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MODELLING OF PLUVIAL FLOODING CONSIDERING STORMWATER INLETS AND PERMEABLE PAVEMENTS

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KEY POINTS

- *Pluvial flooding is modelled using the HEC-RAS software to simulate different rainfall events, stormwater inlet efficiency and permeable pavement scenarios.*
- *Stormwater inlets were surveyed over the study area, evaluating their maintenance level and assigning their head-flow relationship based on geometrical characteristics.*
- *Pluvial flooding is shown to derive mostly from the insufficient capacity of the stormwater drainage network, and the permeable pavements are shown to produce significant improvement.*

1 INTRODUCTION

Pluvial flooding in the urban environment occurs when rainfall intensity surpasses the capacity of the drainage systems to effectively manage surface runoff. It is a growing concern in many urban areas due to the increasing impermeabilization of soil and the ageing of the drainage infrastructure. As natural surfaces are progressively replaced with impermeable ones, existing drainage systems must handle an increasingly larger volume of precipitation, even though they were originally designed to meet substantially different requirements. Additionally, underground drainage systems may become obstructed or damaged, while drainage inlets are susceptible to partial or complete blockage due to the accumulation of debris caused by both natural factors (e.g., leaves fall) and anthropogenic activities (*Palla et al.* 2018).

Numerical modelling of pluvial flooding scenarios proved to be an effective approach in the planning, design, and analysis of stormwater drainage systems within urban areas (*Aronica & Lanza* 2005; *Bulti & Abebe* 2020). In the present work, a two-dimensional overland flow model is implemented in HEC-RAS (a modelling tool with high computational capabilities and a flexible data structure) to evaluate the effect of surface drainage. Although stormwater inlets are not explicitly available in the model, HEC-RAS includes special features that allow simulating their hydraulic behaviour using the pumping station tool. Inlets in the study area are simulated by considering their respective positions, size, and maintenance conditions. The model also simulates the presence of permeable pavements, here introduced as a form of mitigation to reduce run-off (Cauteruccio et al., 2024). The model does not simulate the underground drainage system, just removing rainwater from the domain once it enters any stormwater inlet.

The impact of different rainfall events, inlet conditions and permeable surface scenarios on the occurrence of pluvial flooding is evaluated for the case study of the Sampierdarena district of Genova, which recently demonstrated a high susceptibility to pluvial flooding (see e.g., Figure 1a).

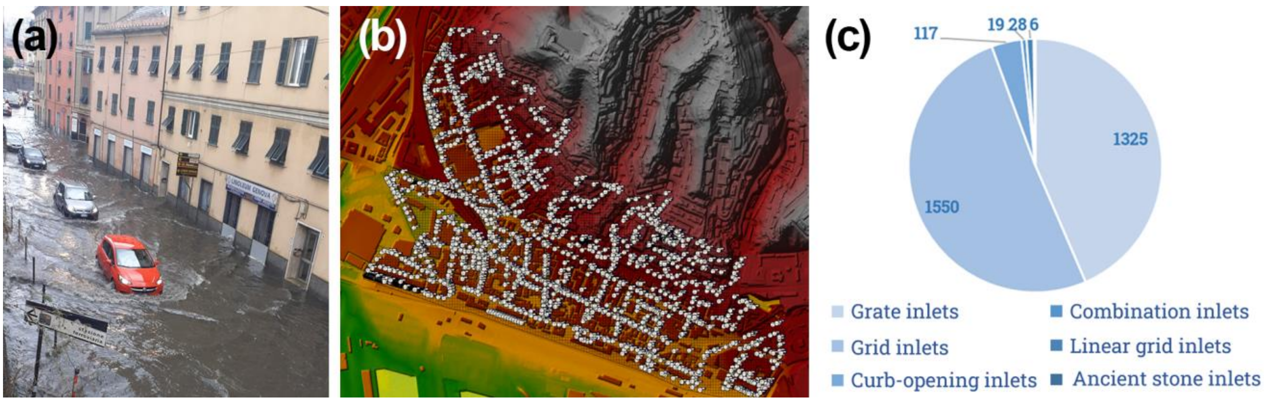

Figure 1. (a) Pluvial flooding event of Sept. 24th, 2022, in the Sampierdarena district of Genova (photo from genova24.it). (b) Spatial distribution of the 3045 stormwater inlets surveyed within the study area. (c) Distribution of different types of stormwater inlets as identified during the survey operations.

2 METHODOLOGY

Spatial information is provided by a high resolution (1m) Digital Terrain Model (DTM), where sinkholes and depressions were removed, and buildings added using a GIS software.

2.1 Stormwater inlets survey

The detailed survey of the stormwater inlets within the study area was carried out within the framework of the RUN project (*Cauteruccio et al.* 2023). For each stormwater inlet, the type, geometry, size, position (coordinates) and degree of observed obstruction were collected. The total number of inlets surveyed in study area is 3045 and their spatial distribution is shown in Figure 1b. The data collection is quite comprehensive, except for a few small size areas, which could not be accessed during survey operations.

