Infiltration-Exfiltration System for Stormwater Control: A Full Scale Test

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Abstract: The current approach on stormawater management should focus on dealing with water on its source. The Sustainable Urban Drainage Systems (SuDS) promotes runoff peak flow and volume attenuation, load removal and while providing ammenites and biodiversities, but can be difficuld to apply on developed urban centers. An infiltration-exfiltration system (IES) placed on road gutters can function on receiving runoff from roads and directing them to the sewers system reducing peak flow and volume. This research follows up a full scale test of a IES installed in São Paulo, Brazil. The IES has 49 x 1880 m dimension and a cross section of 49 x 30 cm with a pervious concrete surface layer. The pervious concrete showed mechanical results acceptable for a low vehicular traffic and infiltration rate that allows water infiltration. Rainfall-runoff modelling showed that the proposed IES had low effect on runoff peak flow and volume attenuation. A deeper gravel layers depth and outlet flow restrictor would improve performance. The proposed IES function on avoid ponding, promoving water treatment and reducing inlet maintenance.

Keywords: stormwater management; SuDS; pervious concrete

1. Introduction

The traditional approach of stormwater management on collecting, conveying and discharging runoff is becoming impractical on the current growing urbanization scenario and altered precipitation patterns, with high intensity events being observed more frequently. The contaminants present on runoff after washing off surfaces are an important cause of rivers and streams pollution. To avoid saturation of the urban drainage system and improve water quality the currently strategies for stormwater management acts on management water on its source and encouraging systems that also function on water treatment. These systems are often referred as SuDs (sustainable urban drainage systems), green infrastructures, BMPs (best management practices), LIDs (low impact developments). This approach is already mentioned on public policies on urban drainage and land use, specially by limiting the discharge and requiring detention or retention tanks [1].

Application of these strategies for stormwater control may be difficult, especially in fully developed urban areas. Retrofitting of such areas is usually more expensive and may be limited to few urban spaces. One of the more feasible and effective interventions is the change of traditional road, pavement and parking surfaces with permeable ones.

However, these alterations are limited by the need to find a trade-off between good infiltration performances and sufficient strength to traffic loads. That's the reason for which this solution is often applied only to roads with low traffic loads.

An alternative is to limit the adaptations to road gutters, that are less stressed by dynamic loads. The use of an infiltration-exfiltration system as street gutters, consisting of a porous concrete surface with a gravel base, may achieve several goals. First, stormwater runoff to be discharged into the sewer network is reduced. Second, peaks of stormwater flow into the sewer network are reduced, due to the temporary storage inside the porous layers of the part of stormwater runoff that can't be infiltrated. Third, the porous surface acts as filter, promoting load removal from runoff. Previous researched analyzed the IES performance on runoff peak flow and volume reduction [2] and on load removal [3].

2. Material and methods

2.1. Experimental area

An IES road gutter was installed on the headquarters of the Brazilian Portland Cement Association (ABCP) located in São Paulo, Brazil. The system has 49 cm width and 1880 cm length and a cross section consisting of a 10 cm surface of pervious concrete and 20 cm of gravel over a natural soil subbase, without geotextile and is connected to an inlet PVC pipe (Figure 1).

