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INFILTRATION-EXFILTRATION SYSTEM FOR STORMWATER RUNOFF VOLUME AND PEAK ATTENUATION

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ABSTRACT

Urbanization alters the hydrological cycle increasing surface runoff water volume and peak flow. The traditional approach on urban drainage is being updated to an integrated approach of managing the water on its source. This study proposes a strategy based on urban retrofit of impervious surfaces using an infiltration-exfiltration linear system of runoff collection. The proposed system is based on street side channels and is composed by a porous asphalt top layer, aggregates base and drainage underdrain. The aims are to promote infiltration, filtration and adsorption of stormwater. Storm water management model was used to simulated pre and post-retrofit response for extreme single events on the city of Milan from 2006 to 2015. The system has positive effects on runoff reduction and hydrograph attenuation reaching from 18% reduction to full infiltration of runoff volume.

Keywords: stormwater, SUDs, sustainable drainage, floods

1 INTRODUCTION

Traditional urban road drainage consists on directing runoff water to the kerbs, collecting on catch pits placed on suitable intervals across the roads that proceeds to the sewers system [1]. The saturation of the sewer system often occurs on high intensity events creating the necessity of storage tanks across the drainage system [2]. However, this traditional solution has become impractical on current urbanization scenarios pushing towards comprehensive measures such as promoting stormwater management on its source [2, 3]. These measurements are commonly known as SUDs (sustainable urban drainage systems), BMPs (best management practices) or LIDs (low impact developments) and have a different approach of solutions to achieve a long term and sustainable urban drainage management [4]. This study proposes a solution based on the integration of porous pavement and traditional drainage system. An infiltration-exfiltration system is placed along the road replacing the traditional gutters, composed by a porous asphalt top layer and aggregate base, allowing infiltration to the underground soil. This solution promotes attenuation on extreme rainfall events, aquifer recharge and water quality improvement. The objective of this preliminary study is to evaluate the linear infiltration-exfiltration system performance in terms of runoff volume reduction and peak attenuation.

2 BACKGROUND

The city of Milan suffers with increasing frequency from floods, especially on the North area – in the last 140 years 342 floods were registered (i.e. 2.4 per year), 108 of which from 1976 only (i.e. 2.6 per year). The river Seveso, that crosses the city, often causes flooding and a solution using storage tanks would have a cost estimated on 130 million Euros [2]. The 1937 km of roads provide significant contribution to surface runoff water and management this water volume locally could alleviate the sewer system saturation. On [5] a prototype infiltration-exfiltration device was constructed on the side of a pavement section of a urban road on Cincinnati, United States, obtaining positive impacts on flow reduction and load removal.

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The system was also model using a 2D numerical unsaturated flow model (VS2DT) to evaluate different soil types and rainfall events concluding that on the study conditions the peak flow and total flow decreased even with different type of soil on the surroundings of the system

The Storm Water Management Model (SWMM) from EPA-US (United States Environmental Protection Agency) is often used to model the rainfall-runoff transformation processes and the hydrograph estimation in both pre and post-retrofit scenarios [6–11]. SWMM provides dynamic rainfall-runoff simulation for both single event and long term (continuous) simulation of runoff quantity and quality specially on urban areas. The model provide from EPA-US operates on a collection of subcatchment areas that receive precipitation and generate runoff and pollutant loads [12]. The model has an in-build option to model LIDs including infiltration devices and permeable pavement. Although often used, the LID block of SWMM may overestimate the results on volume and peak flow [13]. A robust model will depend highly of the parameters estimation, whereas area and imperviousness have the most significant impact on the hydrograph [12].

3 METHODOLOGY

The city of Milan is circled by two road rings, the inner one with 11.2 km surrounding the historical old city centre and the outer one, with 19.5 km, surrounding most of the XX century quarters. The linear infiltration-exfiltration system was tested on a potential application along both rings to evaluate the impact of road retrofitting at catchment level.

The potential benefits of installing the proposed infiltration-exfiltration system on both roads were analysed through simulation of effects on stormwater runoff infiltrated and diverted from the sewer system.