For the calculation of head-flow relationship, seven different classes of inlets were defined according to their type and geometry. Most of the surveyed drains are of the "spout" and "grate" types, with only 170 inlets (5.58%) deviating from these two categories. The category distribution is shown in Figure 1c. As for the maintenance conditions, about 83% of the detected inlets are completely free of obstructions, 9% are partially obstructed, while 8% are totally obstructed and do not contribute to the overall surface drainage.

2.2 Permeable pavements

In the simulation, sidewalks and traffic island pavements (initially assumed as impervious) are replaced with permeable pavements. The associated hydraulic response– described in Cauteruccio et al. (2024) – cannot be directly modelled in HEC-RAS and is therefore computed externally. The precipitation occurring over such areas (clustered in suitable blocks) is first omitted from the calculation, ensuring that they do not directly contribute to run-off. Using an external code, both sub-surface run-off and the infiltration amount are computed for each block under the same rainfall scenarios. Then, the sub-surface flow that contributes to the street run-off, is introduced in HEC-RAS in the form of an inflow hydrograph, that is consistent with the rainfall scenario and is positioned at the block boundary (see Figure 2a). This allows modelling both the detention effect and the run-off reduction (function of the infiltration coefficient r) obtained by introducing the permeable surfaces.

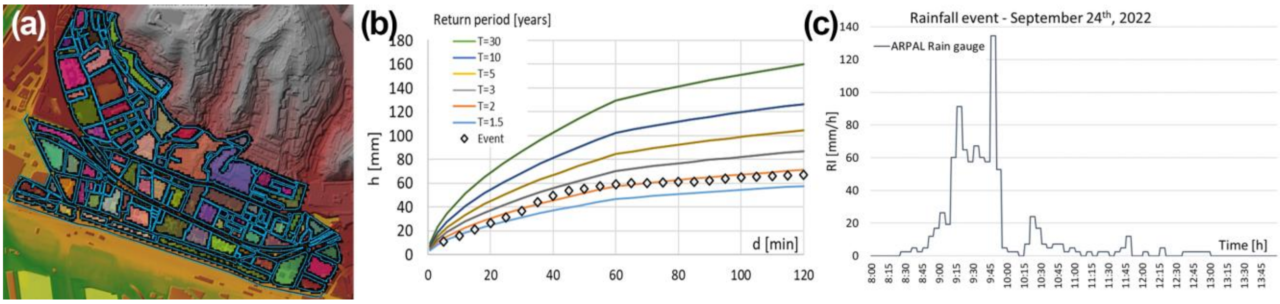

Figure 2. (a) Blocks of permeable pavements obtained by aggregating sidewalks and traffic islands using a GIS software. (b) DDF curves obtained from the 1-min rainfall dataset available from the DICCA meteorological station. (c) Sample precipitation event at a 5-min resolution measured by the ARPAL rain gauged located within the study area.

2.3 HEC-RAS implementation

Stormwater inlets are modelled in the HEC-RAS software as pumping stations, controlled by a set of operating rules that reproduce their head-flow relationship (*ASCE* 1997) as a function of the water surface elevation over their inlet position. Stormwater inlets and permeable pavement blocks were inserted in the domain by modifying the HEC-RAS files with an external code.

2.4 Precipitation scenarios

Rainfall scenarios include one historical event and four synthetic events associated with return periods of 2, 5, 10 and 30 years. Synthetic scenarios were derived using the Chicago method (Keifer & Chu 1957) from the Depth Duration Frequency (DDF) curves obtained from the 1-minute rainfall time series of the Villa Cambiaso meteorological station (see Figure 2b). For each return period a Chicago hyetograph was constructed with a duration of 1 h and a time resolution of 5 minutes. The historical scenario reproduces the event observed on the morning of September 24th, 2022, which gave rise to a significant pluvial flooding event, localised mainly in Piazza Nicolò Montano (see e.g. Figure 1a). Rainfall data was obtained – at a 5-minute resolution – from a rain gauge located within the study area (see Figure 2c). By comparing this event with the DDF curves the event can be associated with a return period of about two years (see black diamonds in Figure 2b). Rainfall is assumed as uniform in space due to the limited extent of the study area while the urban surfaces are assumed impermeable. Precipitation falling on roofs was assumed to be directly diverted to the drainage network (downspouts are connected to the stormwater pipes) without producing any direct surface run-off.

3 SIMULATION RESULTS

Results refer to stormwater inlets in operating conditions as observed during the survey operations.

3.1 Simulation results for the Sept. 24th 2022 event

Simulation results for both the measured precipitation event of Sept. 24th, 2022, and the synthetic Chicago hyetograph with a return period of 2 years show limited flooding in the area of Piazza Nicolò Montano. Meanwhile, publicly available images taken from citizens during the event (se e.g. Figure 1a) show significantly more intense flooding than model results. This fact holds true even considering partially clogged inlets while comparable levels are achieved only in the case of fully clogged inlets.

3.2 Blocks modelling approximation

To evaluate the effect of modelling permeable pavements externally, comparative simulations were carried out. Impermeable blocks (r = 0) results are compared with a second model - without blocks - representing the same impermeable state of the domain. Maps of the flow depth are shown in Figure 3a and Figure 3b for the first and second model, respectively. Both were obtained using a synthetic hydrograph with a return period of 10 years. Figure 3c compares the evolution of the flood water volume present in the domain for the two models.