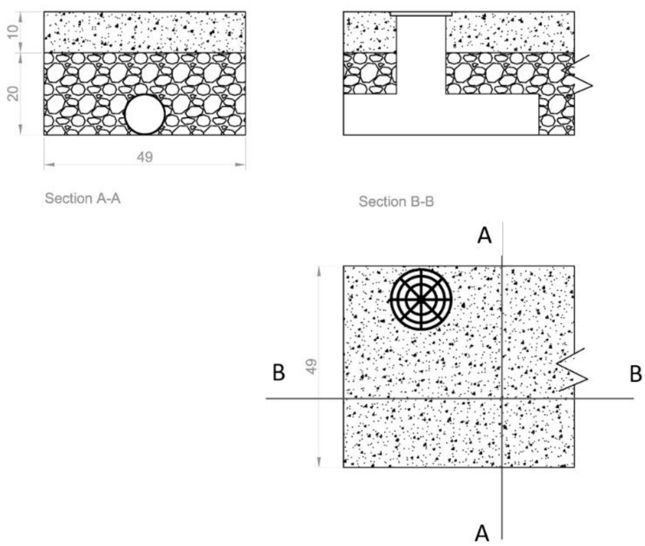

Figure 1 – IES details: plan view, section A-A (longitudinal section) and B-B (cross section).

The IES was placed on the entrance road and receives stormwater of 1626 square meters contribution area consisting on half of the entrance road and two parking lots with hexagonal concrete blocks surface and two grass garden areas according Table 1 and Figure 2.

Table 1 – Contribuition areas and slope.

Description	**Area [m²]**	**Slope [m/m]**
Parking lot + garden	1050	0,01
Parking lot	365	0,01
Garden	143	0,03
Main road (half)	59	0,01
IES	9	0,01

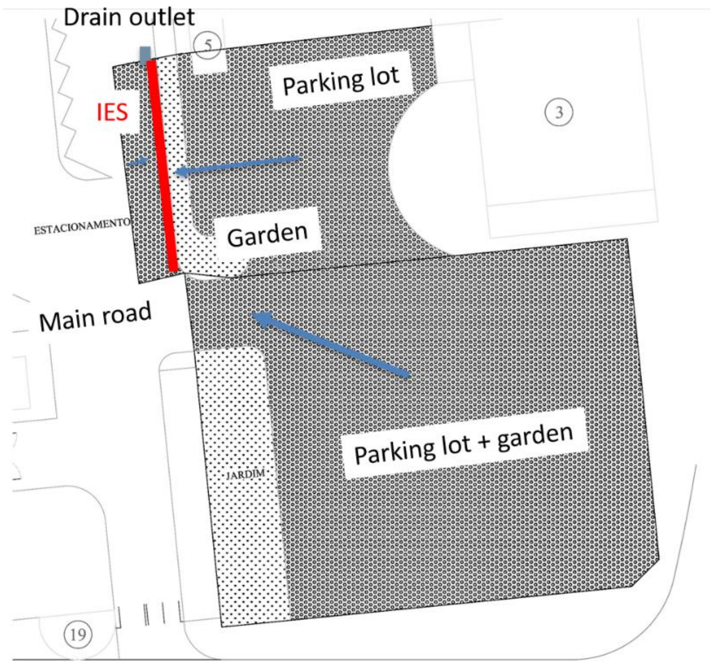

Figure 2 – Experimental area.

The pervious concrete was placed over the gravel layer and compacted using a manual compaction hammer due to space restriction. It is important to notice that compaction can alter pervious concrete characteristics [4].

2.2. Pervious concrete characteristics

The pervious concrete surface consists of a mix design containing a cement type CP V Ari (high initial resistance), aggregates and admixture. Specimens mold on laboratory were tested for compressive strength on a cylindric specimen (ABNT NBR 5739), flexural strength on a prismatic specimen and diametral compressive strength. Samples extracted from the finished area were tested for water absorption, void content and density.

2.3. Infiltration rate

Permeability test where held on the finish area using a falling head permeameter with a 30 cm diameter and a water head test level between 10-15 mm according with ABNT NBR 16416. Detais of the permeability test method can be found on [5]. The first test (02/10/2019) was held after a rainfall event carried particles load from the garden area towards the IES visually clogging the system. Before the second measure (17/10/2019) the IES was cleaned by regular sweeping and before the third test (23/10/2019) with pressure water.

