Pumping Scheduling in Object Oriented Simulation of Hydroelectric Power Systems

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Content

- **Introduction**
- Data representation
- Simulation method
- Results
- Conclusions

Introduction (i)

- Hydro scheduling is very important:
  - Very low variable cost of energy (only O&M)
  - Large regulation capability
  - Allows the storage of energy for reliability purposes (specially by the recent increasing penetration of wind power)
- Hydro production in Spain ranges from 15 % to 20 % of the energy demand of the ordinary regime (except renewable resources)

Introduction (ii)

- Objective:
  - Analyze and test different management strategies of hydro and pumped-storage plants

- Simulation is the method chosen to model them
  - because of its flexibility and
  - the complex characteristics of hydro basins

Introduction (iii)

- Key features of simulation models:
  - Time: Static vs. Dynamic
  - Stochasticity: Deterministic vs. Stochastic
  - Time step: Fixed vs. Event-oriented

- This hydro simulation model is
  - Dynamic (up to one year)
  - Stochastic hydro inflows
  - Fixed (one day)

Introduction (iv)

- Model aims:
  - Economic planning of hydro operation:
    - Yearly and monthly planning
  - Update the yearly forecast:
    - Operation planning up to the end of the year
  - Short term detailed operation:
    - Detailed operation analysis of floods and droughts, changes in irrigation or recreational activities, etc.

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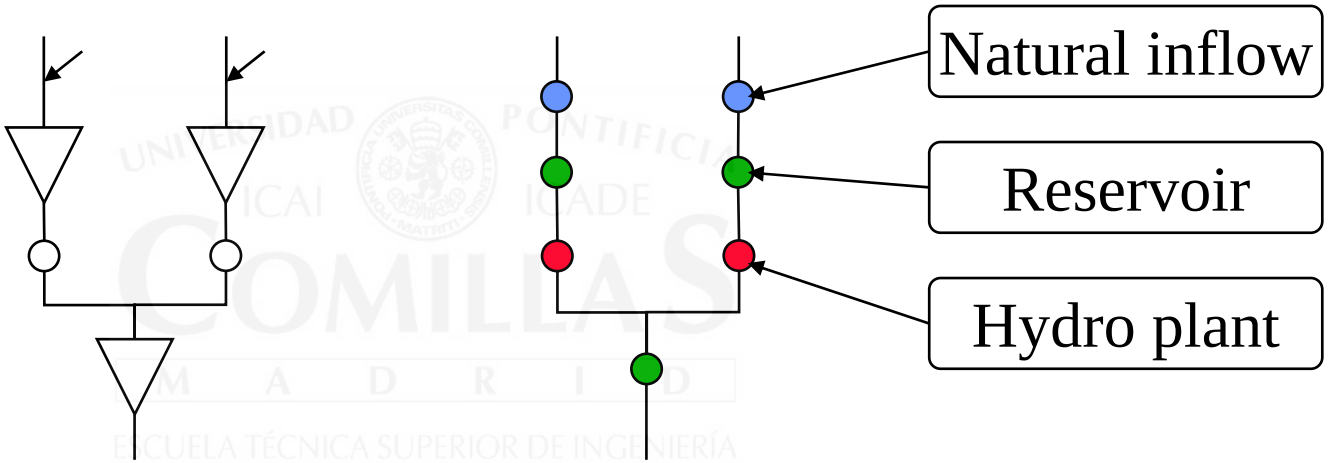
Data representation (i)

- Basin topology is represented by a graph of nodes where each node is an element:



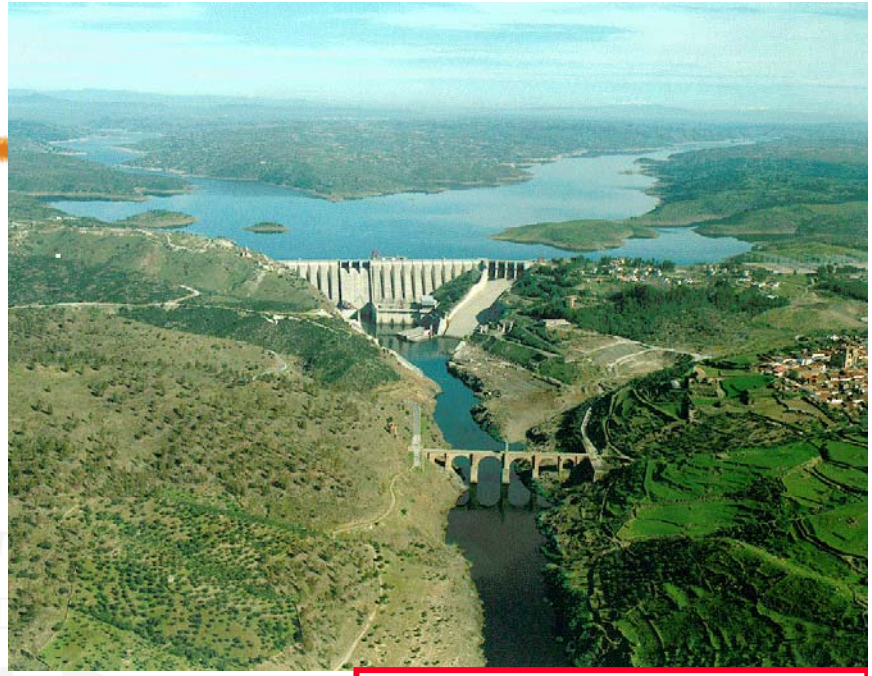
- Connections among nodes are physical junctions through the river.
- This structure induces the use of
  - Object Oriented Programming (OOP)

Data representation (ii)

- Five types of nodes (objects) are needed:
  - Reservoir
  - Canal
  - Plant
  - Inflow point
  - River junction

- Each node is independently "operated" although it may require information from other elements

Data representation (iii)



