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Blue and green infrastructures (B&GI) are nature-based solutions considered as particularly efficient to reduce the potential impact of new and existing developments with respect to stormwater issues. In order to assess their performance at some large scales compatible with urban projects, adapted distributed rainfall-runoff models are required. The latest advancements of the Multi-Hydro platform have made possible the representation of such B&GI. Applied in a virtual new urban development project located in the Paris region, Multi-Hydro has been used to simulate the impact of B&GI implementation, and their ability to fulfil regulation rules authorizing the connexion to the sewer network. The results show that a combination of several B&GI, if they are widely implemented, could represent an efficient tool to meet regulations at the parcel scale, as they can reduce runoff volume about 90%.

Key words: blue green infrastructures, stormwater management, distributed modelling

1 Introduction

Blue and Green Infrastructures (B&GI), including green roof, bio-retention swale, porous pavement, harvesting tank, soakaway or pond for instance, can provide multiple benefits to urban areas affected by both climate change and urbanization effects: urban heat island reduction, biodiversity conservation, reduced buildings energy requirements,... Last but not least, they appear to be particularly efficient in stormwater management (Liao et al, 2017). By detention, infiltration and evapotranspiration processes, they can be used to control urban runoff at the local scale.

The hydrological performance and benefit of B&GI have been shown in numerous studies conducted at small scales: Kamali et al. (2017) for porous pavement, Chapman and Horner (2010) for bioretention system, or Stovin et al. (2012) for green roofs. Nevertheless, their performance and interaction at higher scales (urban project) are still uncertain and insufficiently quantified. Modelling tools are required to consider B&GI configuration and optimize their performance, as most of the existing models are focused on one or very few assets such as green roofs (Versini et al., 2015). Few of them are technically able to combine dynamically several infrastructures, but usually in a semi-distributed approach that mixes several types of landcover (road, house, grass, park…), and implies some huge difficulties to adjust *a priori* the parameters without observed data. It is the case of the Storm Water Management Model, as shown in Lucas et al. (2015) or Palla and Gnecco (2015) among others. To properly assess B&GI performance on a large set of spatial scales, a hydrologic model characterized by a high spatial resolution is also required. Such a structure is necessary to consider heterogeneous surfaces, and the associated dynamics due to the layout of impervious and pervious areas.

Based on these considerations, the main objective of this research note is to assess the performance of B&GI in stormwater management at the urban project scale. A distributed modelling approach has been chosen to especially study the respective performance of a B&GI set, and their evolution regarding storm event return periods.

2 Presentation of the case study: the "Echangeur" project

The virtual urban project called "Echangeur" has been designed by a group of students during a specialized master training devoted to the "Ecodesign of Sustainable Cities". Supported by the Academic Chair on the Eco-design of building sets and infrastructure established by ParisTech and the Vinci group (see Kotelnikova et al., 2016 for a detailed presentation), the main activity of this course is to design a sustainable neighborhood materialized by a layout plan. Located in the eastern suburbs of Greater Paris (Champs-sur-Marne, France) and covering an area of 10.66 ha, the plan proposed by the students for the Echangeur project (Figure 1) hosts accommodation for 5900 inhabitants and activities with the creation of 1150 jobs. This plan must also fulfill stormwater management requirements concerning the connection to the stormwater network. Here the discharge at the parcel outlet has to be lower than a reference threshold of 10 l/s/ha for a rainy event characterized by a 20-years return period. In the Paris region, this corresponds to a 30-minute rainfall event characterized by a 50 mm/h intensity.

Figure 1. Layout of the Echangeur catchment differentiating the different land use classes

Due to a lack of space, the construction of a large storage unit has not been considered. Several blue and green infrastructures have been planned to fulfil this stormwater regulation rule: (i) Green spaces (grass, forest and vegetable gardens), (ii) green roofs, (iii) green swales (swaled drainage course with sloped sides and filled with vegetation and riprap), (iv) small retention basins, (v) porous pavement.

3 Materials and method

3-1 The Multi-Hydro model

The Multi-Hydro distributed rainfall-runoff model represents a well-adapted tool to assess hydrological impacts at the urban scale (Giangola-Murzyn, 2014, Ichiba et al, 2017). For each time step, Multi-Hydro provides overland water depth (flooding) and infiltration maps, but also discharge values for each pipe and junction of the stormwater network. Multi-Hydro is currently being developed at the XXX to take into account the wide complexity of urban environments. The latest advancements have made possible the representation of several "resilience infrastructures" such as basins, barriers, and green roof (see Versini et al., 2016 for details). Based on these previous works, Multi-Hydro has been adapted to reproduce the hydrological behaviour of the mentioned B&GI planned in the Echangeur project.

