ESD.S30

Electric Power System Modeling for a Low Carbon Economy

Hydrothermal scheduling. A case study

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Introduction

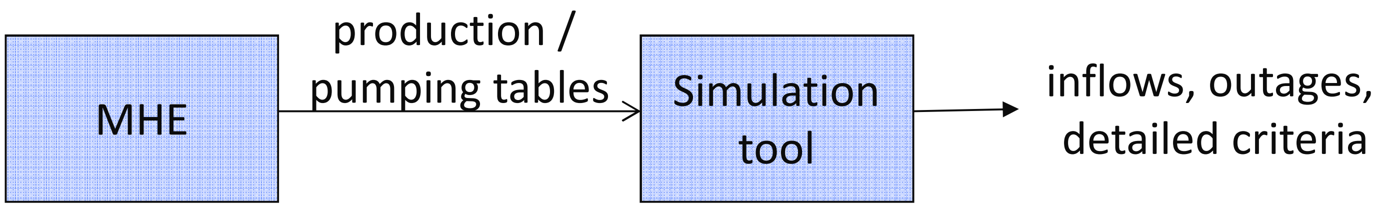
Introduction

- Relevance of hydroelectric power
  - Reduces electric system operation cost
  - High flexibility to integrate intermittent generation
  - Important role in the generation mix

- Objectives of hydro scheduling
  - To optimize the water value in an stochastic environment, fulfilling all the operation constraints (to minimize the operation cost)
  - To analyze and test different scheduling strategies of storage hydro and pumped storage hydro plants

Procedure in two steps

1. Stochastic Hydrothermal Coordination Model (MHE) to deal with a large-scale electric system and with the dimensionality of stochastic hydro inflows
   - Based on Stochastic Dual Dynamic Programming (SDDP)
   - Scope: 2 years. Time step: week. Load levels: peak and off-peak
   - Some hydro details must be simplified in order to reduce the size of the problem
2. Simulation-based model to deal with hydro cascades in a more detailed way
   - Receives the main outputs from the optimization model and performs daily simulations



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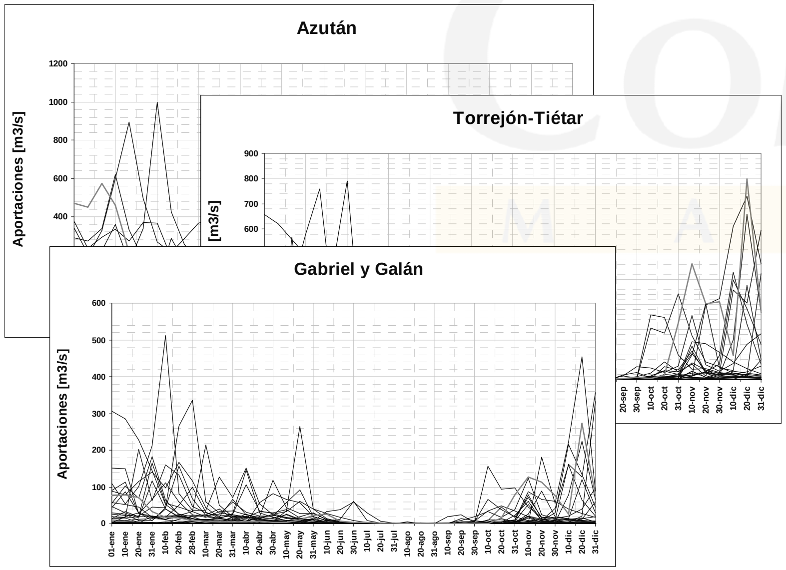
Long-term stochastic hydrothermal scheduling model

Stochastic Hydrothermal Coordination Model (MHE)

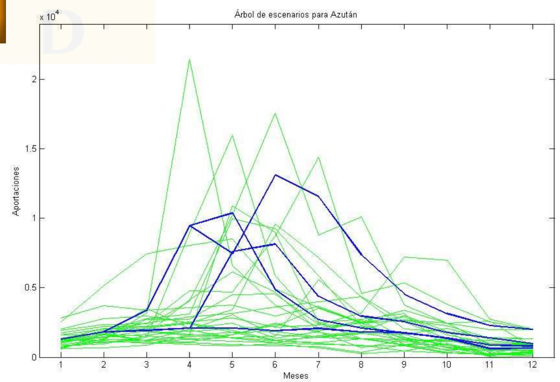
MHE model creates DISCHARGE, PUMPING and PRICE TABLES

- Hydrothermal model (Spanish or Iberian Electricity Market)
- Detailed modeling of the hydro system
- Less detailed modeling of demand and the rest of the generation mix
- **Representation of inflows through weighted scenario trees**



Data for generating the scenario tree:

- **Starting date**
- **Current inflows**
- **Tree structure**



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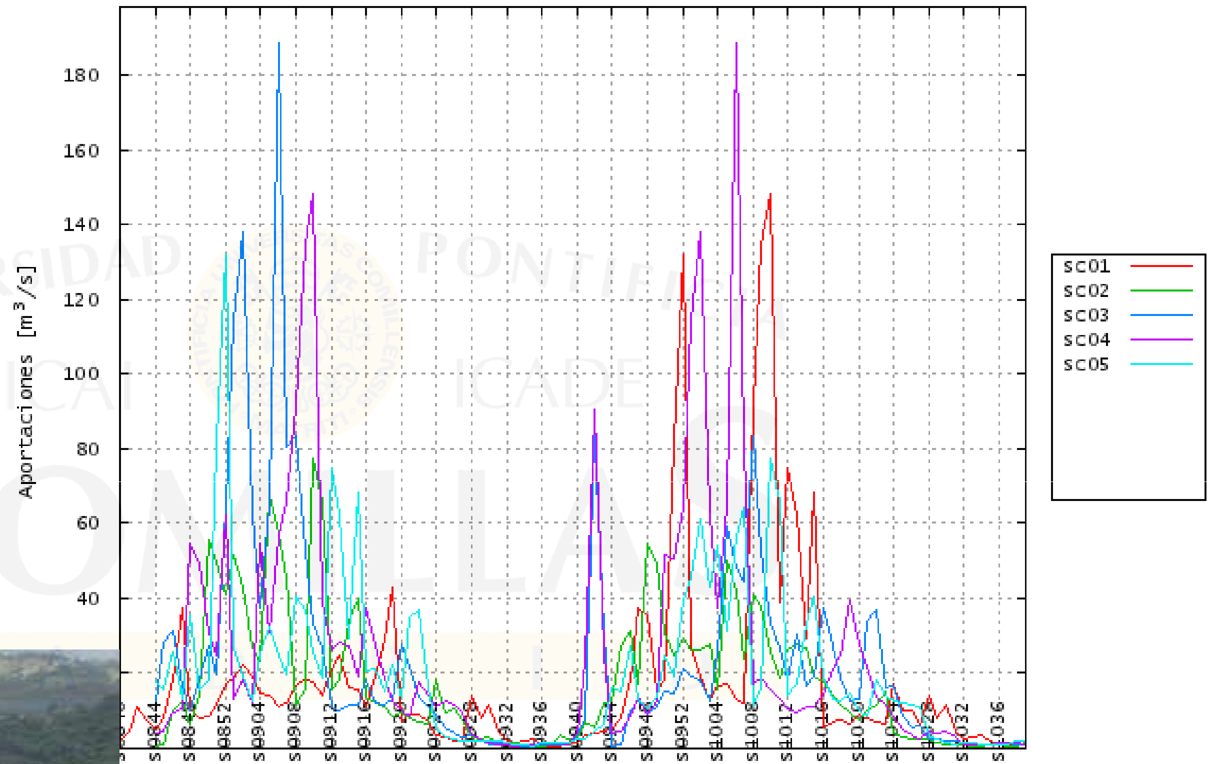
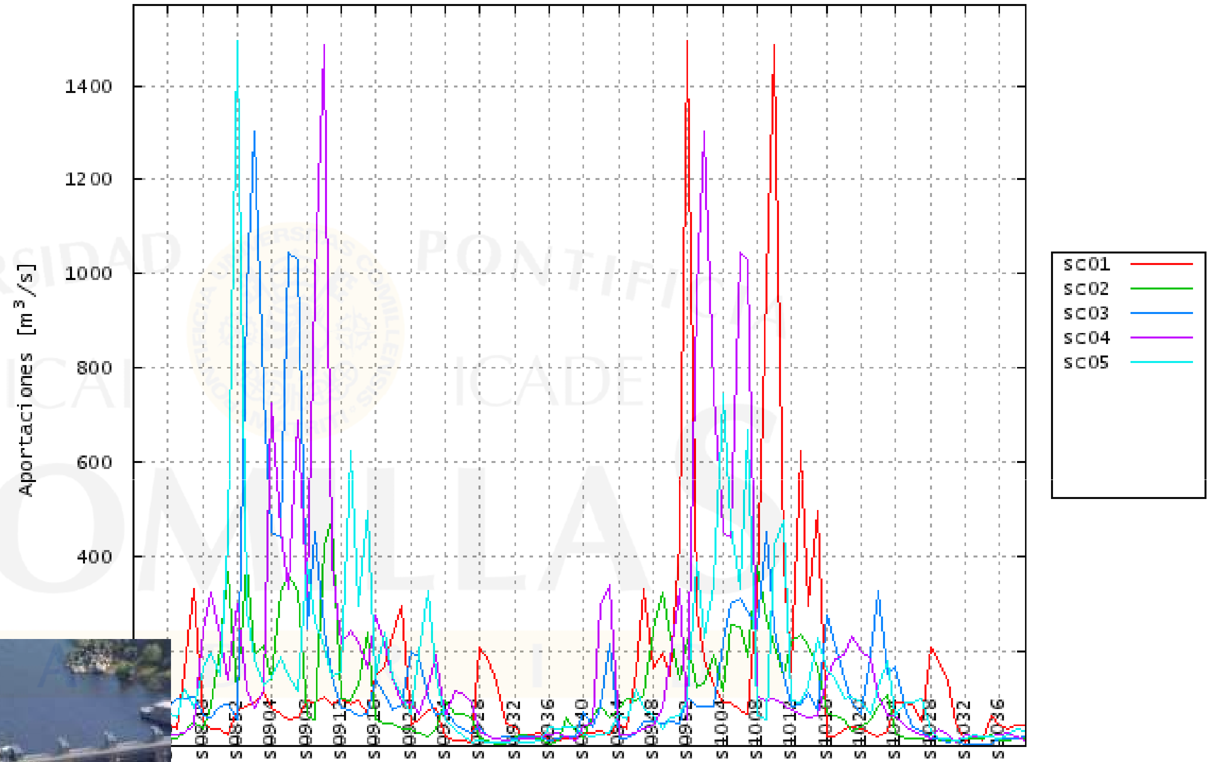
Two-year scope case study

