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The hydraulic response of urban drainage networks equipped with green roofs

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Abstract
The rapid growth of urbanisation profoundly affects the urban hydrological cycle by augmenting stormwater runoff, reducing surface roughness, and increasing impermeable surfaces. In these circumstances, sewer networks may become overwhelmed, resulting in pressurised flows and backwater effects occurrences in the sewer conduits. Sustainable Drainage Systems (SuDSs) can represent a valid strategy to mitigate these effects. In this regard, the present study investigates the impact of green roof installations on the reduction of pressurised flow conditions within sewer networks. Numerical simulations were performed by simulating the flow behaviour of an urban drainage network with a basic topology and serving urban subcatchments with an increasing percentage of green roof extension. At this aim, the software EPA SWMM 5.2 was used. Preliminary findings show that green roofs can improve the hydraulic functioning of urban drainage systems by reducing filling ratios, mitigating pressurisation risks and the flood occurrence.

Highlights
- The effect of green roofs on the pressurised conditions in drainage networks is analysed.
- Non-dimensional indexes are defined to evaluate the urban drainage functioning.
- Green roofs have a significant effect on the reduction of the network node filling ratio.

Introduction
Urban stormwater management holds considerable ecological, economic, and social significance. The growing urbanisation and the climate change are the main factors contributing to excessive runoff that conventional stormwater management systems cannot effectively manage. Urbanisation causes significant changes to the natural environment, putting additional strain on existing stormwater management systems (Chen et al., 2016). In this regard, urbanisation has a significant impact on the hydrologic cycle as a result of:
- the proliferation of impermeable surfaces, such as pavements and structures, which can increase surface runoff (Ertan and Çelik, 2021);
- the reduction of surface roughness due to decreased vegetation and surface levelling, which may accelerate the hydrologic response of the urban catchment (Fletcher et al., 2013);
- and the installation of new drainage pipelines, which can accelerate pipeline confluence (Miller et al., 2014).

In this context, it's frequent that existing drainage systems get flooded by the extra volume and velocity of runoff created by impermeable surfaces and may experience pressurised flow conditions. The occurrence of pressurised phenomena can cause critical consequences such as backflows onto streets, flash flooding, stormwater geysering, and manhole covers removal.

Sustainable Drainage Systems (SuDSs) are an innovative approach to urban stormwater management as they aim to return the developed catchment to the pre-development hydrological conditions (i.e., to replicate natural water cycles) (Van Roon, 2007; Damodaram et al., 2010). Specific examples of stormwater controls used as SuDSs include green roofs, swales, permeable pavements and infiltration basins. These measures reduce extra runoff caused by urbanisation within the catchment and alleviate the hydraulic load on the sewer networks, thereby improving their hydraulic performance.
The study aims to assess the effect of the green roof installation in enhancing the hydraulic behaviour of the sewer pipes of a UDN and, at the limit, in preventing the transition from free surface to pressurised flow in sewer pipes. To this end, an idealised drainage system with a dendritic topology (Vasconcelos et al., 2024) was analysed. Numerical simulations were carried out by using the EPA SWMM 5.2 software (Rossman and Simon, 2022), by assuming that the urban subcatchments connected to the inspected drainage network presented an increasing percentage of green roof occupation.
Preliminary findings suggest that green roof installation can help to reduce the occurrence of pressurisation events in stormwater networks. Simulation results highlight the beneficial effect of green roofs in reducing the manhole filling ratios and, consequently, in mitigating the risk of urban flooding.

Methodology

Case study description

The case study replicated the layout of the dendritic drainage system analysed by Vasconcelos et al. (2024). This system consists of 121 nodes (120 junctions and one outlet node) and 120 circular conduits, all of them with a diameter *D* of 1.0 m and a length *L* of 100 m. As illustrated in Figure 1, each junction is linked to a subcatchment with a total area of 1.00 ha. The simulated SWMM subcatchments are completely covered by impervious surfaces and the roofs occupy 50% of the total area.

