RESERVOIR MANAGEMENT MODEL OPTIMIZED FOR FLOOD RISK PERIODS. A PORTUGUESE CASE.

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1. Introduction

Reservoirs enable spatial and temporal redistribution of water flow of the rivers, and their operational management is usually subject to multiple objectives.

A reservoirs management model is a key piece in a **forecasting and decision support system for flood control** in regularized river basins → **minimize downstream effects**

Nevertheless, few forecasting systems containing that component exist.

Due to conflicts that may arise in meeting the various uses, reservoir management can be problematic for their operators.

The stochastic nature of inflows tends to accentuate this complexity.

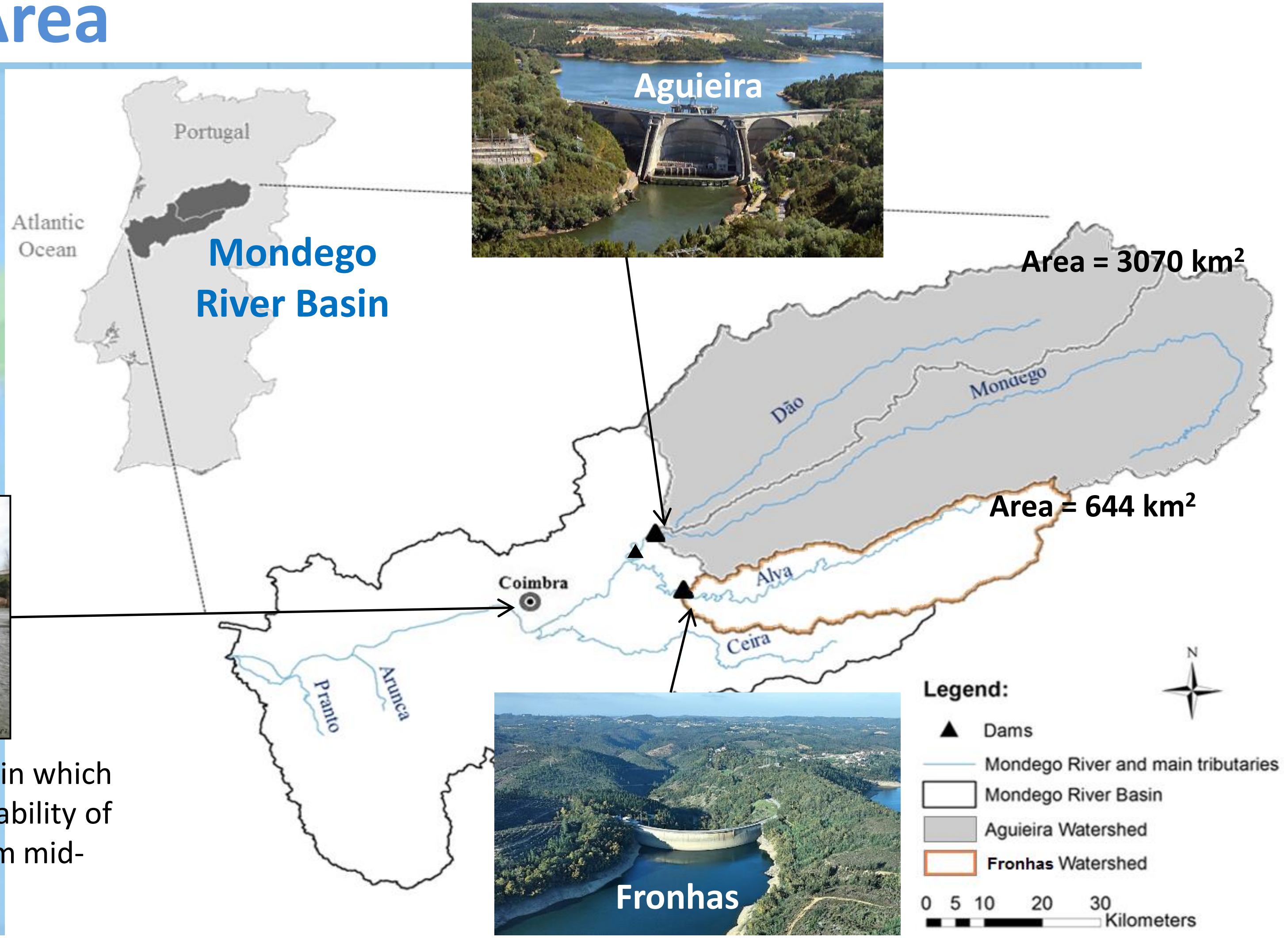
1. Introduction

This study presents a decision support model to optimize the operational management of a Portuguese multi-purpose reservoirs' system in flood risk situations, where the downstream flood control function can be a constraining factor for the remaining uses of the system.

The optimization model,

- based on daily streamflow forecasts, including inflows to reservoirs of the system, for the next 10 days' period,
- allows the computation of the volume to be discharged in the next 24 hours by each reservoir in the system, in order:
