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A tool to forecast future performance of green infrastructure

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Highlights

- Retention performance of a combined green infrastructure was assessed with daily time series;
- URBIS was found to be a fast and adaptable tool to study combined green infrastructure;
- A set of scenarios at different locations and climate condition was considered.

Introduction

Green infrastructure aims reducing the impact of urbanisation on environment, especially aquatic ecosystems, by means of nature based (biomimetic) solutions. They shall be designed to account for future conditions, including evolutions in rainfall and evapotranspiration linked to climate change conditions due to greenhouse gas emissions (IPCC, 2014). In Norway, according to the IPCC RCP 8.5 scenario, temperature and precipitation are supposed to increase by the end of the century. Local and short time scales data are thus required to design adequately green infrastructure: downscaling climate projections like those developed e.g. by the EURO-CODEX project (Jacob et al., 2014) are useful to assess how both the retention and detention performance of green infrastructures will be affected by climate change.

The three objectives of this study are to: *i*) compare the performance of a set of green infrastructure combinations; *ii*) assess their performance sensitivity with respect to climate change at different geographical locations in Norway and, *iii*) assess the use of Urbis, a stormwater planning and design model, as a tool to compare retention performance in future and current conditions using daily time series projections;

Methodology

Input data

Three locations in Norway, with different climatic conditions, were considered, Trondheim (Dfc climate class), Bergen (Cfb) and Oslo (Dfb) (Peel et al., 2007). Input data for future conditions (2071-2099) were spatially interpolated from a 1 km resolution grid of 10 models for climate projection (scenario RCP 8.5) with a daily resolution (made available by the Norwegian Centre for Climate Services). The use of all the available models was assumed to capture a part of the uncertainty linked to climate projection (Wong et al., 2016). Data for the current climate (1961-1989) were provided by the Norwegian Meteorological (met.no).

Combined green infrastructure scenarios

Different scenarios (B, C and D) of combination of green infrastructure based on the green roof and the raingarden (Table 1) were compared to two reference cases A1 and A2:

- A1, with a 1000m²-impervious cell representing a flat roof or an impervious parking lot.
- A2, with two 1000m²-impervious cells representing the association of a flat roof and a parking lot

Table 1. Table of the different scenarios

Scenario	A1	B1	C1	D1	A2	C2	D2	NS 10	NS 20
Impervious area [m ²]	1000	-	1000	-	2000	2000	1000	-	-
Green roof [m ²]	-	1000	-	1000	-	-	1000	-	-
Raingarden [m ²]	-	-	50	50	-	100	100	-	-
Natural Soil [m ²]	-	-	-	-	-	-	-	2000	2000

Two supplementary scenarios to model natural soil with 10 and 20 mm of depression storage (DS) were also implemented (with an infiltration rate of 0.5 cm/hour as a first approach) to compare with scenario A2.

Urbis, a newly developed software, based on the combination of different source-control techniques represented by boxes, was used to conduct in this study (Sandoval et al., 2019). Urbis is designed to run simulations with time steps of a few minutes with delays between boxes to account for water transfers. In this study, no delay was considered between the different boxes due to the daily time step.

Figure 1 represent the green roof and the raingarden considered in this study for comparison with Kristvik et al. (2019). The green roof was modelled with a single box for green roof. The raingarden was modelled linking the infiltrated volume from an open basin (box 1) to an underground basin (box 2).

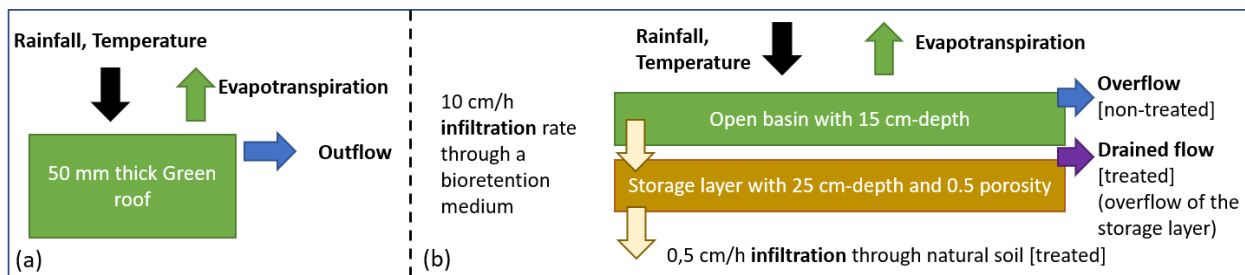


Figure 1. Characteristics of (a) the green roof, and (b) the raingarden modelled with Urbis

Performance

Evapotranspiration, infiltration through native soil, drainage toward pipe network and overflow were measured as annual performance indicators for each scenario. The annual percentage of retention (resp. treated flow rate) was defined as the sum of infiltration and evapotranspiration (resp. evapotranspiration, drained flow and infiltrated flow). The indicators were normalized by mean annual precipitation.

