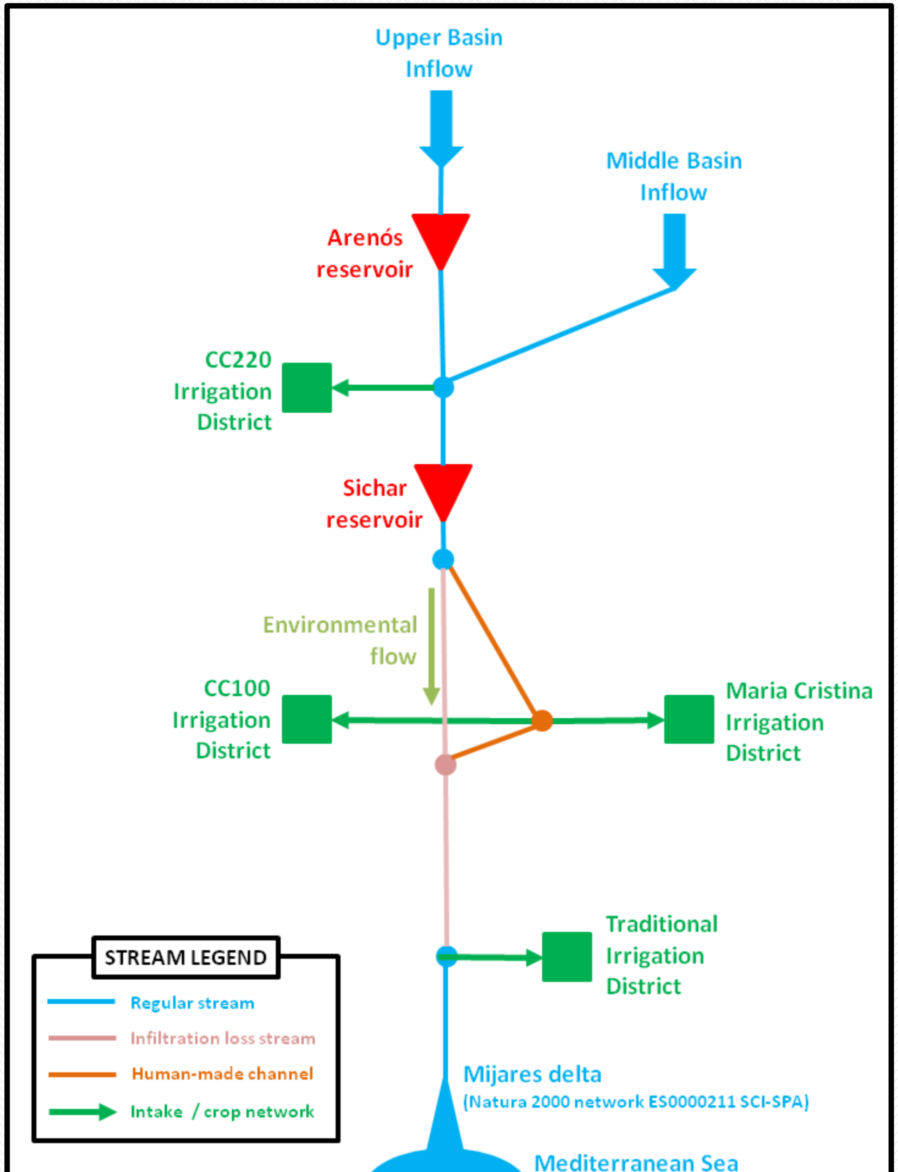
Initial system state

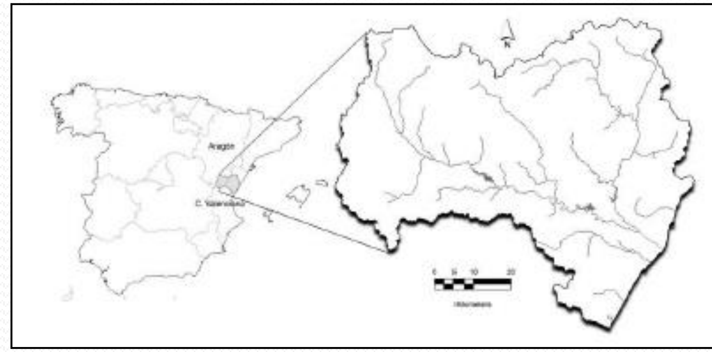
Immediate benefits

Benefits-to-go

CASE STUDY: MIJARES RIVER

General view



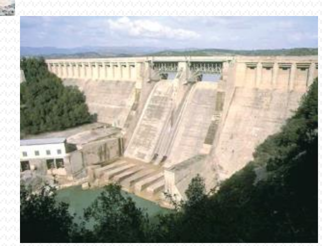


NAME	CAPACITY	START	MAIN USE	DEMAND
Arenós	93.00	1959	Agricultural	120.18
Sichar	49.00	1980	Agricultural	
MEAN ANUAL INFLOW (1980-2009)				196.00

Units in Mm^3

Arenós

Source: CEDEX



Sichar

CASE STUDY: MIJARES RIVER

Purpose: test the performance of the tool in the Mijares river

Approach: to build the following models:

- A hydro-economic SDP model
- A hydro-economic deterministic optimization model
- A simulation model

And compare their economic performance

Model features CASE STUDY: MIJARES RIVER

Historical data records for the 1940-2010 period

System features included:

