Porosity-based shallow water models for urban floods

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The porosity approach for shallow water models was first proposed by Defina et al. (1994) and Defina (2000) to incorporate subgrid-scale topographic effects. The approach was applied to urban floods by Hervouët et al. (2000). The equations in conservation form allowing for shock capturing were derived by Guinot and Soares-Frazão (2006) (see also Lhomme (2006), Soares-Frazão et al., 2008). A number of numerical developments followed (Cea and Vazquez-Cendon, 2010; Finaud-Guyot et al., 2010 ; Benkhaldoun et al., 2016 ; Ferrari et al., 2017), as well as laboratory experiments on building drag modelling (Velickovic, 2012; Velickovic et al., 2017).
The question soon arose of how the anisotropy of the urban layout should be incorporated in such models. Sanders et al. (2008) proposed that two porosities be distinguished: a storage porosity and a connectivity porosity. Formulating the upscaling problem in an integral fashion (hence the term "Integral Porosity") allows anisotropy effects to be accounted for (Schubert et al., 2012 ; Kim et al., 2015). The Integral Porosity (IP) approach has since then be extended to depth-dependent porosity laws (Özgen et al., 2016a-b). Note that anisotropy can also be incorporated in Single Porosity models by defining anisotropic conservation laws (Viero and Valipour, 2017).
The Multiple Porosity (MP) model (Guinot, 2012) was proposed in order to better account for the preferential flow directions induced by the street network in densely urbanized areas. It was shown to outperform the single porosity model (Guinot, 2012).
Comparing the wave propagation properties of the SP, IP and MP models (Guinot and Delenne, 2014) indicates that the behaviours of the three models are very different under transient conditions. Seeking correct wave propagation properties for the IP formulation led to the design of the Dual Integral Porosity model (Guinot et al., 2017). While based on the same governing assumptions as the IP model, the DIP uses much more accuracte flux formulae, thus allowing accurate wave propagation properties to be obtained. However, the IP and DIP models have been shown recently to exhibit a strong dependence to the computational mesh (Guinot, 2017) and a lack of accuracy in reproducing the preferential flow directions in strongly anisotropic building layouts (Guinot, in press). There is thus still room for model improvement.

The potential of shallow water models with porosity is illustrated by the following application case, taken from Guinot et al. (2017). Figure 1 shows the finite volume mesh used to model the beaching of a levee in the immediate vicinity of a neighbourhood of the Sacramento city (USA). Over 76,500 computational cells are needed to mesh the area shown on Figure 1, left. Figure 2 shows the same area meshed using a shallow water model with porosity, with a total 1065 cells. Figure 3 shows the free surface elevations computed at t = 120s after the hypothetical levee breach. Besides the ability of the porosity model (Figure 3, right) to reproduce the large scale features of the refined flow simulation (Figure 3, left), the porosity model is more than 300 times as fast as the refined flow model.

