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SWITCH MONITOR

SWITCH in Belo Horizonte, Brazil: infiltration and detention systems for more sustainable stormwater control in Belo Horizonte

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Abstract Belo Horizonte, Brazil, is one of the demonstration cities of the SWITCH project. Flooding and wet weather pollution are major issues for the city. Because of this SWITCH in Belo Horizonte has focussed on more sustainable urban drainage systems (SUDS). Demonstrations are being conducted of infiltration and detention devices, artificial wetlands, and rainfall harvesting. This paper focuses on the use of detention and infiltration trenches to control runoff and abate wet weather pollution. Preliminary results indicate that use of these devices have potential for significantly mitigating suspended matter such as heavy metals originating from road surfaces.

1 SWITCH in Belo Horizonte

Belo Horizonte, Brazil is the capital of the State of Minas Gerais. It is located in a mountainous region of tropical soils with an average yearly rainfall of 1,500 mm and average yearly temperature of 21°C. The rainy season lasts from October to March when 90% of the rainfall occurs. Over 2.2 million people live in this high density (6,900 inhabitants/km^2) city and almost 4 million in the metropolitan area. Almost all residents are connected to the water supply but only about 92% to the wastewater system. During the rainy season there are numerous problems associated with flooding and wet weather diffuse pollution. Initially, SWITCH Learning Alliance activities were mainly oriented towards local community actions. Since 2008 a much larger Learning Alliance has been formed to set a vision and strategic direction for urban water management in the city.

2 Sustainable urban drainage systems (SUDS)

The relevant role of SUDS 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

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the abatement of wet weather non-point source pollution (e.g.: David and Sousa 2008; Tonoto and Sakakibara 2008; Daywater; Ciria 2007; Pasche et al. 2009). 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. Because SUDS makes the existence of water more visible it enables more opportunities for people to be involved in decision making and management of the urban environment.

Wider adoption of SUDS will require significant improvements of water governance and institutional development in urban areas. Their adoption by municipalities as a stormwater management approach depends upon a wide range of factors from the technical, institutional, economical, social and managerial domains. This is certainly the case when it comes to adopting SUDS for new urban developments and even more so when the focus is on retrofitting SUDS in existing developed urban areas. Some of the more common limiting factors include restrictions on land availability, interferences with existing infrastructures and retrofitting costs (e.g.: Todorovic et al. 2008; Lotourneau et al. 2008; Shuster et al. 2008). The objectives of improving stormwater management in urban areas in order to meet sustainability criteria require 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).

Part of the strategy of SWITCH is to address these issues by (1) 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).

3 Demonstrating SUDS in Belo Horizonte

SWITCH in Belo Horizonte has focussed on more sustainable urban drainage systems (SUDS). Demonstrations of infiltration and detention devices, artificial wetlands, and rainfall harvesting are being conducted. The specific objectives of these demonstrations are to: (1) establish criteria for identifying where and which type of urban drainage systems are appropriate for use in Belo Horizonte; (2) establish procedures for the design, implementation and operation of SUDS; (3) define SUDS operational and maintenance requirements; (4) assess building and maintenance costs and life cycle costs; (5) develop professional skills and capacity building on stormwater management with focus on SUDS. This paper focuses on the details and results of the infiltration and detention trenches demonstration.

Demonstration infiltration and detention trenches receive 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 3,880 m^2, essentially draining a stretch of the 4-way avenue oriented northward (Fig. 1). The runoff generated in this area is drained through gutters to an inlet where it is collected and conveyed to the experimental area. The runoff volume and discharge 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 (Fig. 1).

A 10-year design rainfall, based on the IDF regional equation for the Belo Horizonte Metropolitan Area–BHMA (Pinheiro and e Naghettini 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 (Hendricks 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 (Fig. 2).

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

Fig. 2 Infiltration trench (*left*); detention trench (*right*)

The experiment monitoring protocol comprises the following quantitative and qualitative variables: (1) rainfall, measured by a tipping bucket rainfall sensor; (2) inflows to each device measured by water pressure sensors (Parshall flumes); (3) water levels at each trench measured by water pressure sensors; (4) 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, temperature, turbidity, total suspended soils, metals (Cu, Ni, Zn, Cd, Mn, Pb, Cr) and PAH. These parameters are determined according to the APHA/AWWA standards.

The monitoring also includes the collection and physical and chemical analyses of sediments and solid wastes settled at the road drainage inlet. This analyses data will be associated to rainfall characteristics of intensity, volume and antecedent dry periods. 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. Prior to device operation these samples were submitted to physical and chemical analyses in order to detect the presence of metals (Cu, Ni, Zn, Cd, Mn, Pb, Cr), PAH, Norg_{tot} P_{tot} and COD_{tot}. for characterisation of the initial state of the soil at the trench site. This will be compared to the same parameters obtained from soil samples after 3 years of the trench operation. This procedure will contribute the risk assessment of soil contamination.

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

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

For both 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-min time interval by Eq. 1. The wet weather diffuse pollution characterization is performed by the graphical analysis of pollutograms, mass-volume curves (Eq. 2) and the calculation of inflow and outflow EMC (event mean concentration) (Eq. 3).

$$\frac{\sum_{i=1}^{j} C_i Q_i \Delta t}{\sum_{i=1}^{N} C_i Q_i \Delta t} = f\left(\frac{\sum_{i=1}^{j} Q_i \Delta t}{\sum_{i=1}^{N} Q_i \Delta t}\right) = f\left(\frac{\sum_{i=1}^{j} V_i}{\sum_{i=1}^{j} V_i}\right) \quad (2)$$

$$EMC = \frac{M}{V} = \frac{\int_{0}^{t} C_t Q_t dt}{\int_{0}^{t} Q_t dt} = \frac{\sum C_t Q_t \Delta t}{\sum Q_t \Delta t} \quad (3)$$

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.

