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Implementation and calibration of a distributed hydrological model based on the finite volume method

M. Sanz-Ramos[1], E. Bladé[1], A. Amengual[2], R. Romero[2], H. Roux[3]

[1]Flumen Institute (Universitat Politècnica de Catalunya – CIMNE), Barcelona, Spain
[2]Grup de Meteorologia (Dept. De Física, Universitat de les Illes Balears), Palma, Spain
[3]Institut de Mécanique des Fluides de Toulouse (Université de Toulouse, CNRS-INPT-UPS), Toulouse, France

1. INTRODUCTION

The **characterization and quantification of the runoff based on rainfall-runoff transformation programs** is very common for academics and technicians. The first models were based on simple equations, only valid under certain conditions (specific basin characteristics, rain, etc.). Later software able to solve the 1D hydrodynamic equations in order to represent more accurately the runoff processes (flow generation and propagation) appeared.

More recently the necessity to avoid some uncertainties in the process (e.g. the determination of the time of concentration or lag-time), the improvements on data (DTM, land uses, rain rasters, etc.) and the decreasing of the computing times, has allowed to develop new tools that can solve more complex equations.

In this context**, a distributed hydrological model was developed on the basis of Iber** (Bladé *et al.*, 2014), a previously existing **two-dimensional hydrodynamic model**.

In this work the model has been **implemented and calibrated** with precipitation and discharge data to simulate flood events in the basin of La Muga (northeast of the Iberian Peninsula), within the European project "*Forecasting and management of flood risk in the Euroregion Pyrenees Mediterranean*" (PGRI-EPM).

2. NUMERICAL MODEL: IBER

The mathematical model Iber is a numerical tool for hydraulic simulations. It solves the full two-dimensional Shallow Water Equations (SWE) or Saint Venant 2D equations using the **Finite Volume Method** (FVM) based on Roe (1986) scheme.

The model has been enhanced to **be used as a hydrological model adding the precipitation and losses processes as new source terms** (R, rain, and f, losses) on the mass conservation equation.

A new **DHD scheme** (Cea and Bladé, 2015) was implemented in order to solve more efficiently and properly the SWE for hydrological purposes.

The following equations represent the mass conservation equation ([1]) and the momentum conservations equations for the X ([2]) and Y ([3]) components of the two-dimensional SWE based on DHD scheme:

$$\frac{\partial h}{\partial t}+\frac{\partial q_x}{\partial x}+\frac{\partial q_y}{\partial y}=R-f \quad [1]$$

$$\frac{\partial q_x}{\partial t}+\frac{\partial}{\partial x}\left(\frac{q_x^2}{h}\right)+\frac{\partial}{\partial y}\left(\frac{q_x q_y}{h}\right)=-gh\frac{\partial z_s}{\partial x}-gh\frac{n^2|\mathbf{q}|}{h^{10/3}}q_x \quad [2]$$

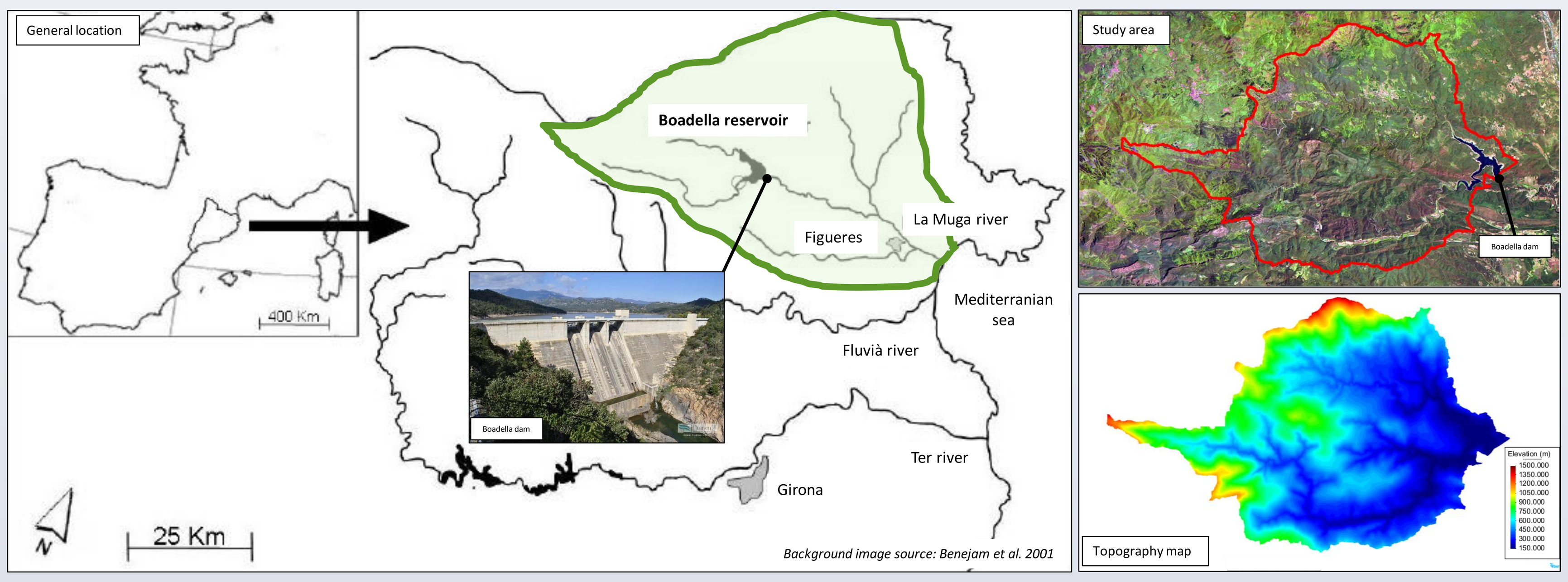
$$\frac{\partial q_x}{\partial t}+\frac{\partial}{\partial x}\left(\frac{q_x q_y}{h}\right)+\frac{\partial}{\partial y}\left(\frac{q_y^2}{h}\right)=-gh\frac{\partial z_s}{\partial y}-gh\frac{n^2|\mathbf{q}|}{h^{10/3}}q_y \quad [3]$$

