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Improving SuDS Design With Future Time Series Based on IPCC Scenarios Downscaling and A Probabilistic Approach

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Abstract

Historically, sustainable drainage systems (SuDS) have been usually event-based designed, like traditional pipe and storage grey infrastructure, by applying design storm events derived from intensity-duration-frequency (IDF) curves established with rainfall data records. However, this approach has several drawbacks, especially: i) it neglects the dry inter-event periods which play a key role with evapotranspiration for vegetated SuDS like e.g. green roofs, ii) the design storm events themselves are considered as fully deterministic and not as a stochastic input, and iii) storm events based on past records do not account for climate change. The paper presents a more refined approach, named Highly-Informed-Design-Evaluation-Strategy (HIDES), which considers both i) long term simulations with future rainfall and potential evapotranspiration time series generated by means of downscaling IPCC modelling scenarios, and ii) stochastic design events for different levels of performance (day to day rain, major events, extreme events). An application to two green roofs simulations is shown.

Introduction

Historically, sustainable drainage systems (SuDS) have been usually event-based designed, like traditional pipe and storage grey infrastructure, by applying design storm events with given return periods derived from intensity-duration-frequency (IDF) curves established with rainfall data records. Depending on local regulations and context, return periods of the design events may vary from 5 to 30 years or more. For example, in both France and Norway, the recommended design includes three levels with different rainfall events categories: i) frequent or day-to-day events, ii) major events, and iii) extreme events, with levels of performance or service adapted to each category [1, 2]. This design approach mainly aims to size the facilities but does not explicitly account for the analysis in case of failure (insufficient capacity, overflow, succession of storm events which may be less critical than the design storm events, etc.) and it does not help to represent how the facilities will behave during the successive rainfalls events and inter-event dry periods during which evapotranspiration plays a significant role for vegetated SuDS like e.g. green roofs. Moreover the design storm events themselves are considered as fully deterministic events and not as a stochastic input, which may lead to an overestimated confidence in the design. Lastly, as the design storm events are based on historical records of rainfall, the approach cannot properly deal with climate change which is becoming a critical issue in urban drainage.

This research work proposes a more elaborated approach, named Highly-Informed-Design-Evaluation-Strategy (HIDES), which applies both i) long term simulations with future rainfall and potential evapotranspiration time series generated by means of downscaling IPCC modelling scenarios, and ii) sets of stochastic design events with different return periods for different levels of performance (day to day rain, major events, extreme events).

Material and methods

The HIDES method is summarised in Figure 1.

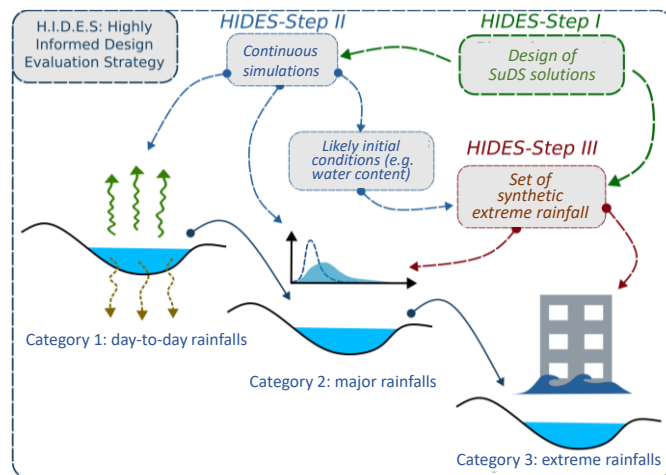


Figure 1. The HIDES approach for SuDS design.

Input data generation

A climate-change-robust downscaling model based on multiplicative random cascades was developed to generate rainfall time series for different cities in Norway and France [3]. The depth corresponding to 24-hour precipitation obtained from IPCC regional models' outputs was downscaled from 1 day to a 6-minute timestep. A 29-year long time series was generated for continuous simulation (CS) of two green roofs. The model was also used to generate 10^5 hyetographs of design storm events for each return period from 2 to 200 years (LES – local event sampling). In addition, to represent usual future climate design events in Norway, a multiplicative factor 1.4 was applied to existing IDF curves.

Green roof modelling

Two green roofs were modelled in this work: an extensive green roof (E-green roof) and a detention-based extensive green roof (D-green roof). The E-green roof consists of a 30-mm layer of substrate with a 10-mm layer of storage, represented globally with a single discharge function. The D-green roof consists of one 100-mm layer of clay aggregates and one 30-mm layer of substrate, represented as the sum of two discharge functions, one for each layer. The green roof model is based on a non-linear reservoir and was calibrated using data from extreme rainfall tests performed on a large-scale pilot roof [5].

