Large-scale 1D/2D coupled model for the Barcelona Metropolitan area: development and data-gap filling methods

*Àlex de la Cruz-Coronas [1 2,] *; Beniamino Russo [2] & Daniel Yubero [1]*

[1] *Climate Change & Resilience Unit, AQUATEC (AGBAR Group), Barcelona, Spain*

[2] *FLUMEN Research Institute, Universitat Politècnica de Catalunya, Barcelona, Spain*

** Corresponding author email: alex.cruz@aquatec.es*

Abstract

A large-scale 1D/2D coupled model is being developed for the Barcelona Metropolitan Area. It aims to enhance the urban flood modeling capabilities for the region as a tool to improve preparedness against flash flood risks. The model employs a hybrid approach to runoff routing, integrating both semi-distributed and fully distributed methods to accurately simulate runoff behavior in urbanized environments. Key elements include the representation of drainage systems, particularly the role of grate inlets, which facilitate water exchange between different domains. The model generates flood maps that depict water depth and velocity allowing to quantify the damage on infrastructure and services, including direct and indirect tangible impacts as well as intangible risk for people. A significant challenge addressed in this research is the data gap in sewer network information, as only 25 out of 36 municipalities have available data. To overcome this limitation, a synthetic sewer network generation methodology has been developed, utilizing geographic information and structural parameters to approximate sewer layouts. This innovative data gap filling methodology enhances the possibility to develop 1D/2D coupled models under scarce data conditions. The methodology has been tested with satisfactory results in a municipality of the area of study.

Highlights

- Metropolitan scale 1D/2D coupled model
- Data gap filling methodology for sewer network information

Introduction

Flash floods stand as one of the most damaging natural disasters for infrastructures and human activities and climate change projections indicate they can become more frequent in the future (Kundzewicz et al., 2014; Svetlana et al., 2015). Urban areas, due to their intrinsic characteristics (extensive impervious areas, limited drainage capacity and complex topography), are especially vulnerable to this hazard. In addition, they concentrate a lot of interdependent services and infrastructures that can exacerbate the impacts. Urban flood modelling is key to understand, improve preparedness and mitigate the effects of these events (Henonin et al., 2013). In particular, 1D/2D coupled models are an advanced approach to assess urban floods. However, the large data requirements to characterize the 1D domain (including all the geometric, topologic and operational characteristics of a sewer network) limits their development (Montalvo et al., 2024). This abstract presents the development of a 1D/2D coupled model of the Metropolitan Area of Barcelona (AMB). It focuses on two main aspects: (1) the data collection and model setup process, and (2) a synthetic sewer network (SSN) generation process developed to fill existing data gaps.

Case study

The AMB is the larger conurbation in the western Mediterranean. It consists of 36 municipalities and is home to 3.3 million inhabitants with an extension of 636 km^2. It combines densely populated cities and industrial areas in the coastal and deltaic plains which are surrounded by mountainous terrain. The yearly average rainfall is around 600 mm, but often a 50 % of it occurs during two or three single events (Monjo et al., 2023). The recent floods that affected the neighbouring region of Valencia in November of 2024 highlight the vulnerability of a similar region to this hazard (Camara de Comercio de Valencia, 2024).

Methodology

Metropolitan 1D/2D model

A 1D/2D coupled model is being developed for the presented case study with the commercial modelling software Infoworks Ultimate version 2025.1. The hydraulic domain of approximately 636 km2 results in a non-structured mesh of 7.2 million elements in the range of 25 to 100 m^2. Infiltration and roughness are characterized with Horton's equation and Manning's coefficients respectively and their parameters are defined according to the different land uses found in the areas of study. The runoff routing is modelled following a hybrid approach that accurately represents the actual behaviour of water in urbanized areas. The runoff generated in building areas is directly routed to the sewer network (semi-distributed approach), while streets and non-urbanized areas are discretised in a mesh (fully distributed approach) to compute the overland flow of the runoff (see Figure 1a). The model includes the presence of grate inlets as the key element to allow the exchange of water between both domains. Their drainage capacity is expressed as inlet hydraulic efficiency, which corresponds to the ratio between intercepted and approaching flow rates. Figure 1b illustrates the main elements included in the model.

