How Important Is the Physical Interpretation and the Role of the Model User in Urban Flooding Simulation?

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Abstract. Computational models for flood simulation were consolidated in recent years as a design tool. Due to technological evolution, the use of 2D mathematical models has become more frequent. However, the choice of 2D models is not always accompanied by an actual physical based demand that justifies this process, and often the problem that is solved does not need a 2D approximation or even does not actually configure a 2D solution surface. This study aims to present an alternative modelling in order to bring back the physical interpretation and highlight the modeller role as key elements in the interpretation and representation of the real systems. We used a Quasi-2D flow-cell model that solves 1D equations, constructed in a conceptual and interpretive way, as an alternative to the use of 2D models, showing the possibility of maintaining the same degree of representativeness. The Quasi-2D model was subjected to a test proposed by the British Environmental Agency. The results have demonstrated the importance of the modeller, emphasizing that the knowledge of the physical reality, of the hypotheses and simplifications adopted in the model construction, guarantees an optimized simulation and the quality of the results.

Keywords: Quasi-2D · Urban floods · ModCel

1 Introduction

With the diffusion of 2D models, the demand for information to use and calibrate these models became the main constraint for their application. The Light Detection and Ranging (LiDAR) technology is becoming the usual way to represent terrain details in the modelling process, allowing to refineme the modelling mesh with higher resolution information, but it is more expensive and more difficult to be processed. Moreover Abdullah et al. (2017) compared many LiDAR filtering algorithms and found that none of them is fully reliable in capturing some important urban features. Problems related with 2D models in urban regions are pointed out by Abily et al. (2013) that highlighted

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rapid changes in the flow regime and numerical problems with the drying and flooding of mesh elements modelled throughout the simulation. Almeida et al. (2016) find that small changes in the representation of the urban landscape are not observed in resolutions greater than 1 m. However large basins do not support this refined mesh (Jamieson et al. 2012). The computational cost makes it unfeasible. Leandro et al. (2016) point out that the surface flows in urban areas are highly complex due to the interaction with artificial structures, which makes the application of a 2D model more complex. After confronting problems in calculating flow velocities and suggesting more detailed meshes, Néelz and Pender (2013) affirmed that simple mesh refinement is not a viable solution, since it can make modelling impracticable in computational terms, overcoming the ability to perform multiple simulations, quantify uncertainties, perform risk studies, calibrate models and so on.

By observing trends in the modelling process more comprehensively, Abbott and Vojinovic (2009) point out that currently the application of numerical models undergoes a major change influenced by the way that knowledge is currently produced and used in society. This change, representative of the shift from modernity to post-modernity, or using Bauman's (2001) words from "solid modernity" to "liquid modernity", is marked by the shift from a society of knowledge providers to a society of knowledge consumers. In this context, Abbott and Vojinovic (2009) divided the hydrodynamic numerical models into five generations. The authors highlight that until the 3rd generation there was practically no difference in modelling knowledge between users and developers. However, a relatively large gradient appeared in the 4th generation, and it is even larger in the 5th generation of models, where modelling is developed as a service and offered electronically encapsulated over the internet, what lead to a user that is distant from the modelling process and not really aware of model potentials and limitations. Cunge (2014) pointed out that except for very simple situations, the model user must be aware of basic hypotheses and physical laws that were considered in the software. Only then the user will be able to distinguish coherent modelling results from results completely incompatible with the physical reality of the system.

This article offers a counterpoint to the tendency of indiscriminately move towards more sophisticated models that use more input data but forgets to interpret physical reality. The current facilities tend to be used in a mechanical way, not always demanded by a technical question that could justify this process. In addition, this work seeks to stress the importance of the modeller as a key element in the modelling process, highlighting the physical interpretation and the importance of knowing model hypothesis and simplifications. The novelty of this article falls on demonstrating that a quasi-2d model associated with physical interpretation procedures and supported by simple integrated information can represent a real system with the same fidelity of (and faster than) a complete 2D model using sophisticated terrain information.

This alternative way starts with a detailed preliminary analysis of the system to be modelled, and a clear question to be answered, seeking its comprehension, listing the main points that need to be represented and evaluating the necessary spatial scale for the model to present the answers that are sought. To couple with this approach, we chose an interpretive Quasi-2D model called MODCEL (Miguez et al. 2017), which can represent the flow in several directions in the two-dimensional plane, but which uses widely tested one-dimensional equations. Moreover, this model is completely dependent on physical interpretation. It is important to highlight that MODCEL cannot function by a blind automatic application. In fact, its application has to be preceded by several decisions on how to represent the terrain, the flow paths and the hydraulic behaviour of the modelled element. It rather obliges the modeller to investigate and understand how the real system works. This apparent weakness turns into strength, once this process inevitably leads the user to know more about the problem under investigation.