- Spanish electric system
  - 118 thermal units
  - 3 main basins with 57 hydro plants and 7 pumped storage hydro plants that operate 39 hydro reservoirs
- Inflows uncertainty
  - Recombining tree with 5 branches every 4 weeks: 5^{25} scenarios

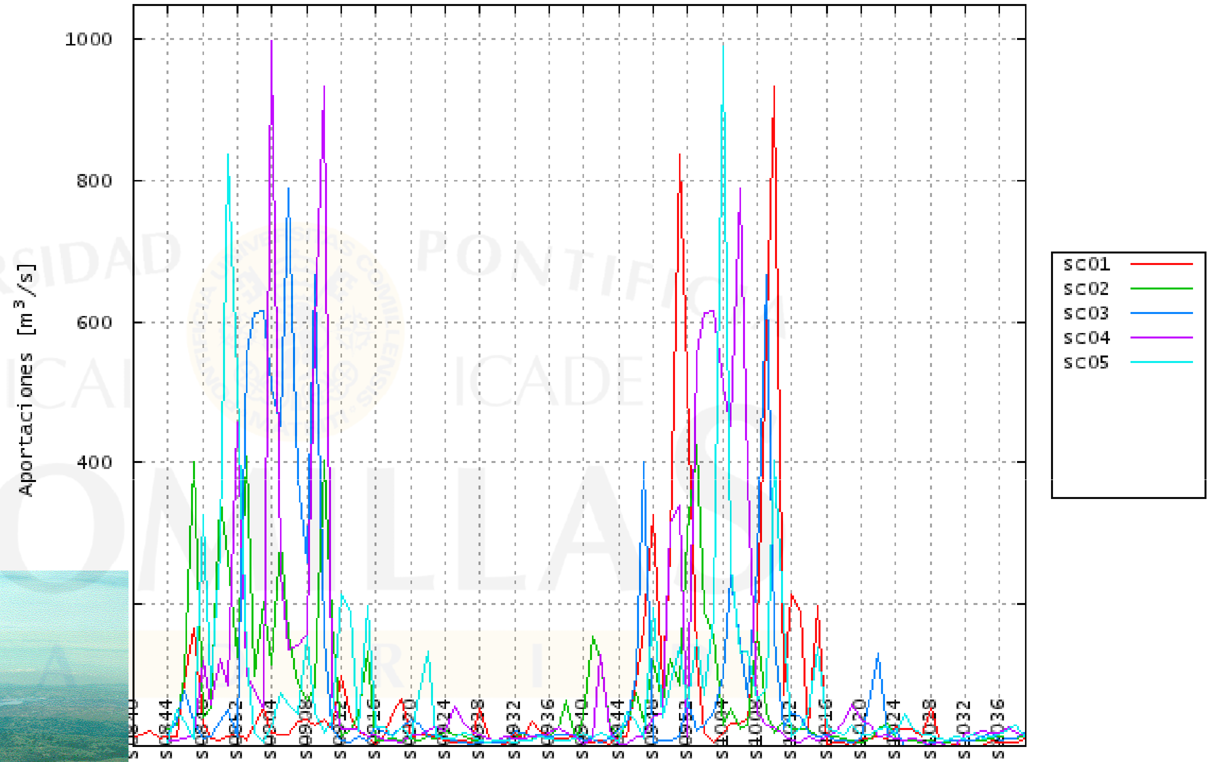
Historical natural hydro inflows in an small reservoir



Historical natural hydro inflows in a medium reservoir



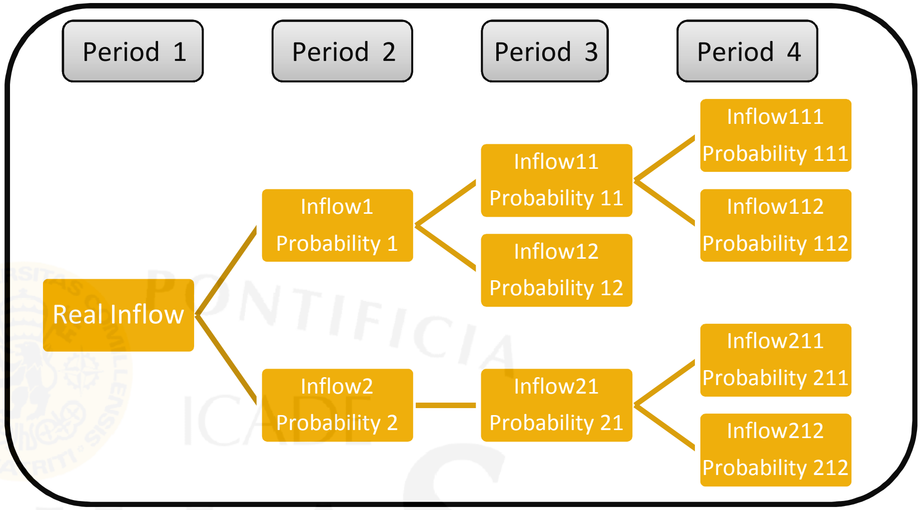
Historical natural hydro inflows in a large reservoir



Optimization process of MHE

Input data

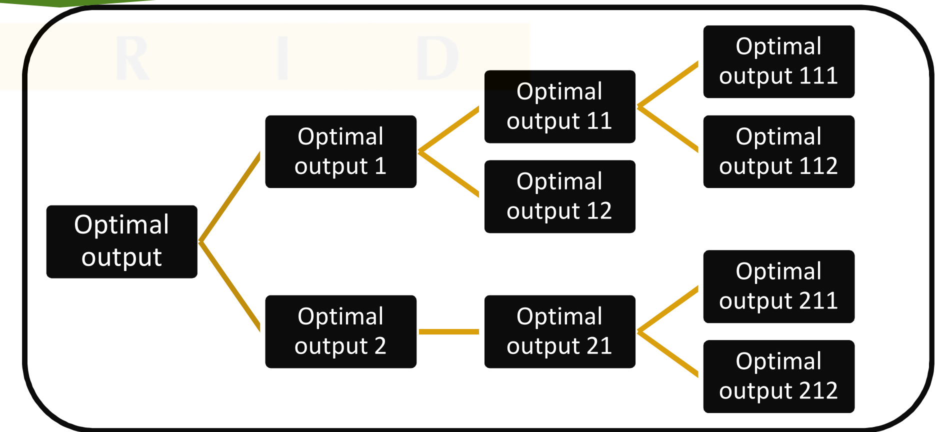
- Demand forecast
- Non dispatchable renewable energy
- Thermal units and their variable costs
- Hydro plants and their cascaded topologies
- Scenario tree with probabilities of inflows