  - i) to minimize downstream impacts when a flood occurs;
  - ii) not to constrain the remaining uses of the reservoirs, when there is no forecast of flood occurrence, keeping water levels as high as possible without risking structural safety.

2. Study Area



Flood season – period in which there is a greater probability of flood occurrences: from mid-October to mid-April

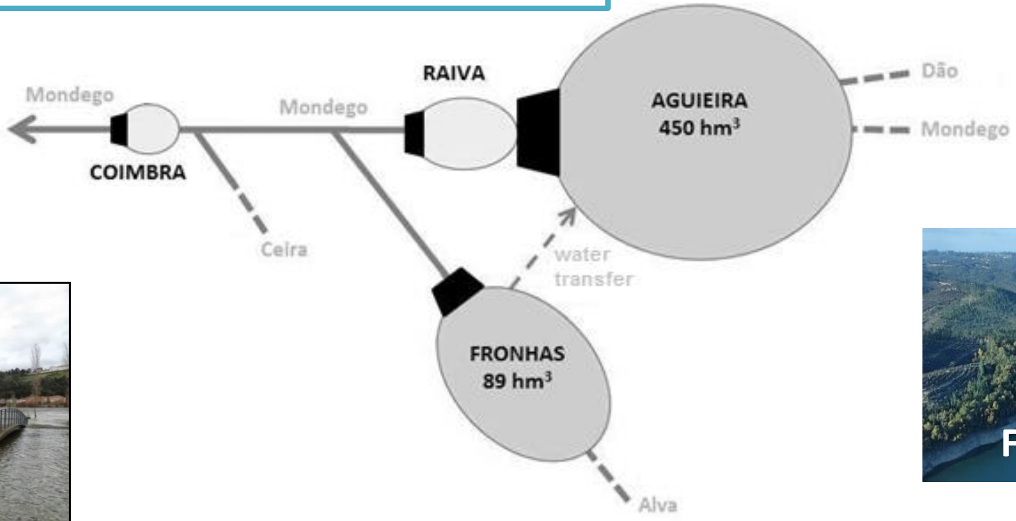
2. Study Area

Reservoir System

<u>Current management of the reservoir</u> system during the flood season is constrained by rules **<u>which impose the maximum water levels</u>** that may be reached <u>every day</u> in each reservoir, namely in the flood season.

The maximum water levels to be ensured daily are defined based on the **average value of reservoir inflow in the previous day.**

In addition, there are **flow discharge operations** defined to be applied when the real-time water storage level reaches some referenced values



Reference water levels have been set for the different flow discharges to open.

The <u>current operating rules essentially aim</u> at limiting the streamflow to the section of <u>Coimbra</u> to the value of 1200 m^3/s upon the occurrence of floods with a return period of up to 100 years.

