A simulation tool for comparing the hydrological performance of various associated stormwater source-control techniques at the scale of buildings and blocks

Un outil de simulation pour la comparaison des performances hydrologiques de différentes combinaisons de techniques alternatives de gestion des eaux pluviales à l'échelle de la parcelle

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ABSTRACT

This study presents the development of a simulation and decision support tool for assessing and comparing the hydrological performance of stand-alone and interconnected stormwater source-control techniques (SCTs) (green roofs, swales, retention basins or permeable surfaces) at the block and building scale, based on long-term time series. This tool is tested with a case study including various SCTs connected to a 600 m^2 real green roof (Orléans, France), using rainfall and evapotranspiration time series over 2 years (2016-2017) measured with a 5 minutes time-step. Results led to compare the temporal variations of storage volumes (in the different retention zones), inflows (rainfall or upstream flows) and outflows (evaporation / evapotranspiration, regulated flowrates, infiltration flows and overflows) for each of the planned SCTs, throughout the 2 year simulation period. This tool also allows including simulations results from external pre-existing conceptual models.

RÉSUMÉ

Cette étude présente développement d'un outil de simulation et d'aide à la décision permettant d'évaluer et comparer les performances hydrologiques de plusieurs scénarios mettant en œuvre différentes techniques alternatives de gestion des eaux pluviales, autonomes et interconnectées (toitures végétalisées, noues, bassins de rétention ou surfaces perméables) à l'échelle de la parcelle, mettant en œuvre des séries chronologiques de longue durée. Cet outil est testé au moyen d'un cas d'étude de différentes techniques alternatives connectées à une toiture végétalisée réelle de 600 m^2 (Orléans, France), en utilisant des données de précipitation et d'évapotranspiration mesurées sur 2 ans (2016 - 2017) au pas de temps de 5 minutes. Les résultats permettent de comparer les variations temporelles des volumes de stockage (dans les différentes zones de rétention), des volumes d'entrée (précipitations ou écoulements en amont) et des sorties (évaporation / évapotranspiration, débits régulés, débits d'infiltration et débordements) pour chacune des techniques alternatives modélisées, au cours de la période de simulation de 2 ans. Cet outil offre également la possibilité d'inclure des simulations de modèles préexistants externes.

KEYWORDS

Conceptual modelling, decision-making tools, software development, stormwater management, urban planning.

1 INTRODUCTION

Stormwater Source-Control Techniques (SCTs) (also known as Low Impact Development or Sustainable Urban Drainage Systems – Fletcher *et al*., 2015) have been widely recognized as a valuable alternative to traditional sewer systems. Specifically, SCTs offer a solution to mitigate flooding in urbanized areas, reducing stormwater peak flows and runoff volumes (Hammond *et al.*, 2013). However, one fundamental aspect that significantly limits the implementation of SCTs in construction projects comes from the lack of adequate analytical and modelling tools (Elliot and Trowsdale, 2007). Nowadays, most popular models for SCTs are conceptual, *i.e.* simplified physically non-rigorous descriptions of the systems. This type of models have shown important benefits compared to detailed physically based models, in terms of computational requirements, as well as their potential ability to be integrated into decision support tools (Palla *et al*., 2012; Soulis *et al*., 2017). However, such conceptual models for a given SCT are rarely calibrated by means of long-term time series (e.g. water levels, rainfall and evapotranspiration). In addition, different sets of interconnected SCTs, e.g. in terms of overflows, regulation or/and infiltration flows are still challenging to be represented with current modelling tools at the block and building scale (García *et al.*, 2015; Peng and Stovin, 2017).

Therefore, this study aims to develop a simulation and decision support tool for assessing the hydrological performance of different stand-alone and interconnected SCTs, such as green roofs, swales, retention basins or permeable surfaces, by means of calibrated conceptual models when experimental are available. The implemented models are conceptual simplifications of these systems into a set of interconnected boxes or reservoirs that represent e.g. the storage zone or the substrate of each structure (Bertrand-Krajewski and Herrero, 2017). The adaptability of this tool is then tested by means of a case study layout of SCTs connected to a 600 m^2 real green roof (Orléans, France), using time series of rainfall and evapotranspiration measured in this site over 2 years (2016-2017) with a 5 minutes time-step (Payet, 2018) as model inputs.