where z_s is the free surface elevation, h is the water depth, q_x and q_y are the unit discharge (X and Y components), $|\mathbf{q}|$ is the unit discharge module, n is the Manning coefficient, g is the gravity acceleration and R and f are the source terms represents respectively rainfall intensity and losses (infiltration, evapotranspiration, interception and surface retention).

Iber allows to calculate in a coupled way rainfall-runoff (hydrological) and inundation (hydraulic) processes .

3. STUDY CASE: La Muga basin

La Muga basin has 961 km^2 and is located on the northeast of Iberian Peninsula (highlighted in green), on the south of the oriental Pyrenees. It is characterized by a typical Mediterranean weather with **heavy rain events** concentrated in a few days or hours.



The middle and lower part of La Muga basin historically has suffered recurrent inundation events. Human activities (residential, agricultural and industrial) are consolidated, so the consequences of a flooding are economically and societally important.

The main river called La Muga is regulated by Boadella dam (located between the middle and the upper part of the river). It contains 61 hm^3 with three spillways that regulates its storage capacity. Its function is to supply water for human consumption (for local inhabitants and tourism population), for irrigation and for reducing the risk of floods.

Upper catchment of La Muga

A hydrological distributed model was implemented at the upper part of La Muga basin (till to Boadella dam, 182.1 km^2).

The main goal of this model is to **reproduce accurately the rainfall-runoff process**, taking into account the dam, in order to manage the water resources.

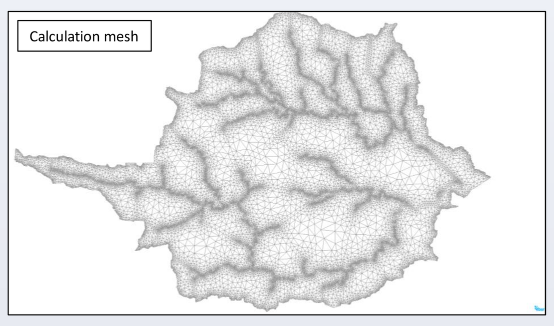
A hydrological and hydraulic modelling has built up (Iber) to **manage the flood risk and optimizing water resources using forecasting data** (main goal of PRGI-EMP project).

4. IMPLEMENTATION AND CALIBRATION

Implementation

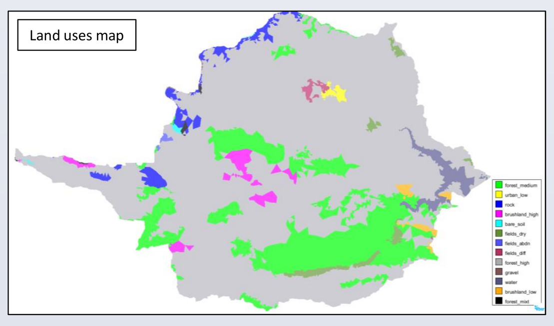
The model was built balancing accuracy for the results and fast computational time in order to use rain forecasting data obtained a few days before the rain event.

As mesh criteria, 30 to 1000 meters size of triangular mesh elements for the river line and the land respectively were used. The total number of elements was around 50000.



The computation time depends of the length of the event. **The analysed events lasted from 2 to 5 days, and the computation time varied from 1.5 to 4 hours.**

A spatial distributed map based on CORINE Land Cover 2012 project (EEA 2007) was used to represent de land uses in the model. From this map, the spatial distribution of the roughness coefficient was defined.