Alcántara Reservoir

- **Reservoir**:
  - Manages the water
    - One or more natural inflows
    - One outflow
  - May have associated:
    - Minimum outflow
    - Volume curves that guide its operation:
      - Minimum/maximum target curves
      - Lower/upper guiding curves
      - Avoiding spillage curve
    - Minimum and maximum volume
    - Optimal production table (input from long term hydrothermal models)

Data representation (iv)

- **Canal**:
  - Doesn't manage the water
  - Flow transportation between nodes with a limit

Data representation (v)

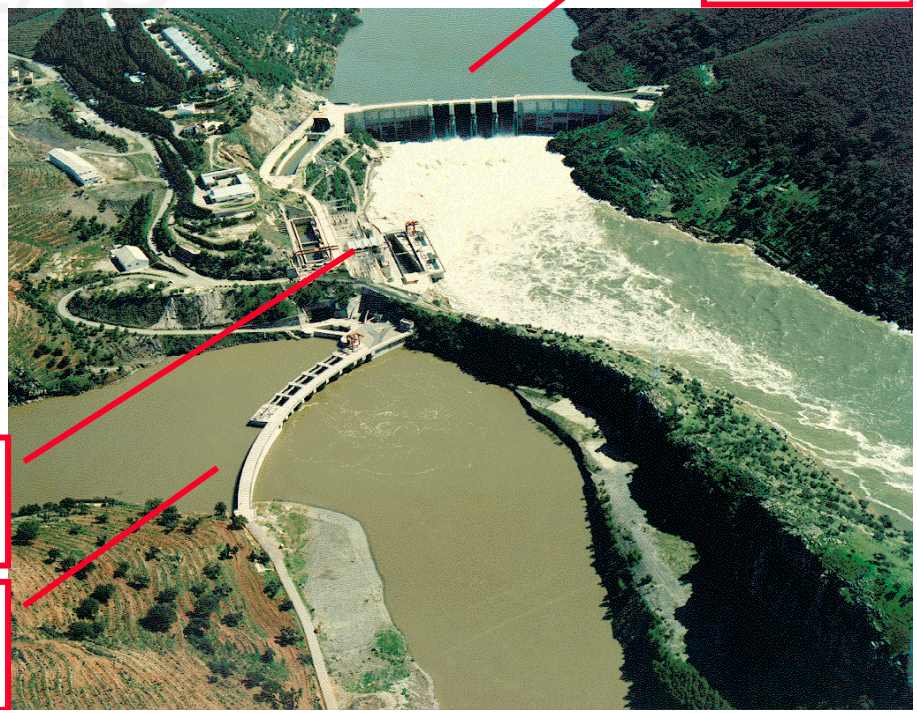
- **Plant**:
  - Produces electric energy from hydro inflow
  - Coefficient of efficiency depending linearly on the head
  - May also pump

Data representation (vi)

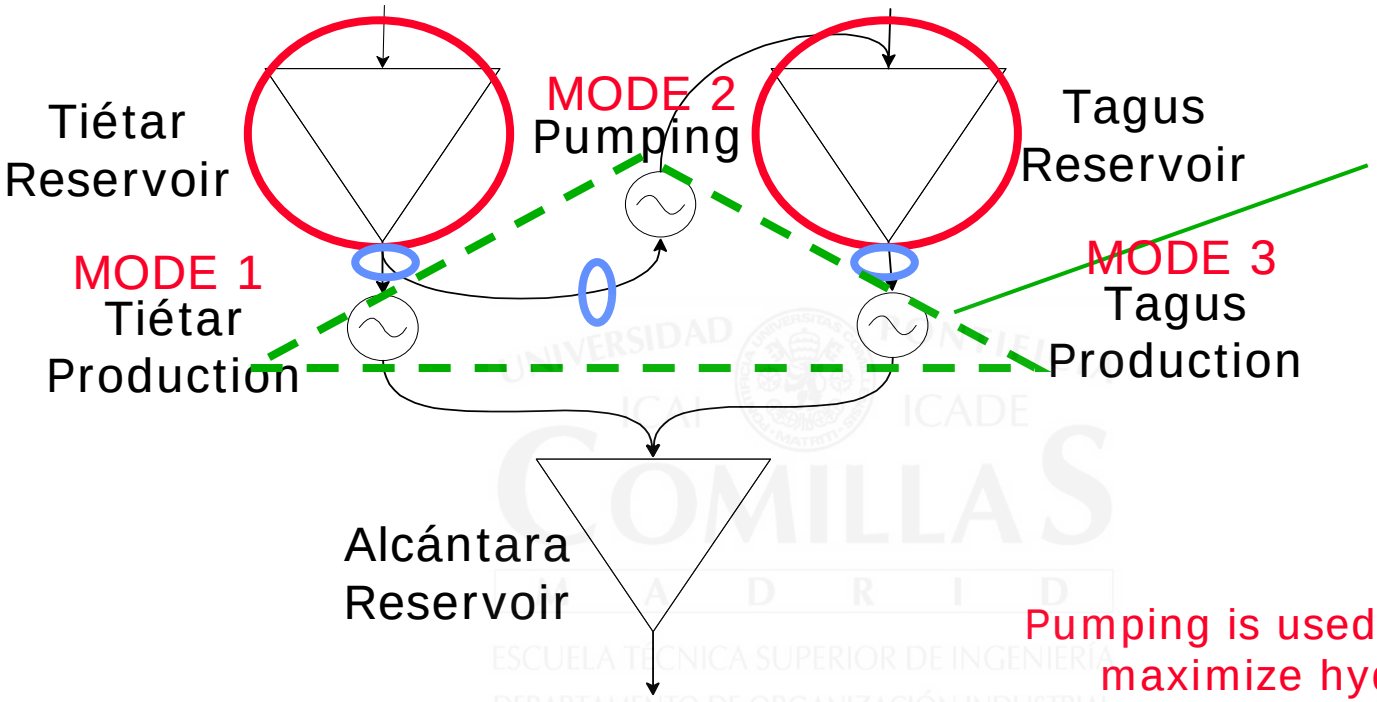
- **Natural inflow point**:
  - Introduces water into the system
  - Uses historical series or synthetic inflows

