Infiltration and detention systems for stormwater control in Belo Horizonte: assessment of demo performance and perspectives for use

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Abstract

The present paper describes an experiment with two stormwater control devices, an infiltration and a detention trench, carried out in Belo Horizonte, a Brazilian city with 2.4 million of inhabitants. The experiments focus on assessing the efficiency of these devices on runoff control and wet weather pollution abatement in the particular context of a city from a developing country, located at a tropical climate environment. The devices receive runoff flow from a 3,600 m^2 contributing area composed by a stretch of a 4-way avenue. The runoff generated in this road is drained through gutters till an inlet where it is collected and conveyed to the experimental area. The experiment monitoring protocol comprises rainfall, inflows to the devices, storage and water quality monitoring by means of inflow and outflow composed samples: conductivity, pH, temperature, turbidity, total suspended soils, metals (Cu, Ni, Zn, Cd, Mg). The paper describes and evaluates the first hydrologic year of the experiment operation, comprising rainfall events of different characteristics. The performance of the devices is evaluated in terms of runoff control and wet weather pollution abatement for each observed event. During the first year of operation, the devices presented acceptable performance and suggest their interest for runoff and diffuse pollution control.

Keywords: stormwater quality, infiltration trench, detention trench, SUDS performance

1 Introduction

The relevant role of SUDS (sustainable urban drainage systems) on the implementation of integrated sustainable urban water management policies is well reported in the literature. Infiltration trenches and basins, pervious pavement, filter drains, soakaways, swales and ponds act in the sense of reducing impacts of urbanisation on hydrological processes in urban catchments by promoting the detention and infiltration of excess runoff as well as the abatement of wet weather non-point source pollution (e.g.: David and Sousa, 2008; Tamoto and Sakakibara, 2008; Daywater, Ciria, 2007; Pasche et al., 2009). Moreover, when well planned and adequately associated to the urban development project, SUDS may contribute to a general enhancement of the local environment and to improving aesthetic aspects of the urban area. Also, SUDS make more visible the existence of water in the urban environment, offering good opportunities for people involvement on the decision making and management of the urban environment.

These characteristics of SUDS will certainly require significant improvements of water governance and institutional development in urban areas. Their adoption by municipalities as a current stormwater management approach depends upon a wide range of factors of technical, institutional, economical, social and managerial domains, actually requiring and probably leading to a paradigm change in the water management in the urban context. This is certainly the case when it comes to adopt SUDS for new urban developments. Moreover, when the focus is on retrofitting SUDS in urban areas already occupied the process is particularly more demanding due to the obvious restrictions on land availability, interferences with existing infrastructures and retrofitting costs, to nominate some of the more common limiting factors (e.g.: Todorovic et al, 2008; Latourneau et al, 2008; Shuster et al, 2008). Notwithstanding, the objectives of improving stormwater management in urban areas in order to meet sustainability criteria requires considerable efforts on adapting the built environment. This is particularly the case of Brazilian cities with their core of densely occupied old urban developments or their poor neighbourhoods of informal settlements (shantytowns).

It is part of the strategy of the 6th EU Framework project, SWITCH, to address these issues by (i) *the identification, application and demonstration of a range of flexible and proven scientific, technological and socio-economic approaches and solutions that will contribute to effective and more sustainable IUWM (integrated urban water management)* (Nascimento et al, 2007), and by the constitution of a consortium of *key groups of organisations and leading individuals (or "champions") having a shared interest in and vision of future urban water management within their respective metropolitan areas and in the implementation of alternative innovative approaches* (Nascimento et al, 2007).

Belo Horizonte, the capital of the state of Minas Gerais, in Brazil, is one of the demonstration cities of the SWITCH project. In Belo Horizonte, the SUDS demonstration experiments involve infiltration and detention devices, artificial wetlands, and rainfall harvesting. This paper focuses on the demonstrations about the use of detention and infiltration trenches aiming at runoff control and wet weather pollution abatement. The specific objectives of these demonstrations are as follows: (i) establishing criteria for identifying where and which type of SUDS may be appropriate for use; (ii) establishing procedures for the design, the implementation and the operation of SUDS; (iii) defining SUDS operational and maintenance requirements; (iv) assessing building and maintenance costs and life cycle costs; (v) developing professional skills and capacity building on stormwater management with focus on SUDS.