3.1 Simulations

Table 1 shows the subcatchment parameters used on the simulations. The considered area regards a stretch of road served by one inlet, the width represents the flow path, N represents

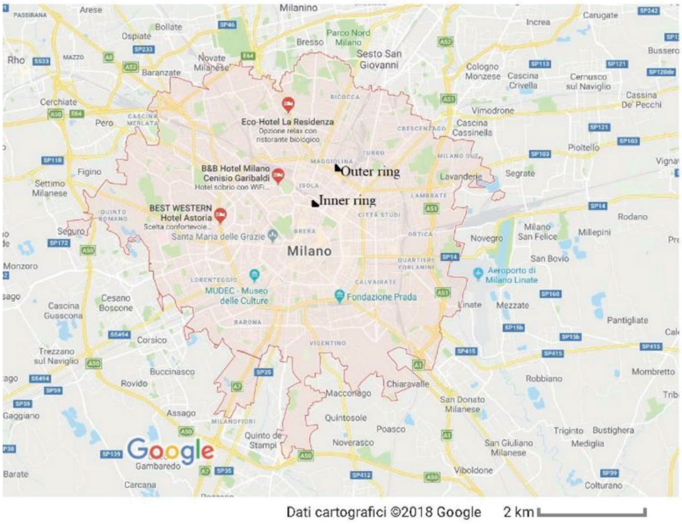


Figure 1: Inner and outer ring road of Milan.

Table 1: Parameters used on the rainfall-runoff simulation

Parameter	
area (ha)	0.008
width (m)	8
% slope	2
N-imperv	0.017
N-perv	01
D-store-imperv (mm)	1.1
D-store-perv (mm)	5

the roughness considering the Manning's number, D-storage represents depression storage. The parameters where estimated considering the half road area, typical urban road slope, typical N and D-Storage for old asphalt. The model was calibrated using runoff data from a similar road for the city of Cincinnati, United States [14]. The linear infiltration-exfiltration system was model as a LID system using the in-build function on SWMM.

3.2 Design storm

The rainfall data was recorded in the Lambrate Station on the city of Milan, Italy, between 2006 and 2015. A IETD (minimum interevent time) of 1 hour was considered to define independent events [15]. Table 2 presents main statistics of this series yearly and Table 3 for the complete period. Simulations were then performed for ten extreme single events, extracted from the series (Table 4). The highest event record was registered on 2009 with a 121.2 mm rain depth and maximum intensity of 176.4 mm/h.

3.3 Linear infiltration-exfiltration system

The linear infiltration-exfiltration system consists of a porous asphalt surface layer, an underlying gravel layer and receives the sheet flow from the corresponding strip of street. The

Table 2: Rainfall events recorded in each year of the series.

Year	T_r	θ [hours]	H_{tot} [mm]	t_{sr} [days]	i_{max} [mm/h]
2006	80	9	730	49	156
2007	55	4.5	388.8	111	26.4
2008	113	5	1245.40	42	136.8
2009	109	9	1112	25	176.4
2010	135	6.5	1467.2	23	68.4
2011	64	4.5	548.8	35	69.6
2012	93	7	1061	58	106.8
2013	120	9	1249.6	33	112.8
2014	163	12	1639	28	81.6
2015	85	5.5	778.4	32	84

T_r: total rainfall events, θ: maximum rainfall duration, h_{tot}: yearly total rainfall, t_{sr}: maximum dry period, i_{max}: maximum rainfall intensity.

Table 3: Average rainfall statistics in the recorded rainfall series.

	Milan-Lambrate
Number of years	10
Total number of events	1017
Average number of events per year (E_v)	101.7
E_v standard deviation	31.3
Average yearly rainfall (h_{tot}) [mm]	1022.0
h_{tot} standard deviation	382.1
Average number of dry days (t_{sr})	43.6
Maximum number of dry days	111
t_{sr} standard deviation	24.7
Average peak flow intensity (i_{max}) [mm/h]	101.9
i_{max} standard deviation	42.9
Average rainfall duration (θ) [hours]	7.2
θ standard deviation	2.4

Table 4: Characteristics of extreme rainfall events used for simulations.