Data representation (vii)

- **River junction**:
  - Groups elements in a river junction
  - Limits the maximum joint outflow
  - Management determined in tho steps:
    1. Independent initial decision
    2. Reduction of the initial value following a priority order up to the maximum flow
       - Production that can not be retained
       - Pumping that can not be retained
       - Production and pumping that can be retained



Tagus-Tiétar river junction



It is just one hydro plant
Two hours are needed for changing from one mode to the other

Pumping is used to avoid spillage, maximize hydro production

Algorithm

- Production that can not be retained at Tiétar / Pumping that can not be retained at Tiétar
- Production that can not be retained at Tagus
- Production that can be retained at Tiétar / Pumping that can be retained at Tiétar
- Production that can be retained at Tagus

Reservoir operation strategies

a) Optimal outflow decision taken from a precalculated optimal production table depending on:
   - Week of the simulated day
   - Hydrologic index of the basin inflows (type of year)
   - Volume of the own reservoir
   - Volume of a reference reservoir of the same basin
   - Table calculated by a long term hydrothermal model
   - Usually for the main reservoirs of the basin

b) Outflow equals incoming inflow (usually for small reservoirs)

c) Go to minimum target curve (spend as much as possible)

d) Go to maximum target curve (keep water for the future)

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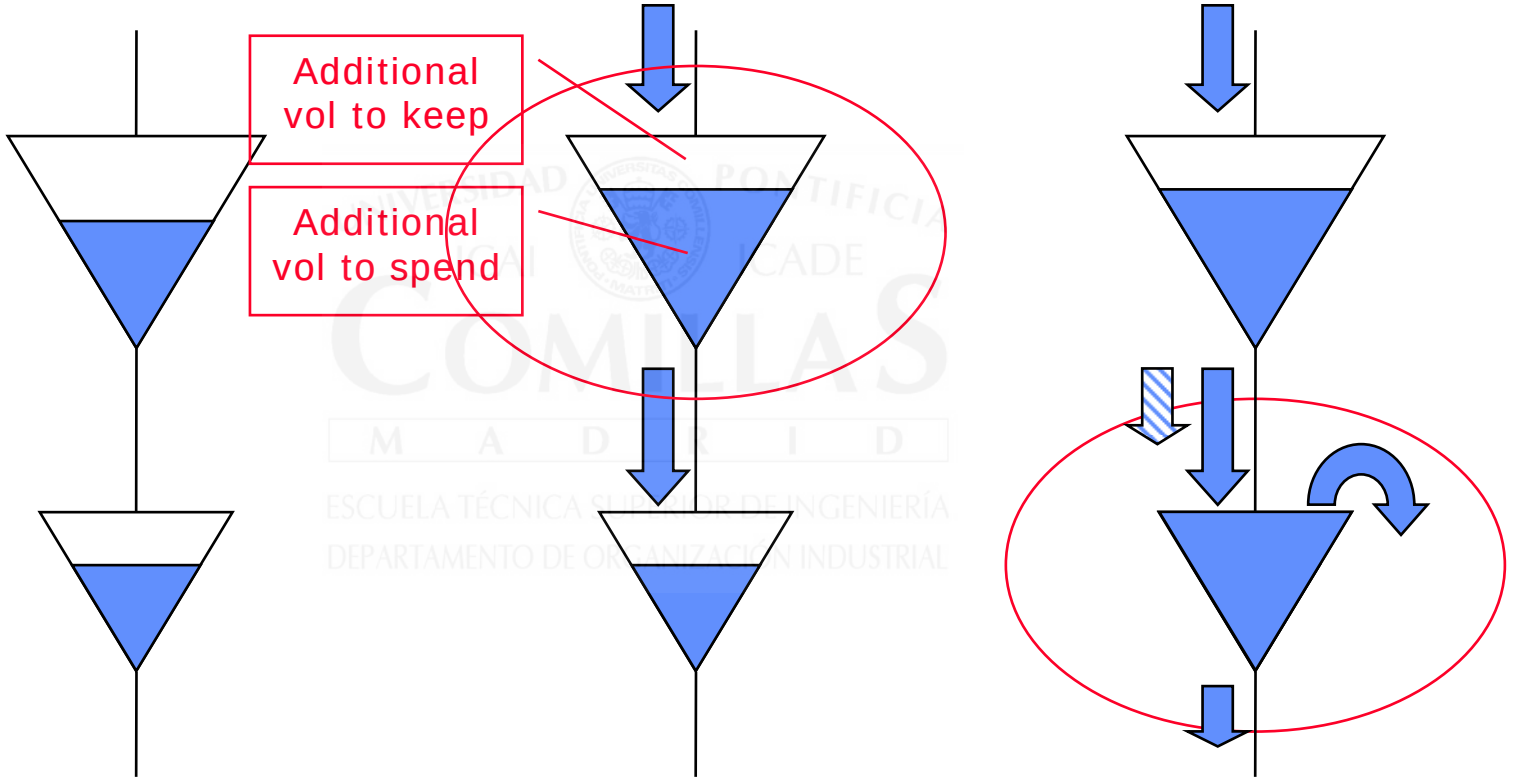
Simulation method (I)

- Main objective:
  - Maximize hydro production following the reservoir operation strategies
  - Other objectives:
    - Avoid spillage
    - Satisfaction of minimum outflow (irrigation)
- The proposed method requires three phases:
  1. Decides the initial management
     - Blind decision for each element
  2. Modifies it to avoid spillage and produce minimum outflows
  3. Determines the electricity output for previous inflows

Simulation method (II) – Phase 1

- Downstream
- Each element is individually operated according to its own operation and strategies
- Additional information is collected:
  - In reservoirs
    - Spillage and non served minimum flow
    - Additional volume to spend or to keep
  - In all the elements:
    - Accumulates those values for the own element and those located upstream