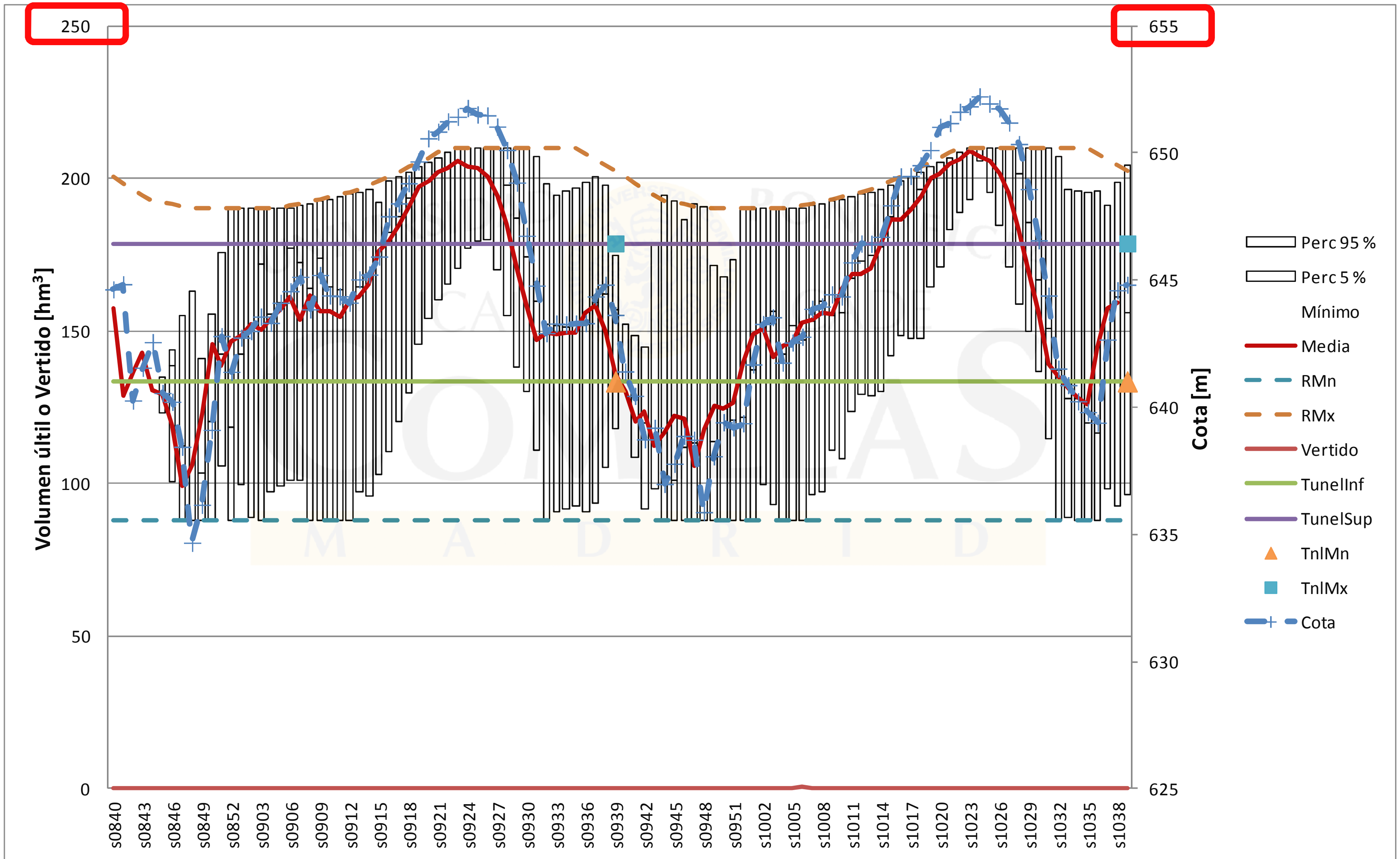
STOCHASTIC OPTIMIZATION

Output results

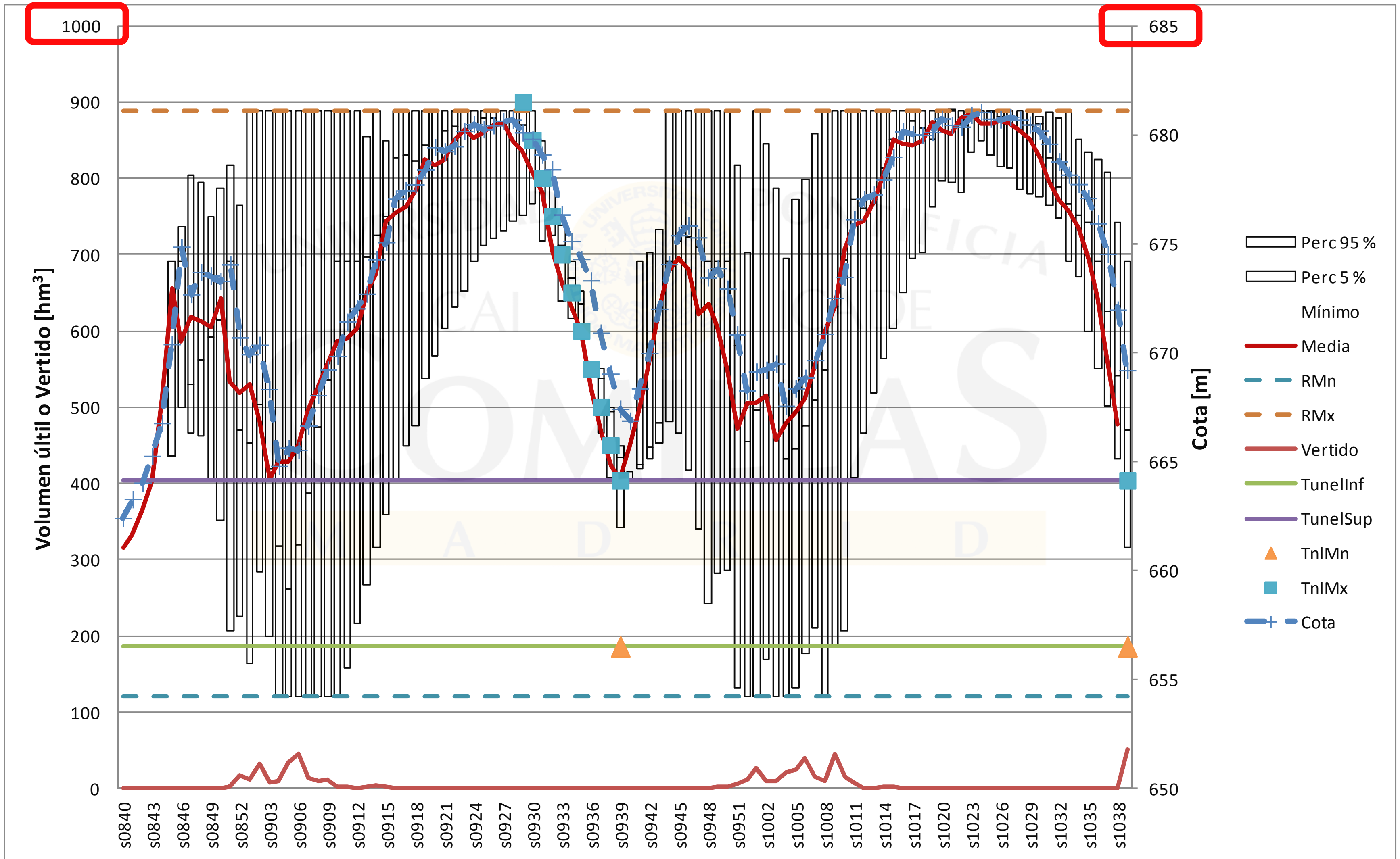
- For each node it obtains the optimal solution
- Through interpolation methods it obtains multidimensional tables that show the optimal output of hydro power plants depending on
  - Week of the year
  - Level of the reservoir
  - Natural inflows
  - Water reserve in the basin



