Validating new insights for sizing of stormwater treatment practices by comparing a design model to HEC-HMS

Validation de nouvelles perspectives pour le dimensionnement des techniques de traitement des eaux pluviales par comparaison d'un modèle de dimensionnement à HEC-HMS

Altair Rosa*, Marina Batalini de Macedo*, Eduardo Mario Mendiondo*,**, Vladimir Caramori Borges de Souza***

*Sao Carlos Engineering School/University of Sao Paulo (EESC/USP), Brazil (altair.rosa17@gmail.com); ** National Center for Monitoring and Early Warning of Natural Disasters (CEMADEN), Brazil; *** Federal University of Alagoas

RÉSUMÉ

Le système de drainage en cours au Brésil n'a pas évolué aussi vite que la croissance urbaine de ces dernières décennies. Les structures traditionnelles de drainage des eaux pluviales sont incapables de gérer et de résoudre de nombreux problèmes de ruissellement contemporains. Le développement de technologies telles que le Low Impact Development (LID), ont émergé comme une solution de remplacement de drainage afin de combler cette lacune. Cependant, des méthodes robustes pour évaluer la performance des études prospectives sont nécessaires. Normalement, les méthodes pour concevoir des Techniques Compensatoires (TC) sont basées sur le contrôle de la qualité ou le contrôle de la quantité : il n'y a aucune approche d'intégration qualité-quantité. Cette recherche présente des expériences démonstratives sur TC en mettant l'accent sur une approche intégrée dans les aspects de la qualité et la quantité du système de drainage urbain. Nous recherchons des méthodologies de conception globale et d'évaluation de l'efficacité de TC. L'approche expérimentale comprend le dimensionnement modulaire de dispositifs de dissuasion pour contrôler le ruissellement et les charges en polluants, ainsi que la biorétention. Le but de cette étude est de comparer le modèle de conception développé (BIRENICE) avec un modèle existant pour une pratique de LID, à savoir la biorétention. Le modèle choisi était un modèle numérique, un Système de Modélisation Hydrologique (HEC-HMS 3.5). Les performances à long terme de simulation de biorétention indiquent que BIRENICE est une méthode efficace et recommandée pour la poursuite des recherches dans le sujet présenté, ce qui démontre la nature robuste de la méthode de conception basée sur des événements.

ABSTRACT

The current drainage system in Brazil did not grow in the same rate that the urban growth did in the past decades. Traditional stormwater drainage structures are unable to manage and solve many contemporary runoff problems. The development of technologies such as Low Impact Development (LID), have emerged as an alternative drainage solution in order to fill this gap. However, robust methods to evaluate performance of prospective designs are needed. Normally, the methods to design Compensatory Techniques (CT's) are based on quality control or quantity control: there is no quality-quantity integration approach. This research presents demonstrative experiments on CT's, focusing on an integrative approach in quality and quantity aspects of urban drainage system. We are looking for generalized methodologies to design and to evaluate CT's efficiency. The experimental approach includes modular dimensioning of deterrent devices to control runoff and pollutant loads and bioretention. The aim of this study is to compare the design model developed (BIRENICE) with an existing model for an LID practice, i.e., bioretention. The chosen model was numerical model, Hydrologic Modeling System (HEC-HMS 3.5). Long-term performance of the simulated bioretention indicates that BIRENICE is an efficient method and recommended for further research in the presented topic which demonstrates the robust nature of the event-based design method.

KEYWORDS

Treatment practices sizing, LID, bioretention, modular sizing, quality-quantity

1 INTRODUCTION

Historically, urban drainage in Brazil has focused on surface runoff hydraulic treatment, resulting in the concept of conduit based drainage systems, as highlighted by Pompêo (2000). In the 1990's the brazilian research centers dealing with urban drainage sought to adapt the so-called "stormwater treatment practices" to offset the effects of urbanization on runoff, whose review and typology are discussed by Baptista et al. (2005). These experimental and adaptive approaches have been termed as Sustainable Urban Drainage Systems-SUDS, Water Sensitive Urban Drainage-WSUD, Best Management Practices-BMP and Low Impact Development-LID (ROSA *et al*, 2013).

According to Fletcher et al. (2012), these new approaches prioritize induced infiltration, retention, runoff bio-filtration, and control at the runoff source, landscape integration with the urban space, no transfer of downstream impacts and a multidisciplinary approach with environmental, educational and social participation.

