ENVIRONMENTAL ASSESSMENT OF STORMWATER INFRASTRUCTURES BUILT WITH BEST MANAGEMENT PRACTICES

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ABSTRACT: Although some infrastructures were built for environmental purposes, there is a growing concern about their actual environmental impacts. In the context of hydrologic risk management, Best Management Practices (BMPs) are compensatory techniques in urban drainage based on physical processes for the temporary storage or infiltration of stormwater. The environmental burdens taking place in the different life-cycle stages of a service, i.e., raw materials extraction, construction, transportation, use and maintenance and end-of-life can be estimated, analysed and discussed following the Life Cycle Assessment (LCA) methodology. The objective of this study is to apply LCA to quantify the environmental impacts of the implementation of new flood prevention systems, based on the BMPs. In this case, the infiltration system consists of a grass filter, swale and infiltration trench (FST) located in São Carlos (São Paulo, Brazil). After conducting the impact assessment, an estimated carbon footprint of $1.5{\cdot}10^4$ kg of CO_2eq was obtained, considering a lifespan of 10 years and a runoff storage capacity of 110 m^3. The main contributors to this impact are the infiltration trench and the grass layer that covers the entire surface of the system. To the authors' knowledge, no other studies have analysed the environmental impacts of an FST from a life-cycle perspective. Therefore, future studies should work towards the assessment of the net environmental benefits (i.e., the burdens and the benefits) resulting from the implementation of this type of infrastructure.

Key Words: Life Cycle Assessment, flood risk management, construction, eco-efficiency, infiltration trench

1. INTRODUCTION

1.1 Urban Environments and Flood Risk

The rapid expansion of urban settlements all over the world has led to the proliferation of artificial environments and, consequently, to severe effects on the water cycle. Covering the ground with impervious materials implies an increase in the stormwater runoff and a reduction in the infiltration rate. When combined with sudden and intense precipitation, it can end up in flooding events and pollution of water bodies because of the wash-off of pollutants and sediments (Butler and Davis 2000). Moreover, economic and social costs deriving from these events are rising because of buildings and personal property damage (Ntelekos et al. 2010). Hence, working towards the implementation of Best Management Practices (BMP) is essential in order to reduce the risk of flooding in urban areas, especially in those regions with adverse climatic conditions. In Brazil, for instance, certain regions have an average annual rainfall of 1500 mm (INMET 2014) and are affected by flooding events every year.

Although the implementation of BMPs has many benefits in terms of human, material and environmental costs, their construction also derives in a series of environmental burdens and economic costs. Therefore, they must be taken into account to be aware of the net benefits of this type of infrastructure.

1.2 Environmental Assessment of BMPs

Many studies dealing with the environmental effects of different flood prevention infrastructures have been performed in the past (Table 1). They mainly assessed the so-called “green infrastructure”, which includes source-control devices such as green roofs, bio-retention tanks and permeable pavements, among many other alternatives.

Table 1: Types of BMP and potential benefits resulting from their implementation (Source: compiled by the authors)

Type of infrastructure	BMPs	Potential benefits
Green infrastructure	Green roofs Bio-retention tanks/ basins Permeable pavements Grass filters Infiltration trenches Bio-infiltration rain gardens Infiltration planters Constructed wetlands Rainwater harvesting infrastructures Grass filter, swale and infiltration trench (FST)	↓ stormwater quantity ↑ stormwater quality ↑ avoided environmental impacts ↑ natural infiltration to the aquifers ↓ wastewater treatment ↑ rainwater reuse for non-potable purposes
Grey infrastructure	Separate sewer networks Detention tanks	↓ wastewater treatment ↑ rainwater reuse for non-potable purposes

Green roofs have been thoroughly analysed because of their potential to retain stormwater runoff (Lee et al. 2013). In Brussels (Belgium), for instance, installing green roofs in 10% of the buildings would result in 54% runoff reduction (Mentens et al. 2006). Moreover, they can also act as environmental mitigation technique given that green roofs can sequester up to 375 g $C{\cdot}m^{-2}$ through the layer of vegetation (Getter et al. 2009). In addition, the environmental impacts deriving from their implementation can be estimated using Life Cycle Assessment (LCA) (ISO 2006), which considers the burdens of the life-cycle stages of a good or service from the material extraction to the end-of-life of the materials. Energy savings in the heating and cooling of the building and a longer lifespan result in green roofs having lower impacts than conventional roofs (Saiz et al. 2006, Kosareo and Ries 2007).