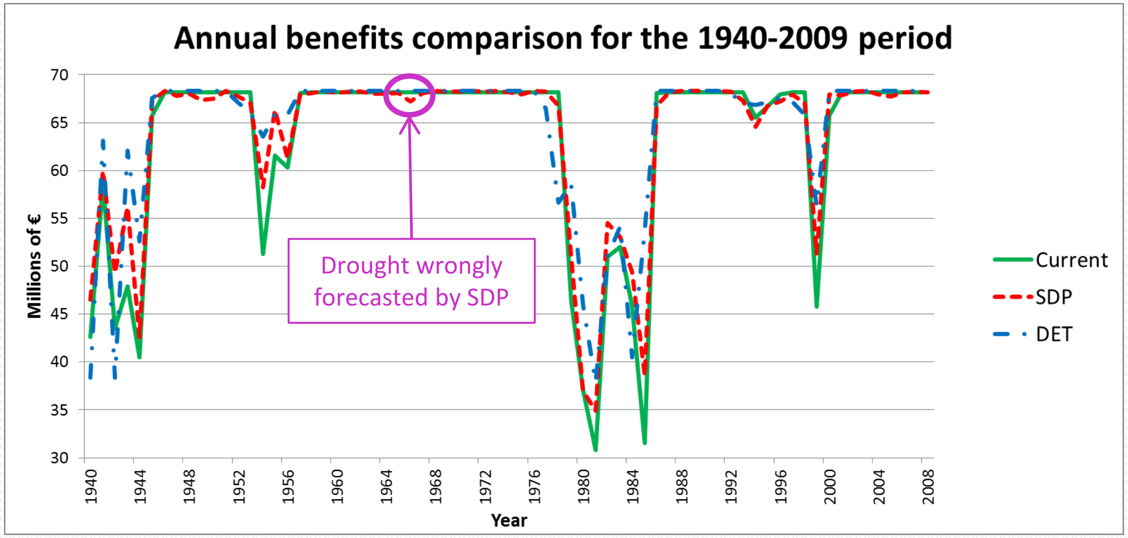
- Physical: connectivity matrices, sub-basins, storage features, stream features, demand features, etc.
- Economic: demand curves, network costs, etc.
- Environmental: minimum flows and storages

State variables discretization:

- Storage: 91-point discrete grid
- Inflows: 16-point discrete grid
- Lag-1 Markov Chain

CASE STUDY: MIJARES RIVER

Comparison for the 1940-2010 period



SCENARIO	ECONOMIC BENEFIT (M€)
Current policies	63.06
Stochastic Optimization	63.86
Deterministic Optimization	64.39

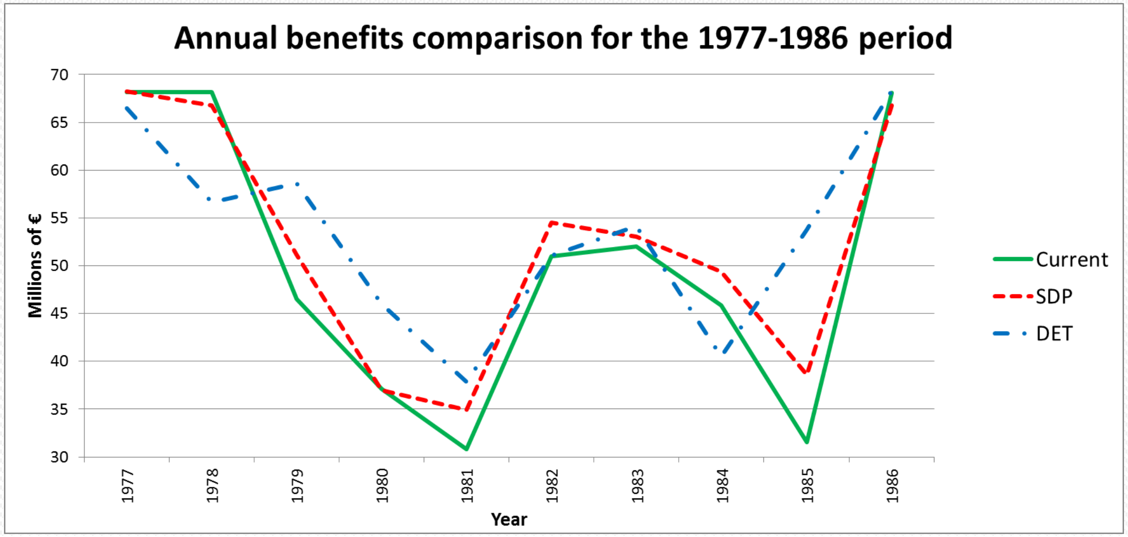
All demands are fully met except during large droughts (steady inflows)

SDP performance between simulation (non-optimal policies) and deterministic optimization (with perfect foresight). It covers 60% of the gap

Results

CASE STUDY: MIJARES RIVER

Comparison for the 1977-1986 period (the worst drought)



SCENARIO	ECONOMIC BENEFIT (M€)
Current policies	49.93
Stochastic Optimization	52.04
Deterministic Optimization	53.34

SDP covers 62% of the gap (similar than the whole period)

Economic differences between alternatives grow: optimal policies specially improve drought management

Advantages / disadvantages

Advantages of SDP_GAMS

- Friendly user interface
- General-purpose
- GAMS skills are not required
- Modular structure saves time

Disadvantages of SDP_GAMS

- Curse of dimensionality
- Hard constraints (inflows & storages)
- Demand curves as polynomials
- No aquifers

Further developments

- Improve the interface (GUI)
- Overcome the curse of dimensionality (switching from SDP to SDDP)
- Include aquifer and stream-aquifer interactions (embedded multireservoir or eigenvalue models)
- Adaptation of the tool to explore climate change effects
- Coupled quantity-quality analysis
- Etc.

THANK YOU FOR YOUR ATTENTION

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