2.4. Rainfall-runoff modelling

The storm water management model (SWMM) was used to simulate the rainfall-runoff transformation considering the previous scenario, before the IES installation, and after. The simulation used typical urban area subcatchments parameters. For the concrete blocks pavement area was used a 0.01 Manning Number. For both garden areas it was used the Horton infiltration model with a minimum infiltration rate of 0.5 mm/h. The depression storage was adopted as 0.05 mm for both pervious and impervious areas. For the IES simulation it was used the LID build-in function of SWMM considering a seepage rate of 0.3 mm/h, coherent with the low permeability soil typical on that area, and a drain placed on the lower part of the storage layer (gravel layer). For the simulations it was adopted the Chicago-storm hyetograph obtained with the IDF (Intensity-Duration-Frequency) equation from IAG-USP [6]. With the rainfall-runoff simulations it was obtained the outlet and subcatchments hydrograph for the pre and post retrofit scenario and the IES performance data.

3. Results

Results obtained for the pervious concrete characteristics, infiltration rate test on the IES surface and the rainfall-runoff modelling results.

3.1. Pervious concrete characteristics

Laboratory samples molded with the proposed mix design presented the results gathered on Table 2, Table 3 and Table 4. On Table 5 are the resuls for water absorption, void content and density from the samples extracted from the finished experimental area.

Table 2 - Compressive strength on a cylindric specimen (ABNT NBR 5739).

Specimen	Molded	Test	Age	Compressive strength	
			[days]	[MPa]	
PC1	29-ago	30-ago	1	12,9	
PC2	29-ago	30-ago	1	12,2	12,9
PC3	29-ago	02-set	4	21,3	21,3
PC4	29-ago	05-set	7	19,9	
PC5	29-ago	05-set	7	20,4	20,4
PC6	29-ago	12-set	14	20,8	20,8
PC7	29-ago	26-set	28	18,7	
PC8	29-ago	26-set	28	20,8	20,8

Table 3 - Flexural strength on a prismatic specimen.

Specimen	Molded	Test	Age	Flexural strengths
			[days]	[MPa]
PC1	29-ago	05-set	7	2,15
PC2	29-ago	05-set	7	1,87
PC3	29-ago	12-set	14	2,3
PC4	29-ago	12-set	14	2,09
PC5	29-ago	26-set	28	2,42
PC6	29-ago	26-set	28	2,45

Table 4 - Diametral compressive strength.

Specimen	Molded	Test	Age	Diametral compressive strength
			[days]	[MPa]
PC1	29-ago	26-set	28	2,17
PC2	29-ago	26-set	28	2,47

Table 5 - Water absorption, void content and density for extracted samples.

Item	Unit	Value
Water absorption	%	6,35
Void content	%	14,3
Density(1)	g/cm³	2,64

(1) Ms/(Ms-Mi) Ms: dry mass (g) Mi: mass after boiling (g).

3.2. Infiltration rate

The infiltration rate results are gathered on Table 6. The infiltration rate obtained on 02/10/2019 was precede from a rainfall event that clogged the IES surface with soil particles load, however the obtained rate is still enough to allow water infiltration. Before the second test (17/10/2019) the IES was cleaned by regular sweeping presenting an increase on infiltration rate. The IES was then cleaned with pressure water achieving a infiltration rate of 17786 mm/h.

Table 6 – Infiltrate rate obtained with a in situ falling head permeameter.

Test date	Infiltration rate	
	[m/s]	[mm/h]
02/10/2019	6,00E-04	2174
17/10/2019	1,60E-03	5767
23/10/2019	4,90E-03	17786

3.3. Rainfall-runoff modelling

The rainfall-runoff simulation allowed to obtain the runoff peak flow, runoff total volume and the hydrograph from the outlet, IES and subcatchments for the pre and post-retrofit scenarios (Table 7,Table 8, Table 9, Figure 3, Figure 4).

Table 7 - Pre-retrofit runoff peak flow and total volume.