Another alternative connected to vegetation is the use of grass filters. Apart from inducing stormwater infiltration, they can also sequester carbon and they could be applied next to roadways. In the United States, up to 5 kg $C{\cdot}m^{-2}$ were removed from the environment by wetland swales adjacent to roads (Bouchard et al. 2013). Further, a grass filter could reduce between 46 to 86% of the pollutant load of the runoff (Delectic and Fletcher 2006). From a life-cycle perspective, a bio-infiltration rain garden was assessed and it was reported that the main environmental and economic impacts derived from the construction phase, whereas there were avoided impacts during the operation phase (Flynn and Traver 2013). Similarly, constructed wetlands contribute to the runoff reduction and the water quality improvement (Butler and Davis 2000). In this sense, Risch et al. (2014) performed an LCA to compare conventional activated sludge technologies and an alternative vertical flow reed bed. In all indicators, the former scored worse than the latter, with differences of 3 orders of magnitude in some cases.

Green infrastructure can also be compared to “grey infrastructure” (i.e., separate sewer networks and detention tanks). Considering the existent drainage systems, disconnecting stormwater from combined sewers can reduce combined sewer overflows and water pollution (Semadeni-Davis et al. 2008). Using

LCA, De Sousa et al. (2012) compared different green and grey strategies to reduce overflows. The first scenario considered the construction of permeable pavements, bio-retention tanks and infiltration planters. The second and third scenarios considered an end-of-pipe detention tank without and with treatment, respectively. The results showed a reduction in 77% and 95% of the environmental impacts when scenario 1 (19,000 tonnes of CO_2eq over 50 years) was implemented instead of scenarios 2 (85,000 tonnes of CO_2eq) and 3 (400,000 tonnes of CO_2eq), respectively. The main reasons for the lower impacts were the sequestered carbon and lower treatment requirements. In terms of water quality improvement, Wang et al. (2013) performed a consequential LCA and determined that the most cost-efficient alternative was the bio-retention basin.

By contrast, there are other types of infrastructure that can be used in dry regions, apart from being a source-control device. In the case of rainwater harvesting systems, various analyses have been performed to determine the environmental and economic impacts of urban domestic water tanks (Hallmann et al. 2003, Angrill et al. 2012, Vargas-Parra et al. 2014). Farreny et al. (2011) also conducted an analysis to identify the most suitable roof type to harvest rainwater and concluded that the potential of sloping smooth roofs can be 50% greater than that of flat rough roofs. To account for the energy requirements in the construction of storage tanks, Vargas-Parra et al. (2013) reported that locating them on the roof of high-density buildings is the most efficient option in terms of exergy or useful energy.

Among all these BMPs, this study focuses on induced infiltration systems, specifically grass filter, swale and infiltration trenches (FST). Little information was found on the environmental costs resulting from the construction of this complex system in the case of regions with high risk of flooding; hence it would be useful to determine the environmental impacts of this type of BMP using LCA.

2. GOAL AND SCOPE

2.1 Goal

The main objective of this study was to estimate the environmental impacts of the construction of a grass filter, swale and infiltration trench (FST) and to determine the most environmentally friendly design for the city of São Carlos (Brazil) with respect to other alternatives. To achieve this goal, the specific objectives were (a) to compose an inventory of the materials and energy inputs in the life cycle of a FST; (b) to identify the impacts of the construction of a FST using LCA, and (c) to compare the impacts of a FST with other BMPs reported in previous literature.

2.2 Functional Unit

The impacts of the system were related to a functional unit (FU). In this case, it was defined as the construction of one FST consisting of a channel, manifold and infiltration trench with a lifespan of 10 years and a maximum storage capacity of 110 m^3 of stormwater in a region with an average annual rainfall of 1500 mm.

3. MATERIALS AND METHODS

3.1 Description of a FST

The FST under analysis is a real-scale system built in 2009 in the campus of the Federal University of São Carlos (UFSCar), located in São Carlos (São Paulo, Brazil), for the control and quality improvement of the building's direct runoff. The system was supported by a legal apparatus – the Participative Master Plan for Cities. This BMP prevents flooding events by collecting and directing stormwater directly underground. An area of 1701 m^2 is responsible for the rainwater contributions to the infiltration system and is located at the roof of the building of the Department of Medicine. The path of the runoff consists of six steps (Figure 1):