2 Demonstration description and methods

The experiment on infiltration and detention trenches receives runoff flow from a main road linking the central area of Belo Horizonte to its North districts, the Presidente Carlos Luz Av. The contributing area is 3,600 m^2, essentially draining a stretch of the 4-way avenue oriented Northward (Figure 1). The runoff generated in this area is drained through gutters till an inlet where it is collected and conveyed to the experimental area. The runoff volume and discharge effectively collected by the inlet depends on its inflow efficiency, which is a function of the flow magnitude. Estimates of the maximum peak flow that the system is able to collect are around 44 l/s (Figure 1).

Figure 1. Partial view of the contributing area (left); Inlet installed at the gutter (right)

A 10-year design rainfall, based on the IDF regional equation for the Belo Horizonte Metropolitan Area - BHMA (Pinheiro & Naghetini, 1998), was adopted for the design rainfall. The design rainfall duration was defined by simulation of different durations, adopting the one leading to the highest device peak outflow. Inflow hydrographs were calculated using a synthetic hydrograph based on the rational method. Hydrograph routing through the devices was performed by the modified Puls method. In order to estimate the infiltration trench outflow, several measurements of the saturated hydraulic conductivity were performed in the area, using a Guelph permeameter (Hendrickx, 1990). The saturated conductivity adopted for the devices design was $K = 5.21\ 10^{-5}$ m/s, the average of the field values, typical for silt soils. The infiltration trench is 20.0 m long, 1.0 m wide and 1.5 m deep. The dimensions of the detention trench are: length = 12.0 m, top width = 3.0 m and depth = 1.5 m. The outflow of the detention trench is controlled by an orifice with a diameter of 0.1 m (Figure 2).

Figure 2. Infiltration trench (left); Detention trench (right)

The experiment monitoring protocol comprises the following quantitative and qualitative variables: (i) rainfall, measured by a tipping bucket rainfall sensor; (ii) inflows to each device measured by water pressure sensors (Parshall flumes); (iii) water levels at each trench measured by water pressure sensors; (iv) water quality was monitored on line with an electric conductivity sensor and by means of inflow and outflow composed samples. In March 2009

an automatic ISCO sampler was included in the experimental set. Monitored parameters are conductivity, pH, temperature, turbidity, total suspended soils, metals (Cu, Ni, Zn, Cd, Mg) and PAH. These parameters are determined according to the APHA /AWWA standards.
The demonstration monitoring also includes the collection and the physical and chemical analyses of sediments and solid wastes settled at the road drainage inlet, which is going to be associated to rainfall characteristics as intensity, volume and antecedent dry periods to the observed rainfall events. Also, during the construction of the infiltration trench, soil samples were collected at 4 different depths: 0.5, 1.0, 1.5 and 2.0 m from its bottom level. These samples were submitted to physical and chemical analyses in order to detect the presence of metals (Cu, Ni, Zn, Cd, Mg), PAH, Norg_{tot} P_{tot} and COD_{tot} previous to the operation of the infiltration trench. These parameters characterise the initial state of the soil at the trench site and will be compared to the same parameters obtained from soil samples coming from the same site, after three years of the trench operation. This procedure will contribute the risk assessment of soil contamination due to the infiltration trench operation.

The runoff control performance assessment is done by a water balance calculation (Equation 1).

$$S_j = S_0 + \sum_{i=1}^{j} \left(I_i - Q_i \right)$$

(1)

For each one of the trenches, the inflow (*I*) and the volume of water stored (*S*) in time during the event are estimated through the water level measurements at the Parshall flume and at the trench, respectively. Outflows (*Q*) are obtained for each 1-minute time interval by Equation 1.

