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Simulation of the December 2017 flood on the Enza River using a 2D SWE code coupled with a levee breach erosion model

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ABSTRACT

The levee breach that occurred on the Enza River (Italy) on December 12th 2017 and the resulting flood are simulated with a GPU-accelerated 2D SWE code, where a simple erosion model was implemented to describe the breach evolution in detail.

1 INTRODUCTION

Dam and levee breaches can cause large flooding in the surrounding areas; for this reason, the correct modelling of these phenomena is particularly important for flood hazard mapping and for civil protection planning. While 2D numerical models based on the integration of Shallow Water Equations (SWE) are by now established tools for the simulation of the flood propagation, the prediction of the breach triggering and evolution remains an open issue, especially as regards riverine levee breaches. In fact, due to the unsteadiness of the flow and the presence of non-standard bathymetric features, simplified dam breach models are not applicable in these cases; hence, trapezoidal breaches are often hypothesized, defining the final breach width and the opening time as parameters [2]. A more physically-based approach (such as an erosion or solid transport model), which considers the influence of the flow field and the levee material characteristics, would be more appropriate for simulating this type of breaches and the related flooding.

In this work, a simple erosion model is implemented in a GPU-accelerated 2D SWE code so that the levee breach evolution can be simulated, overcoming the disadvantages of a purely “geometrical” approach. The model is applied to the simulation of a real event, which took place on December 12th 2017 on the Enza River (Italy).

2 NUMERICAL MODEL

The PARFLOOD model [3] integrates the SWE with an explicit finite volume scheme with first- or second-order accuracy in space and time. The intrinsic parallelization of computations on GPU is exploited by the CUDA/C++ implementation of the code.

The following equation is applied locally to describe the breach evolution:

$$\partial z/\partial t = -E/(1-p) \tag{1}$$

where z is the bed elevation, t is the time, p is the bed porosity, and E represents the bed erosion rate (eroded volume per unit time per unit area), which can be estimated according to a linear erosion law:

$$E = k_d\,(\tau-\tau_c) \quad \text{if } \tau>\tau_c; \qquad E = 0 \quad \text{if } \tau\leq\tau_c \tag{2}$$

where k_d is the erodibility coefficient of the material, and τ and τ_c are the bed shear stress and its critical value, respectively. Through this simple equation, the breach development depends on the flow field (via τ), and on the material characteristics (via k_d, τ_c, and p). These latter values are currently assumed as model parameters to be calibrated.

Moreover, a bank failure algorithm is added to the model, since bank collapse is recognized as one of the main mechanisms for breach enlargement. When the local slope φ exceeds the critical slope φ_c of the material, it is reduced to the critical value (e.g. [1]).

3 APPLICATION

The model is employed to simulate the flood event that recently took place on the Enza River (Italy). A severe flood event followed the prolonged heavy rainfall occurred on the river basin on December 10th-11th 2017, resulting in the highest water levels ever recorded at all the gauging stations along the river. On December 12th 2017 (at 05:30 a.m.) water overtopped the right levee near Lentigione di Brescello (Reggio Emilia), initially triggering three very close breaches (Figure 1a), which tended to merge into a single large one in time (the final width is about 250 m). The breach enlargement took approximately 4-5 h, and preliminary estimates quantified the volume overflow in roughly $20 \cdot 10^6$ m^3. The total flooded area was about 6.3 km^2, restricted by the levees of the Enza and Po Rivers, by a road embankment and a channel levee (see Figure 1b).

The domain was discretized with square cells of minimum size 2 m × 2 m, and the terrain elevation was obtained from a LiDAR survey. Upstream and downstream boundary conditions were obtained from available water level recordings at gauging stations. The breach opening is automatically triggered when levee overtopping starts.

Figure 1c shows details of the breach evolution. It must be noticed that the model predicts a single breach, which enlarges in time, instead of three small ones, since, obviously, discontinuities and singularities in the levee material cannot be taken into account by the model. However, the final breach width is correctly predicted. The subsequent flood propagation is also well caught by the model (see Figure 1b, where the water surface elevation contour map 12 h after the breach opening is compared with the actual flooded area).

A sensitivity analysis on the levee material parameters was also performed in order to evaluate the uncertainties related to their values. As for the simulation run time, the ratio of the physical time to the computational time is equal to 17, confirming the good performance of GPU-accelerated models for high-resolution simulations.

4 CONCLUSIONS

The erosion law, easy to implement in a SWE model, is able to predict the levee breach evolution reasonably, even if the material erodibility parameters must be calibrated. Comparisons with an Exner-based solid transport model are in progress.

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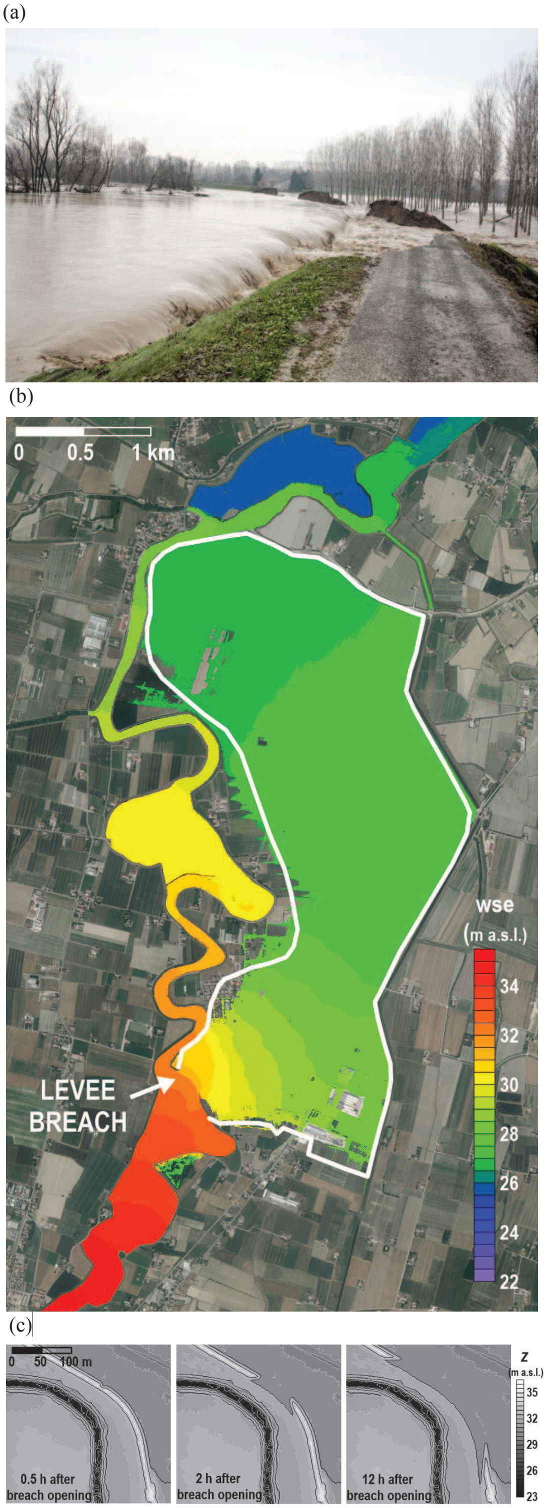

Figure 1. (a) Lateral photo of the breach (from "Reggio Report"); (b) simulated flooded area 12 h after the breach opening, compared with the surveyed area (purple line); (c) details of the breach evolution at three selected times.