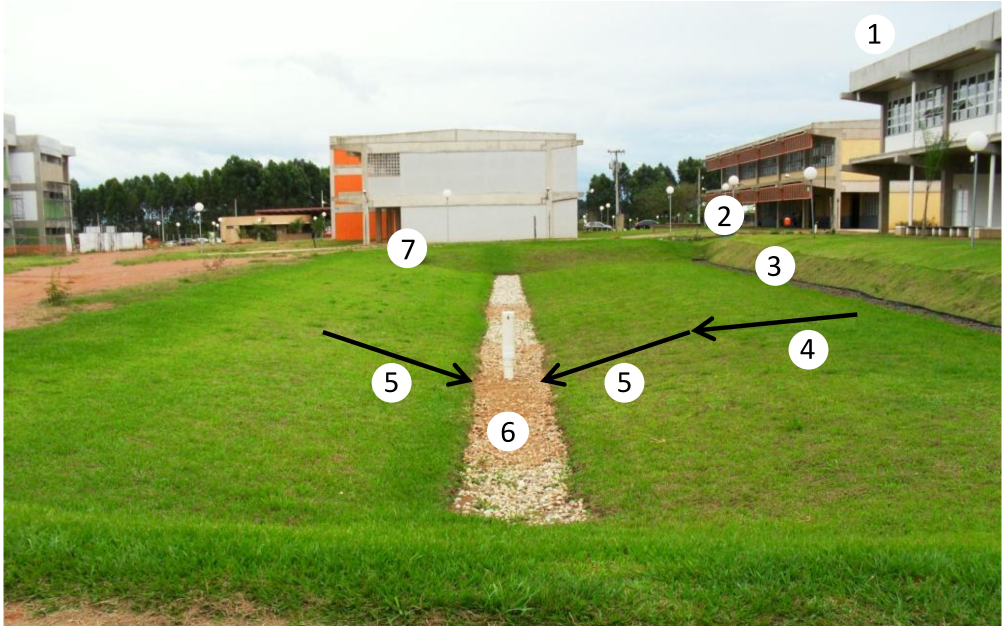

Figure 1: Design of the FST in São Carlos

(1) rainwater drained from the roof of the building is conducted through a network (2) and a channel that is 0.60 m wide and 7 m long to a triangular weir for flow measurement; (3) the flow is distributed via a manifold and (4) a 4-metre-wide grass filter, with 2% incline plane (5) to finally reach the swale and (6) the infiltration trench and (7) an overflow weir.

3.2 System Boundaries

Following the LCA methodology, the life-cycle stages of the FST that were considered are the raw material extraction, production of manufactured goods, transport to the construction site and the construction of the channel, manifold, infiltration trench and grass cover (Figure 2). Facilities related to the building such as concrete beams were excluded from the analysis because it was assumed that they existed before the construction works of the FST began. The operation stage was excluded from the analysis, assuming that it can be neglected and the system must be totally replaced when the infiltration bed is blocked by sediments.

Regarding the end-of-life, only the excavated soil was considered, as this type of waste is generated during the construction phase and must be disposed of. However, the waste material deriving from the demolition process was not accounted for because the treatment or disposal alternatives applied in this case were unknown, but considered negligible. According to the cost analysis performed by Fairfax (2005), an infiltration trench has an estimated lifespan of 10 years. This time span was considered the study of the FST.

With respect to inventory data, the UFSCar was responsible for sizing the infrastructure and provided high-quality data that were used to estimate the material and energy flows required to build the FST (Table 2). The diesel consumed by the machinery to compact and backfill the soil and filling materials was calculated using the MetaBase ITeC (2010) for construction materials. Of all the subsystems, soil compaction only occurs in the channel. As for the other cases, compaction would not enable the natural infiltration. An average distance of 30 km was assumed for the transport of local-sourced materials, such as concrete, cement mortar, gravel or sand, to the construction site; an average distance of 100 km was used for plastics and metals and 10 km to the landfill (Doka 2009).