The wet weather diffuse pollution characterization is performed by the graphical analysis of pollutograms, mass-volume curves (Equation 2) and the calculation of inflow and outflow EMC (event mean concentration) (Equation 3).

$$\frac{\sum_{i=1}^{j} C_i Q_i \Delta t}{\sum_{i=1}^{N} C_i Q_i \Delta t} = f\left(\frac{\sum_{i=1}^{j} Q_i \Delta t}{\sum_{i=1}^{N} Q_i \Delta t} \right) = f\left(\frac{\sum_{i=1}^{j} V_i}{\sum_{i=1}^{j} V_i} \right)$$

(2)

$$EMC = \frac{M}{V} = \frac{\int_0^t C_t Q_t \, dt}{\int_0^t Q_t \, dt} = \frac{\sum C_t Q_t \Delta t}{\sum Q_t \Delta t}$$

(3)

where: C_i is the pollutant concentration at each time step; Q_i is runoff discharge; V_i is the runoff volume; Δt is the time step; M is the event total pollutant mass and V the event total runoff volume.

3 Results

3.1 Runoff control and peak flow attenuation

At the end of May 2008 the trenches were already installed at the UFMG campus. Nevertheless, apart from the inlet collection of sediment deposits, no other measurements were performed up to October 2008 due to the 6-month dry season typical of the local climate. Regarding hydrologic monitoring, ten events could be measured and had the data processed from the beginning of the rainy season. The experiment had to be interrupted during at about a month, in January, for reparation on the boxes containing the data loggers and modifications on the water sample procedure at the infiltration trench.

Table 1 contains the main results on peak flow attenuation calculated for the observed events. The results put in evidence the infiltration trench effectiveness in absorbing the runoff coming from the road for most of the observed events, with the exception of the 1st November 2008 event already described in Nascimento et al (2009). Actually, this particular event exceeded the 10-year design event characteristics. The other observed events have estimated return periods inferior to 10 years and even when the peak inflow is higher than that of 1st November as it is the case for the four last observed events in Table 1, their runoff volume is not sufficient to saturate the device.

Table 1 – Performance on runoff abatement

Data	**Infiltration trench**			**Detention trench**		
	Peak inflow (l/s)	**Peak outflow (l/s)**	**Attenuation (%)**	**Peak inflow (l/s)**	**Peak outflow (l/s)**	**Attenuation (%)**
1/11/2008	19.4	12.5	35.6%	19.4	16.1	17.1%
7/11/2008	6.7	0.0	100%	5.3	4.1	21.5%
13/11/2008	6.9	0.0	100%	5.8	4.8	17.3%
17/11/2008	5.2	0.0	100%	4.6	4.3	6.8%
19/11/2008	11.6	0.0	100%	11.4	5.8	49.6%
28/11/2008	17.5	0.0	100%	18.7	7.7	58.6%
29/11/2008	25.1	0.0	100%	27.0	13.7	49.1%
22/12/2008	22.5	0.0	100%	24.4	10.5	57.2%
27/12/2008	24.0	0.0	100%	26.3	11.3	57.0%
3/1/2009	25.1	0.0	100%	27.3	12.5	54.3%

The detention trench performance in peak flow attenuation presented a larger variability, from at about 7% up to 60% attenuation. Actually, its effectiveness is dependent of different factors related to the rate of runoff peak and volume. Better performances were obtained for sharp hydrographs with elevated peak flow.

3.2 Diffuse pollution abatement

TSS were evaluated on composed samples for five events since the beginning of the rainy season regarding the detention trench performance (Table 1). All the events are frequent, with return periods lower than 1 year. They show major differences in terms of their duration and antecedent dry period.

High values of TSS are observed when compared to the literature for road system wet weather diffuse pollution (see, e.g.: www.daywater.org). This is possibly explained by two factors; the first one is related to the process of water sampling initially adopted for this experiment, based on composed samples, which may have introduced a bias due to first flush effects, by not collecting the total hydrograph duration. Another factor is the deterioration of the asphalt of the paved road during the rainy season which showed points of intense erosion processes.