Despite more than two decades of study about these technical operation and sizing, most studies have focused on hydrologic and water quality performance limited to the laboratory-scale. There are also remaining gaps in how to predict the hydrologic and water quality effectiveness of particular LID practice designs. Additionally, little research work has focused on real LID practices deployed in urban catchments, and very few have been conducted in subtropical climates such as those found in Brazil. There is a lack of understanding in the basic physical processes through which LID actually works when applied in field interaction, visual integration issues, waste and water quality issues, and potential risk of environmental degradation (LIU *et al,* 2014). A particular need is to address the sizing issue, what size is appropriate for a real watershed (ROY-POIRIER *et al*, 2010).

Given the increasing adoption of biofilters and bioretention cells, it is important that their size should be based on rigorous study, incorporating key design parameters within an integrative approach. This paper presents a bioretention cell design and sizing methodology contained within a developed computational simulation model, called BIRENICE, which uses a simple metric system known as load detention.

The proposed methodology considers the range of hydrological effects governing the treatment processes from the individual lot to the micro drainage scale. Qualitative and quantitative effects are also incorporated. It was also built a bioretention system cell using an incremental approach. Therefore, simulations were made for the years 2013 (current) and 2025, using the developed simulation model BIRENICE and comparing with model HEC-HMS, targeting a past situation (estimated by 1900).

2. METHODOLOGY

2.1 BIoREteNtIon CEll Method - BIRENICE

The proposed methodology incorporates the following parameters in its calculation: hydrological risk, rainfall intensity, contributing drainage area, soil properties, net precipitation, runoff coefficient, drained peak flow, stored volume, bioretention geometry, mass reduction, inflows, spillway and infiltration outflows, pollution load, reductions in inflows and discharges. In order to simulate the device water budget and to validade the size methodology, we used the Level Pool Routing - PULS method, asa propagation approach.

To facilitate the design of a bioretention cell a computational model was developed to simulate and optimize its design, using unique parameters to each cell given its specific location. A key feature of the method is the fact that it estimates the eventual size of the bioretention cell for multiple, cumulative scenarios. This enables the designer to select a variety of trial sizes and iteratively simulate each bioretention cells in steps, by setting the desired time intervals and the input parameters. To test its field application, a bioretention device was sized in Campus – Area 2 of USP São Carlos using an incremental approach. The scenario was set for the period of 2013-2025, using 20-minute rainfall durations, since it is the most frequently observed duration in São Carlos.

2.2 HEC-HMS SIMULATION

For the simulation with HEC-HMS, the same two scenarios were adopted: with 1900 land use as a period of unchanged vegetation, and the altered (urbanized) scenario projected to 2013 – 2025. Both of them represented by the change in a runoff prediction method coefficient in each simulation. In this paper, it was adopted the Curve Number method; and CN coefficient values were varied according to land use for future scenarios.

It was proposed the evaluation of the catchment response to a 20-minute rainfall event of 10-year return period. For the simulation, a short-term water balance was assumed in order to estimate the size of the bioretention cell. In the HEC-HMS structure, a reservoir represents the bioretention cell at the outlet, composed by a thin wall triangular spillway. The useful volume of the cell is adopted as the soil empty ratio. A stage-volume curve characterizes the cell's geometry.

3. RESULTS AND DISCUSSION

3.1 BIRENICE sizing

The model was structured for use with multiple scenarios rather than build a single structure to meet a final plan (in 2100). Initially only the first module is built, which will meet the first stage (2013-2025). In 2025, the second module will be built, being an expansion of the first, which will attend the second stage (2025-2050), then, in 2050, the third module will be constructed, which will meet the third stage (2050-2100). The structure should be built from upstream to downstream; consequently, the input structure could be used in all stages, avoiding rebuilding. The area required for the final plan (2100) is reserved from the start. In Figure 1, it is possible to observe a scheme containing the experimental bioretention dimensions.

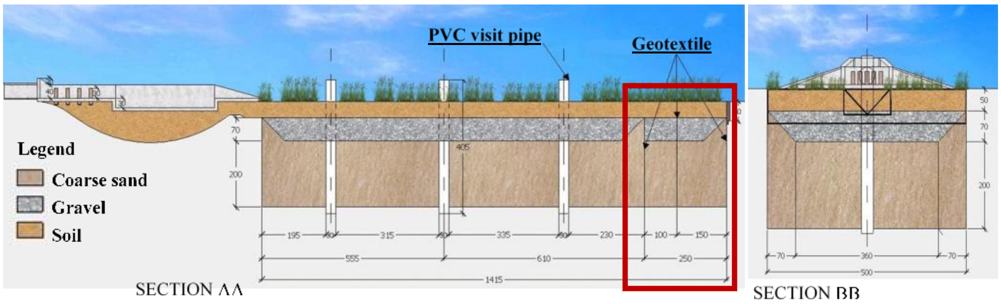

Figure 1 – Bioretention dimensions considering modular expansion (in red).