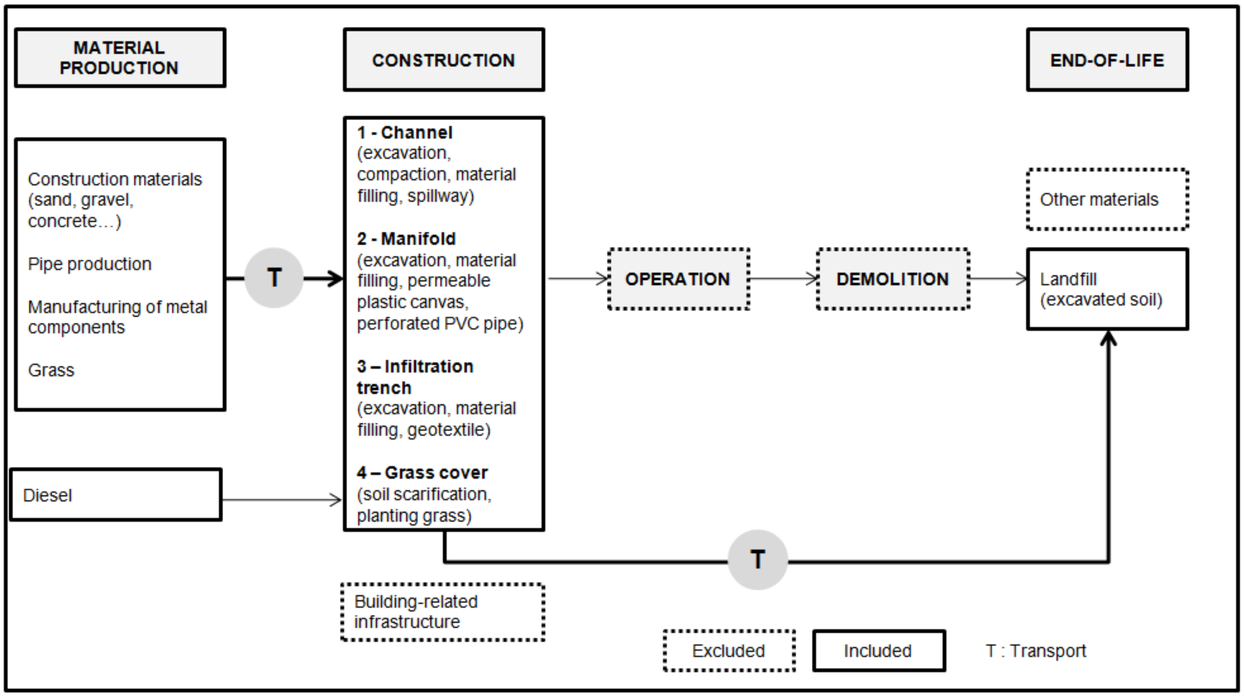

Figure 2: System boundaries

To perform the impact assessment, the classification and characterisation phases included in the LCA methodology were considered. The CML IA method (Guinée et al. 2002) was used. Of all the impact categories included in this method that could be reported in a study on construction materials (EN 15804:2011)(i.e., Abiotic Depletion Potential, Acidification Potential, Eutrophication Potential, Global Warming Potential, Ozone Depletion Potential, Human Toxicity Potential and Photochemical Ozone Creation Potential), only the Global Warming Potential was selected due to its current importance. This way, the impacts resulting from this system can be compared to the ones obtained in other BMPs.

To do so, the ecoinvent 2.2 (ecoinvent 2009) database, linked to the software SimaPro 7.2.0 (PRé Consultants 2010), was used for the evaluation of emissions related to the materials and energy. All processes were adapted to the Brazilian electricity mix of the year 2011 (IEA 2014).

Table 2: Inventory data of an FST with a lifespan of 10 years

Flows	Total material and energy flows			
	Sizing		Estimated Flows	
Concrete	0.8	m^3	1,803	kg
Concrete block	0.6	m^3	1,552	kg
Brick	22.6	m^2	1,109	kg
Roughcast plaster	34	m^2	340	kg
Cast iron	0.38	m^2	52	kg
Steel	0.01	m^3	83	kg
Gravel	48	m^3	80,451	kg
Sand	5	m^3	7,735	kg
Perforated polyvinylchloride (PVC) pipe	44	m	91	kg
Polyethylene (plastic canvas)	56	m^2	6	kg
Polyester resin (geotextile)	174	m^2	52	kg
Grass	1,432	m^2	28,640	kg
Excavated soil	337	m^3	546,136	kg
Diesel			7,309	MJ
Metal product manufacturing			135	kg
Extrusion process (plastic pipes)			91	kg
Extrusion process (plastic films)			6	kg
Transport by lorry (to construction site)			7,355	tkm
Transport by lorry (to landfill)			10,923	tkm

4. RESULTS AND DISCUSSION

According to the technical features of the FST analysed in this study, the environmental impacts deriving from the LCA imply a carbon footprint of $1.5 \cdot 10^4$ kg of CO_2eq. When the system is divided into its main parts, the main contributors to the total impacts of the infrastructure can be identified (Figure 3). In this case, the infiltration trench and the grass cover account for approximately 40% of the impact, respectively. On the one hand, the infiltration trench has the greatest material and energy requirements of the system, leading to large transport burdens. On the other hand, there is an important amount of grass that needs to be produced to cover the entire surface of land. The ecoinvent process that best represents this type of grass refers to the intensive production in Switzerland. Therefore, it must be taken into account that other technologies could be used in Brazil and the impacts deriving from them could be lower or greater.