Simulation method (III) – Phase 1



Simulation method (III) – Phase 2

- Upstream from the end of the basin
- Modifies the Phase 1 operation
  - To avoid spillage forces the reservoirs to keep water
  - To serve a minimum flow increases the production of reservoirs
  - Pumping can be used for both purposes
- Splits the changes proportionally to the capacity of each element with respect to all the remaining elements located upstream

Simulation method (IV) – Phase 3

- Determines the plant output
  - By using a coefficient of efficiency
  - Depending on the average water head of the day
- Splits the production between peak and off-peak hours:
  - Put as much energy as possible in peak hours
  - The rest in off-peak hours

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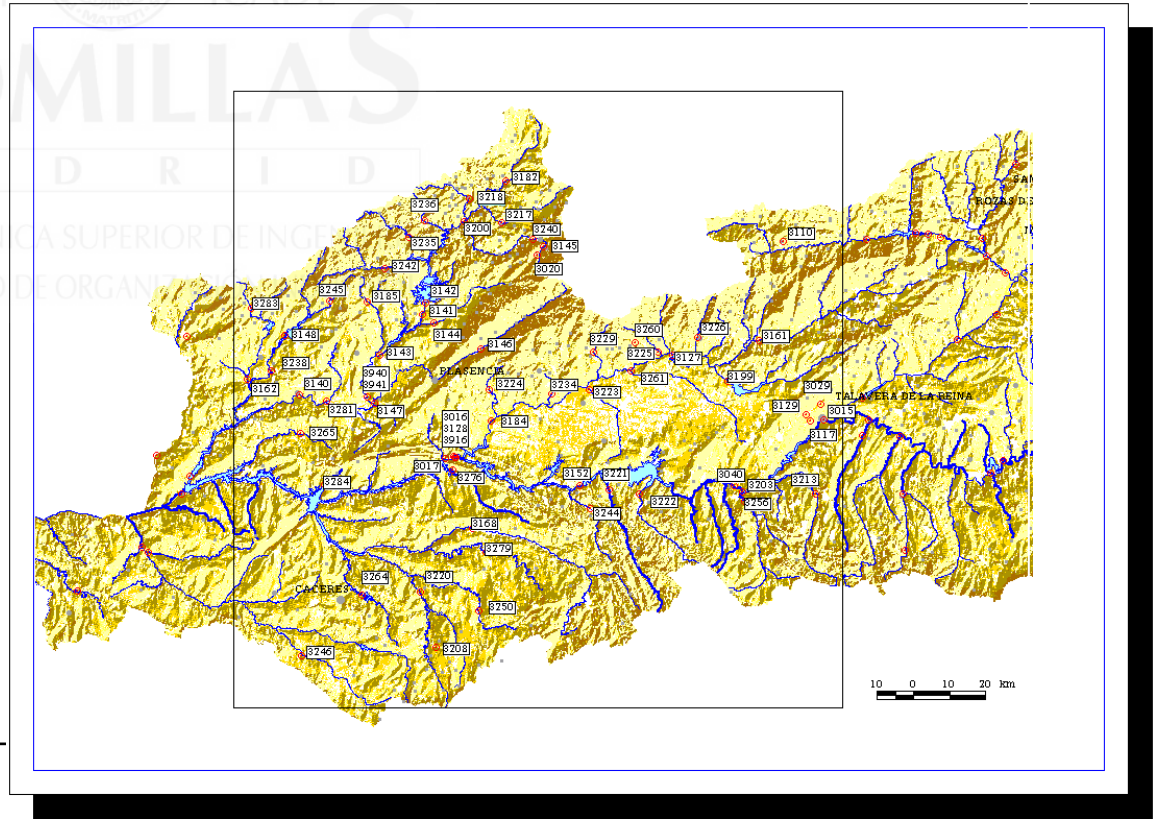
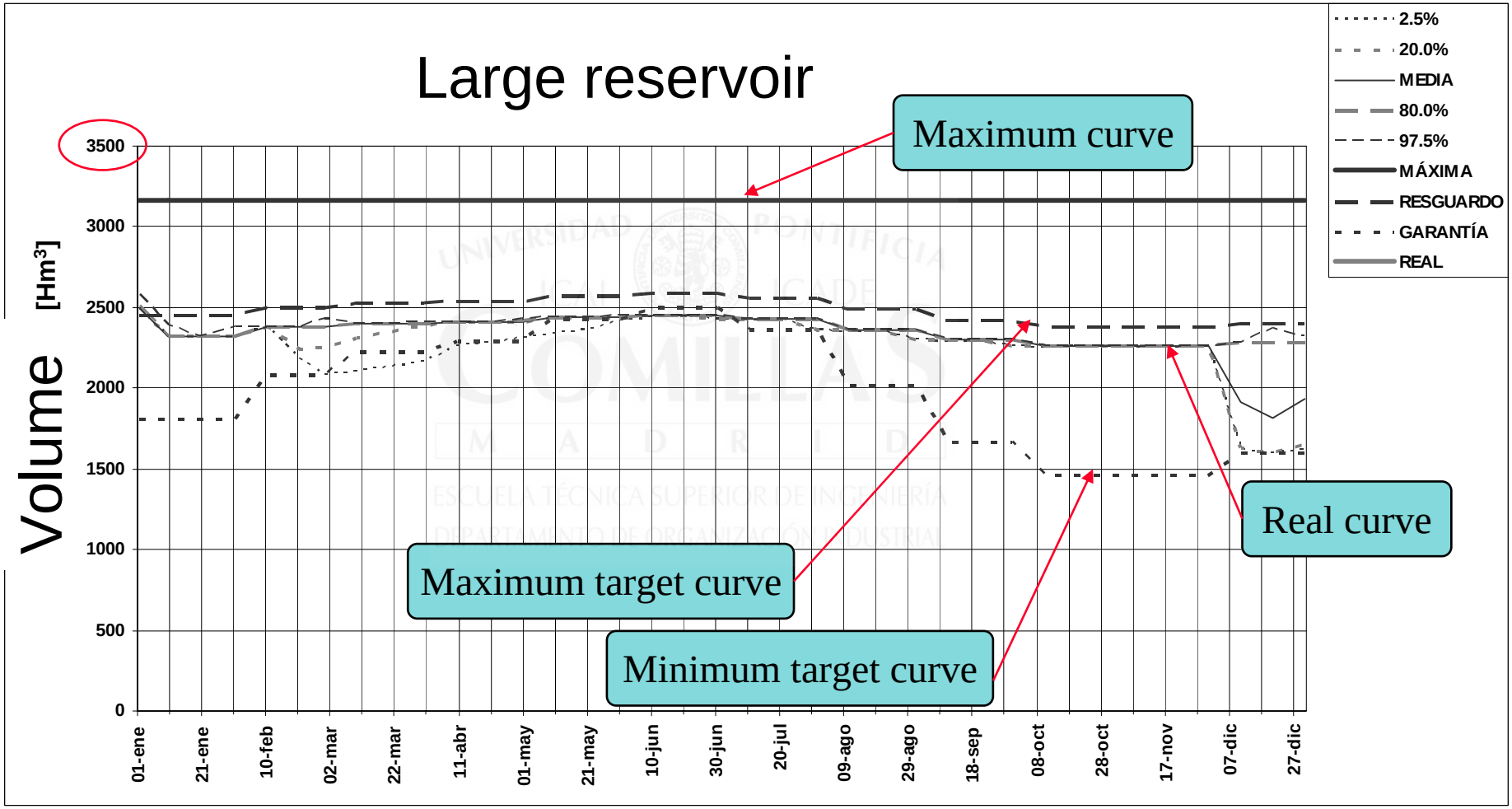
Case study