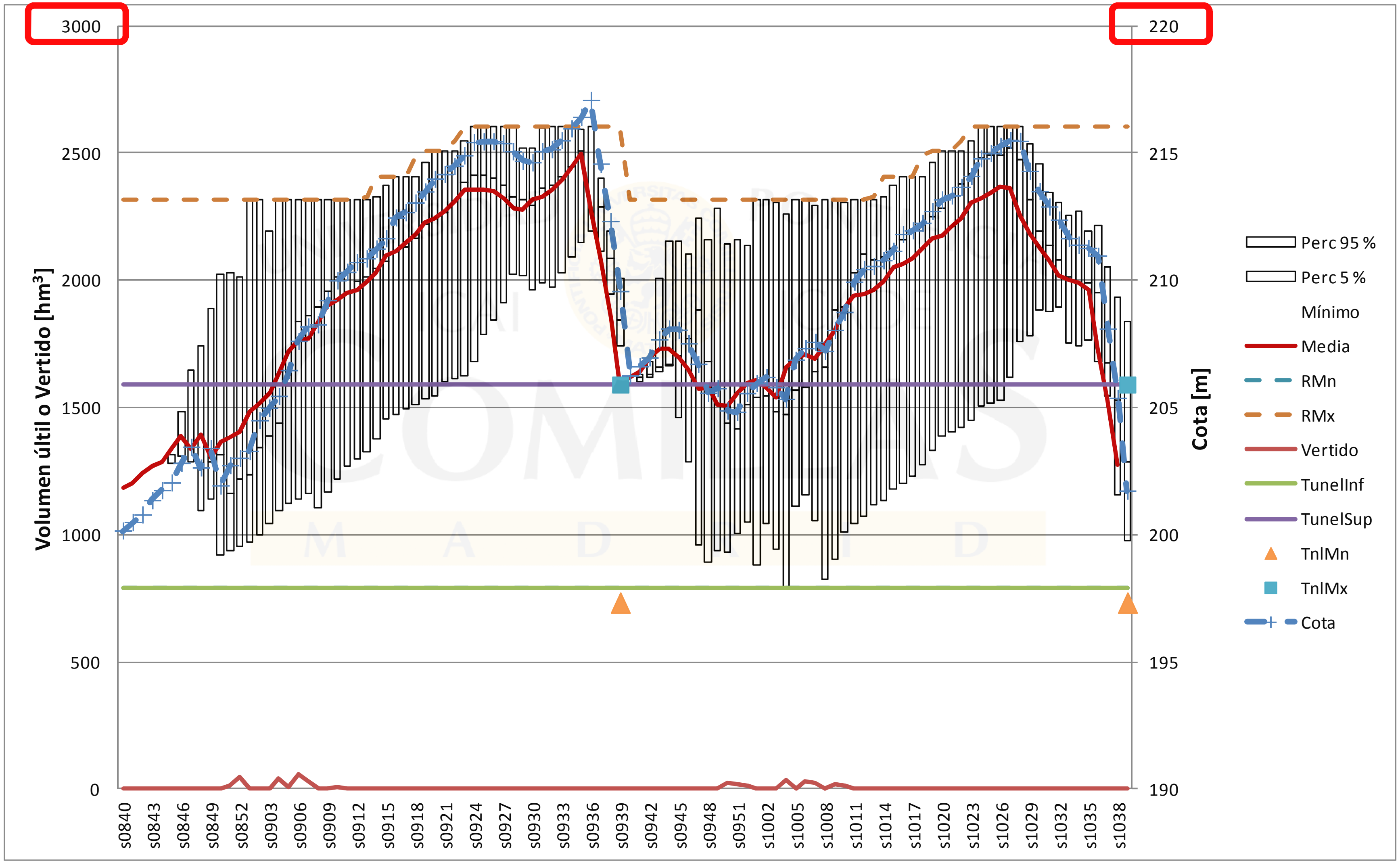
Volume and water head in an small reservoir



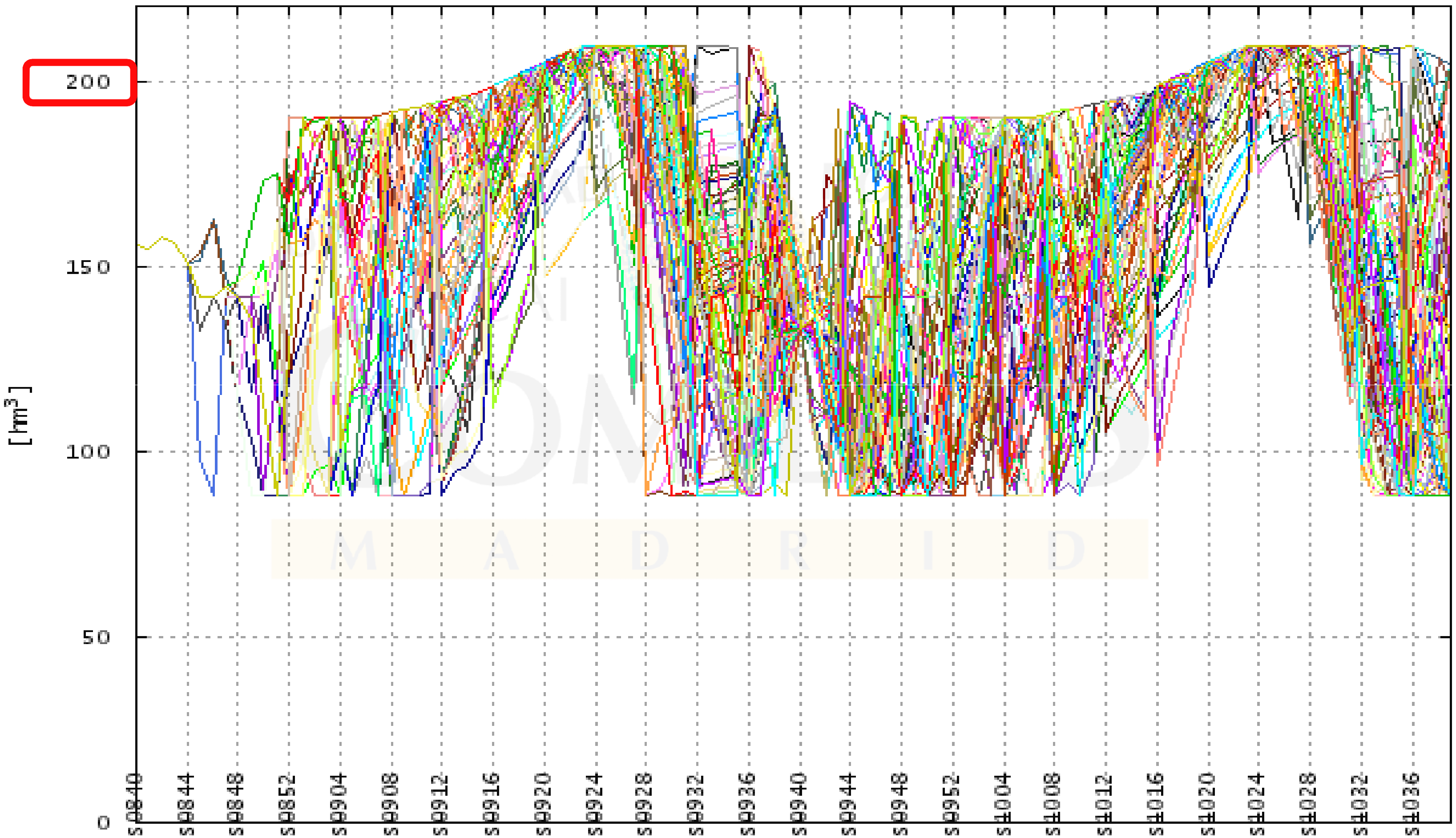
Volume and water head in a medium reservoir