Multi-Hydro has been implemented on this case study to simulate its hydrological response with a resolution of 5 m in space and 5 minutes in time. Based on the layout plan, the input data required by the model (map of topography, landuse and stormwater network) were produced by using adapted GIS tools.

3-2 Land use scenarios

In order to study the relative contribution of each implemented B&GI, different land use scenarios have been established: (0) there is no blue or green infrastructure, but only impervious surfaces such as roads, buildings and pavements, (1) Green spaces are implemented, (2) Every building roof is covered with an extensive green roof, (3) Green swales are implemented, (4) Impervious pavements are replaced with porous ones on the pedestrian area, (5) Most of the stormwater network outfalls are connected to two small retention basins, (6) All of the B&GI mentioned above are implemented.

3-3 Rainfall scenarios

To quantify the relative performance of B&GI regarding stormwater management issue, several rainfall scenarios have been provided. These are synthetic hyetographs characterized by a homogenous precipitation and based on the specific Intensity-Duration-Frequency relationship (established in a station located 20 km away from the studied area by Météo-France). They were computed for a 30-minute duration (close to the watershed concentration time) and several return periods (see Table 1).

Table 1. Rainfall intensity (expressed in mm/h) for the 8 considered return periods

3-4 Work plan

Multi-Hydro was applied on every land use and rainfall scenario (7x8 simulations). Some of the resulting hydrographs are illustrated in Figure 2 and analysed in the following. Note that two indicators were used to assess B&GI performance: runoff volume *(ΔV)* and peak discharge *(ΔQp)* reductions:

$$\Delta Qp(\%)=\frac{(Qp_0 - Qp_i)}{Qp_0}\ 100 \qquad \text{(Eq. 2)}$$

$$\Delta V(\%)=\frac{(V_0 - V_i)}{V_0}\ 100 \qquad \text{(Eq. 3)}$$

Where Qp_0 and V_0 refer to peak discharge and runoff volume computed for the impervious situation, whereas Qp_i and V_i correspond to those computed for the different B&GI scenarios.

4 Presentation of the results

For the impervious situation, most of the rainfall volume is transferred to the basin outfalls. Only initial losses and water stored in local depression can be deduced.

Regarding 30-minute duration events, peak discharge reaches 200 l/s to 1200 l/s. It is worth noting that regulation threshold is exceeded whatever the return period of the considered storm event.

When 11.6% of the total area is covered by green spaces (Scenario 1), runoff volume and peak discharge decrease by approximately 10-15% for the more frequent events, and less than 10% for the strongest ones. In these cases, infiltration capacity of green spaces is reduced, and some water is finally drained to the stormwater network

The green roof implantation proposed in Scenario 2 -representing 42.3% of the watershed area- induces both runoff volume and peak discharge reduction starting from 15% to 25% for the more frequent storm events, and dropping to about 5% for the heaviest ones. Green roofs appear to be particularly efficient at the beginning of the storm, when they can temporarily store water in the substrate.

In Scenario 3, Green swales represent a small part of the studied basin (5.5%), but they drain water from surrounding elements (almost 30% of the total area). It is illustrated by some runoff volume and peak discharge reductions that vary from 30% for the 1-month event to 17% for the 20-year one.

As porous pavements represent 31.5% of the whole area, their implementation in Scenario 4, characterized by a high storage capacity, significantly influences the hydrological response of the catchment. Both runoff volume and peak discharge decrease about 30-40% depending on the considered rainfall event.

Retention basins drawn up in Scenario 5 represent the most effective infrastructure in terms of runoff reduction as they drain two thirds of the catchment area. Both runoff volume and peak discharge decrease of about 70% for the more common storm events. For the highest events, the total storage capacity (1300 m^3) is reached. From that time, the exceeded water is routed to the stormwater network and produces a "step" in the catchment response.

The implementation of all of the B&GIs on the Echnageur project (Scenario 6) is obviously the most effective configuration. Both peak discharge and runoff volumes are reduced by about 90% on the wide range of return periods, and the regulation rule of 10 l/s/ha is almost always met (except for the two main events).

Figure 2. Presentation of the simulated hydrographs for different rainfall events and B&GI scenarios. Orange horizontal solid line corresponds to the 10 l/s/ha regulation.

5 Conclusions and perspectives

A combination of B&GI appears to be the best solution to significantly reduce the quantity of water flowing into the sewage network during storm events, and to fulfil regulation rules established by local stormwater managers. The distributed structure of Multi-Hydro and the possibility to reproduce a large set of B&GI allow the realization of such detailed and dynamic impact studies. As Multi-Hydro is still in development, additional B&GI could be added in the future, and among these, different configurations could be tested (ie. several green roofs differentiated by their substrate porosity or thickness).