Results and discussion

Urbis was successfully used and improved to be able to handle several time series for each placement scenarios. Table 2 summarize the annual performance of each scenario. The performance depends on the increase of precipitation and temperature. Results of scenario B1 were found similar to Kristvik et al. (2019). A compared analysis between Bergen, Trondheim and Oslo on scenario B1 shows that evapotranspiration is likely to increase in Oslo and Trondheim but slightly decrease in Bergen. Indeed, increasing temperature tend to increase potential evapotranspiration in cold climate while increasing rainfall volume reduce the annual evapotranspiration fraction. However, modelling with daily time step entailed a bias in the results which should be interpreted carefully. Results of Scenario C1 differed from those of Kristvik et al. (2019), which can be explained by the use of the Green-Ampt equation in Urbis instead of a constant hydraulic conductivity. Overflow is also different as it depends on the temporal distribution of rainfall. Thus, the rate of overflow could have been overestimated with Urbis.

Table 2. Annual performance for each scenario R represents retained fraction [%] and T the treated fraction [%]

Location	Climate period	Annual rainfall [mm]	A1		B1		C1		D1		A2		C2		D2		NS 10	NS 20
			R	T	R	T	R	T	R	T	R	T	R	T	R	T	R	R
Bergen	[1961-1989]	2310	-	15	15	42	49	49	55	-	42	49	47	53	57	81		
	[2071-2099]	3050 ± 290	-	14	14	34	40	42	47	-	34	40	39	44	47	71		
Oslo	[1961-1989]	790	-	36	36	65	72	79	83	-	65	72	75	80	80	95		
	[2071-2099]	920 ± 40	-	39	39	60	66	75	80	-	60	66	71	76	74	93		
Trondheim	[1961-1989]	1040	-	26	26	65	72	73	79	-	65	72	71	77	81	95		
	[2071-2099]	1190 ± 120	-	30	30	61	68	72	77	-	61	68	68	74	76	93		

The topography of the natural area has a significant importance on the theoretical retention of the area. Scenario D2 approached the performance of scenario NS10. Nevertheless, the fraction of evapotranspiration is lower in the case of NS10 and the infiltration higher. This is linked to an assumption made in Urbis that the

crop coefficient is higher on green roofs than on natural soils ($C_{crop}=1$ for a green roof and $C_{crop}=0.8$ for a natural area).

A comparison of the scenarios depending the location show that it is possible to combine different green infrastructures in Trondheim and Oslo to restore the natural water cycle, while precipitations in Bergen are likely generate significant overflow (Figure 2), even with the natural water cycle. Infrastructure with higher capacity and performance should thus be considered in this location. In all locations, the fraction of infiltrated volume is likely to decrease as rainfall volume increase more than infiltrated volume (scenario C1, 8 to 4% loss of retention). Scenario relying on infiltration were found to be more sensitive to climate change than scenario relying on evapotranspiration. The error led to higher uncertainty in Bergen than in Trondheim.



Figure 2. Performance of scenario D1, 1000 m² of green roof with combined to a 50 m² raingarden; various climate conditions

Conclusions and future work

This study shows that future hydrologic performance of green infrastructure linked to climate change can be estimated with the open access software Urbis. It demonstrated the importance and potential gain of including climate scenarios in the early design phase. The performance of green roofs was found similar to Kristvik et al. (2019); other implementation scenarios were investigated. In future work Urbis should be improved to offer a larger range of models. Using sub daily time series should improve the accuracy of the results and extend the performance to detention.

The projected performance in Bergen suggest that green infrastructures with higher retention performance than in Trondheim or Oslo should be used. It showed the relevance to assess the long-term performance of combined green infrastructure facing climate change in various Oslo locations.

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