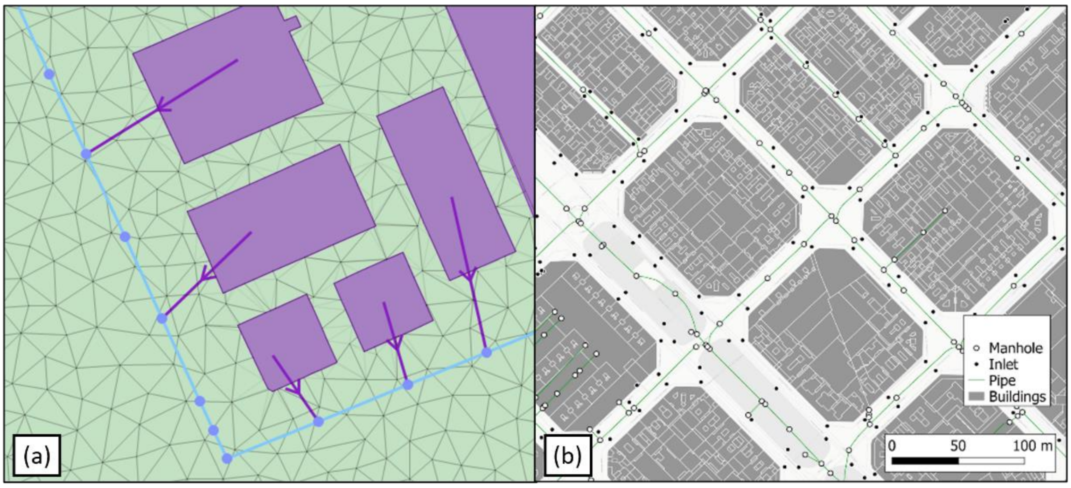

Figure 1. 1D/2D model setup: (a) hybrid model structure depicting the 2D mesh elements (green triangles) and the built areas (purple polygons) draining directly to the sewer network (blue elements); and (b) detailed representation of the drainage network and its main elements

The main output of the model are flood maps showing water depth and velocity in the affected areas. These results are coupled with sectoral impact models that support a comprehensive assessment of the tangible direct and indirect effects on services and critical assets of the AMB (e.g. properties, transportation, electricity distribution network, waste management services, wastewater treatment plants). Furthermore, intangible impacts associated with risk for pedestrians and vehicles are be considered. Importantly, the specific vulnerability and exposure of risk receptors are considered following the risk assessment approach proposed in the IPCC's AR6.

As mentioned, the AMB consists of 36 municipalities each one owning its sewer system. Additionally, the metropolitan authority owns a "supra municipal" or "metropolitan" network that collects wastewater from all municipal networks and brings it to one of the 7 wastewater treatments plants in the region. This reality translates into a puzzle of ownerships and data managers that has difficulted the data collection process. After collecting this information, the model development involves a data processing to fit the model requirements and the linkage between the municipal and metropolitan networks. However, out of the 36 municipalities sewer network information is only available for 25 cases. This means a critical data limitation for 11 of them, representing a 196 km^2 and 0.35 million people of the AMB.

Synthetic sewer networks

To overcome this data gap, a methodology has been developed to generate synthetic sewer networks at a municipal level. It consists of a python process that can approximate the layout and dimensions of a sewer network based on geographic information, usually available in open-source repositories, and a set of parameters to define the structural characteristics of the sewer elements.

In more detail, the SSN generation process involves several key steps. Initially, input data is pre-processed, including the hydraulic domain, Digital Terrain Model, street layout, building locations, water courses, and network element characteristics. The sewer network layout is then defined based on the street map, with manholes placed at junctions and regular intervals and other algorithms based on similarity criteria among the different networks of the analysed region. Outfalls are positioned at the lower end of the model domain. The Digital Terrain Model undergoes modifications to suit hydrologic modelling requirements. Network dimensioning is performed by assessing preferential water paths, assigning order numbers to streams and pipes, and determining pipe diameters and depths accordingly. Finally, a routine identifies and corrects potential errors in the generated SSN, ensuring consistency and accuracy in the final network. This methodology has been tested in the municipality of Sant Feliu the Llobregat (within AMB). Two 1D/2D coupled models were developed in parallel. One was based on the actual sewer network (ASN) information obtained from the last local drainage masterplan, while the second included a SSN generated with the mentioned methodology. A total of four rainfall scenarios were simulated in both models, corresponding to 1-hour synthetic rain events with return periods of 1 (T1), 2 (T2), 5 (T5) and 10 years (T10). The results of both models have been compared considering the one based on the actual sewer as the benchmark to evaluate the validity of the synthetic one.

Results and discussion

The results and comparatives presented demonstrate the validity of the proposed methodology to conduct approximated urban flood assessments when sewer network data is not available. As reflected in Figure 2, the SSN presents a similar layout to the actual drainage network in terms of extent and pipes connexions. In addition, there is a good coincidence between the location of primary networks, which correspond to pipes with a width of 2 m or more. This aspect is crucial to ensure that results based on the SSN are reliable. However, the methodology fails to represent the existence of parallel pipes and the location of conduits under non urbanized areas. The maximum flood maps under each simulation scenario have been contrasted with different performance indices that allowed to do a cell-per-cell quantification of the accuracy of the flooded areas. These indices are: Hit Rate, False Alarm Ratio and Critical Success Index (CSI) (see Table 1). In general terms, the SSN is capable to adequately reproduce the benchmark results. The highest accuracy is observed for the higher return period simulations, while in lower ones the SSN tends to overestimate the extent of the flooded area.

