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## Can we sum the performance of green infrastructures? The potential of system-based planning

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**Abstract:** This study demonstrated, through a conceptual case study, that separate design of Green Infrastructure can lead to large range of probability to meet the target (e.g., 0.05 to 0.55), even in the case where individual unit fulfil the design requirement. It also highlights that planning at neighbourhood scale is an opportunity to achieve more robust performance with possibly fewer resources.

**Keywords:** Green Infrastructure modelling; Extreme events; Design

### Introduction

Green infrastructure has become an integral part of many stormwater solutions over the past decades. Compared to conventional piped (gray) solutions the green solutions have some distinct properties in that they: *i*) they deliver other benefits than hydrological *ii*) they can be owned by private owners, but at the same time be part of the stormwater management system. Their design, monitoring and maintenance, with respect to ownership and governance level (Comby et al., 2019), remains a challenge which had led to uncertainty in performances.

Green Infrastructure (GI) are often designed for extreme events with limited and/or simplified methods (Pons et al., 2021). Even when they are not designed for stormwater, the capacity to attenuate water remains crucial to achieve robust decision-making (Walker et al., 2013). Especially, the intermediate scale between plot and catchment scale still needs investigations.

The objective of the study is therefor, through modelling, *i*) to investigate if the performance of green infrastructures can simply be summed and *ii*) to which extent system or neighbourhood scale planning can help to improve the performance of overall system leading to better performance than the sum of individual performances.

### Method

#### Green Infrastructure and Neighbourhood scenarios:

Several LID units were used in this study. A detention-based extensive green roof (D-GR), and Extensive green roof (E-GR) and a storage unit (StU). Based on these units 4 solutions were designed (**Table 1.1**) based on the variational method against a 20-year Return Period rain with a 1.4 climate factor and a limiting threshold of 0.33 mm/min (Trondheim Kommune, 2015). The unmodified D-GR and E-GR (no plot specific adjustments), and the absence or failure of GI were also included in the study.

A neighbourhood of 20 houses with sizes varying from 80 m<sup>2</sup> to 150 m<sup>2</sup> was used as a study area. The delay to the outlet of the residential area varied from 1 to 4 min depending on the location of the houses.

Different implementation scenarios were generated: *i*) single solution scenarios, *ii*) random scenarios (500 scenarios per configurations (**Table 1.1**)). Due to its directed-acyclic-graph structure, the neighbourhood scale model, based partly on the in-development version or URBIS(Sandoval et al., 2019), worked as a summation per unit with respect to the delay relative to the house location. Further development

based on water reuse will require interdependency between solutions (add cycles to the graph).

### Local Event Sampling and Distribution of performance:

Climate data from Trondheim (Norway) were used. The method of Local Event Sampling (LES) (Pons et al., 2021) was applied to the different units for  $10^4$  events of return period 5, 20 and 100 years to account for major, design, and extreme events.

### Result and Discussion

The performances are presented in **Figure 1.1** for the 20-year return period. The performance of the different designed scenarios varies greatly. It shows that fulfilling the municipal design requirements is not a guaranty for reliable performance. The solutions based on the Storage units tend to fill the requirement 50% of the events but fails abruptly when the capacity is exceeded which is not desirable from a system perspective. The failure mode of the designed solution is typically not required by municipalities, but it can differ significantly depending on the unit.

The range of probability to reach the 0.33 mm/min target varies greatly. In scenario *A0* it ranges from 0.05 to 0.55. This implies that a separate design for each unit can lead to poor performance because the peaks runoff contributes from each plot to the system arrive at the same time at the outlet point. While a system-based design offers an opportunity to maximize the robustness of the system.

The absence of GI could improve the robustness of the system in some random configurations: *A1* and *D1* have thicker tail than their counterpart with failing units (*A0* and *D0*). Some scenarios can even achieve higher robustness than the scenarios with only unmodified D-GR which represent the higher bound of performances.

### Conclusion

This study demonstrated that, at residential single family housing scale, the design of single GI units without cooperation runs the risk of leading to poor performance at system (catchment) scale. On the opposite it also demonstrated through random scenarios simulation that some configurations can lead to much higher robustness.

