Simulation of hydrological and morphodynamical processes in a mountain catchment of the Central Pyrenees

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Abstract An efficient and properly calibrated computational model represents a useful tool to provide insight into the catchment dynamics at hydrological and geomorphological levels [3]. In addition, it allows to develop detailed risk management and conservation plans. In this work, we present a coupled hydraulic-morphodynamical distributed flow model and its application to a well characterized experimental catchment (Arnás basin) [2]. The calibration of the water flow model response to rainfall is performed by means of the fitting to experimental outlet hydrographs. On the other hand, the calibration of a suspended and bed load model is also addressed by means of the fitting to experimental outlet sedigraphs. The numerical results show a good agreement between numerical and observed hydrographs and sedigraphs, significantly improving previous published simulations. Additionally, the need to repeat the simulations in the calibration processes is no longer an unapproachable problem.

Keywords: Shallow flows, Mountain catchment, Sediment transport, Infiltration, Coupled models.

Methods

- Governing equations:

- 2D Shallow Water equations:

$$\frac{\partial \mathbf{U}}{\partial t} + \frac{\partial \mathbf{F}}{\partial x} + \frac{\partial \mathbf{G}}{\partial y} = \mathbf{S} \quad \begin{cases} \mathbf{U} = (h,\, q_x,\, q_y)^T \\ \mathbf{F} = \left(q_x,\, \frac{q_x^2}{h} + \frac{1}{2}gh^2,\, \frac{q_x q_y}{h}\right)^T \\ \mathbf{G} = \left(q_y,\, \frac{q_x q_y}{h},\, \frac{q_y^2}{h} + \frac{1}{2}gh^2\right)^T \end{cases}$$

- Source terms of rainfall (R), infiltration (f), bed slope (S_0), friction (S_f) and net solid exchange flux between the flow and the static bed:

$$\mathbf{S} = \left(R - f - \xi\omega_s(\phi - \phi^*),\, gh\left(S_{0x} - S_{fx}\right),\, gh\left(S_{0y} - S_{fy}\right)\right)^T$$

- The suspended solid phase conservation is modeled by an advection equation, leaving aside the consideration concerning diffusion terms:

$$\frac{\partial(h\phi)}{\partial t} + \frac{\partial}{\partial x}(q_x\phi) + \frac{\partial}{\partial y}(q_y\phi) = -\omega_s\left(\phi - \phi^*\right)$$

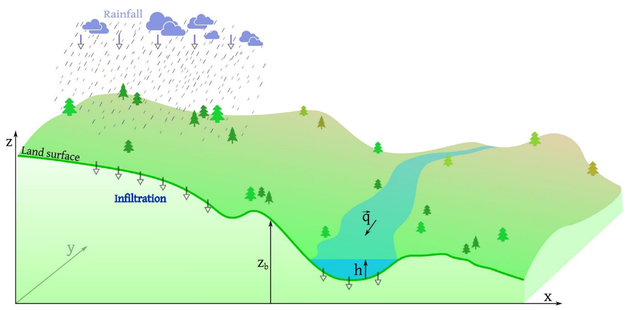


Figure 1: Coordinates representing water depth *h* and bed level *z*.

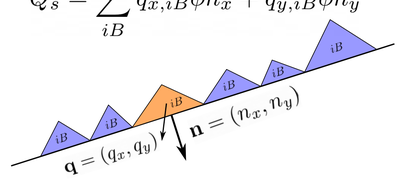
Results and conclusions

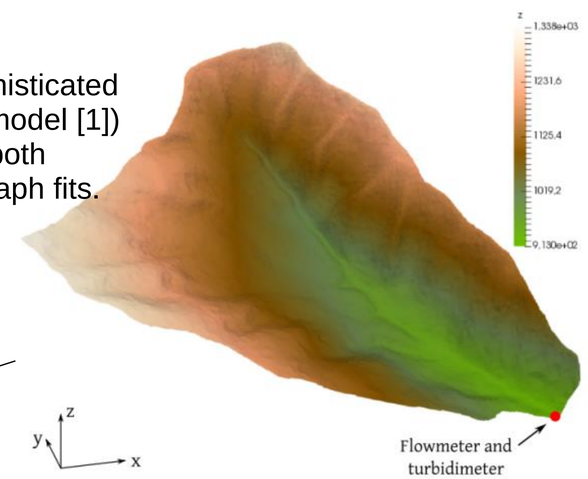
Figure 2 shows the combined fit for numerical hydrograph and sedigraph. The results corresponding to the classical Green-Ampt (GA) model are also depicted for both liquid and solid discharges. In the light of the numerical results, several conclusions can be drawn:

- The GA infiltration model predicts excessive infiltration in the early period of the storm, leading to a wrong reproduction of the outlet hydrograph.
- A wrong fit of the outlet hydrograph generates a wrong numerical outlet sedigraph. In other words, a correct estimation of the infiltration along the whole catchment is essential in order to carry out an adequate sediment transport computation.
- The use of a more sophisticated infiltration law (FOGA model [1]) improves significantly both hydrograph and sedigraph fits.

$$Q = \sum_{iB} q_{x,iB} n_x + q_{y,iB} n_y$$

$$Q_s = \sum_{iB} q_{x,iB} \phi n_x + q_{y,iB} \phi n_y$$





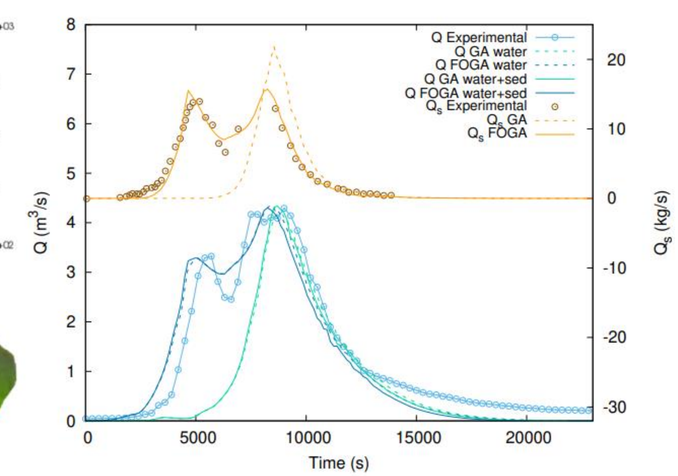


Figure 2: Arnás catchment hypsometry map (left) and discharge integration. Numerical fit to observed hydrograph and sedigraph (right).

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