2 MATERIALS AND METHODS

Alveolar green roofs are an increasingly popular SCT, reporting substantial benefits when compared to retention performances of traditional green roofs (e.g. Arias *et al.*, 2017). This evolution of traditional green roofs includes a supplementary alveolus stock layer underneath the substrate. The principle of alveolar green roofs consists in re-humidifying the substrate during dry weather periods, thus allowing evapotranspiration of the supplementary stormwater volume previously stored in the alveolus zone during the storm event. A conceptual model was developed and successfully calibrated for a 600 m^2 Nidaroof® alveolar green roof in Orléans, France, by means of rainfall, evapotranspiration and alveolar water depth measured over 2 years (Payet, 2018). Conveniently, this model structure, throughout some modifications, resulted to be adaptable for representing a wider variety of SCTs, such as traditional green roofs, open or closed infiltration basins and swales (e.g. Varnède *et al*., 2019). Furthermore, such adaptations also permit to model more detailed outputs of a given SCT such as regulated flowrates, infiltration flows or overflows, when further structures are connected downstream. This family of models is grouped into a simulation and decision support tool, aimed to assess long-term hydrological dynamics and performances for a wider variety of stand-alone or interconnected configurations of SCTs at the block and building scales. This tool is coded as a free distribution software, developed in Python programming language, by INSA Lyon, France in collaboration with Nidaplast / Siplast / AS2C companies. Each SCT to be modelled is described in the software by its main characteristics, e.g. the surface area, the storage or substrate depths. In order to have locally realistic estimations, long-term time series of rainfall and potential evapotranspiration (estimated from humidity, wind speed, solar radiation or/and temperature), corresponding to the local conditions of the project, are strongly recommended to be provided by the user. However, alternative and simplified options are proposed for projects in which this meteorological information is limited or unavailable.

3 RESULTS

The tool is tested for a case study scenario of SCTs composed by a real 600 m^2 green roof located in Orléans, France (Payet, 2018), releasing stormwater overflows to a planned 200 m^2 closed infiltration basin without regulation flowrate, which will also receive overflows from a 1000 m^2 impermeable parking zone (Figure 1). Two years (2016-2017) time series of rainfall and evapotranspiration with a 5 minute time-step are used for the simulations, in order to evaluate the hydrological performance for each SCT and for the ensemble of the configuration. The described layout is created in the main screen menu of the simulation and decision support tool, assigning the physical properties of each SCT (Figure 1).

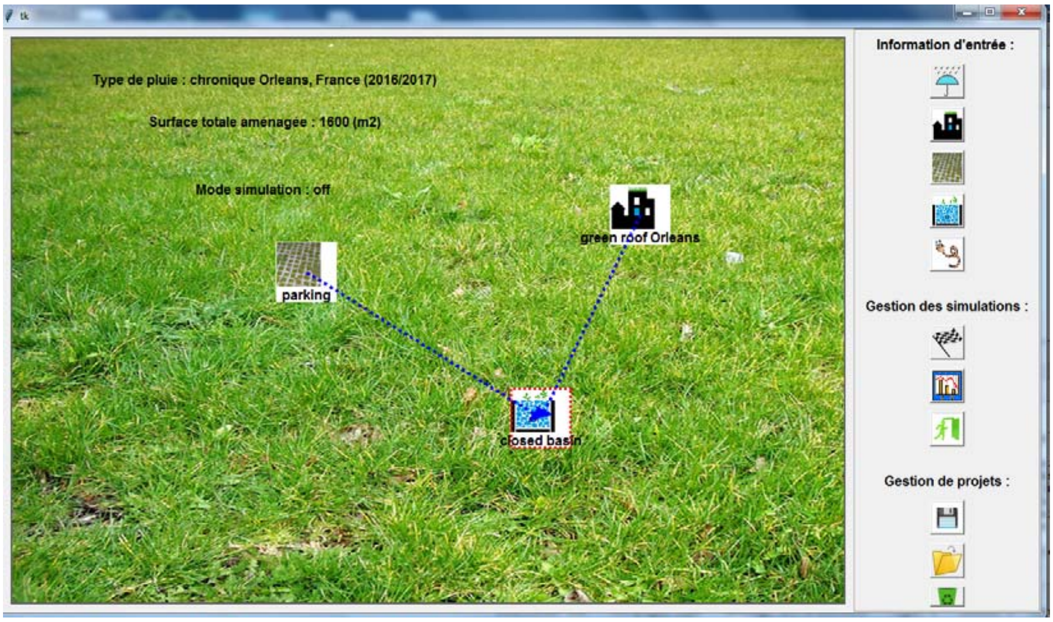

Figure 1. Main menu of the simulation and decision support tool with the studied layout of SCTs