Event Measured	Rainfall duration (min)	Rain depth (mm)	i_{max} (mm/h)	i_{avr} (mm/h)
06/07/2006	240	44	156	10.56
04/07/2007	90	5.6	26.4	3.4
12/07/2008	30	27.4	136.8	82.2
07/07/2009	260	121.2	176.4	26.93
11/07/2010	180	24.6	68.4	7.8
27/05/2011	240	37.8	69.6	8.4
09/06/2012	110	38	106.8	19
24/08/2013	190	26.8	112.8	8.0
24/06/2014	60	37.2	81.6	31.9
25/07/2015	90	34.6	55.2	20.7

system was designed in an analogue way as a detention basin. Due to the short water paths, the system balance was simulated neglecting the rainfall-runoff transformation on the street [1].

$$\theta_w = \left(\frac{Q_u}{2,78.A.\varphi.a.n} \right)^{\frac{1}{n-1}}. \tag{1}$$

$$W_o = 10.A.\varphi.a.\theta_w^n - 3.6.\,Q_{u\,max}.\theta_w \tag{2}$$

where θ w is the critical rainfall duration , Q_u is the outflow discharge, A is the area, φ is the permeability coefficient, “a” and “n” are the 2-parameters IDF curves coefficients for Milano [16]. A limit of 20 l/s/ha was considered for discharges in the sewer network, as provided by local regulations. The possibility of system storage pre-filling from previous events wasn’t considered [17,18].

4 RESULTS

4.1 near infiltration-exfiltration system cross section

The linear infiltration and exfiltration system cross section designed accordingly to above methodology is presented in Fig. 2. To guarantee the limit outflow the underdrain should be placed on a higher position and an eventual flow restriction device should be considered.

4.2 Pre and post retrofit hydrographs

Figure 3 shows the pre and post-retrofit scenarios hydrograph, where the retrofit consists in considering the linear infiltration-exfiltration system replacing the street gutters. Except for the year 2009 the system was able to infiltrate most of the single extreme events, reaching full infiltration for the 2007 event. In all events there was a considerable reduction of peak flow.

Table 5 shows the total runoff volume pre and post retrofit for the considered roach stretch with an average of 60% reduction. The 2007 event was fully infiltrated by the device while the 2009 present a 18% reduction on volume

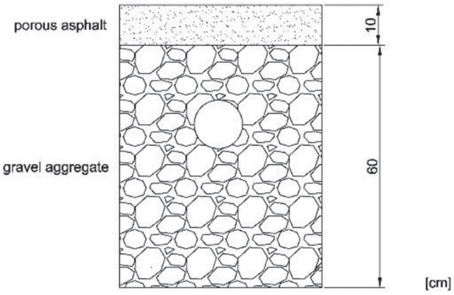
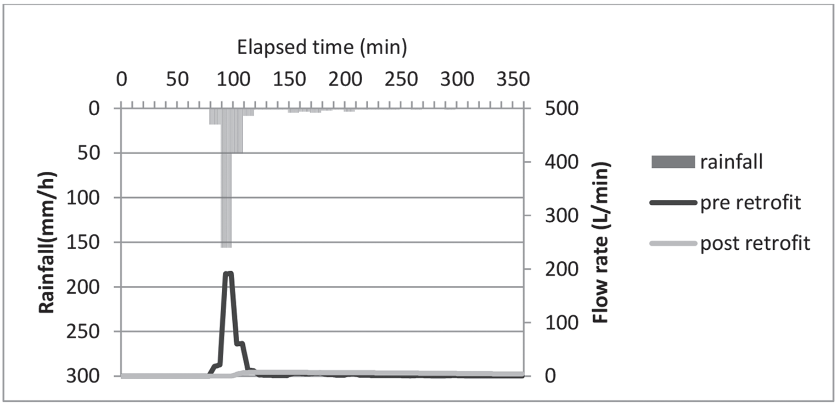
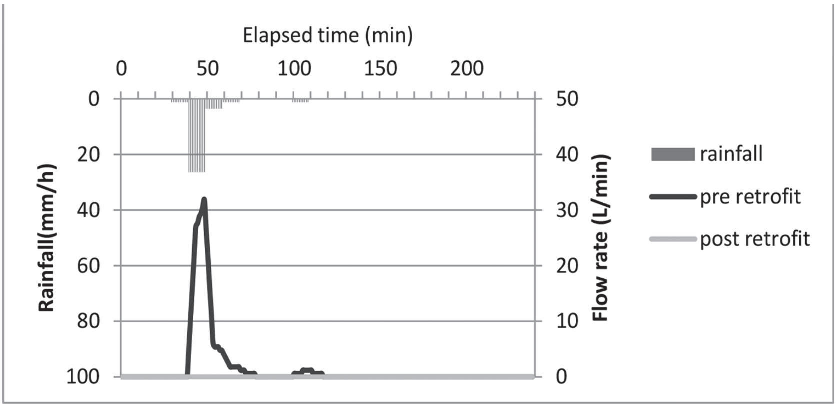


