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Research article

Application of stormwater collected from porous asphalt pavements for non-potable uses in buildings

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ABSTRACT

This study assessed the potential for potable water savings in a building by using stormwater filtered by a porous asphalt pavement located in a parking lot. Stormwater is meant to be used for non-potable purposes (flushing toilets and urinals). Two models of porous pavement systems were constructed, both with porous asphalt mixture over a different combination of porous granular layers. The models were assessed for their filtering capacity; samples of stormwater runoff were collected in a parking lot located near the building where filtered stormwater is meant to be used. The models showed to be capable of filtering some pollutants. However, additional water treatment would be necessary to obtain the quality required for non-potable uses. Then one model was selected for a theoretical analysis on using it in a parking lot. The potential for potable water savings was analysed considering four scenarios as a function of daily local rainfall data. The thickness of the temporary stormwater reservoir layer was calculated in order to meet the design rainfall adopted, and the stormwater tank capacity was estimated using the *Netuno* computer programme. As a result, using a 45,000-litre stormwater tank, potable water savings of at least 53% would be obtained if filtered stormwater were used to flush toilets and urinals. This indicates that porous pavements show a great potential for filtering stormwater runoff to be used in buildings.

1. Introduction

In recent decades, Brazil has been facing a growing and disorderly urbanization process wherein 84% of the population live in urban areas. As also observed in many countries the impervious areas cause impacts on the environment related mainly to changes in the hydrological cycle, which intensifies floods especially in densely populated cities (Jacobson, 2011; Hamzah et al., 2012; Miller et al., 2014; Chughtai et al., 2014).

In the Brazilian urban centres, when rain events occur with high intensity in a short period of time, floods are common and lead to human and material losses. In order to mitigate the effects of urbanization, some urban water management strategies can be used. The use of retention reservoirs may be an alternative, but this requires the use of large areas, not always available. Another example is the use of porous pavements composed of draining layers (concrete, asphalt, bricks as a surface and, granular porous layer) that have a high volume of voids and interconnected voids through which the water can pass through and be filtered.

Porous asphalt pavements are designed to serve as stormwater storage and infiltration systems, as well as providing a rolling surface. They can be used for low traffic roads and parking lots. It is an alternative for public planners to manage stormwater runoff in an environmentally friendly way. These pavements also promote infiltration, improve water quality, control the peak and the total runoff volume and, depending on the type of system, can recharge the groundwater reservoir (Hansen, 2008; TRCA, 2010; UNHSC, 2014).

The potential for runoff reduction using porous pavement was measured by many researchers; it varied from 45% to 99% (Schueler, 1987; Pratt et al., 1995; Legret and Colandani, 1999; James and von Langsdorff, 2003; Kwiatkowski et al., 2007; TRCA, 2010).

In a porous pavement, the stormwater that infiltrates through the layers can be temporarily stored and after that, used (CIRIA, 2015). Once all the structure is permeable, it is able to promote the flow damping, the temporal alteration of the hydrographs and the reduction of the drained volumes (Ferguson, 2005; Hansen, 2008; Roseen et al., 2011; FHWA, 2015).

Palla et al. (2017) proposed a methodology to assess the impact of domestic rainwater harvesting systems in stormwater runoff control in an urban block located in Genoa (Italy). Such systems contributed to

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limit overflow discharges and drainage system failures; reduce the amount of runoff volume that needs to be treated before discharging into water bodies; and decrease the use of potable water.

Pratt (1999) analysed a porous pavement used as a permanent reservoir in a stormwater harvesting system in a hostel in the United Kingdom, in which the pavement stores the stormwater filtered and also the rainwater collected from the roof of the building. After six months, the water quality parameters stayed stable because the surface contaminants of the pavement layers had been washed out. The water quality parameters such as suspended solids and lead were low in value and pollutant outflow loadings were lower than those of impervious surfaces.

In general, parking lots are located in large areas, providing a good space to implement a porous pavement system (Hamzah et al., 2012). In this system, uniformly graded stone reservoir course layer acts as a structural support for the pavement and provides temporary water storage before percolating into the soil. Hamzah et al. (2012) also concluded that a porous parking lot system with 110 cm reservoir course layer was able to withstand about 500 cm/h rainfall intensity.

Rainfall levels in southern Brazil, where this study was performed, are high and there is an accelerated urbanization process and corresponding increase of impervious areas, which result in frequent floods. On the other hand, the potable water consumption is high and the resources are scarce. Therefore, it is important to use alternative water sources in buildings. Stormwater collected from porous asphalt pavement may emerge as an alternative water source for non-potable uses such as toilet flushing, landscaping and car washing (Joon, 2017) in order to save potable water.

The objective of this research was to assess the potential for potable water savings in a building by using stormwater filtered by a porous asphalt pavement that will be located in a parking lot. Stormwater is meant to be used for non-potable purposes, i.e., flushing toilets and urinals. Tests to evaluate the stormwater quality were also performed. The case study was carried out in a building and a parking lot of the Federal University of Santa Catarina, in Florianópolis, Brazil.

2. Porous pavements and water quality requirements

2.1. Porous pavements

Porous asphalt pavement has been studied by several researchers in many applications with worthy results (Berbee et al., 1999; Pagotto et al., 2000; Roseen et al., 2011).