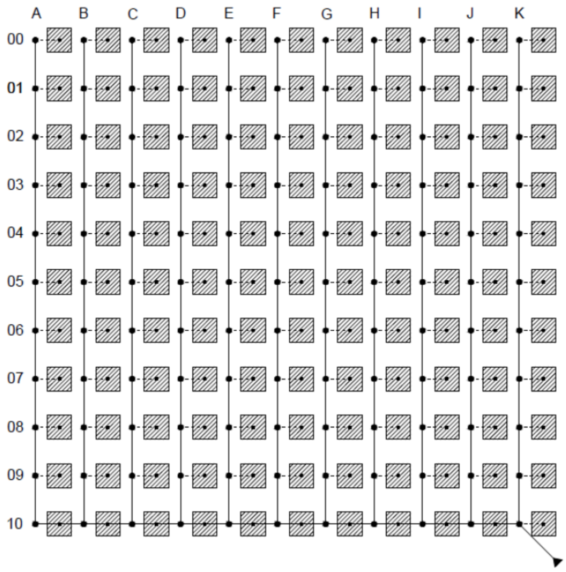

Figure 1. SWMM schematisation of the idealised urban drainage system

The current study considers the implementation of an extensive green roof with a total thickness of 185 mm. The input parameters required by SWMM LID module for the green roof characterisation were based on the research of Orsi et al. (2025).

Experimental program

In this study, different geometrical urban drainage system characteristics were examined. Specifically, the conduit roughness n values were set equal to 0.010 $sm^{-1/3}$ and 0.016 $sm^{-1/3}$, which correspond to typical roughness coefficients for plastic and concrete pipes (ASCE, 1982), respectively. Slope values S_0 were set equal to 0.25%, 0.50% and 1.00%.

Different rainfall events with varying intensity and depth were considered. In particular, the rainfall was modelled by applying the Chicago hyetograph, based on the parameters of the Intensity-Duration-Frequency relationship. In detail, the rainfall duration was assumed to be equal to the estimated time of concentration of the analysed drainage system and the time-to-peak ratio was 0.5. Moreover, increasing percentages of green roof extensions were supposed through the definition of six values of Effective Impervious Area reduction (EIA_{red}), ranging from 0% to 50%. Specifically, EIA_{red} was calculated as A_{GR}/A_{tot}, where A_{GR} denotes the area of the catchment occupied by Green Roofs (GR) and A_{tot} represents the area of the subcatchment (1 ha).

Performance indexes

Two non-dimensional indexes were introduced to evaluate the effect of GR implementation on urban drainage system and assess the GR performance quantitatively. These indexes were computed by analysing the maximum values recorded in the sewer system during the tested conditions, resulting in an envelope of the results.

An average non-dimensional filling ratio h^* for the j-th junction node was defined as follow:

$$h^* = \frac{1}{N}\sum_{j=1}^{N}\frac{h_{max,j}}{D} \tag{1}$$

where, $h_{max,\,j}$ [m] is the maximum head in the j-th junction node and N is the total number of junctions in the drainage network case study.

The shape factor q, as a function of the cross-sectional conduit parameters, was calculated as follow:

$$q = \frac{Q_{out}^{max}}{\sqrt{S_0}}n \tag{2}$$

where, Q_{out}^{max} [m^3/s] is the outflow peak.

Results and discussion

Findings show that the GR installation had a positive effect on the junction filling ratios (*h/D*) within the analysed drainage system by consequently reducing the stormwater runoff. In this regard, Figure 2 illustrates the distribution of the maximum filling ratio through the sewer system.

Specifically, the results indicate that *h/D* decreased with the increase in EIA_{red}. For EIA_{red} =0% (Figure 2a), the drainage system was highly stressed with larger values of *h/D*, whereas there was a reduction in *h/D* with the increase of the EIA_{red} values (Figure 2b-2d).

Even a modest reduction in impervious surfaces, such as EIA_{red} =30%, had a significant influence on the junction filling ratio.