Performance indicators

The city of Trondheim, Norway was used a test case to apply the HIDES method. The Trondheim regulation for local stormwater management sets the peak discharge allowed to be released in the sewer system during a 20-year return period rain event. When connected to a separate sewer system, the threshold is 6.4 L/s for a 800 m² area. When the area is connected to a combined sewer system, the threshold is only 1.65 L/s for 300 m². Those two thresholds were used as references in this work, after conversion and normalisation as 0.48 mm/min and 0.33 mm/min respectively.

Results and discussion

In this abstract, only one example of results is given due to limited space (more results will be shown during the presentation). Figure 2 shows the probability distributions of the peak discharge from both E- and D-green roofs (compared to the reference values 0.33 and 0.48 mm/min) for both existing climate and future climate for 10^5 events with return periods from 2 to 200 years. The proposed LES – Local Event Sampling method is compared with the VM – Variational Method [6] approach using only a low number of rainfall events with constant intensity to estimate the worst peak runoff according to each IDF curve.

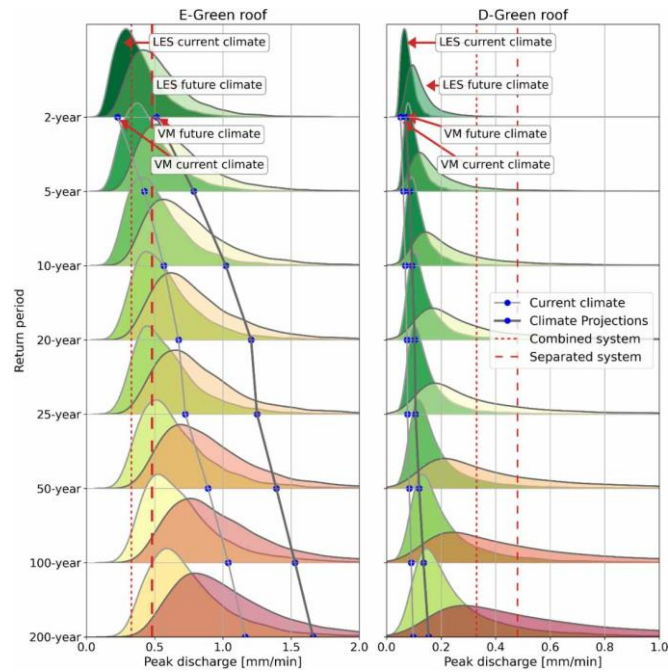


Figure 2. Predicted peak runoff of the E-green roof (left) and the D-green roof (right) using LES (distributions) and VM (thick grey line & blue dot markers) methods, under current climate (light grey) and projected climate RCP 8.5 (dark grey). The colour of the distribution is conditioned by the centroid value: green for low, yellow for medium and red for high. [4].

For the D-green roof, VM tends to underestimate the peak runoff compared to LES distribution mode. For the E-green roof, this is only observed for the 2-year return period. For the D-green roof and a 20-year return period event under current climate, 96% of the simulated events led to a peak runoff lower than 0.33 mm/min. For the E-green roof only 10% of the peak runoff values were less than the threshold. Considering the 0.48 mm/min threshold, the E-green roof is reliable, but not robust. It has a deviation range from 0.17 to 0.45, and under high return period it can deal with fewer than 10% of the events. On the contrary, the D-green roof is robust as it can handle more than 50% of the events up to a 200-year return period, but not reliable as the order of magnitude of its standard deviation changes from 0.02 to 0.5 with larger return periods. Return periods larger than 20-year can be considered as the failure domain of the roofs in the second step of the three-step approach (Figure 1). The roofs are not designed to cope with such events; however, quantifying their behaviour within this failure domain can help to make a more informed decision when dealing with the next steps.

Conclusion

The HIDES method allows a more in-depth analysis of SuDS design and modelling. It accounts for climate change by generating long-term time series of rainfall intensity and

evapotranspiration based on downscaling data sets from IPCC regional models. It also proposes a stochastic approach to generate design storm events representing better their variability than traditional tools. Lastly, it shows that a case-by-case analysis is required, for each SuDS and each location.

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Biography



The presenting author is Professor at the University of Lyon, France, in INSA Lyon (National Institute of Applied Sciences). He was head of the laboratory DEEP (Wastes, Water, Environment, Pollutions) in the period 2014-2022 and is co-president of the multidisciplinary OTHU – Field Observatory for Urban Hydrology (www.othu.org) since 2023. His main research topics are related to urban hydrology and urban water systems, especially hydraulic and pollutants transport modelling in sewer systems, field monitoring and metrology, stormwater management, and integrated approach for urban water systems. More information available on his website at jlbkpro.free.fr.