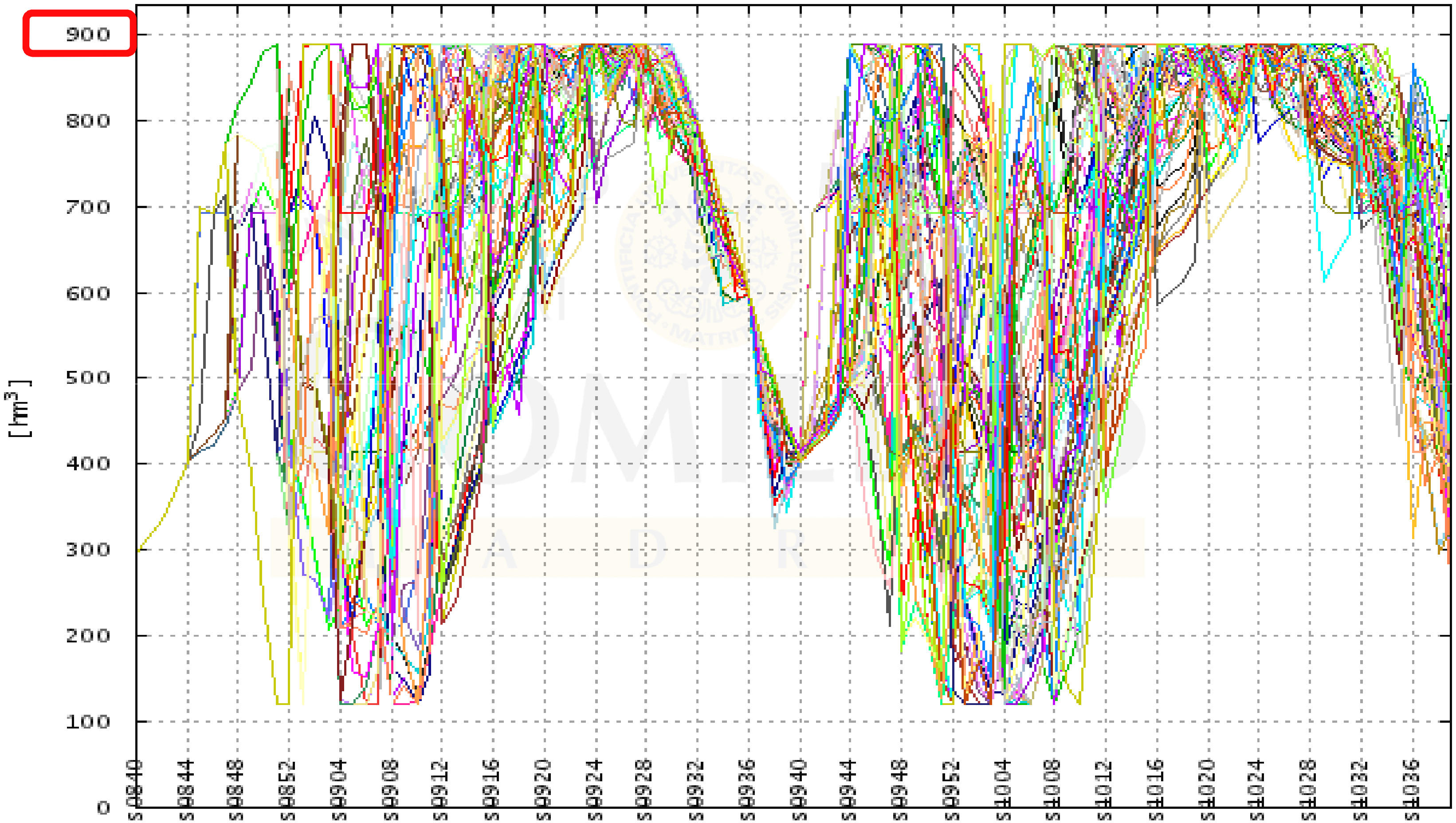
Volume and water head in a large reservoir



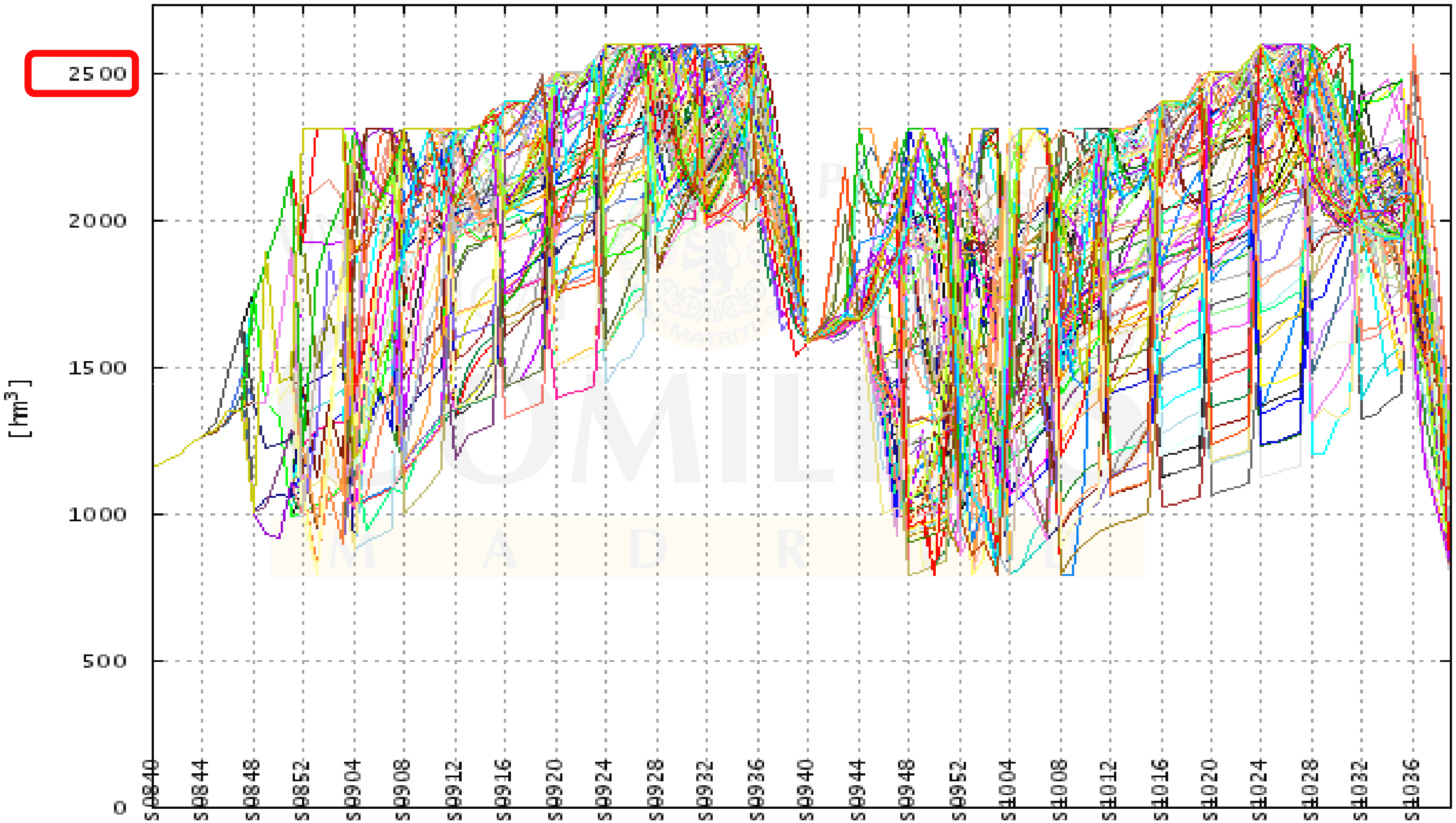
Volume in an small reservoir



Volume in a medium reservoir



Volume in a large reservoir



Water release table

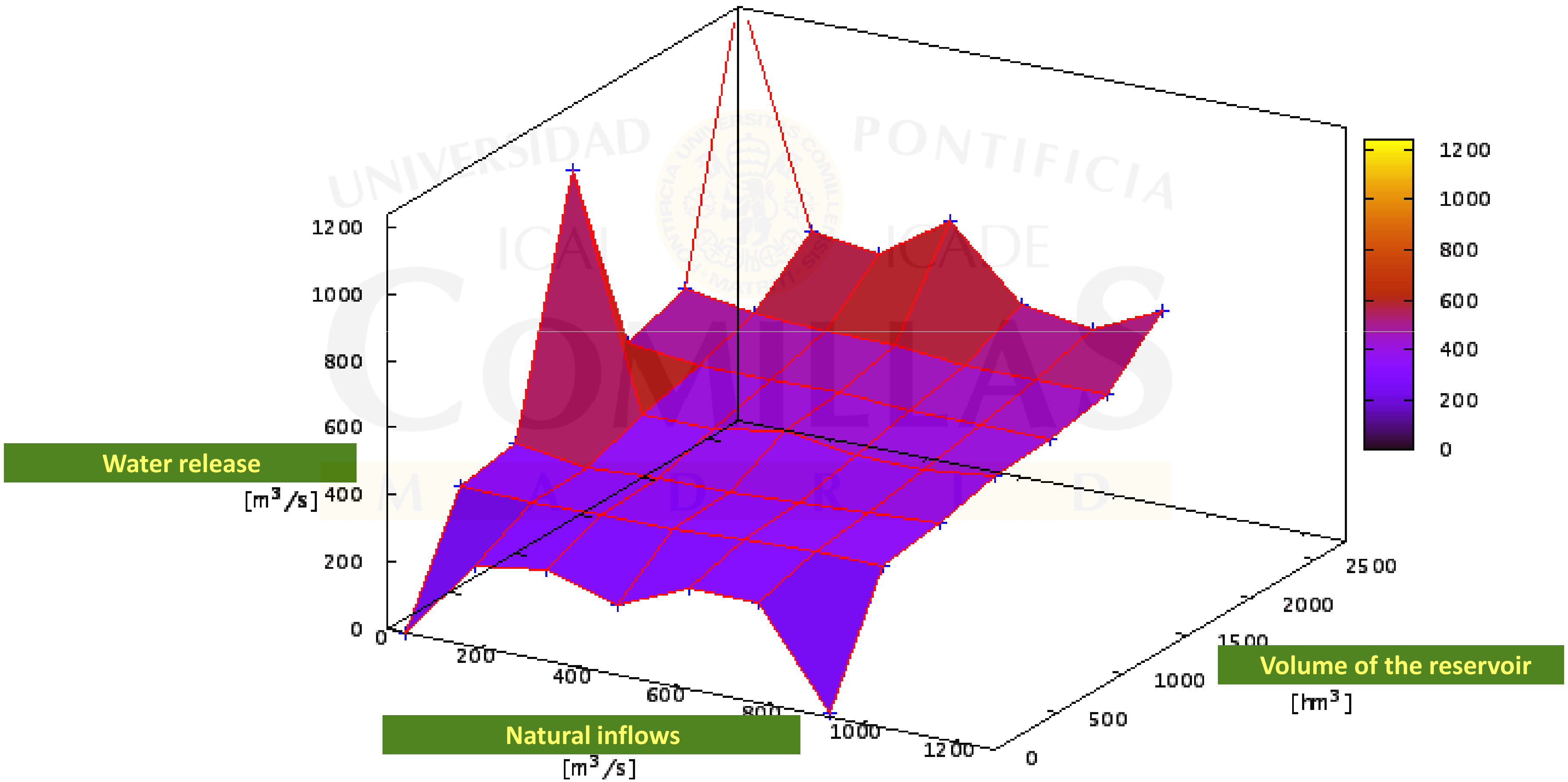
Result: water release
for a volume of reservoir2 = 1609 hm^3
for week February 9-15.