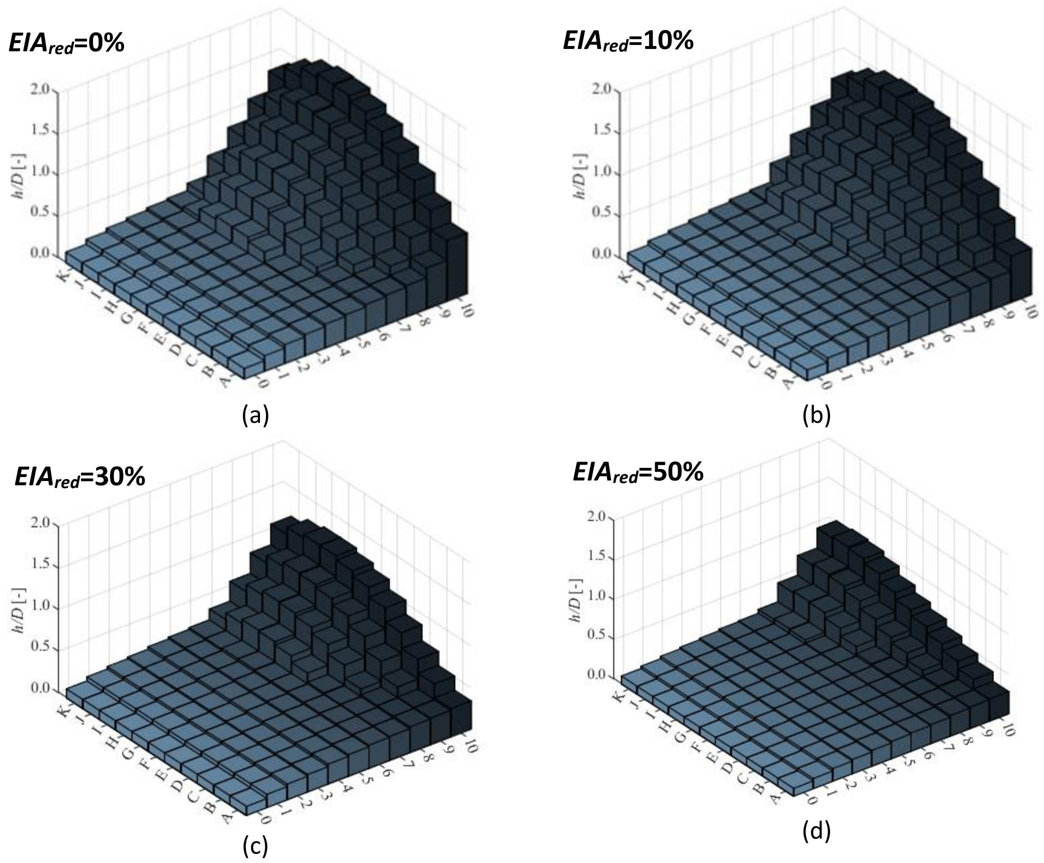

Figure 2. Distribution of the filling ratio in the studied drainage system networks

Figure 3 shows that, as expected, h^* increased with q. Larger values of the shape factor q indicate, indeed, worse hydraulic conditions (in terms of flow rates, roughness and slope), which affects the augmentation of the average junction filling ratio h^*. The beneficial effect of the green roof installation is clear by comparing the datapoints corresponding to different values of EIA_{red}. At a certain value of q, h^* reduced by increasing EIA_{red} from 0% to 50%, and this drop is particularly noticeable for large values of q. In particular, for q larger than 0.30 $m^{8/3}$, the decrease of h^* resulted to be more significant.
Consequently, the occurrence of pressurised flow conditions within the sewer conduits was less likely when green roofs were installed.

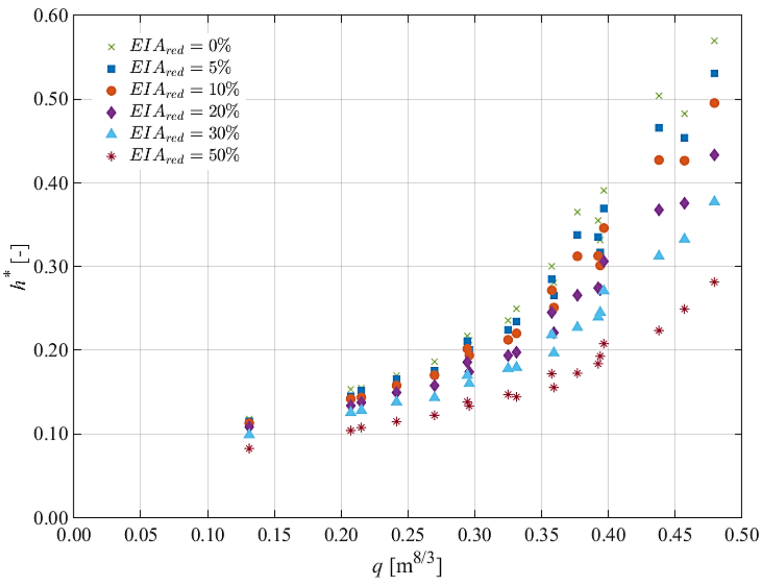

Figure 3. Relation between ***h**** and q as a function of different levels of EIA_{red}.

Conclusions and future work

Preliminary results show the positive effect of green roof installation in preventing the pressurised phenomena occurrence in an urban drainage system and, consequently, in mitigating the risk of urban flood occurrence.
Next steps will investigate the effect of the temporal rainfall variability on the functioning of a drainage system equipped with green roofs and, moreover, the effect of the climate change will be analysed.

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