SUPPLEMENTARY MATERIAL

A unified framework for the assessment of multiple source urban flash flood hazard: the case study of Monza, Italy.

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ARTICLE HISTORY
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1. Model Validation Based on Historical Data

This document is devoted to the description of the validation process of the unified UFF model of the city of Monza. This task is carried out by applying the model to two different historical events occurred in Monza, related to the overflows from the UDS and the river Lambro, respectively.

1.1. *UDS Insufficiency*

The validation of the FLO-2D-EPASWMM integration is performed by simulating a recent intense rain event occurred over Monza, in 2019. The input to the model is the total rainfall curve recorded in the western area of Monza (Figure 1). Since no flood map is available for UDS insufficiency events in Monza, validation is performed by considering the reported interventions of the Civil Protection agency for the 2019 event. The flood map for the simulated event and the Civil Protection interventions are depicted in Figure 2. Details are also reported in Figures 3 and 4. In this case, validation is difficult since the simulated flood map spreads over a wide area. Still, note that none of the interventions falls in an area that is free from simulated inundations. In addition, the model seems to have captured some important areas of inundations, as reported in in Figures 3 and 4. Finally, the absence of Civil Protection interventions in the eastern area of the city is motivated by the fact that the rainfall was not as intense as in the western part of the city. Due to the lack of more detailed data, a uniform rainfall was instead simulated. Note that this problem can sometimes be faced, as suggested in (Zheng et al. 2018), by means of crowdsourcing methods. Still, due to the lack of flood maps allowing for a detailed comparison, this is considered as outside the scope of this work.

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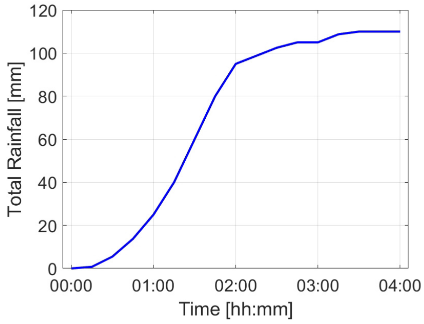

Figure 1. Total rainfall associated to the 2019 rain event.

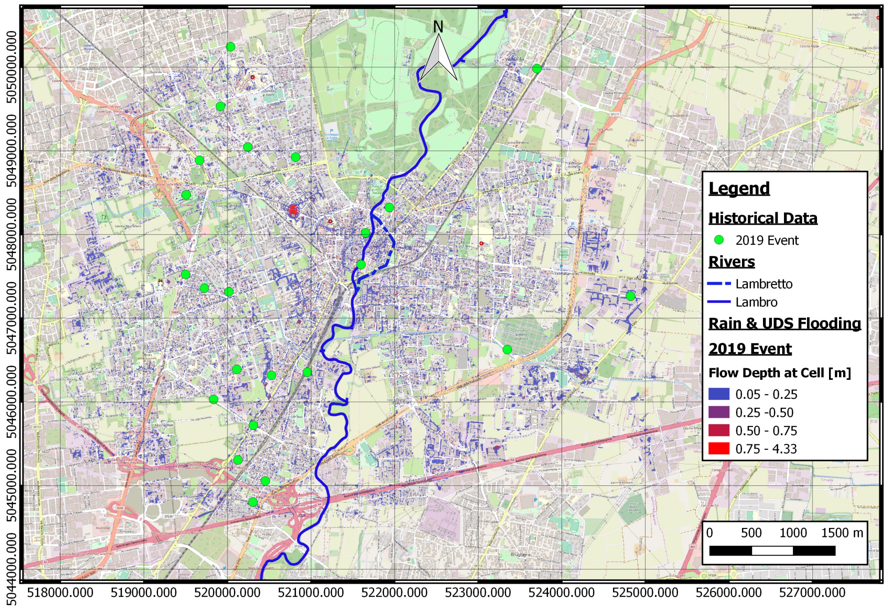

Figure 2. Maximum flow depth map associated with UDS insufficiency for the 2019 rain event and reported Civil Protection intervention.

