Optimized Digital Twin for Flood Forecasting in the Ebro River

Pablo Vallés[1], Isabel Echeverribar[1,2], P. Brufau[1], Pilar García-Navarro[1]

[1]Afiliación: Tecnologías Fluidodinámicas (TFD), Tecnologías Industriales
Instituto de Investigación en Ingeniería de Aragón (I3A)
Universidad de Zaragoza, Mariano Esquillor s/n, 50018, Zaragoza, Spain.
Tel. +34-976762707, e-mail: pvalles@unizar.es
[2]Afiliación: Hydronia S.L., Madrid, Spain

Abstract

Year after year, floods cause high losses in several regions along the Ebro River. Therefore, it is necessary to develope tools based on numerical simulations to foresee the negative effects of these phenomena. Different strategies are proposed towards a digital twin of the river reach.

Introduction

Flooding events are one of the most destructive natural disasters. Damage caused by these events has increased in amount and frequency in our country [1]. Governments are therefore forced to seek and develop prevention plans and tools. One of these tools is the use of predictive models based on numerical simulation, which has been developed and improved over the last decades.

Practical applications require a trade-off between spatial accuracy and computational efficiency, so approximations that reduce the dimensions of the problem or simplify the equations describing the flow are frequently used. Although reality is a 3D problem, a river flood event presents a 2D nature that allows its modelization by averaging the equations in the vertical coordinate to reduce the problem to two horizontal dimensions [2]. The Shallow Water Model (SWE) is a widely used approach to simulate surface geophysical flows in situations that involve large domains and long-time scales. This approach assumes that horizontal scales are larger than vertical scales and assumes a hydrostatic pressure distribution in the vertical direction. However, to achieve the necessary spatial resolution, in many cases quite fine computational grids are needed, so more data storage is required, proportionally increasing the number of operations, and reducing the size of the time step allowed for explicit calculations. For this reason, further dimensional simplifications consider the average of the equations in the cross-section to reduce the formulation to a 1D SWE approximation. At the lowest level of complexity, hydrologic models, also called 0D models or aggregated models, allow to describe in a simplified way certain regions as is the case of a reservoir, without the need to compute some of the hydraulic variables, offering a high computational efficiency.

In this work, different models are used towards the development of a digital twin of the region between Zaragoza and Mequinenza. The interest is frequently flooding in the upstream region, unlike the downstream Mequinenza reservoir, where the flow is practically at rest. Therefore, studies of this region will be carried out using a 2D SWE model and a 1D SWE model to compare the accuracy of the results and computational times. Moreover, a 0D hydrological model is proposed to simplify the dynamics in the reservoir.

Methodology

The SWE equations describing the evolution of the flow are presented for different dimensional approximations. In all the cases, they are solved by means of an explicit upwind finite volume scheme, based on the Roe–Riemann solver [3].

2D SWE Model

The mathematical model that describes the surface flow is given by the hyperbolic 2D SWE based on mass and momentum conservation:

$$\frac{\partial}{\partial t}\begin{pmatrix} h \\ hu \\ hv \end{pmatrix} + \frac{\partial}{\partial x}\begin{pmatrix} hu \\ hu^2 + gh^2/2 \\ huv \end{pmatrix} + \frac{\partial}{\partial y}\begin{pmatrix} hv \\ huv \\ hv^2 + gh^2/2 \end{pmatrix} = \begin{pmatrix} 0 \\ gh(S_{ox} - S_{fx}) \\ gh(S_{oy} - S_{fy}) \end{pmatrix}$$

in terms of the water depth, h, the depth averaged unit discharges hu and hv in the x and y directions respectively. The slopes S_{ox} and S_{oy} are the two components of the bottom surface gradient and S_{fx} and S_{fy} represent friction slopes.

1D SWE Model

The 1D SWE system includes mass conservation and momentum balance along the mainstream direction:

$$\frac{\partial}{\partial t}\begin{pmatrix} A \\ Q \end{pmatrix} + \frac{\partial}{\partial x}\begin{pmatrix} Q \\ Q^2/A + gI_1 \end{pmatrix} = \begin{pmatrix} 0 \\ g[I_2 + A(S_0 - S_f)] \end{pmatrix}$$

where Q stands for transversal discharge, A is the cross section wetted area and I_1 and I_2 are hydrostatic pressure integrals. S_0 is the bottom slope along the longitudinal coordinate of the channel and S_f is the friction slope.

0D Model

0D models describe the time evolution of the flow in the domain, without the need to spatially discretize the entire region to solve the problem, unlike 2D and 1D models do. Our model is based on a volume balance equation:

$$\frac{dV}{dt} = Q_{in} - Q_{out}$$

where V is the storage, Q_{in} the inflow and Q_{out} the outflow. This model is based on the following hypotheses for a reservoir [4]:

- The water surface level H is horizontal.
- The reservoir volume is a function of the surface water level H.
- The outflow discharge is a function of H.

Results

The studied case is an historical flooding event in this region. This case is studied using first a full 2D model; next, a full 1D model; and, finally, a 2D-0D model applying the 0D model to represent the reservoir as the downstream boundary condition for the 2D model. Figure 1 shows the temporal evolution of the water surface level at the Gelsa location for each of the models and compares them with real data measured at that location. Table 1 compares the computational cost and the number of grid cells for each model.

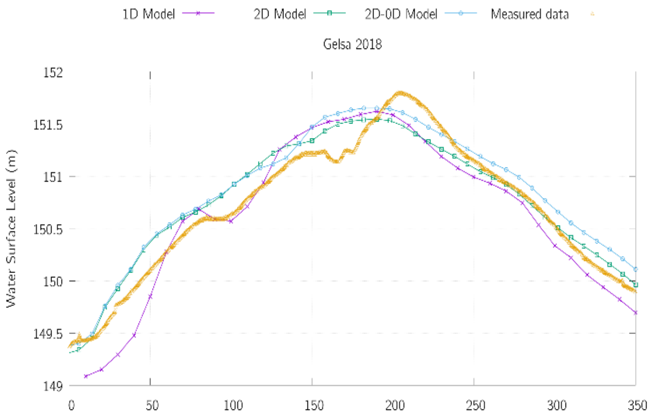

Figure 1. Temporal evolution of the water surface level in Gelsa for all models and for measured data.

Conclusions

From the results shown in Figure 1 and Table 1, it is concluded that the 3 models developed are sufficiently accurate to be able to provide a reliable estimate of the time evolution of the channel, with the 1D model being the most computationally efficient. With respect to the floodplain, it is the 2D and 2D-0D models that provide information about what happens in this area, the 1D model being valid only in the channel itself due to its theoretical basis. With respect to the impounded region, the 2D and 1D models offer more accurate results than the 2D-0D model, which does not discretise and does not obtain the temporal evolution of the velocity in this region.

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Table 1. Computational cost and number of cells for each model

Models	2D	2D-0D	1D
Time	15.47h	14.03h	364s
Cells	633216	602417	2000