For the case of the closed infiltration basin, an example of the results is shown in Figure 2, leading to visualize the simulated infiltration flowrates during 2 years. Such graphs can be automatically generated by the tool, in order to compare e.g. the simulated variations of storage volumes (at the different retention zones), inputs (rainfall or upstream flows) or outputs (evaporation / evapotranspiration, regulated flowrates, infiltration flows and overflows), for each of the structures. In addition, stormwater mass balances over the simulation period are presented for each of the STCs, leading to assess the global hydrological performance of the system.

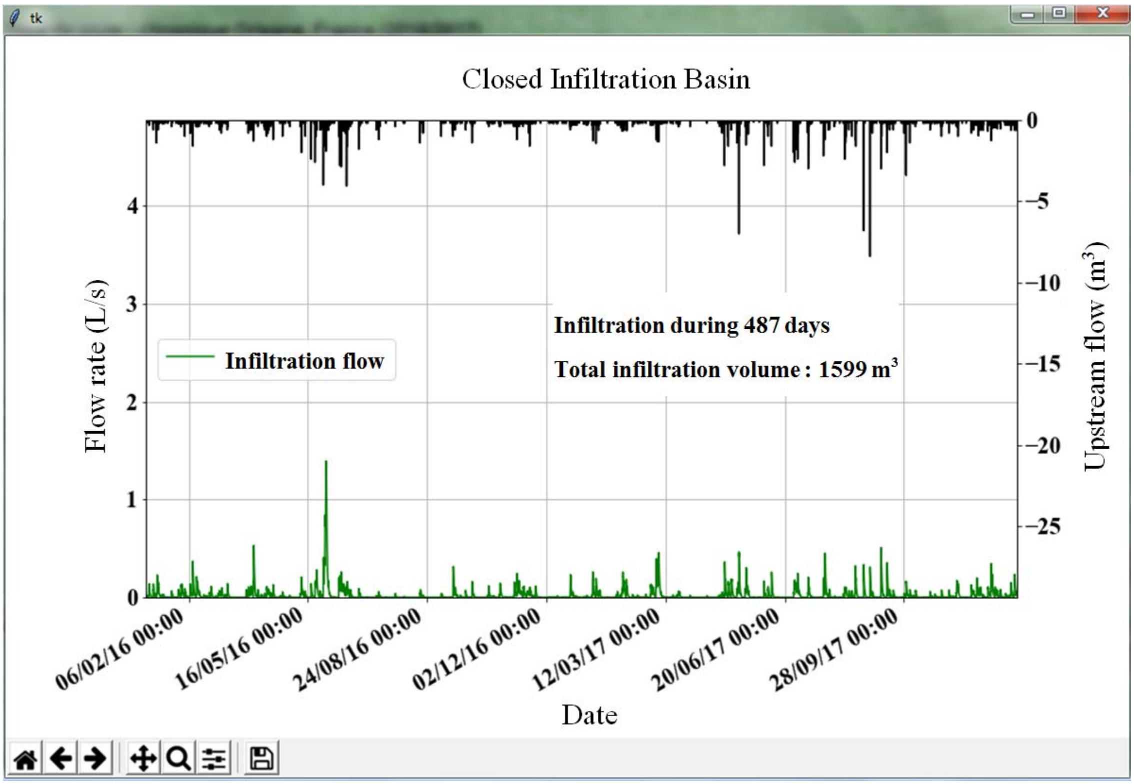

Figure 2. Simulated infiltration flowrate in the closed infiltration basin during 2 years

4 PERSPECTIVES

The tool and its adaptability to various contexts is currently tested by means of different scenarios over the studied urbanized area. Furthermore, given the fast development of new SCTs and existing case-dependent models, the proposed simulation and decision support tool is planned to be able to incorporate simulations from external models. This module has been preliminary implemented by including simulations from other green-roof conceptual models. The developed simulation and decision support tool is planned to assess, for future blocks and buildings construction projects, the long-term hydrological performances for different configurations of SCTs, leading to choose the most appropriate physical layout.

The full paper will present the model structure and will illustrate the results for a diversity of examples of SCTs combinations under various regional climatic conditions.

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