Input: volume of reservoir1

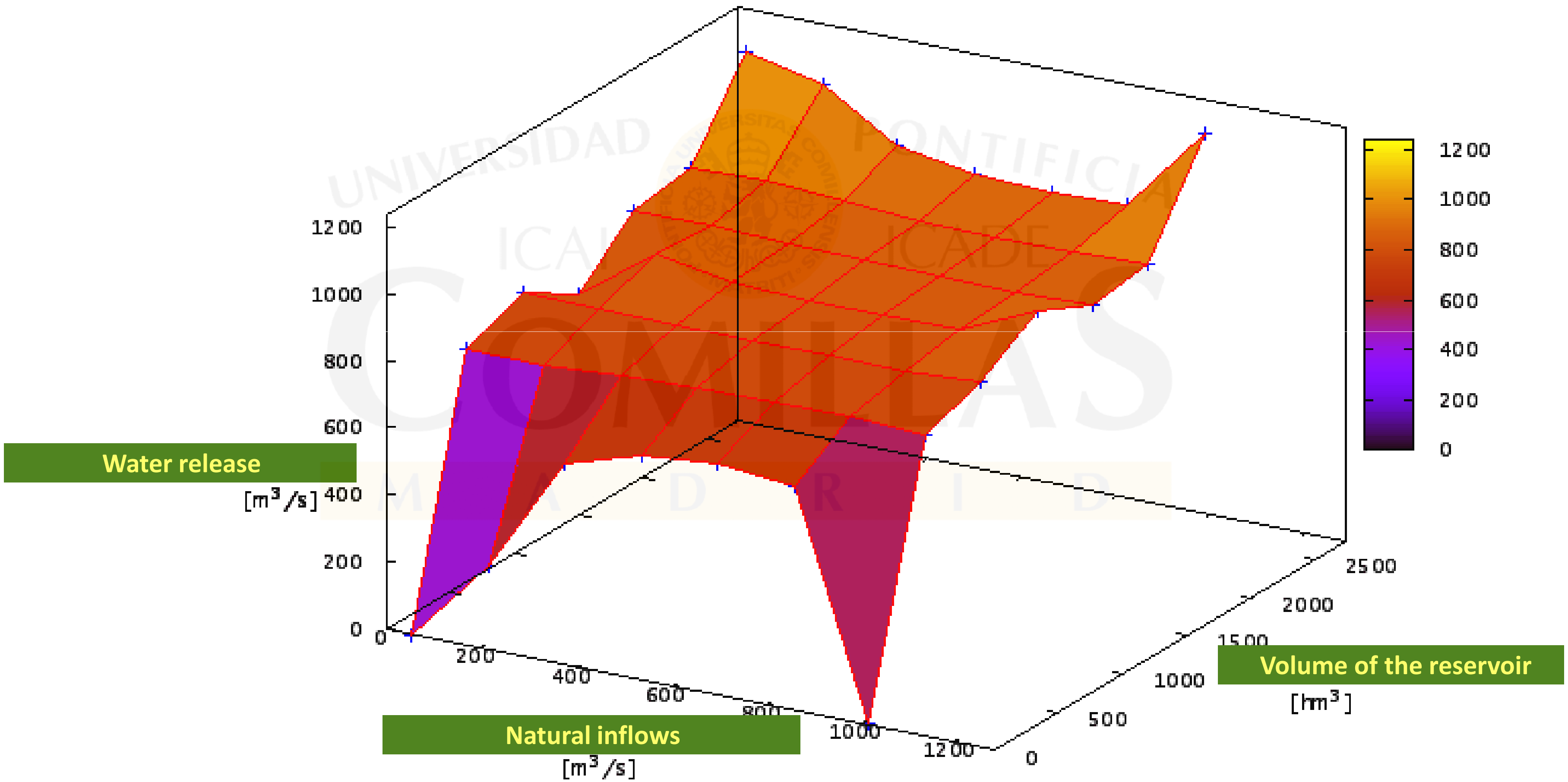
Input: natural inflow

$Q(m^3/s)$							
	2	**181**	**360**	**540**	**719**	**898**	**1077**
37	0.0	104.8	125.8	146.7	167.7	188.6	262.0
47	0.0	104.8	125.8	146.7	167.7	188.6	262.0
62	0.0	104.8	125.8	146.7	167.7	209.6	262.0
86	0.0	115.3	136.2	146.7	188.6	209.6	262.0
108	0.0	115.3	136.2	157.2	188.6	241.0	262.0
216	19.4	125.8	157.2	178.2	230.6	262.0	262.0
227	21.6	125.8	146.7	178.2	230.6	262.0	262.0
258	28.2	125.8	146.7	188.6	251.5	262.0	262.0
375	53.1	125.8	178.2	209.6	262.0	262.0	262.0
704	78.3	125.8	167.7	241.0	262.0	262.0	262.0