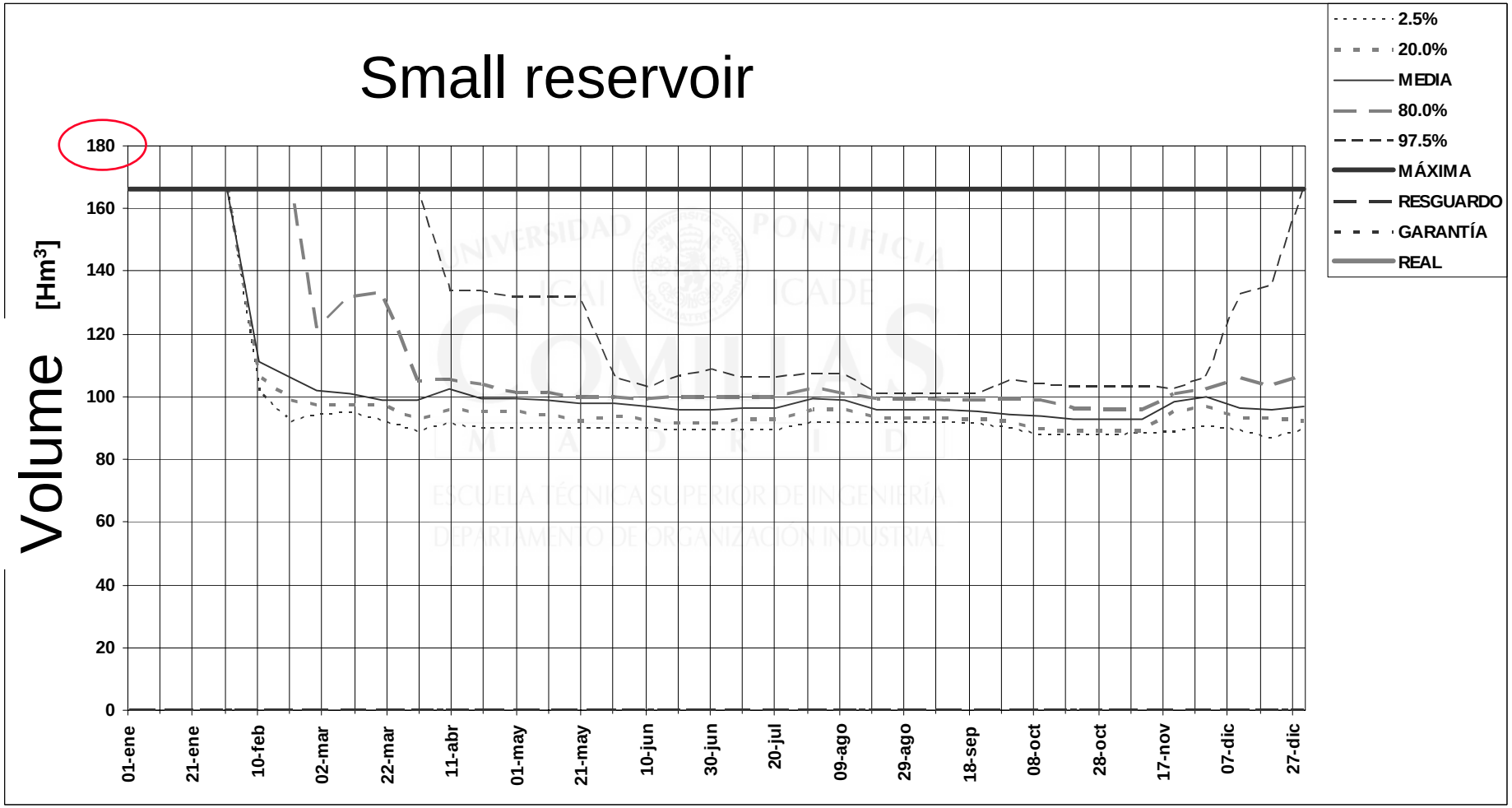
- Application to the Tagus basin belonging to Iberdrola with:
  - 9 reservoirs of different sizes
  - 8 hydro plants
  - 6 natural inflow points
  - 27 historical series of daily inflows