	Description	Area	Discharge	Peak flow	Total volume
	[-]	[m2]	[-]	[l/s]	[liters]
OUTLET	-		-	77,57	92
S1	Garden	143	S3	2,63	3
S2	Parking lot	365	S3	16,04	22
S3	Main road (half)	68	OUTLET	77,67	92
S4	Parking lot + garden	1050	S3	56,98	64

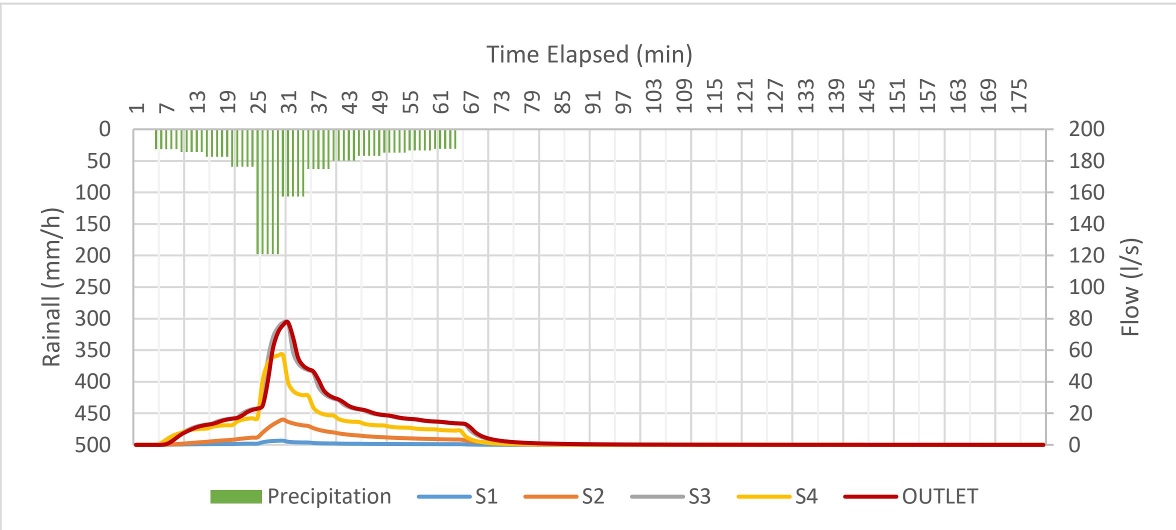

Figure 3 – Pre-retrofit hydrograph.

Table 8 - Post-retrofit runoff peak flow and total volume.

	Description	Area	Discharge	Peak flow	Total volume
	[-]	[m2]	[-]	[l/s]	[l]
OUTLET	-	-	-	78,33	92
S1	Garden	143	IES	2,63	3
S2	Parking lot	365	IES	16,04	22
S3	Main road (half)	59	IES	3,24	4
S4	Parking lot + garden	1050	IES	56,98	64
IES	IES (drain)	9	OUTLET	79,16	92