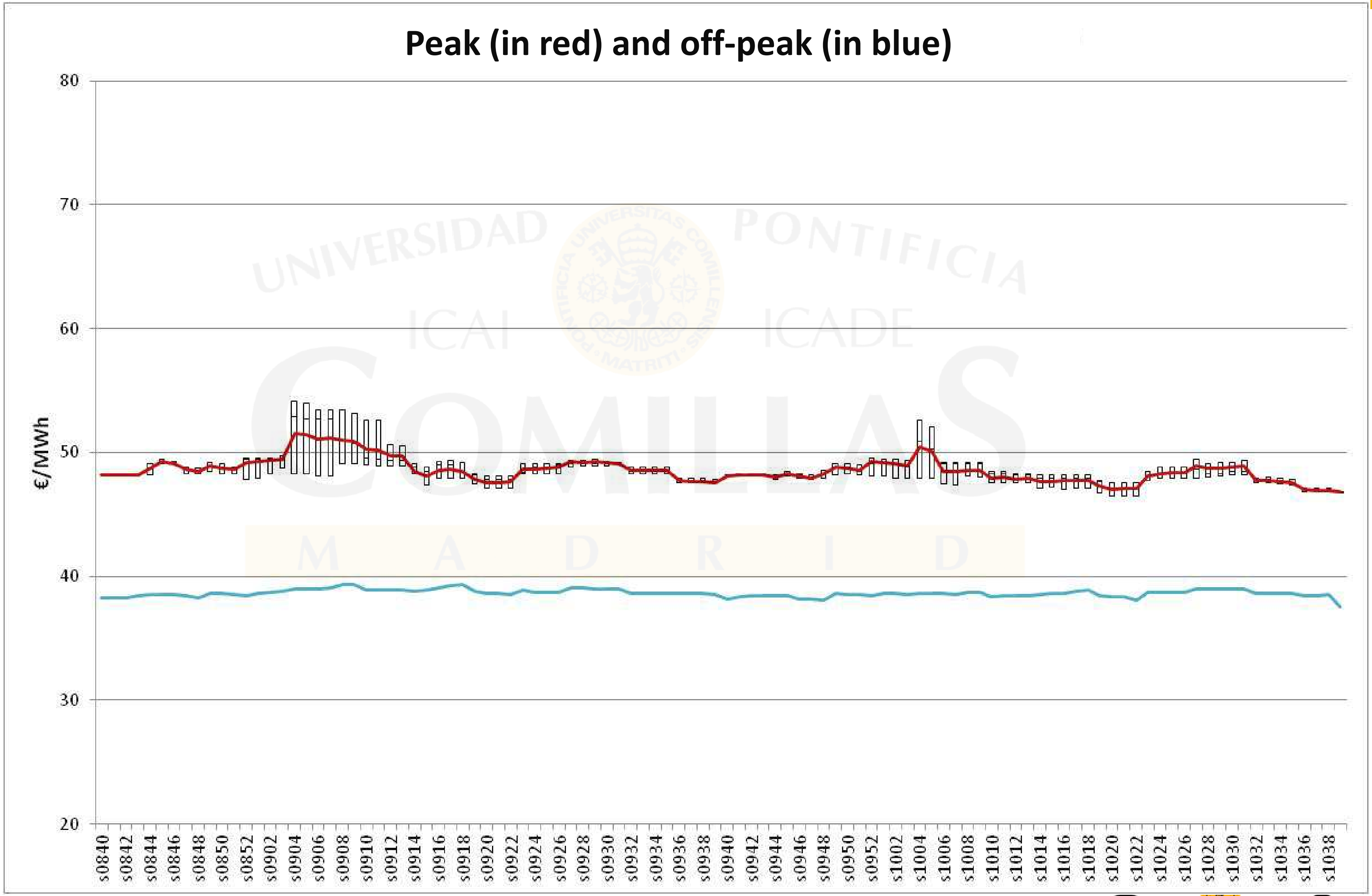
Water release table (for week 52)



Water release table (for week 7)



System marginal cost



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Medium-term simulation model

Introduction

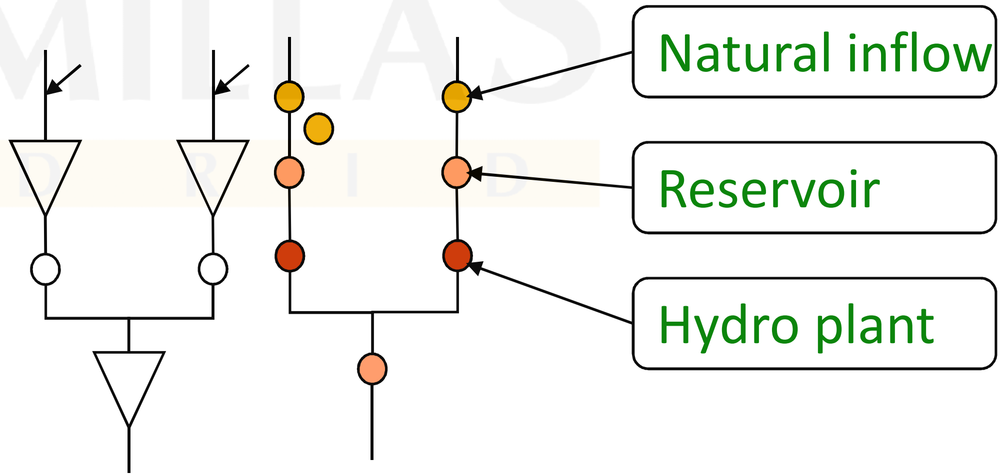
- Simulation allows full detail modeling of hydro plant operation
  - Nonlinearities in the production function
  - Specific behavior of river basin elements
- Simulation can produce scheduling plans
  - Closer to real operation
  - With lower computational requirements

Object oriented programming simulation

Five types of nodes (objects) are needed:

- Reservoir
- Canal
- Plant
- Inflow point
- Special objects

Hydro topology is represented by a graph of nodes where each node is an element



Two kinds of strategies

a) Discharge decision taken from a pre-calculated optimal water release table depending on:

- Week of the simulated day
- Natural inflow
- Volume of the own reservoir
- Volume of a coordinated reservoir, if needed
- Table calculated by MHE stochastic hydrothermal model (usually for the main reservoirs of the basin)

b) Discharge decision taken from guiding curves (usually for small reservoirs) depending on:

- Week of the simulated day
- Volume of the own reservoir
- Guiding curves & associated discharges

Water release table

Result: water release
for a volume of reservoir2 = 1609 hm^3
for week February 9-15.

Input: volume of reservoir1

Input: natural inflow

Q(m^3/s)	2	181	360	540	719	898	1077
37	0.0	104.8	125.8	146.7	167.7	188.6	262.0
47	0.0	104.8	125.8	146.7	167.7	188.6	262.0
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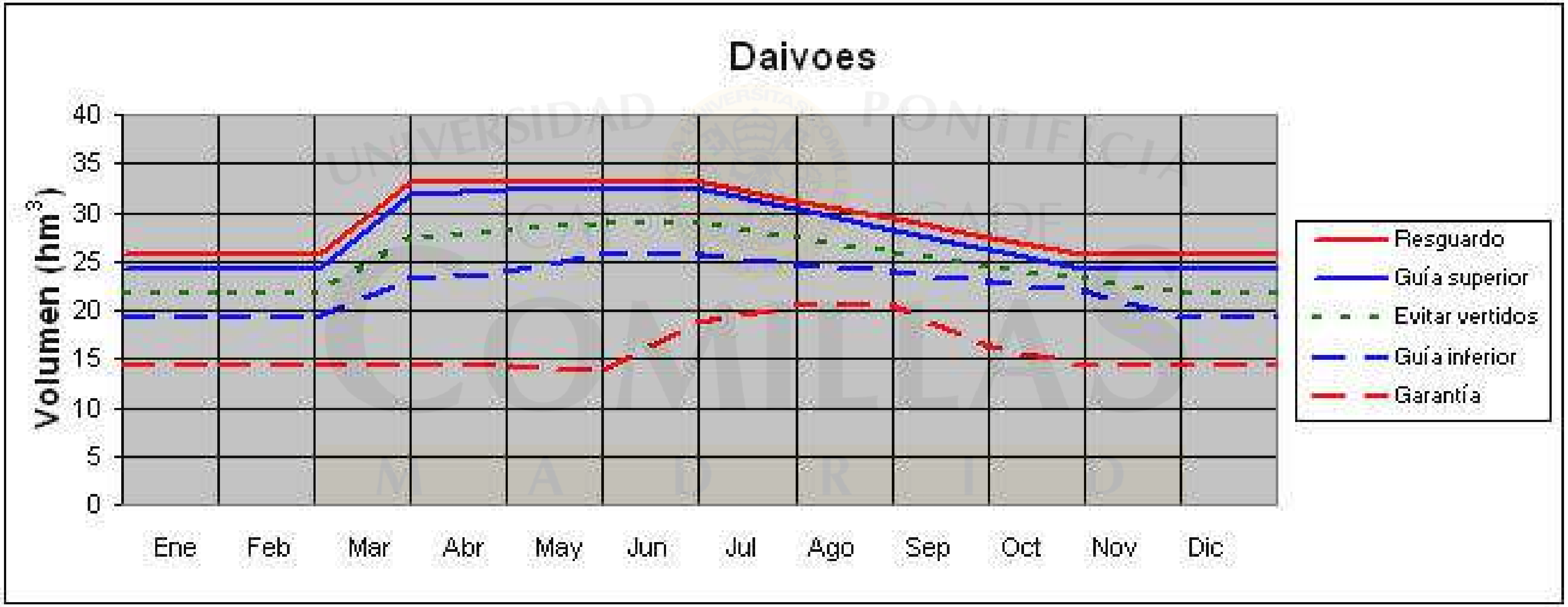
Guiding curves