After the adoption of the automatic sampler in March 2009, a correcting factor relating the concentrations previously obtained to the EMC figures calculated for samples collected by the automatic sampler. With the use of this correcting factor, TSS concentration figures for the runoff entering the detention trench situated in the interval 327-936 mg/l. The detention trench performance in terms of pollution abatement dropped to figures from 18% up to 76%.

The pollution abatement performance is calculated as the rate of TSS concentration of composed samples at the device outlet by the same parameter evaluated at the device inlet.

Table 1. TSS abatement at the detention trench

Event	Rainfall characteristics			Water quality characteristics		
	previous dry weather period (day)	**Duration (min)**	**Depth (mm)**	**TSS (inflow) (mg/l)**	**TSS (ourflow) (mg/l)**	**Efficiency**
31/10/2008	12	30	19.8	1596	308	80.7%
7/11/2008	1.5	420	18.6	616	256	58.4%
27/11/2008	8.0	240	4.2	1955	ND	ND
8/12/2008	9.0	90	13.6	1660	702	57.7%
22/12/2008	3.0	30	4.8	1452	529	63.6%
01/02/2009	4.0	15	4.2	1451	183	87.0%
13/02/2009	0.5	360	62.6	1763	766	57.0%

The detention shows an interesting capacity of suspended solid treatment. Accordingly the total heavy metal content in the effluent is lower (Table 2). In table 2, average pollutant inflow and outflow concentration for six events are listed for the heavy metals monitored parameters as well as pollution abatement performances and corresponding standard deviations. In the case of heavy metals, the figures obtained in this main road are similar to the mean stormwater EMC found in the literature (www.daywater.org, Baptista et al, 2005).

For lead and also for nickel, the device performance in pollutant abatement is sufficient to meet the Brazilian Conama norm for level 2 water quality receiving bodies (CONAMA, 2005). Nevertheless, for Cu, Zi and Mn, the limits are not met. The efficiency on pollutant abatement varies from 44% up to 89%, although standard deviations present relatively high values, which are common in detention devices, frequently associated to re-suspension of previous settled sediments by new events.

Table 2. Detention trench: Elimination of heavy metals for the 6 rain events of 31/10/2008; 07/11/2008; 08/12/2008; 22/12/2008; 01/02/2009 and 13/02/2009

	IN (mg/L)	**% of events with pollutant concentration above the norm (%)**	**OUT (mg/L)**	**% of events with pollutant concentration above the norm (%)**	**Pollution abatement performance (%)**	**STD on abatement performance (%)**
Cr	0.034	0%	0.029	0%	59.0%	26.5%
Cu	0.087	100%	0.069	100%	43.6%	18.8%
Pb	0.047	100%	0.017	0%	88.6%	9.4%
Zn	0.394	100%	0.253	33%	52.1%	19.9%
Ni	0.017	17%	0.015	0%	57.5%	12.2%
Cd	< D.L.		< D.L.		< D.L.	< D.L.
Mn	0.505	100%	0.304	100%	55.1%	22.7%

A set up problem at the infiltration trench resulted in TSS figures that were clearly inconsistent, with negative efficiency on pollutant abatement, although similar behaviour is also reported for other experiments (Tomoto and Sakakibara, 2008). The sampling procedure has recently been changed, nevertheless no results are available so far to be here presented or discussed.

As previously mentioned, from March 2009 on the experiment inlet has been sampled with an automatic device to improve the evaluation of the pollutant load. Figure 3 illustrates electric conductivity and TSS for an event observed on 30th March 2009, with a total precipitation of 4.4 mm in 3h and 20 minutes. Water samples were collected upstream the section where the flow is divided to the infiltration and the detention devices. The hydrograph shown in the figure is the total inflow. In this figure, one can observe that the conductivity shows an inverse proportionality with the flow, a typical dilution pattern with the rain. For this event the peak of flux corresponds to the peak of flow, whereby 50% of the solid flux entered within the first 12 minutes. The suspended solids show a first flush behaviour, although with high level of solids even at the end of the event. The major source of solids is the erosion of the road surface showing more and more points of pavement rupture (wholes) at the end of the rainy season.

