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Environmental and economic assessment of a pilot stormwater infiltration system for flood prevention in Brazil

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ABSTRACT

Green and grey stormwater management infrastructures, such as the filter, swale and infiltration trench (FST), can be used to prevent flooding events. The aim of this paper was to determine the environmental and economic impacts of a pilot FST that was built in São Carlos (Brazil) using Life Cycle Assessment (LCA) and Life Cycle Costing (LCC). As a result, the components with the greatest contributions to the total impacts of the FST were the infiltration trench and the grass cover. The system has a carbon footprint of 0.13 kg CO_2 eq./m^3 of infiltrated stormwater and an eco-efficiency ratio of 0.35 kg CO_2 eq./USD. Moreover, the FST prevented up to 95% of the runoff in the area. Compared to a grey infrastructure, this system is a good solution with respect to PVC stormwater pipes, which require a long pipe length (1070 m) and have a shorter lifespan. In contrast, concrete pipes are a better solution, and their impacts are similar to those of the FST. Finally, a sensitivity analysis was conducted to assess the changes in the impacts with the varying lifespan of the system components. Thus, the proper management of the FST can reduce the economic and environmental impacts of the system by increasing its durability.

1. Introduction

1.1. Floods and stormwater Best Management Practices (BMP)

Flooding events are commonplace in many cities of the world. The agents that lead to this phenomenon include the precipitation intensity, stormwater volume, time span of the precipitation event and degree of urbanisation, among many others (Kundzewicz et al., 2007). With more than 50% of the world's population living in urban areas (UN, 2012), changes in land use become apparent, and the degree of soil imperviousness increases, especially in developing countries. As a result, there is an increase in the stormwater runoff and a subsequent reduction in the infiltration rate. Hence, urbanisation affects the occurrence of floods when the lack of permeability is combined with sudden and intense precipitation (Butler and Davies, 2000). In addition to being a source of water pollution and natural damage, these events also result in relevant economic and social costs because of building and personal property damage (Ntelekos et al., 2010).

Therefore, stormwater runoff must be properly managed to prevent floods and to protect water resources and public health (USEPA, 2013). The so-called stormwater "Best Management Practices" (BMPs) are of paramount importance in terms of flood risk reduction and can be applied in urban areas under several configurations. These strategies are commonly classified into grey and green infrastructures (Fig. 1). The former consist of traditional practices in the field of urban drainage, such as sewers or detention tanks, and normally have a single function, e.g., to store and transport water. In contrast, the latter are multifunctional integrated systems that are designed to deliver ecosystem services in urban and rural areas (European Commission, 2013). This is the case of infiltration trenches, green roofs or permeable pavements. In this study, most attention is paid to filter, swale and infiltration trenches (FST), which are complex, decentralised systems.

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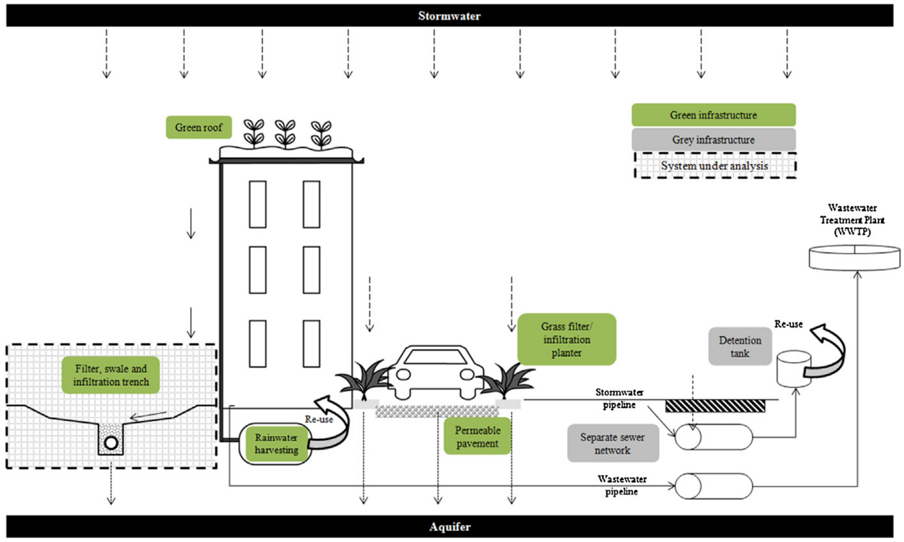

Fig. 1. Strategies of different types of stormwater BMP in urban areas and the system under analysis.