The presented results must be taken with caution, as they depend on the catchment configuration, especially on the combination of impervious and pervious surfaces, but also on its geometry and on the sewage network arrangement. Moreover, it should also be noticed that initial conditions have not been considered in this study. Every B&GI was assumed to be empty / unsaturated at the beginning of every rainfall event. Future versions of Multi-Hydro should take into account evapotranspiration processes and detention basins draining during dry periods to better estimate the initial state of the system. The succession of several rainfall events should also be possible to study B&GI performance in more realistic conditions, as it is usually the case for rainwater harvesting tank or detention basin sizing.

Acknowledgments

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	1 month	3 months	6 months	1 year	2 years	5 years	10 years	20 years
D=30min	8.0	14.4	19.7	25.9	31.4	42.0	50.1	58.2

Figure 1
Click here to download high resolution image

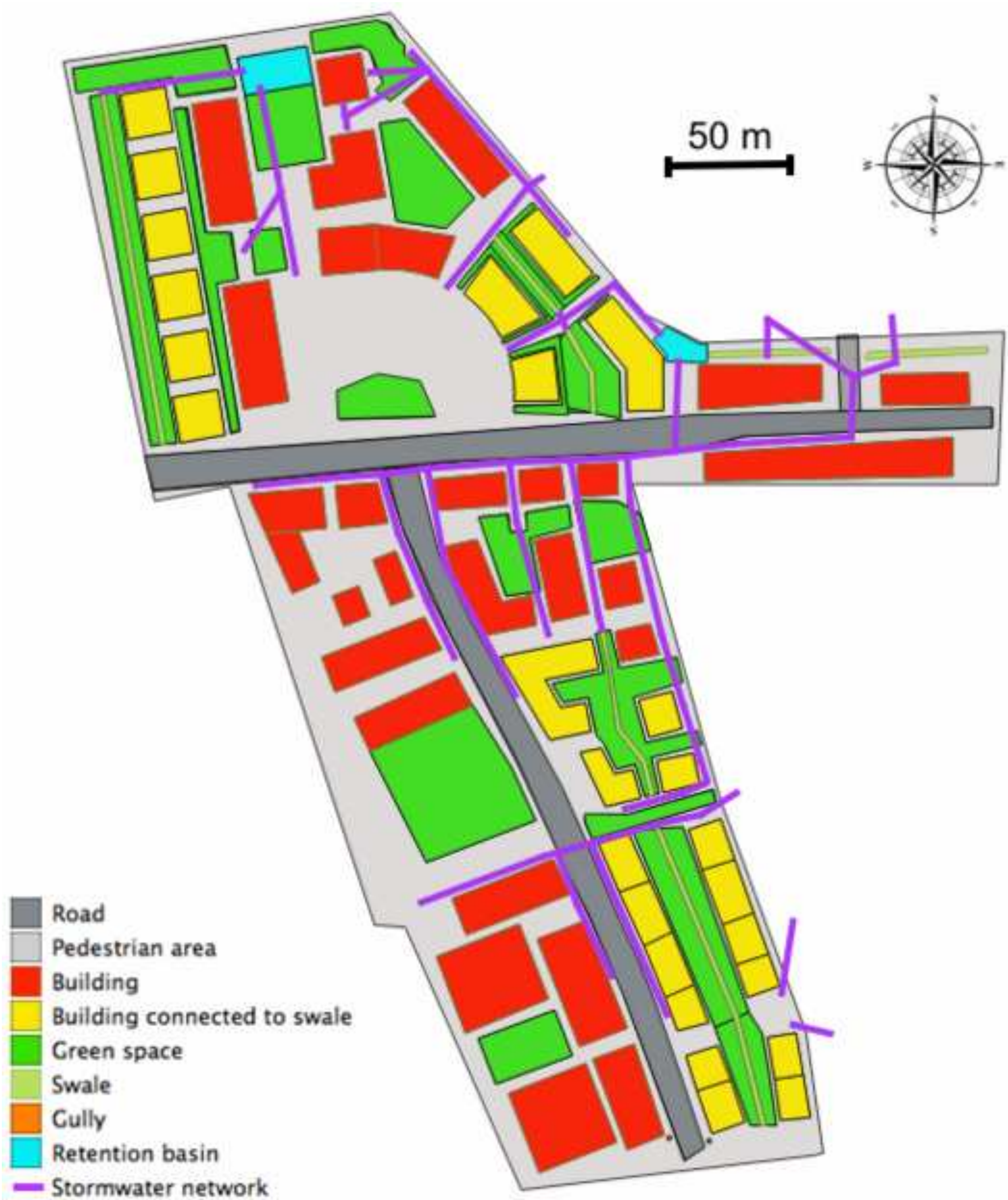

Figure 2
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