4 Initial results

4.1 Runoff control and peak flow attenuation

At the end of May 2008 the trenches were installed at the UFMG campus. Apart from the inlet collection of sediment deposits, no measurements were performed up to October 2008 due to the 6-month dry season typical of the local climate. Ten hydrologic monitoring events could be measured from the beginning of the rainy season. The results obtained to date indicate the infiltration trench is effective in absorbing the runoff coming from the road for most of the observed events, with the exception of the 1st November 2008 (Nascimento et al. 2009). This particular event exceeded the 10-year design event characteristics. The other events, with estimated return periods lower than 10 years, have not produced runoff volume sufficient to saturate the devices, even when their peak inflows are higher than that of 1st November. The detention trench performance in peak flow attenuation presented a larger variability, from about 7% up to 60% attenuation. Its effectiveness depended on different factors related to runoff peak and volume rates. Better performances were obtained with high peak flow sharp hydrographs.

4.2 Wet weather diffuse pollution abatement

One o the parameters used for pollution abatement performance assessment is the TSS (total suspended solids), calculated as the rate of TSS concentration of composed samples at the device outlet by the same parameter evaluated at the device inlet. Total suspended solids (TSS) were evaluated on composed samples for five events since the beginning of the rainy season for the assessment of the detention trench performance (Table 1). All the rainfall events were 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 were 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 water sampling process initially adopted for this experiment that was based on composed samples. This may have introduced a bias due to first flush effects, by not collecting the total hydrograph duration. Another factor is

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

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

the deterioration of the asphalt of the paved road during the rainy season which showed points of intense erosion. After the adoption of the automatic sampler in March 2009, a correcting factor was introduced 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. Detention trench pollution abatement performance could then be estimated, ranging increased from 18% up to 76% according to event characteristics.

The detention shows an interesting capacity for suspended solids treatment including reduction in total heavy metal content in the effluent. (Table 2). In Table 2, average pollutant inflow and outflow concentration for six events are listed for the heavy metal monitored parameters as well as pollution abatement performance 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.

Sampling inflows with an automatic sampler allowed also observing first flush processes for most of the sampled events, as illustrated in Fig. 3 by means of pollutographs and M(V) curves for the event of 30th March 2009.

The assessment of pollutant abatement at the infiltration trench could not be done due to the fact that the drain set up under the detention trench for sampling infiltrated water was also transporting soil from the surrounding sampling point, resulting in negative efficiency; an inconsistent resulted also

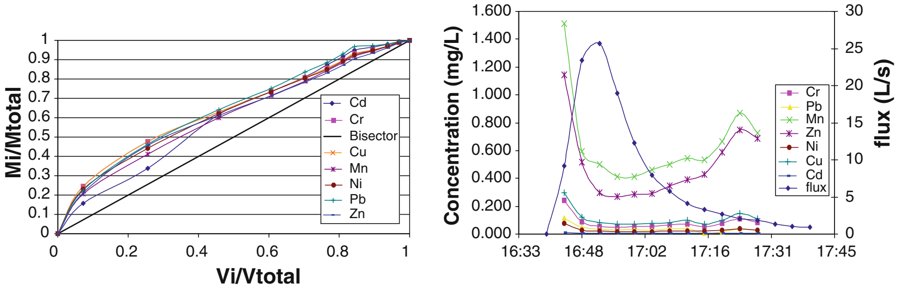

Fig. 3 Curve M(V) and pollutographs for heavy metals—event of 30th March 2009

observed in other experiments (see, for instance, Tonoto and Sakakibara 2008). This sampling procedure has recently be modified but without observed results available up to now.

5 Conclusions

The demonstration and research experiments carried out by SWITCH in Belo Horizonte address relevant questions on stormwater management, which are not usually taken into account by the city's current urban drainage approach. Initial measurement results are being produced through the infiltration and detention experiments for the first operational local rainy season (October 2008–March 2009). Currently data from only a small number of events has been obtained. These results are contributing to the populating 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 presented and evaluated here suggest that the detention and infiltration devices show an interesting possibility for runoff control and wet weather pollutant load abatement originating from road systems. Pollutant load reductions will be principally achieved for pollutants associated with suspended matter like heavy metals or HAP (hydrocarbures aromatiques polycycliques). The results also suggest that improvements to maintenance of the road systems may reduce erosion and therefore play a role in the reduction of pollutants into the drainage system during the rainy season.

Since it was initiated, the demonstration 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 were also presented and discussed in the Belo Horizonte Learning Alliance meetings. As a result of these initiatives, UFMG and the BH Municipality are organising a training activity on SUDS design and use to meet the demand of people involved on stormwater management in Belo Horizonte and neighbouring cities. This is then producing a paradigm shift in terms of stormwater management in the city, from a centralised and "get rid of rainwater" approach to a more integrated, diffuse and source control approach. Also, LA discussions on sustainable stormwater management are resulting in a wider concern on urban waters management, incorporating concepts as urban total water cycle management and enhancing the opportunities for river restoration and water sources protection on on-going and planned municipal projects.

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