Hydraulic and hydrologic modelling to evaluate the design of permeable pavement in a catchment perspective

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Highlights

- Permeable pavement can provide considerable runoff control even with no infiltration in the subsoil
- Modelling can be a good approach to evaluate design methods of stormwater control structures
- The current Brazilian standard for permeable pavement needs to be reviewed and actualized

Introduction

The hydrologic cycle changes due of increase in global mean temperature will have great impact on urban environments and infrastructures. Managing stormwater from the uncertain perspective of climate change is a major challenge in developed countries (Liu et al., 2018) and become a more critical problem in developing countries, where flooding disaster management is reactive yet (Salazar-Briones et al., 2020). This is due to the usual practice of stormwater management hygienist approach, i.e., based on assumption that "it is necessary to drain an area", leading to flow through pipe as quickly as possible (Souza et al., 2013).

In Brazil, the traditional urban drainage (grey infrastructure) has been predominating in most municipalities. However, drainage infrastructure existent no longer has the capacity to keep pace with the urbanisation (Caprario and Finotti, 2019). Even though the use of green stormwater infrastructure to restore natural hydrological functions of urban catchments is not widespread in Brazil, few norms exist to standardize the implementation of these techniques, as the Brazilian standard of permeable pavements with total infiltration in the subsoil NBR16416 (ABNT, 2015).

Permeable pavement is considered a cost-effective stormwater management practice that absorbs treats, and/or stores runoff in highly urbanized areas (Cheng et al., 2019). The Brazilian standard from permeable pavements indicates the design only for pavements with total infiltration in the subsoil. However, due to the presence of low permeability subsoil material or high water table (typical situation in coastal areas), permeable pavement system driven infiltration is not suited. Thus, evaluating permeable pavement design methods that nullify the portion that considers infiltration is crucial for the adaptation this structures in low elevation coastal zones. Therefore, the study aims to compare the modified Rain-Envelope Method considering a pre-development flow with the Brazilian Standard NBR 16416, nullifying the subsoil infiltration for both, through Hydraulic and Hydrologic simulations. The permeable pavements were designed to replace conventional pavements found in the Federal University of Santa Catarina - UFSC area parking lots. Located in Florianópolis, southern Brazil, this coastal urban watershed presents recurrent flooding problems due the low permeability, high water table, unplanned land use and occupation, undersized and poorly maintained drainage systems (Tasca et al., 2020).

Methodology

Design of permeable pavements

Permeable pavement design methods can be basically divided into two categories: mechanical design and hydraulic design. Hydraulic design aims to ensure a sufficient volume in the reservoir layer, while mechanical design aims to provide a better distribution of loads until the subsoil can resist, avoiding failures or excessive deformation (Ballard et al., 2015). The thickness of the pavement's reservoir must attend both hydraulic and mechanical sizing, adopting the highest one.

Due to restrictions found in the subsoil infiltration and considering that Brazilian standard NBR16416 indicates a method of hydraulic design only for total infiltration pavement, the pavements were designed by two methods: (1) adaptation of the Brazilian standard and (2) Rain-Envelope Method modified by Silveira and Goldenfum (2007) considering a pre-development flow in their outlets.

Hydraulic- Hydrological Modeling

To model the the UFSC campus watershed in SWMM, it was subdivided into sub-catchments, taking into account the drainage sections and the Digital Terrain Model through the software ArcGIS, using the Arc Hydro Tools. Thus, the watershed was subdivided into 7 sub-catchments (Figure 1). For each sub-catchment, the following data were entered in the SWMM: area; characteristic width; slope; percentage of impermeable area; Manning coefficient; depression storage of pervious and impervious areas; the infiltration model and the outlet of the sub-catchment.