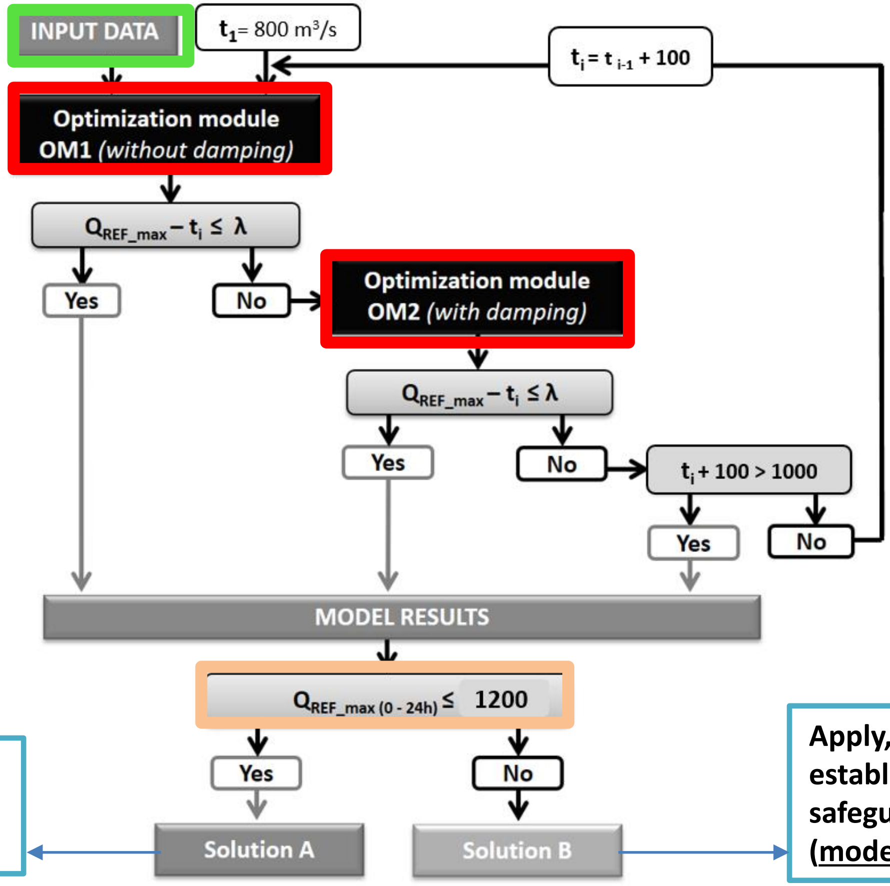
The marginal areas of the city of Coimbra are flooded by the Mondego river starting from a streamflow value of 800 m^3/s.

3. Model description

Reservoir management model

Framework

- Reference inflow (natural regime) forecasts to the reservoirs of the system under consideration (Aguieira and Fronhas), and,
- Corresponding streamflow to a downstream flood reference section (Coimbra).



Adopt the results of the model in the management of the two reservoirs for the next 24 hours

Apply, in each reservoir, the pre-established operating rules to safeguard the safety of structures (model results should be ignored).

3. Model description

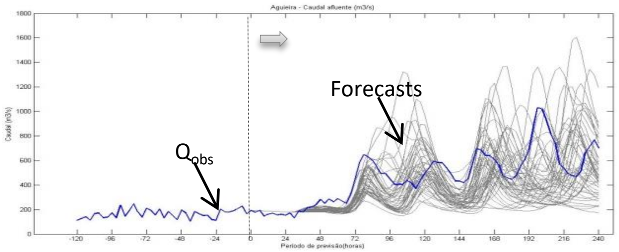
Input data

Data Acquisition and Processing

ECMWF

52 QPF (51 EPS + 1 HRES) with:
- time-step of 3 hours
- forecast horizon: 10 days

Period under analysis:
01/03/2010 e 28/02/2014 (1461 days)



Statistical handling of the ensemble streamflow forecasts in deterministic forecasts (0 to 240 h):
- Percentiles: 25, 50, 75 and 90
- maximum of the distribution

Acquisition and processing of precipitation forecast data

Preparation, calibration and verification of the hydrological model

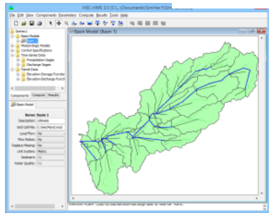
Hydrologic simulation and forecasting

Statistical processing of streamflow forecasts

Uncertainty analysis and selection of reference forecasts

ArcGIS

HEC-HMS



Consistency.:
- Standard deviation (STD)

Skill:
- Mean Absolute Error (MAE);
- Mean Continuous Rank Probability Score (MCRPS);
- Brier Score (BS);
- Relative Mean Error (RME);
- Rank Histogram;
- Relative Operating Characteristic Diagram (ROCD).