2 Materials and Methods

2.1 The Flow-Cell Model for Urban Basins - MODCEL

MODCEL, developed by Miguez (2001) represents the urban space through homogeneous compartments, called cells. The concept of flood cells was initially developed by Zanobetti and Lorgeré (1968) and enshrined by Cunge et al. (1980). MODCEL is detailed in Miguez (2017). These cells cover the whole space of the basin forming a flow network, interconnected by one-dimensional equations. MODCEL is also integrated with a hydrological module that performs the rain-flow transformation in each cell, through the rational method. Thus MODCEL can represent the two-dimensional characteristics of the river watershed, but it only uses 1D equations. The model is capable of describing natural and artificial watercourses and detailed elements of the urban fabric (streets, squares, roofs, etc.), the flow in the underground storm drains, and the mutual connections between theses layers, including possible surcharges and overflows. Different hydraulic equations can represent the connections between each two cells, from the classical Saint-Venant dynamic equation to hydraulic links like weirs, orifices, pumps, flap etc. By rendering the flow through 1D equations written for predefined flow paths, the model preserves simplicity and saves computational time, in a quasi-2D approach. In a particular interpretation, because of the superficial and underground vertically linked layers, MODCEL can be seen as a quasi-3D model. On the other hand, the 1D equations are one of the weaknesses of this representation, since they cannot accurately model real extensive 2D flow surfaces, while not considering the cross-influences of flow velocities on the x, y-Cartesian axis.

2.2 The Case Study

A test proposed by the British Environment Agency (Néelz and Pender 2013) was used to evaluate the application of the interpretative model concept. This benchmarking exercise involves 10 test cases and one of the objectives of this research is to provide a set of data against which a model can be evaluated by its developer. Test 8, in particular, was designed to compare urban flood models and is divided into two parts, 8A and 8B. In this paper, we used test 8A as reference. which assumes that the flood arises from two sources: a uniformly distributed rainfall event applied to the modelled area; and a point discharge source occurring over a time base of approximately 15 min, reaching a peak of 5 m^3/s, 35 min after the rainfall event begins.

2.3 Modelling Alternatives

To evaluate the performance of the interpretive modelling proposition, MODCEL was applied in two ways. In the first alternative application, it was applied as a RASTER model, where the study region was divided into a mesh of cells of identical dimensions and linked to each other by the dynamic equation of Saint-Venant, without considering the inertia terms. The Raster-scale cell model was constructed with 43148 square cells of 9 m^2 each. Following the test requirements, a Manning coefficient of 0.02 was set in the paved areas, and of 0.05, in the other areas. This first representation follows the current trend of using a great mesh, mainly focusing on detailing the terrain model. In the second alternative application, the region was divided into a mesh of cells 163 cells (Fig. 1) considering the physical interpretation presented in Fig. 2, recognizing how the flow net functions.

Fig. 1. Cell division for the modelled area in Test 8.

3 Results and Discussion

The Fig. 3 shows the results obtained with MODCEL, respectively for first application – Called "MODCEL – RASTER", and for the second application, called "MODCEL – QUASI-2D", compared with the published results (Néelz and Pender 2013). Time of simulation using MODCEL to obtain these results was 3 days for first application and 3 min and 10 s for second application, and the simulation time step gave answers at each 1 s. In fact, the pro-active and interpretative behaviour of the modeller allowed to reach these results, saving computational time, without losing quality.

	The first step is to represent the possible paths of flow through streets and thalwegs. In the figure these paths are represented by black arrows in the streets and white arrows in urban thalwegs.
	Second, the cell centers are positioned in the preferred paths of water, marking the changes in the flow directions and the encounter of two or more lines of flows. In the example of this figure the cell centers are represented by points.
	The subdivision of the watershed into cells begins with the definition of the physical boundaries of each cell, taking into account the regions of water accumulation and the existing physical barriers. In the end, the cell individualises the pre-established cell centres and respective cell areas (where storage occurs), defining the flow net

Fig. 2. Cell division methodology.

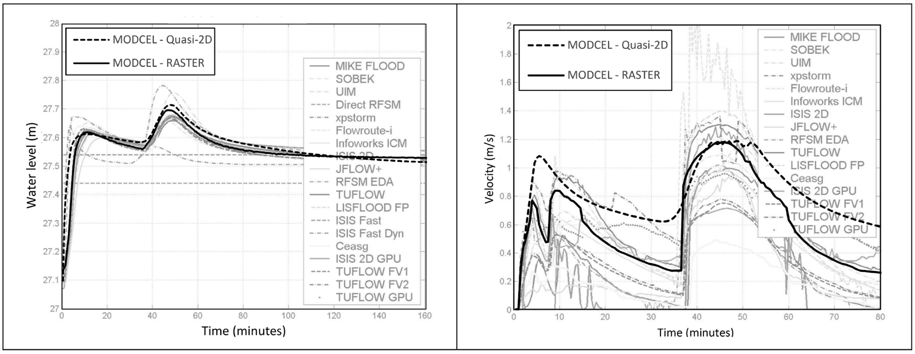

Fig. 3. MODCEL results in points 1 and 6 respectively.

4 Conclusions

MODCEL is a conceptual and physically interpreted based model. Its application imply in an iterative process, where modelling evolves gradually while actual understanding of the system responses to causal factors are gradually understood and key factors are translated into model elements (cells) and links (hydraulic relations). An advantage from this approach refer to less data needs – conventional topography and city maps are sufficient, without any need of a LiDAR survey or similar detailed inputs. Computational processing times are also much lower. Considering the tests conducted in this research, it is possible to conclude that the interpretative approach reached satisfactory results, when compared to other models tested by the British Environmental Agency, revealing the importance of modeller actions. In fact, the final results were obtained with much fewer elements (163 vs. 43148 elements) and much lower computational cost (1350 times lower).

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