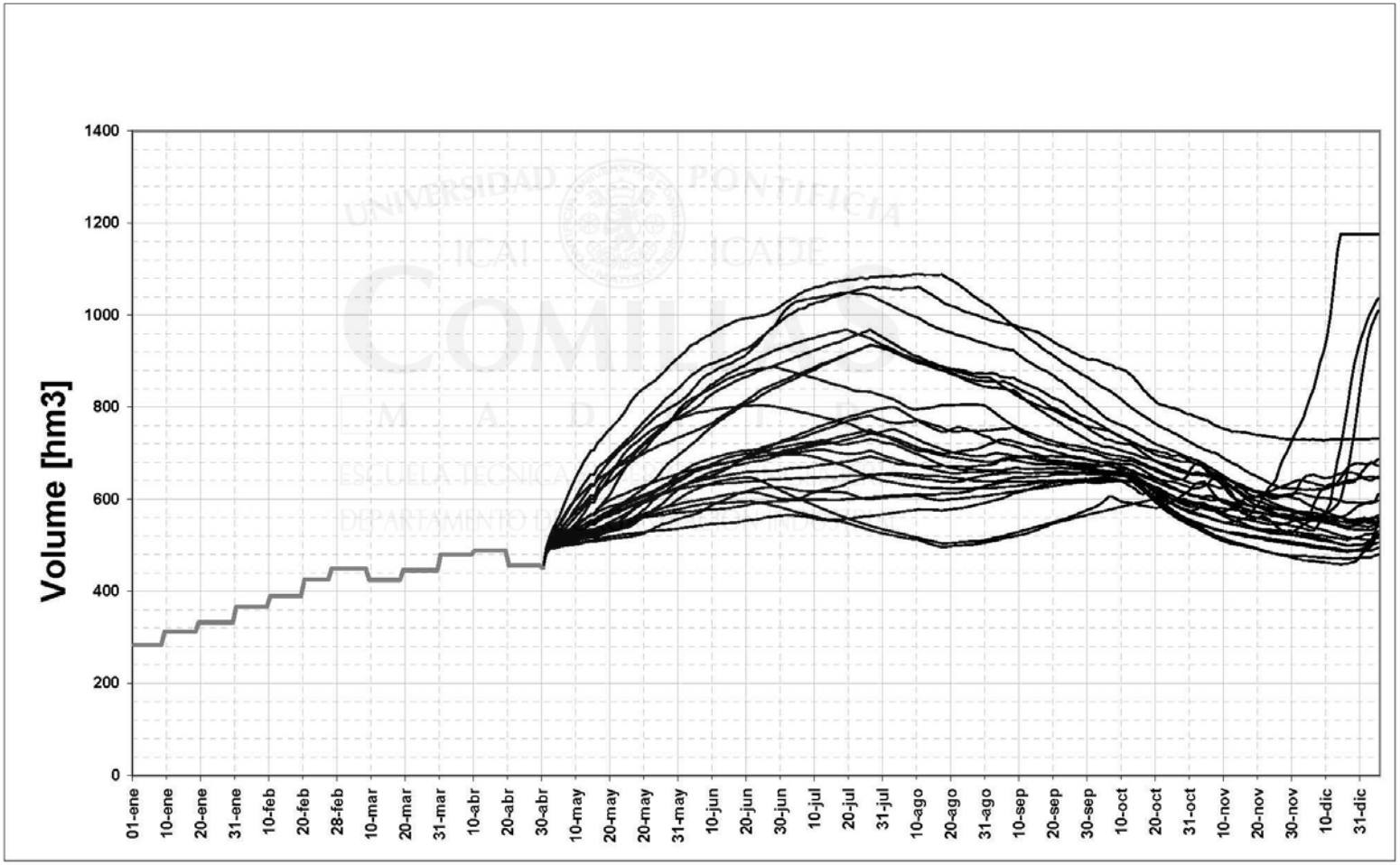
Results (i)


Large reservoir
Maximum curve
Real curve
Maximum target curve
Minimum target curve
Volume [Hm³]
3500
3000
2500
2000
1500
1000
500
0
01-ene
21-ene
10-feb
02-mar
22-mar
11-abr
01-may
21-may
10-jun
30-jun
20-jul
09-ago
29-ago
18-sep
08-oct
28-oct
17-nov
07-dic
27-dic
2.5%
20.0%
MEDIA
80.0%
97.5%
MÁXIMA
RESGUARDO
GARANTÍA
REAL