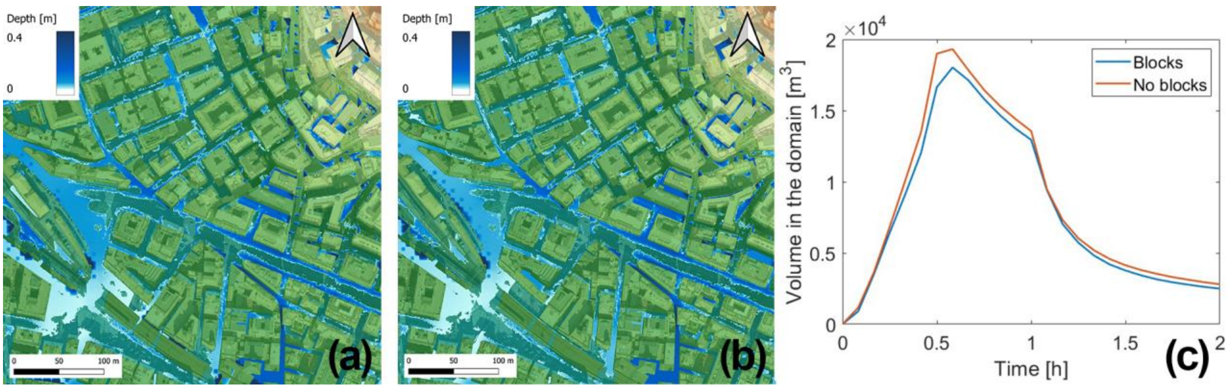

Figure 3. (a) Flow depth due to pluvial flooding in the area surrounding Piazza Montano when using impermeable blocks. (b) Flow depth due to pluvial flooding in the same area when running the model without blocks. (c) Temporal evolution of the total flooded volume in the domain when a Chicago synthetic hyetograph with a return period of 10 years is simulated.

The two models show almost identical flooding extents, with minimal differences, considering that the outflow from the blocks is uniformly distributed around their external perimeter. In terms of flooded volumes, the two models are quite close, with the model using blocks showing a slight underestimation of the peak. This confirms that using blocks to model pluvial flooding in the area is an acceptable approximation.

3.3 Permeable pavements results

Different values of the infiltration coefficient were tested for the blocks, corresponding to different soil type and conditions below the permeable pavement. Flooding maps are shown for the three cases considered in Figure 4a, 4b and 4c, assuming r = 0.25, 0.5 and 0.75, respectively.

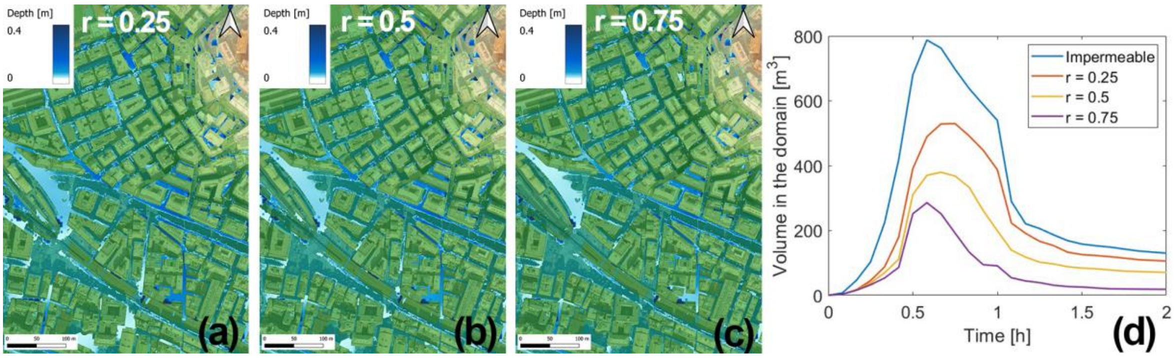

Figure 4. Simulated pluvial flooding using various permeable pavement scenarios with (a) r = 0.25, (b) r = 0.5 and (c) r = 0.75 and (d) comparison of the temporal evolution of the flooded volumes in a sample portion of the domain close to Piazza Montano.

As expected, the presence of permeable pavements reduces both the extension of the flooded area and the maximum water depth reached during the event. The improvement is visualised in Figure 4d in terms of the evolution in time of the cumulated flood water volume within a 100 m radius centred in Piazza Nicolò Montano. The detention effect of permeable pavements is also visible in the form of a time shift of the graph when permeable pavements are used.

4 CONCLUSIONS

The implemented HEC-RAS model is shown to be capable of modelling pluvial flooding in the urban environment considering both the presence of stormwater inlets and permeable pavements. From simulation results it is concluded that the Sept 24th, 2022, event was mostly due to an insufficient capacity of the stormwater drainage network. It is also shown that, even considering a limited infiltration capacity, the implementation of permeable pavements produces a significant mitigation of the pluvial flooding event.

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