Figure 2: Linear infiltration and exfiltration system. Units in cm.



(a)

Figure 3: Pre and post retrofit hydrographs for extreme rainfall single events. (a) 2006; (b) 2007; (c) 2008; (d) 2009; (e) 2010; (f) 2011; (g) 2012; (h) 2013; (i) 2014; (j) 2015.



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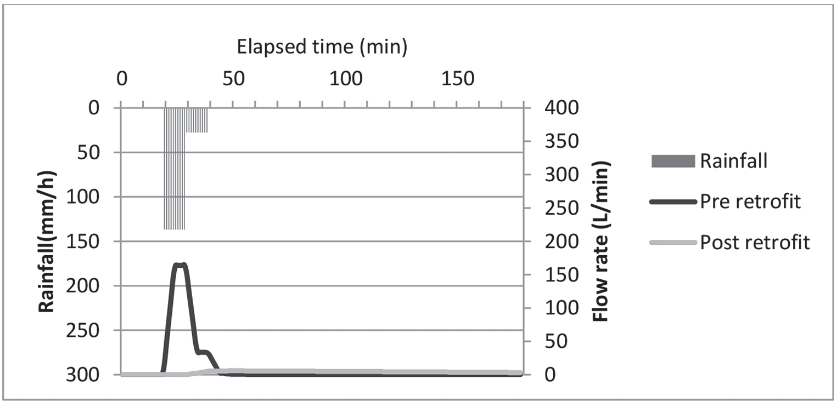
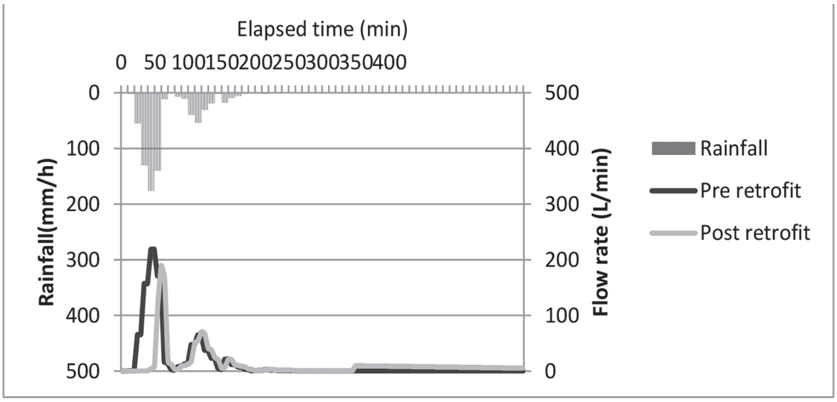
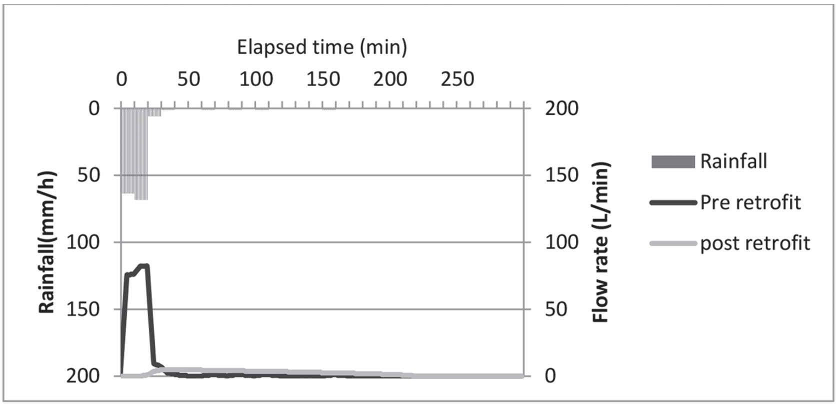