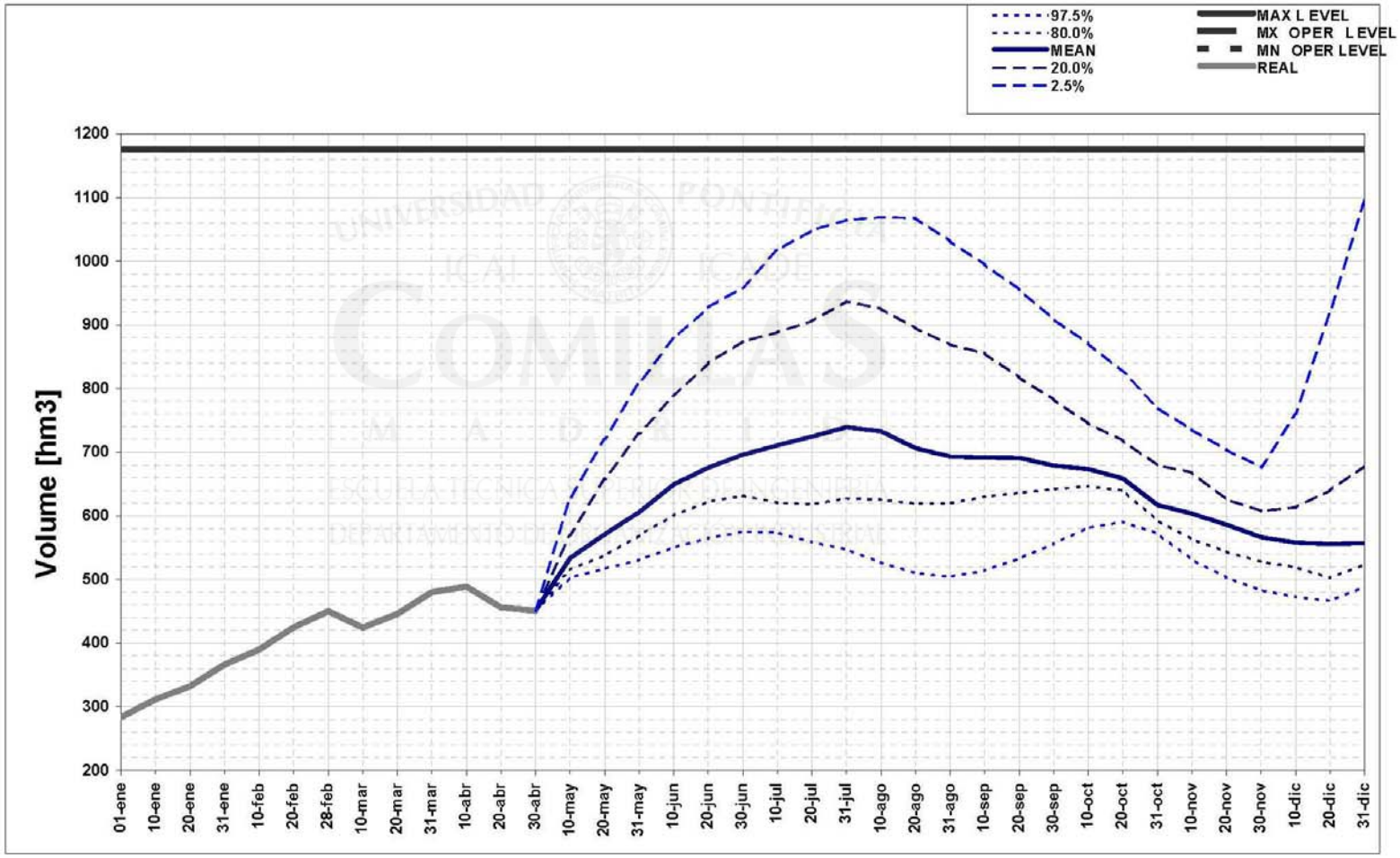
Results (ii)


Small reservoir
Volume [Hm³]
180
160
140
120
100
80
60
40
20
0
01-ene
21-ene
10-feb
02-mar
22-mar
11-abr
01-may
21-may
10-jun
30-jun
20-jul
09-ago
29-ago
18-sep
08-oct
28-oct
17-nov
07-dic
27-dic
2.5%
20.0%
MEDIA
80.0%
97.5%
MÁXIMA
RESGUARDO
GARANTÍA
REAL

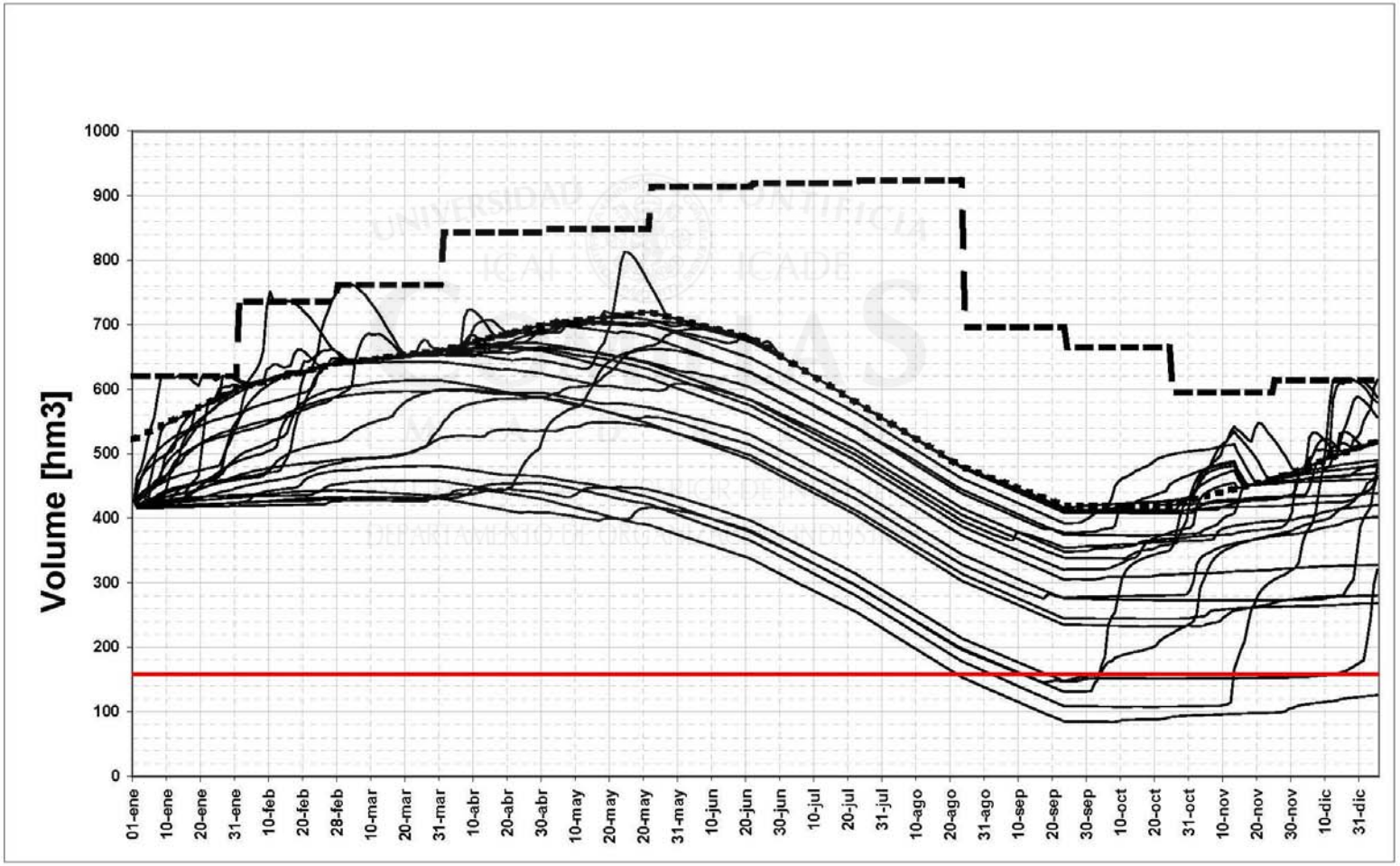
Results (iii)