3.2 BIRENICE and HEC-HMS simulations

In order to simulate using BIRENICE and HEC-HMS methods, a return period of 10 years and 20 minutes rainfall duration were selected as input data. The rainfall intensity was then calculated, giving a value of 91.77 mm/h. First a hydrograph for each year proposed, as simulation scenario, was determined for the catchment area of corresponding bioretention cell. The results were obtained with both methods for years 1900 (pre-urbanization), 2013 (current period) and 2025 (future). It can be noted that, for all scenarios, peak flow occur 20 minutes after the rainfall starts, for BIRENICE, and 30 minutes for HEC-HMS.

The peak flow grows over the years, due to the increasing urbanization of fields, leading to an increasing impermeabilization and; therefore, an increasing of runoff. Comparing BIRENICE to HEC-HMS values it is possible to observe that BIRENICE always simulates greater peak flow amounts. The difference between the peak flows of both methods is ascending, and for greater levels of urbanization (later years) the difference on percentage is higher. This states that the percent difference for the year 1900 is 21%, for 2013 is 24% and for 2025 is 31%.

The inflow hydrograph obtained through BIRENICE method was used as input data to size the bioretention cell, as shown in the previous section. BIRENICE and HEC-HMS also simulate the internal water dynamics in the basin, for the years 2013 (Figure 2) and 2025 (Figure 3).

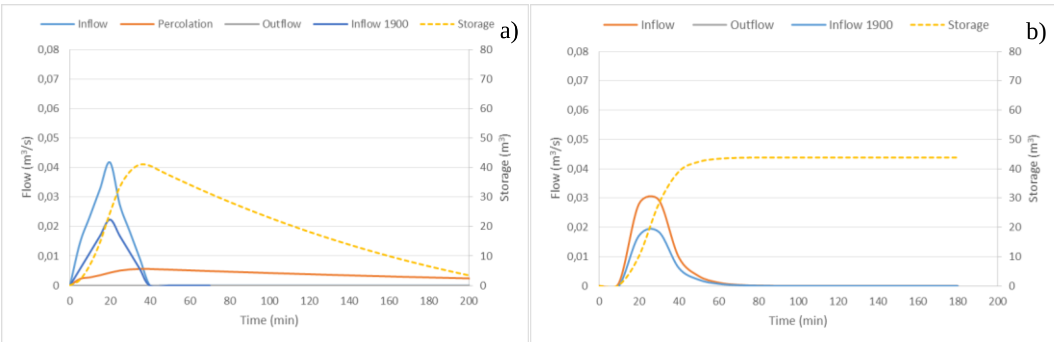

Figure 2 - Internal water dynamics simulation for 2013 with methods a) BIRENICE and b) HEC-HMS

For 2013 and 2025, with both simulations the outflow (outlet spillway) is zero, which means that all the inflow is retained and infiltrated / percolated through the basin. These results show that the bioretention system built is oversized for the urban scenarios and rainfall intensity envisaged. Accordingly, it is expected that the bioretention system supports more intense rainfall events, without exceeding the volume. In addition, considering the data generated, it can be concluded that the time interval for which the modular sizing was conceived can be extended, since the structure support flows of higher intensity.

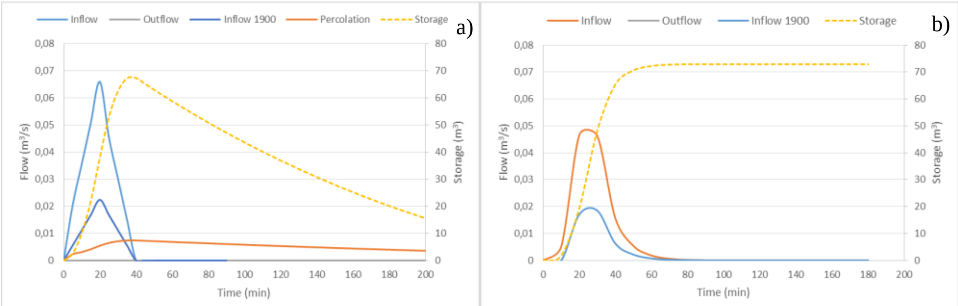

Figure 3 - Internal water dynamics simulation for 2025 with methods a) BIRENICE and b) HEC-HMS