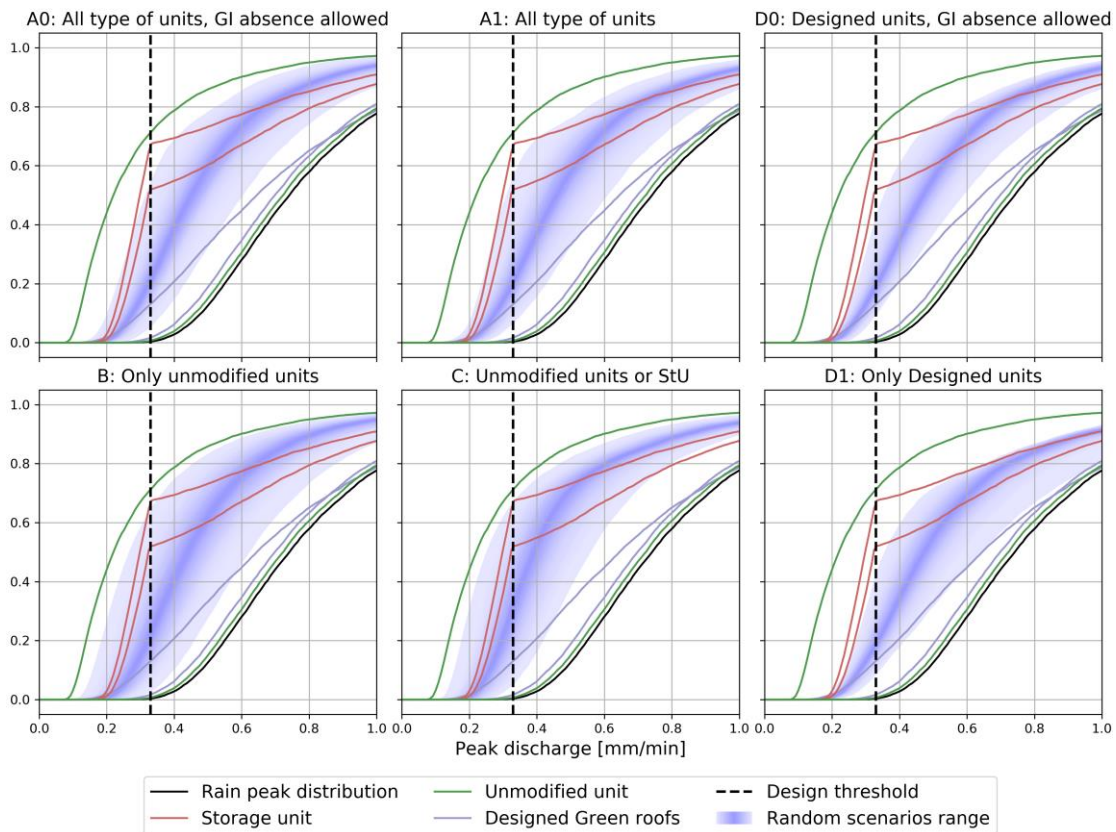
The presence of houses not fulfilling the requirement was found to possibly improve the robustness of the system depending on their placement. These different findings on performance summation means that, even without taking into account interdependencies between infrastructure, designs without cooperation framework runs the risk of wasting resources, while increasing the risk of failure. This work should be extended to interdependency between units.

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**Table 1.1** Different random scenarios configurations

Design Parameter → Scenario ↓	Designed Solutions				Unmodified Solutions		
	E-GR	D-GR	StU	E-GR + StU	E-GR	D-GR	No-GI
	Depth	Area	Area	Area	-	-	-
<b>A0</b>	X	X	X	X	X	X	X
<b>A1</b>	X	X	X	X	X	X	-
<b>B</b>	-	-	-	-	X	X	-
<b>C</b>	-	-	X	-	X	X	-
<b>D0</b>	X	X	X	X	-	-	X
<b>D1</b>	X	X	X	X	-	-	-



**Figure 1.1** Cumulative probability of performance of the different random scenario configurations for a 20-year return period rain. The dark blue lines are single solution type scenarios, the light blue lines represent the random configuration scenarios.