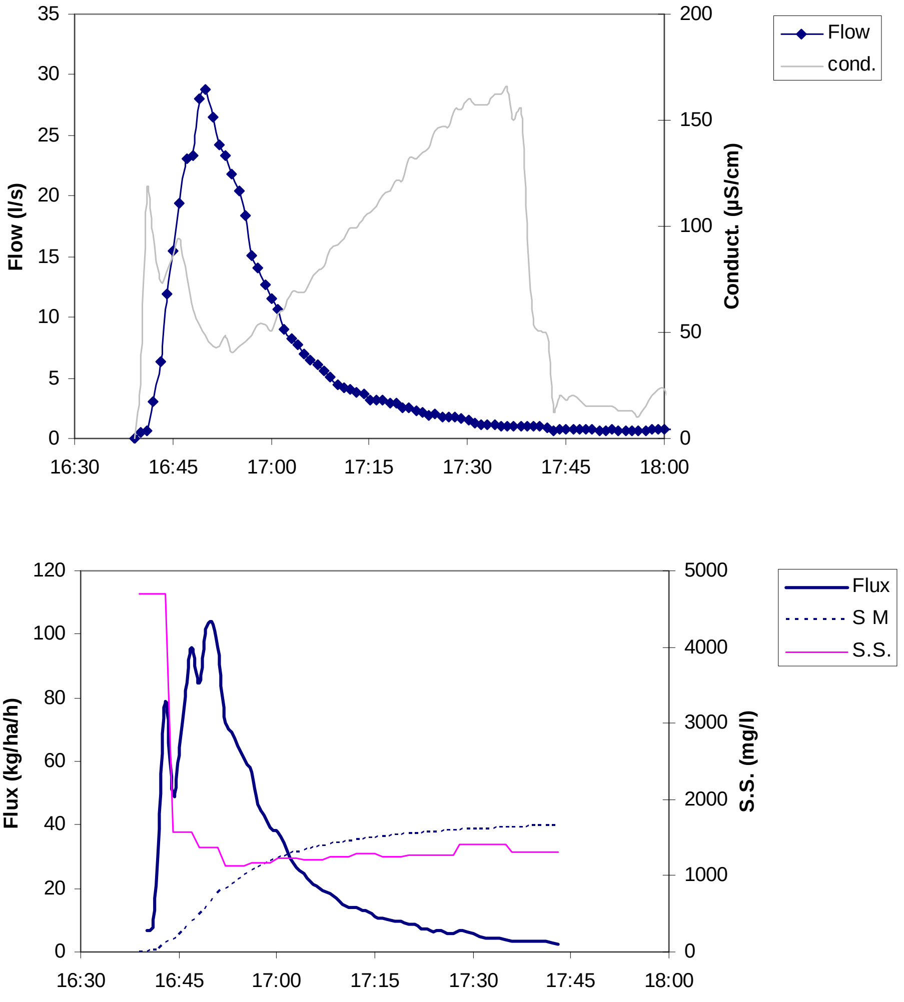

Figure 3. Inflow hydrograph and pollutograph for 30th March 2009:
(Legend: cond: electric conductivity; TSS: suspended soils concentration; SM: cumulated TSS, in kg)

The first flush phenomenon is also observed in the case of heavy metals and TSS by means of the pollutographs and M(V) curves (see Figures 4 and 5).