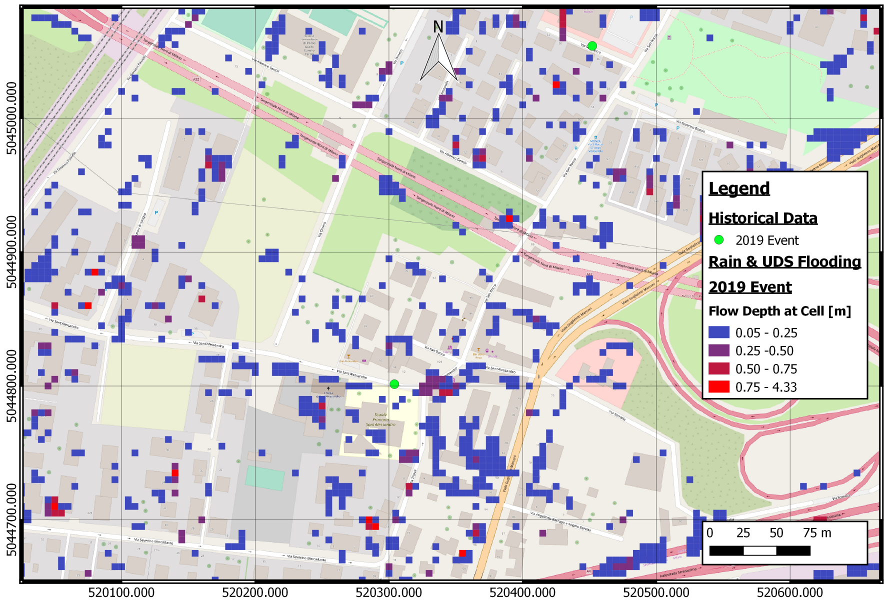

Figure 3. Detail of the maximum flow depth map associated with UDS insufficiency for the 2019 rain event and reported Civil Protection intervention.

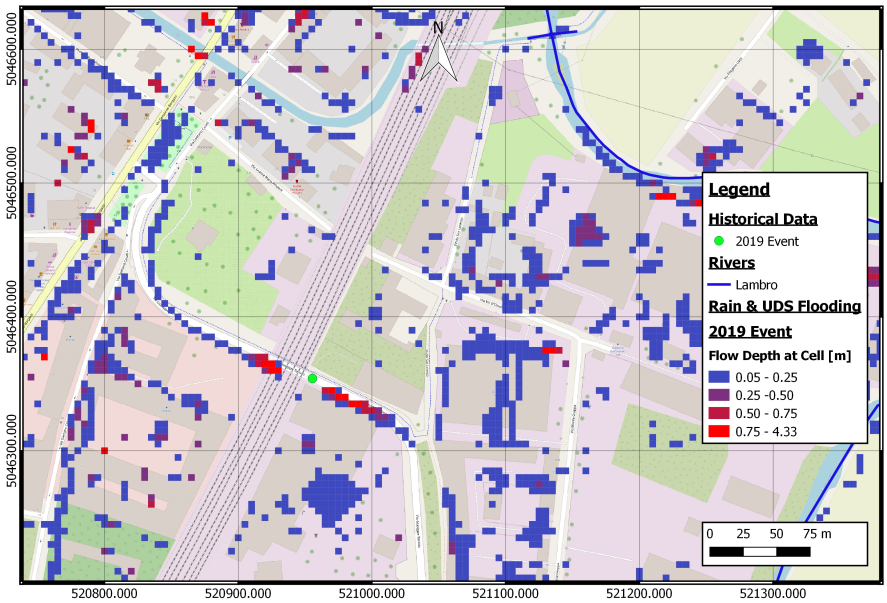

Figure 4. Detail of the maximum flow depth map associated with UDS insufficiency for the 2019 rain event and reported Civil Protection intervention.

1.2. *River Lambro*

As far as inundations of the river Lambro are concerned, the historical data available for model validation are related to an event occurred in 2002. In particular, the input to the model is represented by the hydrograph of the river Lambro at the entrance of Monza (Figure 5) reconstructed for this event on the basis of the recorded peak

Table 1. Metrics adopted for model validation.

Metric	Value
True Positive Rate	0.625
False Positive Rate	0.03
True Negative Rate	0.970
False Negative Rate	0.375

water discharge recorded during the event. The simulated area of inundation is then compared to the flood maps associated with overflows from Lambro and Lambretto related to the 2002 event. A more detailed comparison was not possible due to the lack of historical data. Figure 6 depicts the comparison of the real and simulated event outcome, and shows good accordance between the two, with a slight overestimation of the inundated area downstream the Lambro-Lambretto junction, and a slight underestimation in the city center. To quantitatively asses the performances of the modelling strategy, the following metrics are introduced:

- *True Positive (TP)*: flooded area correctly identified by the simulation as flooded area.
- *False Positive (FP)*: non-flooded area identified by the simulation as flooded area.
- *True Negative (TN)*: non-flooded area correctly identified by the simulation as non-flooded area.
- *False Negative (FN)*: flooded area identified by the simulation as non-flooded area.