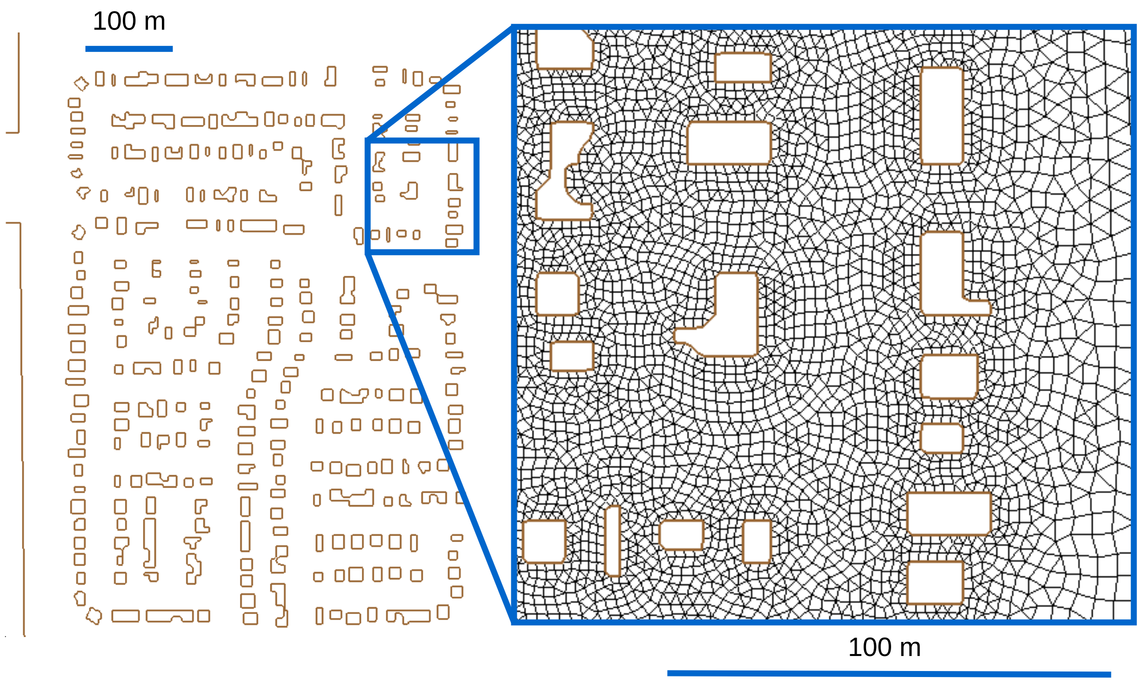

Figure 1. The Sacramento neighbourhood meshed using a classical two-dimensional shallow water model (75450 elements). Reference: Guinot et al. (2017).

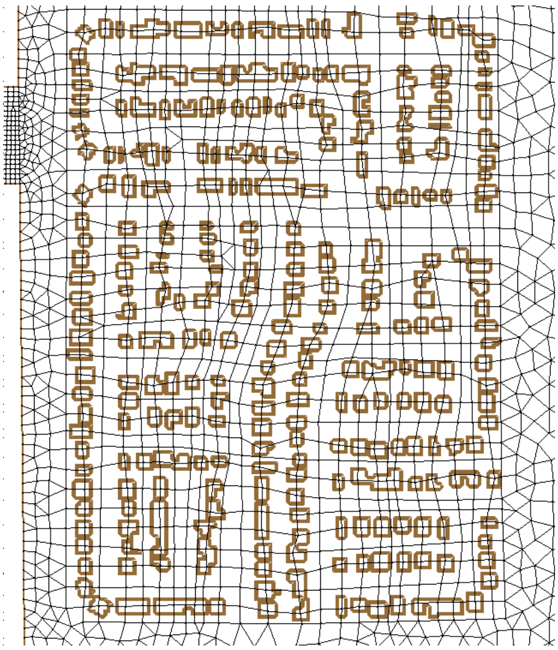

Figure 2. The Sacramento neighbourhood meshed using a shallow water porosity model (1065 elements). Reference: Guinot et al. (2017).

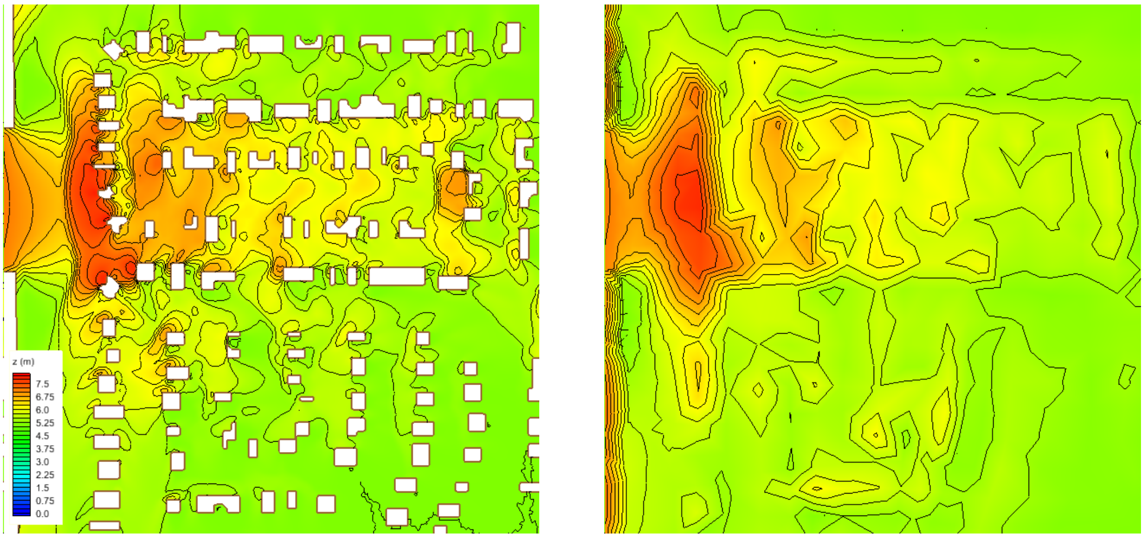

Figure 3. Sacramento neighbourhood, simulation of a levee break. Water depths computed by the refined flow model (left) and the DIP porosity model (right). Reference: Guinot et al. (2017).

The reader interested in the physical and/or computational aspects of shallow water models with porosity may refer to the publications hereafter.

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