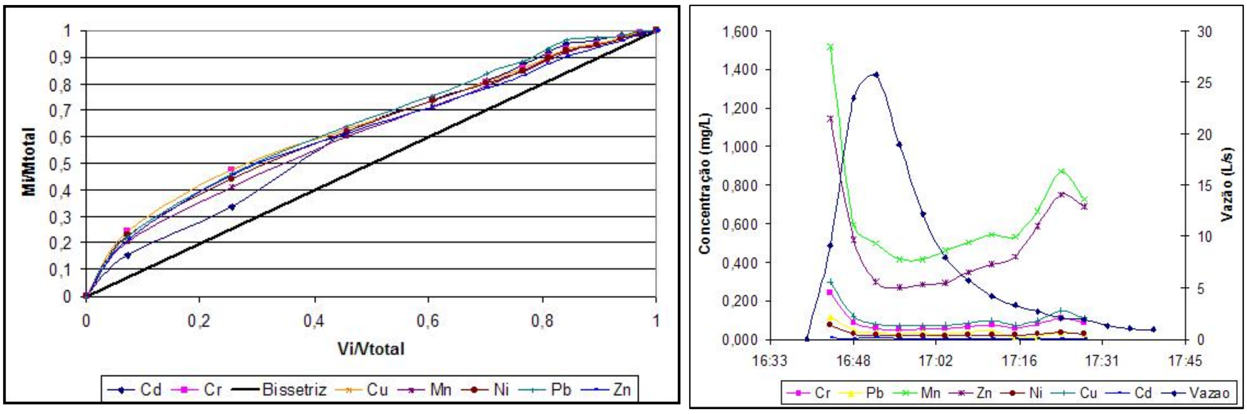

Figure 4. Curve M(V) and pollutographs for heavy metals – event of 30th March 2009.

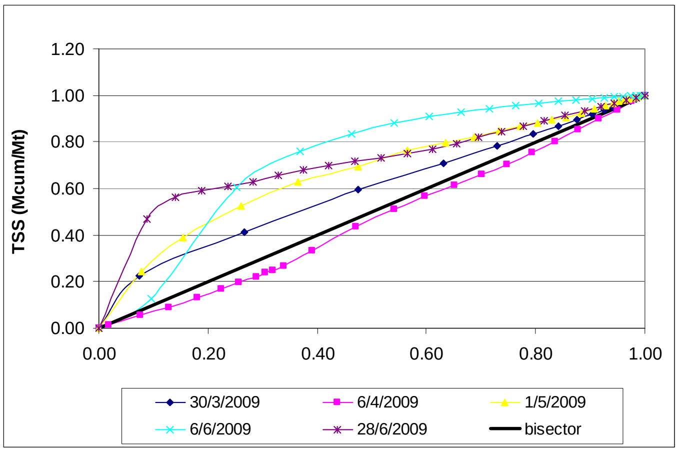

Figure 5. Curve M(V) for TSS – six monitored events.

4 Conclusions

The demonstration and research experiments carried out by the SWITCH project in Belo Horizonte address relevant questions on stormwater management, which are not usually taken into account by the city current urban drainage approach. The first measurement results are being produced through the infiltration and detention experiments for the first operational local rainy season (October 2008 – March 2009). The results concern still a small number of events that are contributing to the constitution of a data-base for further developments in terms of statistical analyses, modelling the rainfall runoff processes and the functioning of SUDS devices and uncertainty analyses on measurements.

In spite of the small number of events obtained, the results here presented and evaluated suggest that the detention and infiltration devices show an interesting possibility for runoff control and wet weather pollutant load abatement having origin on road systems. The reduction of pollutant load will be principally achieved with pollutant associated with suspended matter like heavy metals or HAP. The results also suggest that improvements on the maintenance of the road system may play a role in the reduction of pavement erosion processes during the rainy season.

Since it was settled, the demonstration here described has been visited by different stakeholders and students. A brochure explaining the experiment objectives and potential for use at a large scale was also produced and is distributed to visitors. The main results obtained with the demonstration was also presented and discussed in LA meetings. As a result of these initiatives, UFMG and the BH Municipality will organise a training activity on SUDS design and use in the coming future to meet the demand of people involved on stormwater management in Belo Horizonte and neighbour cities.

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