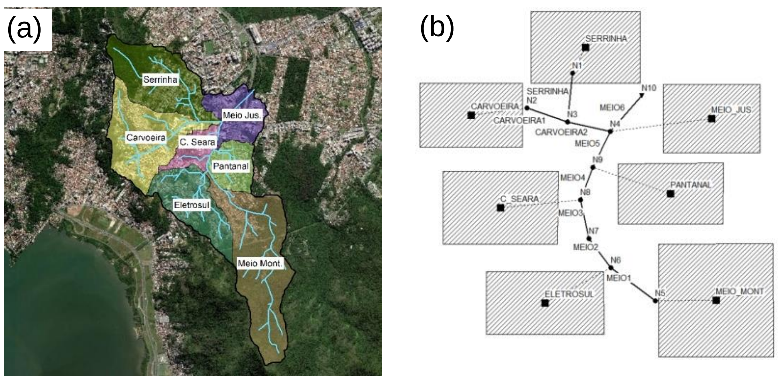

Figure 1 - Representation of UFSC campus watershed in (a) ArcGIS and (b) SWMM.

The SCS method was chosen for the infiltration model. The average CN values for each sub-catchment was obtained by area weighting, using the soil hydrological group and land use data. Parameters related to the sections, roughness and base flow of the channels were inserted in the model.

The model calibration and validation process was supported by PCSWMM software. Water level obtained at the Meio river outfall and rainfall data from the meteorological station were used in this process.

After the calibration and validation processes, the pavements were inserted into their sub-catchments in order to observe their response considering the spatial allocation of the structures. The inserted pavements were evaluated considering a design storm with 60 minutes and a return period of 10 years.

Results and discussion

The design methods resulted in different thickness for the permeable pavements for 32 parking lots in the study area, with higher thickness when using the NBR16416.

The initial simulation obtained the following statistical indices ISE = 2.33, NSE = -0.214 and R^2 = 0.434. After calibration, ISE = 0.18, NSE = 0.202 and R^2 = 0.529 were obtained, which can be classified as "Excellent", "Bad, but acceptable" and "Satisfactory", respectively (Moriasi et al., 2007). The observed and modeled levels before and after calibration are shown below (Figure 2).

For validation, four events had unsatisfactory NSE values, while one acceptable and three from satisfactory to good. Four events were rated from satisfactory to good using R^2 criteria. Regarding the ISE, only one event was classified as bad, the other events obtained a good adjustment in relation to this index.

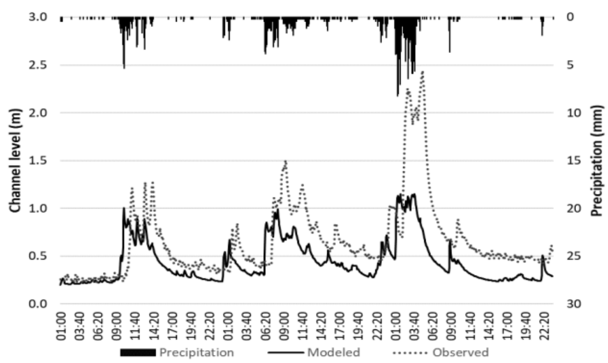

Figure 2 - Meio river's final stretch observed and modeled level.

The pervious pavement reservoirs designed follwing the NBR 16416 method presented thickness much deeper than those obtained by the Rain-Envelope Method. Even the thickness were different for both design methods, the modelled runoff was similar. Modelling results pointed out the potential of pervious pavement, with approximately 35% reduction of the maximum surface runoff generated in the Meio Jusante sub-catchment, while occupying about 10.45% of the area of this sub-catchment. It is noteworthy that due to the characteristics of the study area, the analysed permeable pavement has its working principle only temporary storage, without providing infiltration in the subsoil.

Conclusions and future work

The modified Rain-Envelope method considering a pre-development flow in the outlet has proved to be a good alternative to design permeable pavement with no infiltration in the subsoils. Furthermore, the current Brazilian standard for permeable pavement needs to be reviewed and actualized, especially to include methods to design permeable pavements with partial and no infiltration in the subsoil.

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