As for the volume stored in the basin, for 2013 the BIRENICE method gives a storage peak in 40 minutes (20 minutes after the peak flow from inlet hydrograph), presenting a volume of 40.66 m³ (Figure 5a). After the peak, the storage begins to decrease due to the percolation process. On the other hand, for the HEC-HMS method, the trial did not consider the percolation effect, thus the storage reaches its peak and remains constant. Therefore, for 2013 the storage peak volume is 43.8 m³ and occurs in 80 minutes (50 minutes after the peak flow from inlet hydrograph) (Figure 2b). For 2025, BIRENICE method presented a storage peak also in 40 minutes, with a volume of 67.13 m³ (Figure 3a) and HEC-HMS, presents a maximum volume storage of 72.81 m³, occurring also in 80 minutes (Figure 3b). The simulations have a difference in the order of 7% as basin storage capacity, for both scenarios.

According to the simulation results for outlet hydrographs for the years 2013 (Figure 2) and 2025 (Figure 3), in both methods, it is observed that the bioretention basin is oversized. To optimize its construction, new dimensions have been calculated based on a new outlet hydrograph simulated with a peak flow equal to the year 1900, using HEC-HMS method. This year was considered to be prior to the urbanization process, so its hydrograph represents the natural water cycle for this catchment. Simulating this peak flow value is possible to reach the objective proposed by the use of LID practices.

It is noted that there is a decrease in the basin storage, up to 28%, due to the increasing outflow. In addition, regarding the dimensions it is possible to reduce by 57% the length of the basin for the year 2013 and up to 48% in 2025. The significant reduction on the dimensions will decrease the construction costs, making it more accessible in short term. However, the increase of the basin, according to the modular sizing, would have to be done in a shorter time. Therefore, depending on the availability of financial resources, each option becomes more interesting.

CONCLUSION

The bioretention cell designed for this basin was sized for a 10 year return period, seeking to attenuate peak flow and to reduce runoff volume. Its dimensions were planned for future expansion, called modular sizing. 20-minute rainfalls were used in BIRENICE method, and the eventual bioretention cell was sized in order to prevent overflows to occur for 10 years. Device storage peak occurs shortly after the hydrograph runoff peak, and the structure emptying time is around 295 minutes, for 2013 and 2025. The outflow passing by the spillway, in all cases, is null. It represents an output hydrograph temporal rearrangement, as a consequence of the bioretention device.

The comparison with the HEC-HMS method was used to validate the results obtained by the computational model. The sizing and simulation method proposed, BIRENICE, shows little difference with HEC-HMS results. It is possible to conclude that BIRENICE is an efficient method and recommended for further research in the presented topic.

REFERENCES

BAPTISTA, Márcio B.; NASCIMENTO, Nilo O.; BARRAUD, Sylvie. 2005. *Técnicas Compensatórias em drenagem urbana* (Compensatory techniques in urban drainage). POA: ABRH, 266p.

FLETCHER, T.D., ANDRIEU, H., HAMEL, P. (2012) Understanding, management and modelling of urban hydrology and its consequences for receiving waters: A state of the art, *Advances in Wat. Res.* (in press)

LIU, J., D. SAMPLE, C. BELL and Guan, Y. 2014. Review and Research Needs of Bioretention Used for the Treatment of Urban Stormwater. Water 6: 1069-1099.

POMPÊO, César A. (2000). Drenagem Urbana Sustentável. *Revista Brasileira de Recursos.Hídricos* (Sustainable Urban Drainage. Journal of Water Resources), 5(1): 15-23.

ROSA, A; MENDIONDO, E. M.; SOUZA, V. C. B.. *Biorretention to control diffuse pollution in the urban drainage system: experimental-adaptive approach with ecohydrological basis*. In: XX Simp. Brasileiro de Rec.Hídricos, Bento Gonçalves - RS, 2013.

ROY-POIRIER, A.; CHAMPAGNE, P.; FILION, Y. Bioretention processes for phosphorus pollution control. *Environ. Rev*. 2010, 18, 159–173.