(c)



(d)

Figure 3: (*Continued*)



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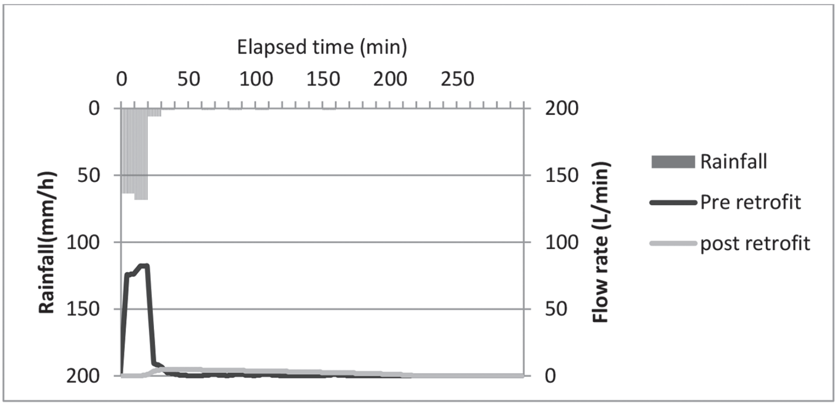
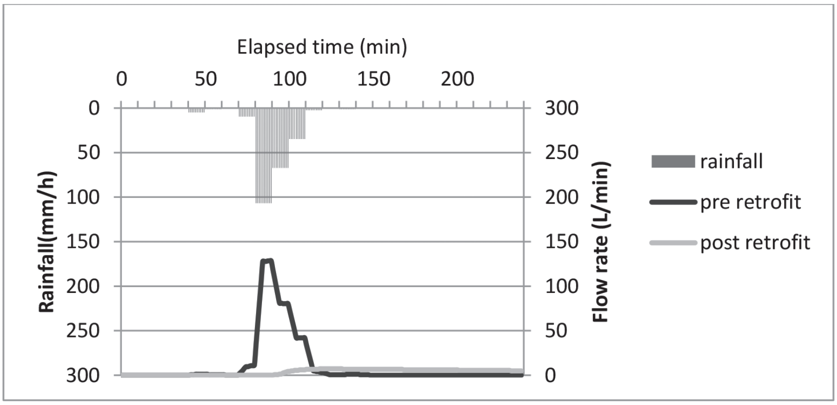
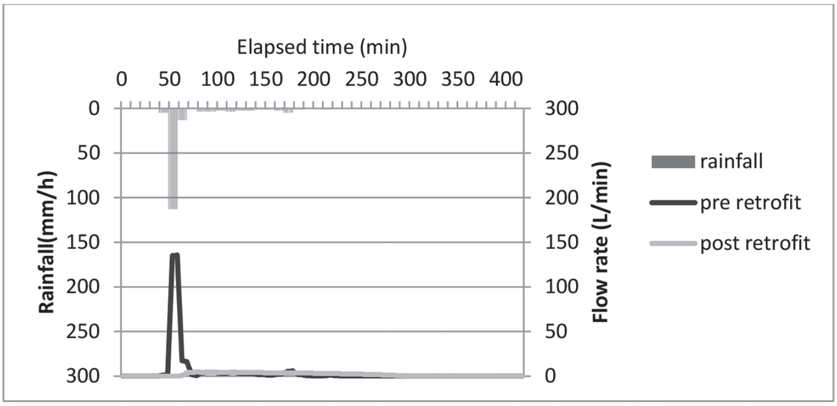


(f)