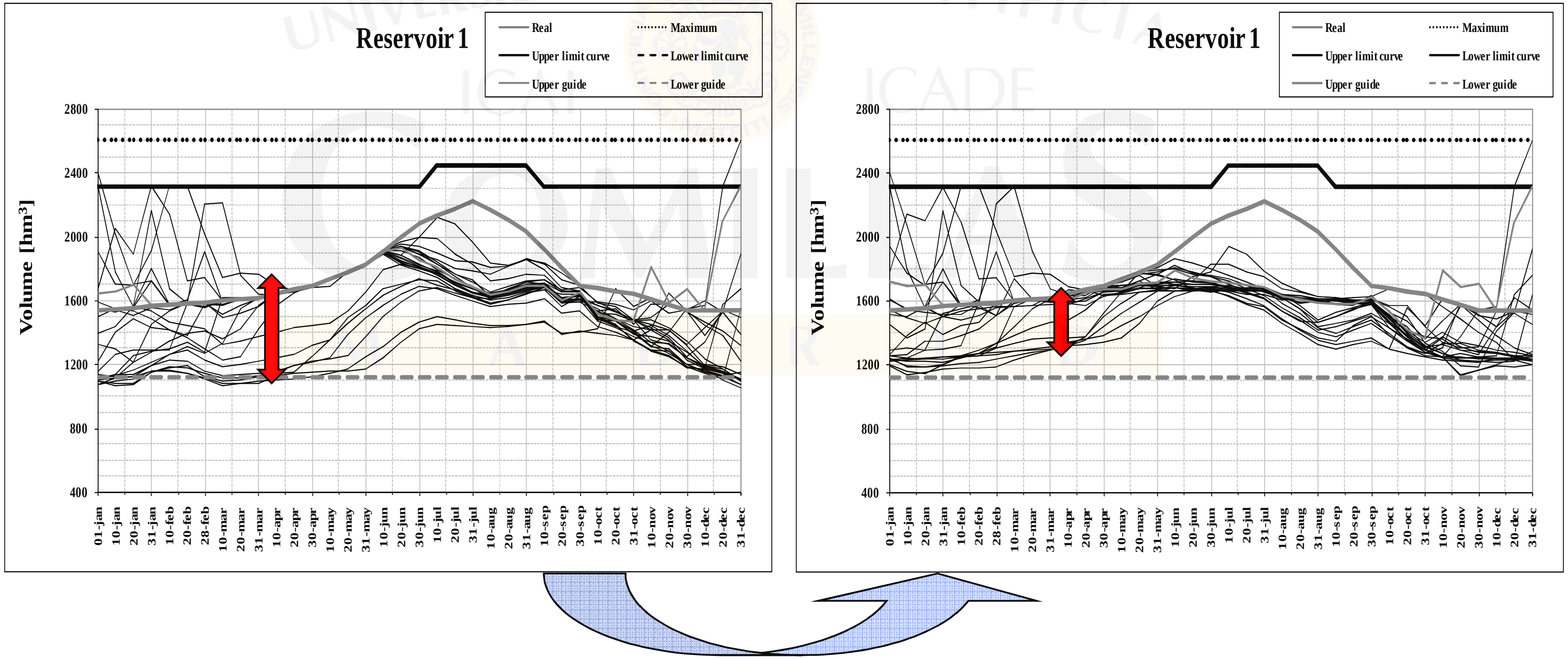


Application case to hydro scheduling (i)

- Two effects studied:
  - Variation of peak and off-peak hourly prices spread
  - Variation of installed thermal capacity
- Realistic case of 9 reservoirs
- Simulation for 24 yearly series
  - Previous generation of production/pumping water release tables for each case
- Results for reservoir yearly operation

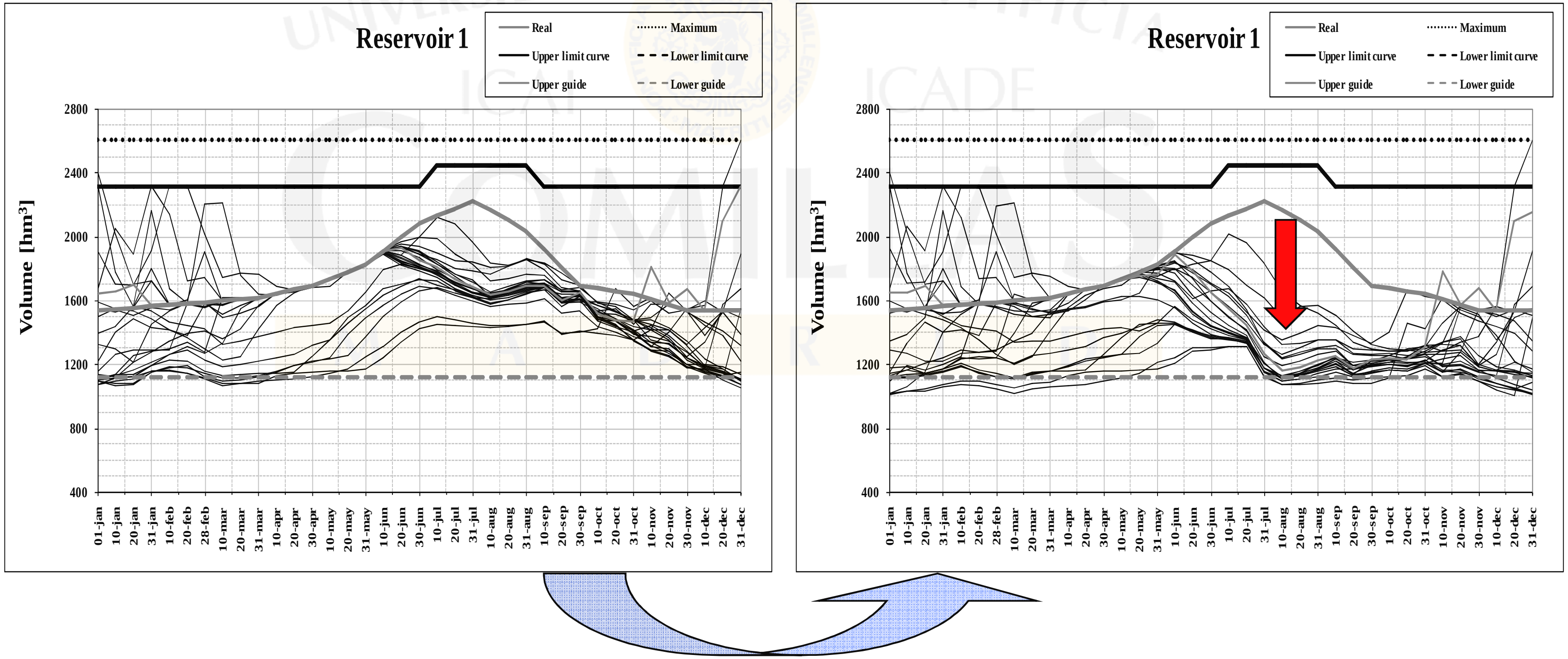
Application case to hydro scheduling (ii)

- Effect of the increased price spread among peak and off-peak hours:
  - Narrower reservoir volume evolutions



Application case to hydro scheduling (iii)

- Effect of the increased installed thermal capacity
  - Allows free allocation of hydro production
  - Does not need to keep a reservoir volume during summer



Application case to hydroelectric scheme design (i)

- Analysis of investment in new power plants in Douro river
- Example case:
  - Simulation of 24 historical series
  - Unplanned outage rate of 5%
- Assessment of the maximum outflow
  - Power plant with up to 4 units of 200 m^3/s and 48 MW
  - Analysis of generation and spilled outflows

Case	Maximum output flow [m^3/s]	Generation flow [hm^3/year]	Spilled flow [hm^3/year]
1a	200	2007	1079
2a	400	2446	641
3a	600	2623	464
4a	800	2725	363

Application case to hydroelectric scheme design (ii)

- Assessment of the maximum outflow
  - Power plant with up to 4 units of 200 m^3/s and 48 MW
  - Analysis of results:
    - Generation increase and spillage reduction
    - Allocation of more energy in peak hours

Case	Generation energy Total [GWh/year]	Peak	Off-peak	Spilled energy [GWh/year]
1a	155	107	48	83
2a	189	153	35	49
3a	202	178	24	36
4a	210	190	20	28

Application case to hydroelectric scheme design (iii)

- Assessment of the number of units (1 to 4):
  - For a fixed outflow of 600 m^3/s
  - Should be combined with the economic valuation of investment costs
  - The increase from 1 to 2 units is more significant than the rest of new units installation

Case	No. of units	Generated flow [hm3/year]	Spilled flow [hm3/year]	Generation energy Total [GWh/year]	Generation energy Peak [GWh/year]	Generation energy Off-peak [GWh/year]	Spilled energy [GWh/year]
1b	1	2454	632	189	158	31	49
2b	2	2610	478	201	177	24	37
3b	3	2615	473	202	178	24	36
4b	4	2659	428	205	180	25	33

Conclusions

- Medium term simulation model
  - Connected to long-term stochastic hydrothermal model
  - Considers detailed operation
  - Stochastic inflows and outages
- Application case to hydro scheduling
  - Provides feasible operation
  - Different operation criteria
- Application case to hydro scheme design
  - Considering several options about installed units
  - Unplanned outage sampling

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