Reference forecast:
- maximum values: 0 to 72 hours
- 75th percentile: 75 to 240 hours.

3. Model description

Optimization model

Linear Programming

Objective-function:

$$Min \sum_{i=1}^{n} (c_i V_i)$$

The objective-function is applied at each instant over the forecast period, i.e., from 3 in 3 hours up to 240 hours

c_i - coefficients of the objective-function (priorities of use of the flow discharger i)
V_i - volumes discharged at each instant ($hm^3/3h$) by each flow discharger i.

Constraints:

Definition of the reservoirs' storage characteristics and of the flow capacity of their dischargers, as well as the imposed to the streamflow in Coimbra

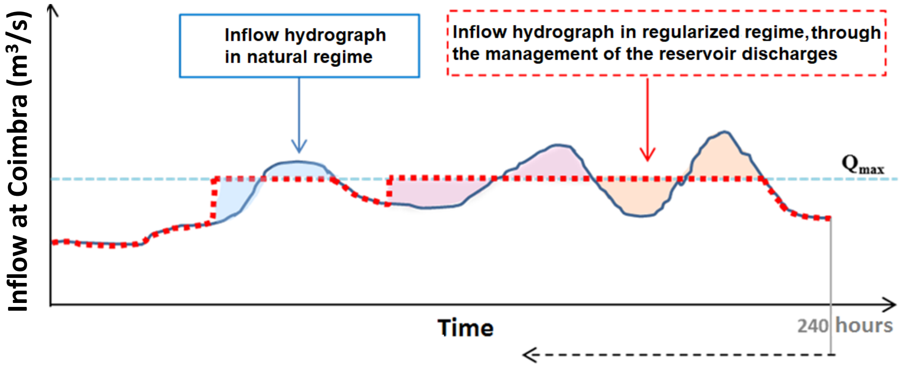
a) Definition of the variables' domain;

b) Reservoirs' water level exploitation thresholds, predefined through relationships with stored volumes;

c) Limitation of the maximum streamflow value at Coimbra:

c1) Taking into account inflow forecasts at each instant

c2) Taking into account the global inflows along the entire forecast period



condition only applicable in the 2nd optimization module, which includes the flood damping process