Finally, let

$$True\ Positive\ Rate\ TPR = \frac{TP}{TP + FN} \quad (1)$$

$$False\ Positive\ Rate\ FPR = \frac{FP}{FP + TN} \quad (2)$$

$$True\ Negative\ Rate\ TNR = \frac{TN}{FP + TN} \quad (3)$$

$$False\ Negative\ Rate\ FNR = \frac{FN}{TP + FN} \quad (4)$$

The values of the metrics are reported in Table 1. Note that the TNR shows a very high value, while the FPR shows a very low value. This means that the model correctly reproduces non-flooded areas. TPR assume and FNR assume reasonable value, but still not very close to 1 and 0, repsectively: some further discussion is therefore required, since the model seems to undrestimate the flooded area. When considering the map reported in Figure 6, it is apparent that there are two main areas where the model fails to reproduce flooded areas: one in the northern part of the town, and a second, smaller one, in the city centre. As far as the northern area is concerned, this is mainly occupied by a wood, with almost no exposed value. As far as the city centre is concerned, the citizens and the Civil Protection of Monza confirm that flooding in this area occured as a consequence of a wall collapse which can not be captured by the model. Finally, the hydrograph used as input to the model was not actually registered during the event but was reconstructed based on the peak flow measured during the event and on the study of ADBPO (Berselli 2019), thus some uncertainty could be ascribed to the hydrograph. For these reasons, the model can be considered sufficiently reliable in the region of interest.

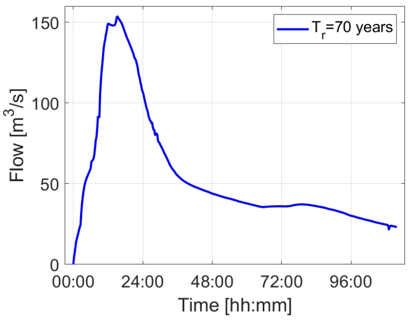

Figure 5. Hydrograph of the river Lambro at the entrance of Monza for $Tr = 70$ years, corresponding to the event occurred in 2002.

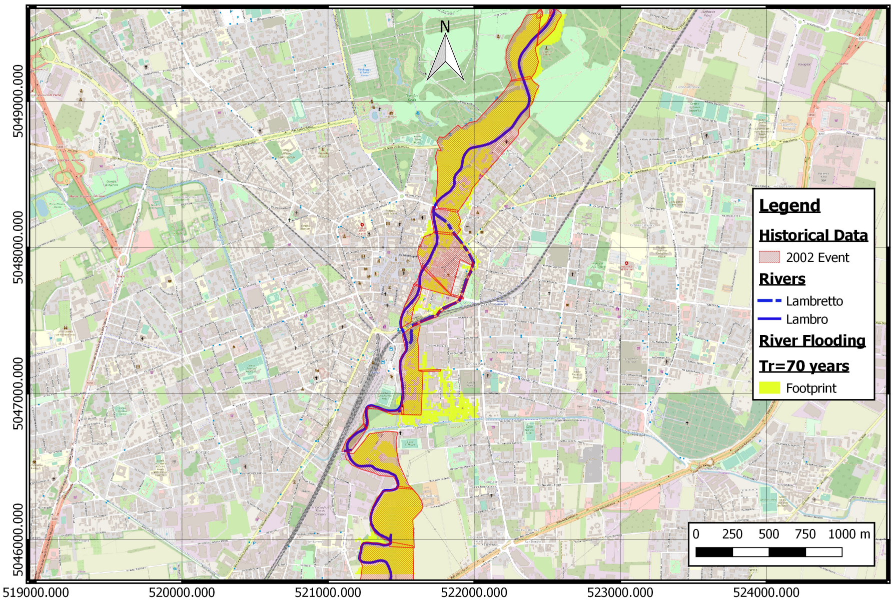

Figure 6. Flood map associated with overflows from Lambro and Lambretto with return periods $Tr = 70 years$, corresponding to the event occurred in 2002. The simulated flooding area is reported in yellow, the flooding area from historical data is reported in red.

References

Berselli, M. 2019. "Autorità di Bacino Distrettuale del Fiume Po Official Website." .

Zheng, F., R. Tao, H. R. Maier, D. See, L.and Savic, T. Zhang, Q. Chen, T. H. Assumpção, P. Yang, B. Heidari, et al. 2018. "Crowdsourcing methods for data collection in geophysics: state of the art, issues, and future directions." *Reviews of Geophysics* 56 (4): 698–740.