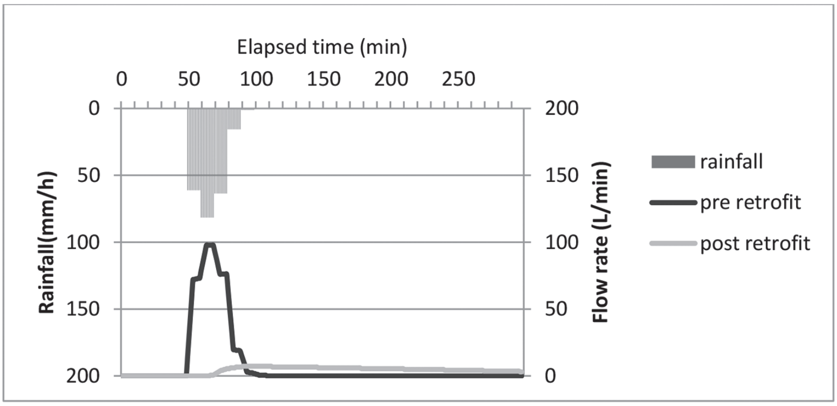


(g)

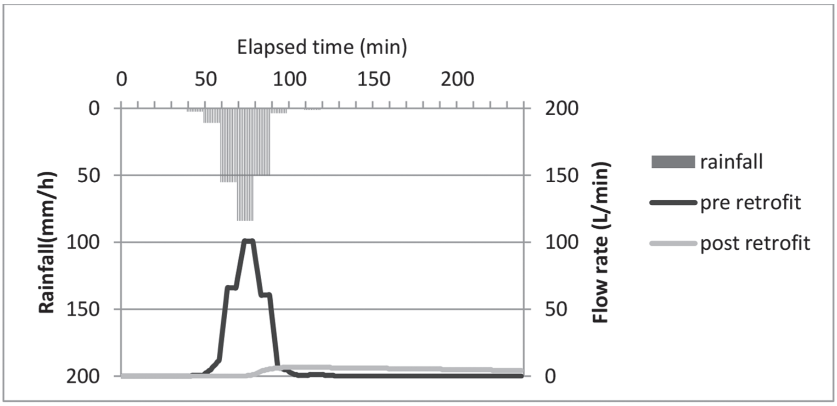
Figure 3: (*Continued*)



(h)



(i)



(j)

Figure 3: (*Continued*)

Table 5: Volume pre and post retrofit for extreme single events.

Event Measured	Volume pre retrofit (liters)	Volume post retrofit (liters)	Volume reduction
06/07/2006	3202	1530	52%
04/07/2007	382	0	100%
12/07/2008	1995	668	67%
07/07/2009	8816	7192	18%
11/07/2010	1750	623	64%
27/05/2011	2466	1167	53%
09/06/2012	2692	862	68%
24/08/2013	1905	733	62%
24/06/2014	2690	1222	55%
25/07/2015	2443	867	65%

Table 6: Volume pre and post retrofit for extreme single events at city level.

Event Measured	Volume pre-retrofit (m^3)	Volume post retrofit (m^3)	Reduction
06/07/2006	4915	2349	52%
04/07/2007	586	0	100%
12/07/2008	3062	1025	67%
07/07/2009	13533	11040	18%
11/07/2010	2686	956	64%
27/05/2011	3785	1791	53%
09/06/2012	4132	1323	68%
24/08/2013	2924	1125	62%
24/06/2014	4129	1876	55%
25/07/2015	3750	1331	65%
Average	4350	2282	60%

4.3 Retrofit impact on city level

Table 6 shows the effect in terms of runoff volume reduction at city level, using the infiltration-exfiltration system along both the inner and outer road street rings of Milano. With an average contribution of 4350 m^3 of water volume on extreme single events the retrofit could reduce this volume on 60% with 2069 m^3 of water being managed on its source. A broader impact could be achieved by using this system on more roads.

5 CONCLUSION

The presented preliminary study shows that the linear infiltration-exfiltration system has a significant effect on total runoff volume and peak flow reduction for extreme single events. The retrofit of the street gutters using this system would reduce on 60% the water volume directed to the sewers. Although the total water volume infiltrated by the system could be considered low when compare with the whole Milan basin this solution could be applied combined with other SUDs to achieve a sustainable and cost effect solution for the flood problem. The system would also have a positive impact on runoff water load removal which is solely a good reason for its application. With satisfactory preliminary results the effects of this type of street retrofitting will be further investigated, enhancing the modelling, for example considering the possibility of system pre-filling in the case of close-range rainfall events in a row, including load removal and applying the system on a higher area.

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