In general, all of the options reduce the quantity of stormwater runoff that needs to be transported through conventional sewers by disconnecting storm- and wastewater pipelines (Semadeni-Davies et al., 2008) or by implementing other alternative systems (Butler and Davies, 2000). In the case of green roofs, for instance, Lee et al. (2013) reported that the stormwater retention capacity is high when the rainfall intensity is lower than 20 mm/h. Therefore, the efficiency of green roofs varies depending on the climate, among other aspects. In this respect, the installation of green roofs in 10% of the buildings in Brussels (Belgium) would result in a 54% runoff reduction (Mentens et al., 2006). In Michigan (USA), a 63–94% reduction could be achieved in extensive green roofs during heavy and light rainfall events, respectively (Getter et al., 2007).

Moreover, techniques involving a layer of vegetation can also improve the stormwater quality and quantity, given that plants are natural filters (Table 1). In this sense, grass filters and swales can reduce pollutant loads by 46–86% (Deletic and Fletcher, 2006). In addition, vegetated systems induce the natural infiltration of stormwater to aquifers when in contact with the soil. In the case of grey infrastructure, stormwater can be re-used for non-potable purposes, such as irrigation, when it is collected by means of storage tanks. In this way, stormwater can be envisioned as a resource. However, separate sewers have only been adopted in some regions because of the economic costs their construction entails. Alternatively, detention tanks are also beneficial, as they can induce a 45% reduction in the discharge impacts of combined sewers in a Mediterranean basin (Llopart-Mascaró et al., 2014).

Generally, BMPs can be implemented in most areas, but they are especially relevant in wet regions or areas with intense rainfall events. In the long term, local and national administrations must keep this issue in mind, given that the current situation of climate change might lead to an increase in the rainfall intensity and peaks worldwide. This phenomenon might be particularly notable at mid and high latitudes (Meehl et al., 2007), and current management systems might become insufficient for addressing stormwater. Therefore, these regions should be thoroughly studied considering both urbanised areas and future building projects.

1.2. Environmental and economic assessment of stormwater BMPs

Different studies have analysed the environmental effects of various BMPs. To do so, Life Cycle Assessment (LCA) (ISO, 2006) is a suitable tool that helps to calculate and discuss the environmental burdens of the life cycle stages of a system, i.e., from raw material extraction to end of life. From this perspective, it was determined that green roof surfaces have lower environmental impacts than conventional rooftops. The former reduce the heating and cooling requirements of a building and extend the lifespan of the roof by protecting the roof membrane (Kosareo and Ries, 2007; Saiz et al., 2006).

In the case of bio-infiltration rain gardens, the construction stage accounts for the major environmental and economic costs because of the contributions of silica sand and bark mulch (Flynn and Traver, 2013). In contrast, the operation stage entails a series of avoided burdens, such as carbon sequestration (40 kg C/year), and the relative impacts are thus lower. Carbon sequestration is common in vegetated layers; as a result, green roofs can also sequester up to 375 g C/m^2 per year according to some estimates (Getter et al., 2009). Similarly, grass filters and swales remove up to 5 kg C/m^2 per year when located next to roadways in the USA (Bouchard et al., 2013).

Furthermore, BMPs can perform additional functions apart from stormwater management. Wastewater treatment is a key function of constructed wetlands and, in this case, the construction phase also plays an important role (Risch et al., 2011). Still, those treatments consisting of vertical flow reed bed filters have up to 3 times less impact than do conventional activated sludge technologies (Risch et al., 2014). Similarly, rainwater harvesting systems can be used in dry areas to take advantage of a scarce resource. In addition to re-using rainwater for non-potable purposes, installing domestic storage tanks is feasible in drier regions, such as the Mediterranean (Farreny et al., 2011). Given that tanks can be smaller than in regions where more rainwater can be collected, their carbon footprint is also smaller (EA, 2010). Construction materials might account for up to 95% of the environmental impacts when the tank is placed on the roof (Angrill et al., 2012). In addition, the location of the tank plays an important role, and an exergy or useful-energy analysis determined that placing the tank on the roof of buildings with a relatively high density is the most efficient option (Vargas-Parra et al., 2013).

Additionally, green and grey infrastructures can be compared considering an equivalent reduction of stormwater runoff. For instance, De Sousa et al. (2012) achieved a 77–95% impact reduction when a combination of green infrastructures (e.g., permeable pavements, bio-retention tanks and infiltration planters) was