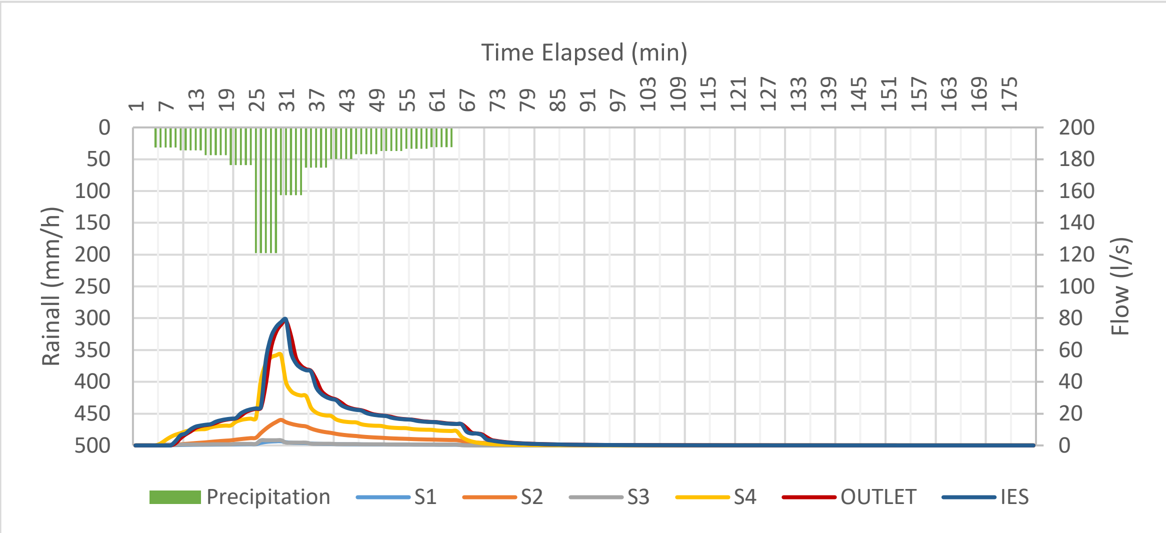

Figure 4 - Post-retrofit hydrograph.

Table 9 – IES performance.

Item	Unit	Value
Total inflow	[mm]	10243
Infiltration loss	[mm]	1
Surface outflow	[mm]	6959
Drain outflow	[mm]	3262
Initial storage	[mm]	0
final storage	[mm]	21

4. Discussion

An infiltration-exfiltration system with 18.8 m length and 0.49 m width was build to receive rainfall from a 1617m2 contribution area. The IES consists on a pervious concrete layer (10 cm) and gravel layer (20 cm) and is connected to the drainage system through a 10 cm diameter PVC pipe. The pervious concrete layer presented a 20,8 MPa compressive strength; 2,43 MPa (average) flexural strength and 2,32 MPa diametral compressive strength for 28 days age and laboratory molded specimens. Samples extracted presented a 14,3% of void content. The IES infiltration rate was measured after a rainfall event presenting a 2174 mm/h. After cleaning with pressure water the infiltration rate raised to 17786 mm/h. Rainfall-runoff simulation for the proposed IED did not registered peak flow and volume reduction comparing pre and post-retrofit.

5. Conclusions

The current urbanization scenario demands a shift on stormwater management, favoring on-source solutions and encouraging reuse, infiltration and temporary storage. These solutions are often referred as SuDs (Sustainable Urban Drainage Systems) and provide runoff peak flow and volume attenuation while delivering amenities and biodiversity opportunities. However, it may be difficult to apply these systems on a fully urbanized envirornment requiring solutions using that may be apply on public space. The infiltration-exfiltration system placed on road gutters function on reducing runoff peak flow and volume, avoiding ponding on gutters and reducing drainage inlet maintenance. Previous research confirmed the performance of such systems.

A IES was built on the ABCP headquarters, in Brazil. The surface layer presented a high infiltration rate that allows stormwater infiltration. The pervious concrete characteristics were coherent with the low traffic vehicular use. The rainfall-runoff simulation did not showed a reduction on peak flow and volume as expected. Considering the results, to improve IES performance on runoff peak flow and volume reduction it would be necessary a deeper depth on the gravel layers and a flow restriction on the outlet tube to facilitate storage. To facilitate infiltration the outlet pipe could be placed on a offset position from the gravel layer and the system could be also combined with soakways. The experimental area is going to be monitored to obtain data to calibrate and validate the rainfall-runoff model and to obtain load particles removal efficiency.

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Author Contributions: Claudio Oliveira conceived, designed and follow up the experiments, Mariana Marchioni contributed with the rainfall-runoff modelling and wrote the paper, Gianfranco Becciu analyzed the data.

Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

The following abbreviations are used in this manuscript:

ABCP: Brazilian Portland Cement Association
IDF: Intensity-Duration-Frequency
IES: infiltration-exfiltrarion system

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