When comparing with another infiltration system, in this case a bio-infiltration rain garden, the impacts of the construction phase is very similar in both cases (Table 3). However, this estimation is made assuming the annual impact of the designed volume. For a better approach, the total runoff stored in these BMPs through a year should be considered. This value is unknown for the FST in Brazil, but should be reported in the future. Moreover, further analyses should also address the possibility of varying the lifespan considering that some part of the FST could last longer.

Table 3: Comparison of the LCA of the FST and the construction of a bio-infiltration garden

Flows	Designed runoff storage volume	Lifespan	Estimated impact
FST	~110 m^3	10 years	15 kg CO_2eq/year/m^3
Bio-infiltration rain garden (Flynn and Traver 2013)	~10 m^3	30 years	16 kg CO_2eq/year/m^3

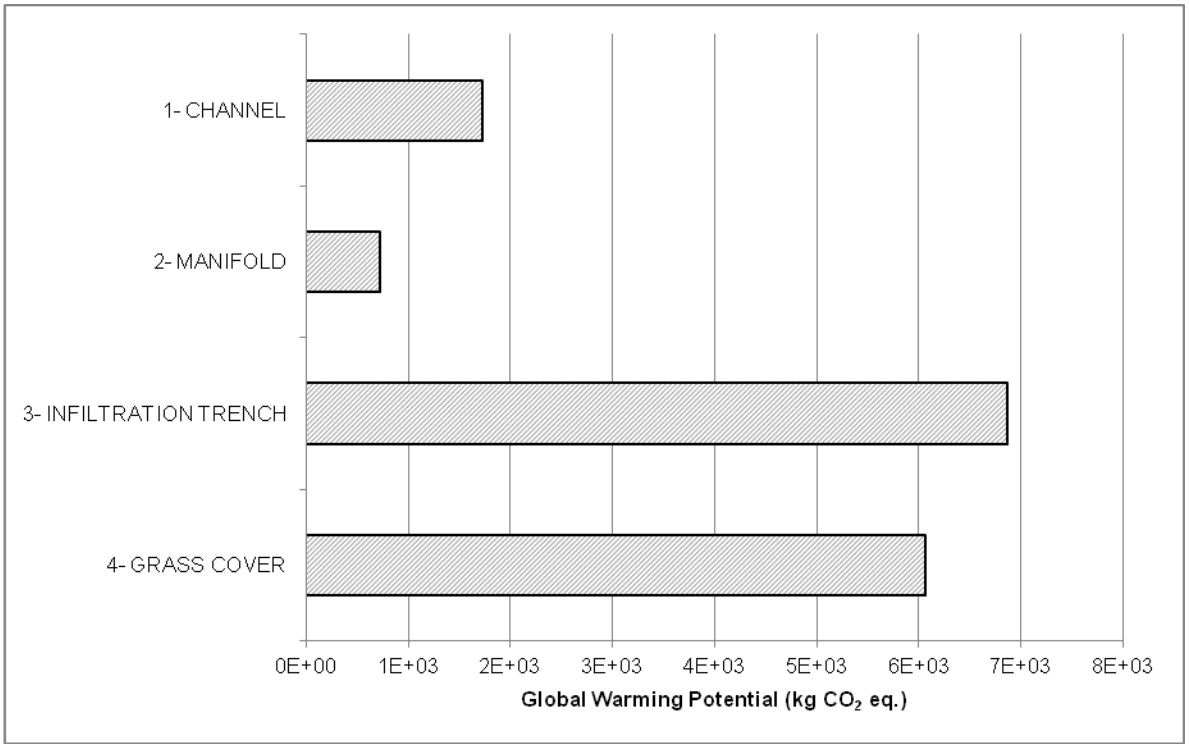

Figure 3**:** Total carbon footprint of the FST divided into subsystems

5. CONCLUSIONS

The environmental impact of a flood prevention technique has been presented in this study and it was found that the FST built in Brazil has a carbon footprint of $1.5 \cdot 10^4$ kg of CO_2eq. This system helps to reduce the quantity of stormwater runoff that is transported by sewer networks and it is an option that should be considered in areas affected by intense precipitation events. In general, the infiltration trench and the grass cover are the subsystems that present greater environmental burdens.

Future studies should analyse the effects of varying the lifespan of the infrastructure or some of the parts that constitute this system. An in-depth analysis should also propose alternatives to the existing materials and energy sources in order to encourage best environmental practices in future construction projects. In addition, studies should also focus on the comparison of the environmental impacts resulting from the construction of this infrastructure and the benefits of its implementation, in terms of avoided economic costs and material loss. In this line, the avoided environmental impacts resulting from carbon sequestration in the grass cover must be addressed to compare the FST with other BMPs and highlight the importance of green infrastructure.

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