Table 1. Performance indicators for the scenarios run in the SSN and the ASN models

Performance indicator	Rain event			
	T1	**T2**	**T5**	**T10**
Hit rate	0.76	0.86	0.86	0.90
False alarm rate	0.11	0.11	0.14	0.09
Critical Success Index	0.69	0.77	0.75	0.82

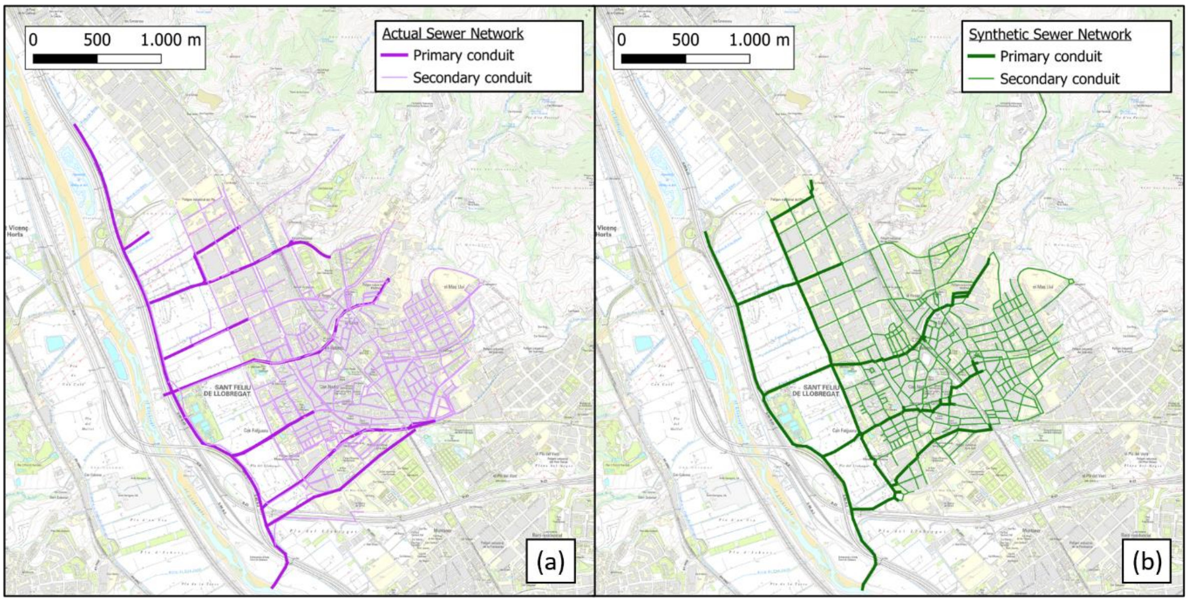

Figure 2. Primary and secondary pipe network of the (a) actual and (b) synthetic sewer network

Conclusions and future work

The main conclusions of the presented work are as follows: (1) 1D/2D coupled modes are a valid approach to assess flood risk of large metropolitan areas; (2) the extensive data requirements of this approach limit its applicability; and (3) the presented SSN generation methodology is a valid data gap filling tool in this context. Future work will be focused on finishing the AMB urban flood model using the mentioned methodology to fill the gaps of sewer network data.

Acknowledgement

This work is developed under the Horizon Europe project ICARIA: Improving Climate Resilience of Critical Assets www.icaria-project.eu (Grant agreement number 101093806).

References

Camara de Comercio de Valencia. (2024). *Informe daño ocasionados por la DANA en la industria de la zona afectada* (p. 30). Camara de Comercio de Valencia.

Henonin, J., Russo, B., Mark, O., & Gourbesville, P. (2013). Real-time urban flood forecasting and modelling—A state of the art. *Journal of Hydroinformatics*, *15*(3), 717-736.

Kundzewicz, Z. W., Kanae, S., Seneviratne, S. I., Handmer, J., Nicholls, N., Peduzzi, P., Mechler, R., Bouwer, L. M., Arnell, N., Mach, K., Muir-Wood, R., Brakenridge, G. R., Kron, W., Benito, G., Honda, Y., Takahashi, K., & Sherstyukov, B. (2014). Flood risk and climate change: Global and regional perspectives. *Hydrological Sciences Journal*, *59*(1), 1-28.

Monjo, R., Locatelli, L., Milligan, | John, Torres, | Luis, Velasco, | Marc, Gait, E., Ortoles, J. P., Redolat, D., Russo, | Beniamino, & Ribalaygua, J. (2023). *Estimation of future extreme rainfall in Barcelona (Spain) under monofractal hypothesis*.

Montalvo, C., Reyes-Silva, J. D., Sañudo, E., Cea, L., & Puertas, J. (2024). Urban pluvial flood modelling in the absence of sewer drainage network data: A physics-based approach. *Journal of Hydrology*, *634*, 131043.

Russo, B., Sunyer, D., Velasco, M., & Djordjević, S. (2015). Analysis of extreme flooding events through a calibrated 1D/2D coupled model: The case of Barcelona (Spain). *Journal of Hydroinformatics*, *17*(3), 473-491.

Russo, B., Valentín, M. G., & Tellez-Álvarez, J. (2021). The Relevance of Grated Inlets within Surface Drainage Systems in the Field of Urban Flood Resilience. A Review of Several Experimental and Numerical Simulation Approaches. *Sustainability*, *13*(13), 7189.

Svetlana, D., Radovan, D., & Ján, D. (2015). The Economic Impact of Floods and their Importance in Different Regions of the World with Emphasis on Europe. *Procedia Economics and Finance*, *34*, 649-655.