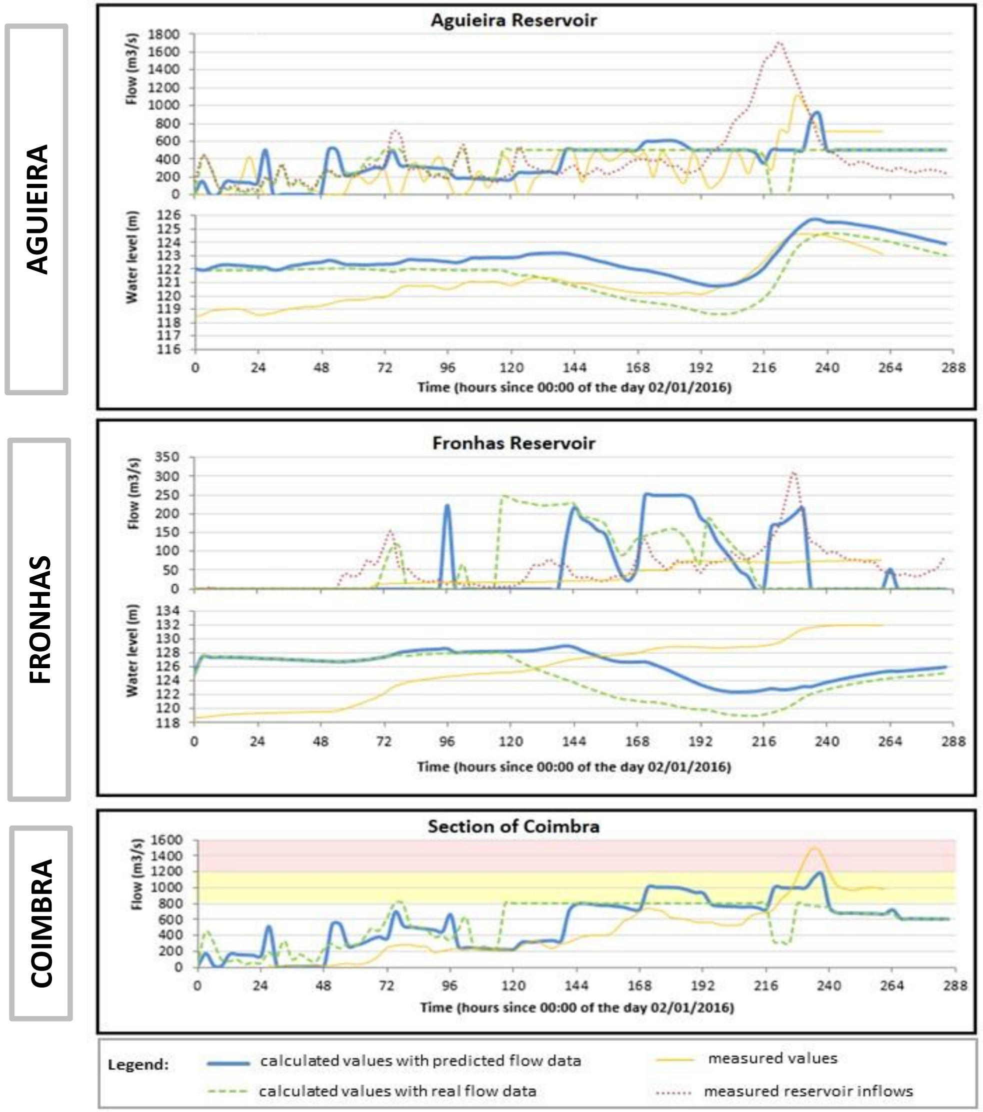
4. Model performance evaluation

Evaluation of the model results for a 12-day period starting at 0:00h on **2nd January 2016.**

The model was applied **<u>to each day</u>** of this period, using as input:

i) the predicted flows and
ii) the observed flow values, as if those were "perfect" forecasts.

Then, the results of the model thus obtained were compared with the <u>corresponding values which actually occurred</u>, as measured at existing hydrometric stations in the respective river sections.



4. Model performance evaluation

Period of evaluation: 12 days from 0:00h on **2nd** January 2016 to 0:00h on **14st** January 2016.

Operation procedure used	I) Mean water level (m)		II) Number of hours that the streamflow (m^3/s) in Coimbra exceeds the value of :				III) Maximum streamflow in Coimbra (m^3/s)	
	Aguieira	Fronhas	800	900	1000	1200		
Model (with predicted flows)	122.83	126.23	45	45	6	0	1165	-22%
Model (with real flow data)	121.67	124.41	0	0	0	0	800	-46%
Measured values (real situation)	120.87	125.51	42	39	21	9	1489	-

5. Conclusions

- ✓ The model application leads to a better reservoir management performance than the operational actions actually followed, which do not take into account hydrological forecast data.
- ✓ Through optimized flood damping , the model enables high water levels to be maintained in the reservoirs, particularly during periods in which there are no significant inflows forecasted, which is beneficial for other uses, in particular energy production.
- ✓ The operational management model proposed in this work fulfills the established objectives and would be useful and beneficial for the operational management of the studied reservoir system.
- ✓ The incorporation of inflow forecasts is an effective advantage for the operational management of reservoir systems. However, the more accurate the predictions are, the better the model results will be.

The next step will be the application and the performance evaluation of the model to a more representative number of flood periods, with different flood magnitudes, and different temporal distribution and duration.

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Thank you for your attention!