A permeable parking lot system consists of a porous surface, in general porous asphalt mixture, over a reservoir structure composed of permeable layers for temporary stormwater retention. The reservoir course layers are filled with washed, uniformly graded stone that allows infiltration and provides structural support for the pavement (Rowe et al., 2009). The porous pavement layers are established according to the function for which they are designed, either for the temporary storage of the water or to improve its quality, as shown in Table S.1 in the Supplementary data.

Porous pavement represents an important opportunity to harvest and store urban stormwater, and this would decrease runoff into the drainage network. Porous pavement has a surface area that is ideal for stormwater harvesting and filtering. The principle is: stormwater infiltrates through the pavement surface, it is filtered by the pavement layers and then it is stored in a tank (Scholz and Grabowiecki, 2007, 2009; Beecham and Myers, 2007; Tota-Maharaj et al., 2009, 2010). When the stormwater passes through the pavement structure it is filtrated and significant improvements in the water quality can be obtained according to the types of permeable pavement layers used. Then, the stormwater can be used for several purposes (Beecham and Myers, 2007).

The porous asphalt mixtures have high content of connected voids (18–25%). Once air and water circulate and go through the pores, an early oxidation and loss of adhesiveness may occur, and the use of modified asphalt is indicated. The aggregates requirements are the same as those for conventional mixtures, but their gradation should be uniform and open graded, with few filler content (passing through sieve #200) (NAPA, 2002; CALTRANS, 2006; Stanard et al., 2007; CALTRANS, 2008).

The choker course layer (or stabilizing course) is composed of clean single-size crushed stone smaller than the stone in the reservoir course layer to stabilise the surface for paving equipment (Hansen, 2008). An optional filter course layer can be used to improve the quality of the stormwater. In this case, a filter blanket layer is needed to prevent that material from the filter course migrates to the reservoir course layer. This layer (also called stone recharge bed) consists of a clean single-size crushed large stone with about 40% voids and serves as a structural layer and also as a temporary reservoir. The geotextile fabric allows water to pass through and prevents that fine material from the subgrade migrates to other layers, especially to reservoir course layer (RWMWD, 2006; Stanard et al., 2007; FHWA, 2015).

The amount of water that infiltrates through the porous pavement depends on several variables, such as, rainfall intensity, evaporation, surface runoff and the stormwater that comes from impervious areas (ASCE, 2013). In order to collect stormwater for non-potable purposes, pipes are placed at the bottom of the reservoir course layer, spaced between 3 and 8 metres (Fig. S.1 in the Supplementary data) (ASCE, 2013; UNHSC, 2014).

The system needs to predict the flow of the water volume in a period of 6–12 h (Araújo et al., 2000) and Tomaz (2006) considers that this time can be 24–72 h. The coefficients of permeability (k) for porous asphalt mixtures, reported by some researchers, differ. On average, k values were 0.16–0.41 cm/s for Welleman (1976), Woelfl et al. (1981) and Gemayel and Mamlouk (1998); 0.13–0.20 cm/s for Hardiman (2004); and 0.12–0.35 cm/s for ASCE (2013).

One disadvantage is that porous pavement requires periodic maintenance to prevent clogging, independent of the surface type. They depend on traffic; the surface must be aspirated and washed with pressurized water from one to four times a year (FHWA, 2015; CIRIA, 2015). James (2003) adds that the effect of high-speed vehicle traffic may contribute to pore cleaning due to air pumping at the tire/surface interface.

The stormwater runoff from urban roads represents an important source of pollution of rivers and lakes (Coleri et al., 2013). The presence of organic and inorganic pollutants in road surface stormwater runoff have been reported by many researchers (Dechesne et al., 2004; Herngren et al., 2005; Soller et al., 2004; Scholes et al., 2008; Kayhanian et al., 2009; EPA, 2011). One alternative to reduce the discharge of the pollutants into water bodies is the use of porous pavement (Jacobson, 2011; Chai et al., 2012; Li et al., 2013; Coleri et al., 2013). The pollutant sources from road surface runoff are classified into three main categories (Table S.2 in the Supplementary data), such as atmospheric deposition, vehicles, and direct and indirect deposition application (WSDOT, 2007).

Table 1 shows the reduction of pollutants measured in the stormwater runoff of porous asphalt pavement in relation to the impervious ones. Table 2 shows a comparison between water pollutants concentration evaluated in porous and impervious asphalt pavements.

Many studies indicated that the passage of stormwater through the porous asphalt pavement can reduce the amount of suspended solids, hydrocarbons and metals in such water (Barret et al., 1995, 1998; Berbee et al., 1999; Roseen et al., 2011; Chai et al., 2012; Abustan et al., 2012; Li et al., 2013; Coleri et al., 2013).

The capacity of porous pavement to remove pollutants, i.e., their filtering capability, is related to the ability of their layers in allowing infiltration. Full infiltration systems, in which the stormwater penetrates through all pavement layers, are more effective because little amount of pollutants are carried to water bodies. In impervious pavements, the stormwater pollutants are carried away by runoff. After that,