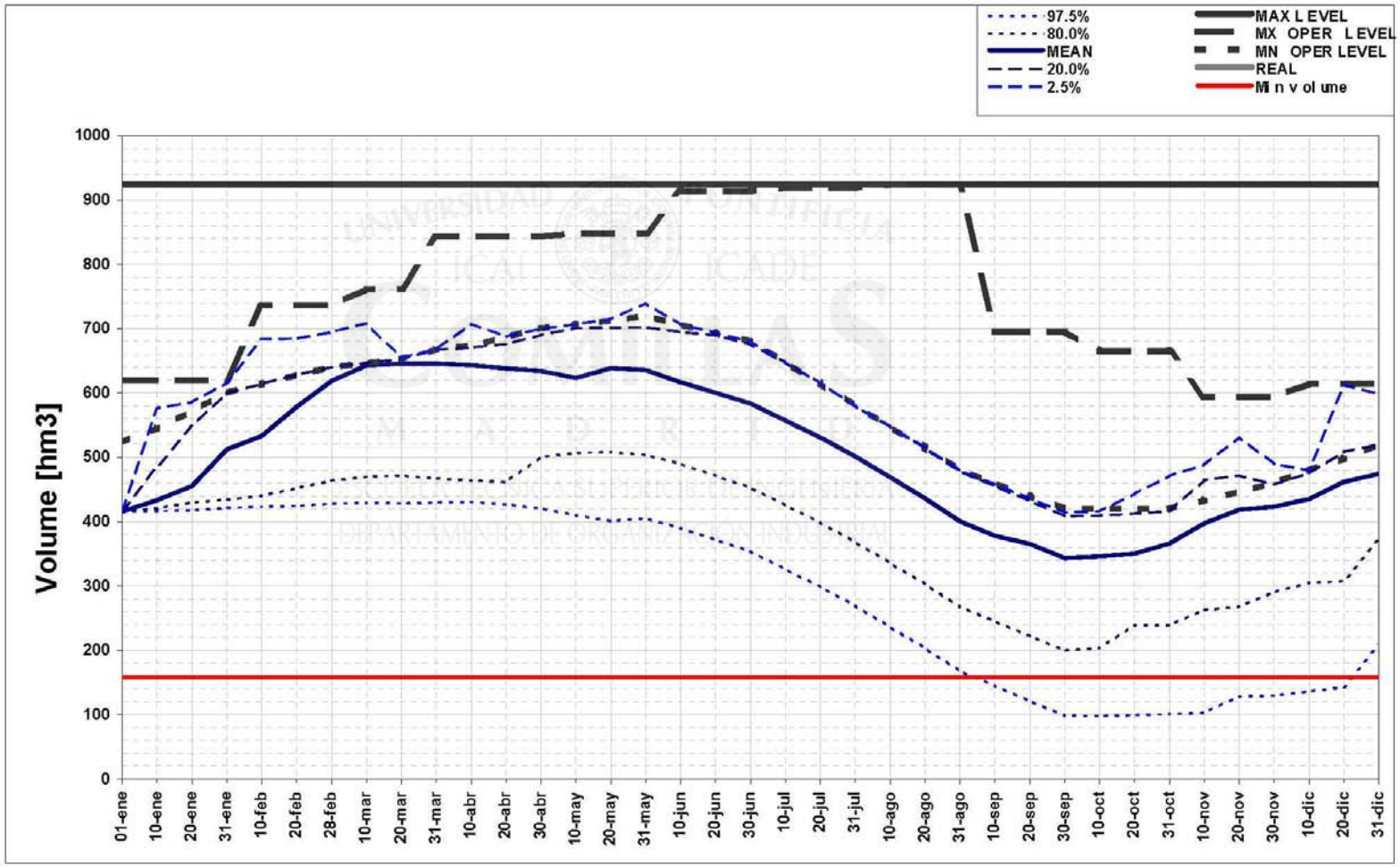
Results (iv)


97.5%
80.0%
MEAN
20.0%
2.5%
MAX L EVEL
MX OPER L EVEL
MN OPER LEVEL
REAL
Volume [hm3]
1200
1100
1000
900
800
700
600
500
400
300
200
01-ene
10-ene
20-ene
31-ene
10-feb
20-feb
28-feb
10-mar
20-mar
31-mar
10-abr
20-abr
30-abr
10-may
20-may
31-may
10-jun
20-jun
30-jun
10-jul
20-jul
31-jul
10-ago
20-ago
31-ago
10-sep
20-sep
30-sep
10-oct
20-oct
31-oct
10-nov
20-nov
30-nov
10-dic
20-dic
31-dic

Results (v)


Volume [hm3]
1000
900
800
700
600
500
400
300
200
100
0
01-ene
10-ene
20-ene
31-ene
10-feb
20-feb
28-feb
10-mar
20-mar
31-mar
10-abr
20-abr
30-abr
10-may
20-may
20-may
31-may
10-jun
20-jun
30-jun
10-jul
20-jul
31-jul
10-ago
20-ago
31-ago
10-sep
20-sep
30-sep
10-oct
20-oct
31-oct
10-nov
20-nov
30-nov
10-dic
31-dic

Results (vi)



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Conclusions

- A general simulation method for hydro basins has been proposed
- A three phase method implements the maximization of hydro production objective including pumped-storage and hydro plants
- Object Oriented Programming paradigm has been used
- A flexible computer application implements this method
- Validated with a case study
- It is currently been used for hydro operation

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