Calibration

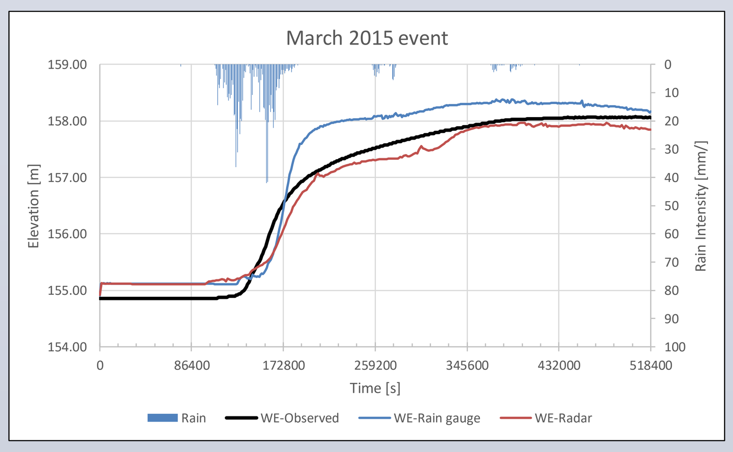
The calibration process was carried out using 5 rain events: all of them with heavy rain (**+100 mm in 2-6 days**), 3 where there were **floods** and 3 with **dam regulation**. It consisted in a double calibration process: first using rain gauge data (non-spatial distributed) and second using rain raster data (spatial distributed).

The field data was obtained from 1 rain gauge station (rain intensity) and 1 meteorological radar (provided by *Agència Catalana de l'Aigua* and *Servei Meterològic de Catalunya*).

The goal was to **calibrate the roughness values** (Manning coefficient) and **losses method** (Curve Number, USDA 1986) using observations of water level in the Boadella Reservoir.

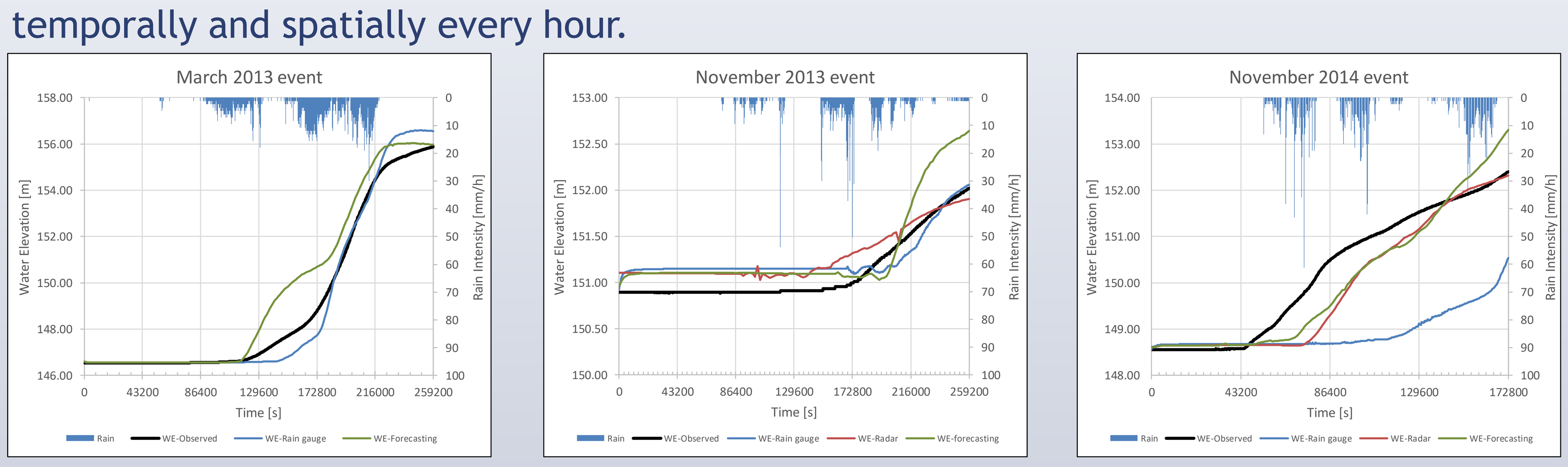
The results obtained from this process were:

- Same **Manning coefficient** for all situations which varies from **0.03 to 0.11 s·m$^{-1/3}$**, within the recommendation of Arcement (1989) and Barnes (1987).
- Different **Curve Number** for each simulation due the rain antecedents and season. The values vary from **48 to 94**.



5. FORECASTING

The meteorological forecast data was provided by the *Grup de Meteorologia* of the *Universitat de les Illes Balears* (UIB) as **WRF-predicted rain intensity raster data**, and it was introduced on the calibrated models of Iber**.** The rain intensity raster changes temporally and spatially every hour.



The results show a similar behaviour between the observed and predicted models.

6. CONCLUSIONS

- **A distributed hydrological** model based on hydraulic model **Iber was implemented and calibrated** for 5 different rain events. Iber uses FVM to solve SWE.
- The model implemented the **DHD scheme**, that provides fast and stable solutions, and has the **capability to use rain raster data**, as source term in the hydrological simulation.
- The calibration process allowed to determine the basin characteristics (roughness coefficients and curve number) for each event.
- Results based on forecasts, using UIB rain raster data, adjusted well to observations.
- **Predictions of the rain-runoff were done in affordable computational times** (< 4 h).
- This results can be used for the dam operation management in order to prevent flooding downstream and optimize water resources.

Acknowledgements

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Contact:
[1]marcos.sanz-ramos@upc.edu - [1]ernest.blade@upc.edu - [2]arnau.amengual@uib.es - [2]romu.romero@uib.es - [3]Helene.Roux@imft.fr