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Calibration of a green roof hydrological model using global sensitivity analysis

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Abstract:
Green roofs are a sustainable solution to manage water runoff from rain events in urban areas. Modeling hydrological phenomena of green roofs over long period is challenging because of the difficulties to both characterize the soil parameters and to take into account the dynamics of the vegetation and the meteorological variables. The water retention capacity is represented by the Van Genuchten - Mualem model implemented in Hydrus-1D©. For the calibration of the model, global sensitivity analysis is exploited to quantify the effects of parameter uncertainties on the water retention capacity. The results of this study highlight the most influential parameters on the water retention capacity and lead to an efficient reduction of the parameter uncertainties.

Keywords: Calibration, global sensitivity analysis, green roof, Van Genuchten - Mualem model

1. INTRODUCTION

In the last decade, soil imperviousness has been one of the main urban issues in the Northeast of France. In case of strong rain events, runoff can lead to the discharge of high volume of water and can cause water system saturation. Among all urban-water regulation systems, Green Roofs (GR) can be used to store and delay the release of rainwater to sewers [Li and Badcock Jr (2014)]. GR are also considered as a sustainable solution that offers benefits such as building insulation, urban heat island cooling during summer and air pollution control.

2. GREEN ROOF HYDROLOGICAL MODELLING

The hydrological performances of GR are directly linked to the outflow of a GR which is mainly related to the water content inside the layers. In order to investigate these performances, the water content needs to be measured and simulated.

Real data have been collected on an in-situ experimental GR installed in Tomblaine, North-East of France. A period of one year has been chosen from January to December 2020 which represents different hydrological phenomena shown in black in Figure 2.

Few models exist to describe the hydrological behavior of soil and can be adapted for GR characteristics such as soil parameters of the different layers, dimension, type of vegetation, etc. In this study, the dynamic of the water content is described by two elements. The first element describes the hydrological infiltration throughout unsaturated porous media and depends on soil parameters. The second element represents the water extracted from the soil due to the vegetation and the weather conditions.

All these models and equations are implemented in Hydrus-1D© software to simulate hydrological behavior [Simunek et al. (2008)]. This software allows the set up of the GR structure, boundary conditions, meteorological data, soil and vegetation parameters in order to reproduce the GR real configuration and can be used as a gray box model with:

- 1 input: rainfall;
- 1 output: Volumetric Water Content VWC;
- 6 soil parameters: θ_s, θ_r, n, K_s, α and l;
- 5 meteorological variables;
- 4 vegetation parameters: crop height $CropH$, leaf index area LAI, $Albedo$ and root depth $RootD$.

The aim of this study is to improve the calibration of this model to get closer to the behavior of the real GR. The challenge is that some of the model parameters, such as the soil or vegetation parameters, are complex to determine as they are difficult to measure accurately through experiments. All the parameter uncertainties are propagated through the simulation of water content and can be analysed to help the calibration. Methods of Global Sensitivity Analysis (GSA) can be applied to quantify the parameter uncertainty impact on the model output. These methods are described in [Hégo et al. (2021)] and will not be detailed here.

In this study, the effects of vegetation and soil parameters are simultaneously analysed in order to provide information to calibrate this new configuration of the GR model. The uncertainties of the parameters θ_s, α, n, $CropH$, LAI and $RootD$ will be analysed. The other parameters are not considered uncertain.

3. MODEL CALIBRATION

Global sensitivity analysis allows to quantify parameter influence on the output model. The least influential parameters are set to their nominal values. This allows to reduce the number of parameters to estimate. The study can then be focused on the most influential parameters. The idea is to iteratively reduce the initial interval of variations of the most influential parameters, in order to converge to the optimal value. For this purpose, the normalized root mean square deviation between the simulated and measured output is used as objective function to minimize.

The proposed calibration approach can be summarized with these steps:

1. Application of GSA with a large uncertainty interval defined by domain experts;
2. Computation of the error between measured data and the simulated model output generated during the GSA;
3. Reduction of the interval according GSA results and error analysis;
4. Exploration of parameter combinations to find the optimal one.

GSA approach allows to obtain sensitivity index dynamics over time and to point out influence evolution. First-order S_i and total sensitivity S_{T_i} indices are represented at the top of Figure 1. S_i represents the influence of only one parameter and S_{T_i} represents the influence of a parameter and all its interaction. It is worth noting that first-order and total indices are not equal for the parameters α, n and LAI. Higher-order indices are non-zero that means there is influence of interaction between parameters. Sensitivity indices of these three parameter interactions (second-order $S_{i,q}$) are represented at the bottom of Figure 1.

To calibrate the influential parameters α, n and LAI, an objective function is defined. The normalized root mean square deviation ($nRMSD$) is defined as the quality criteria.

$$nRMSD = \frac{\sqrt{\left(\sum_{t=1}^{T}(y_{sim}(t) - y_{obs}(t))^2\right)/T}}{y_{obs}^{max} - y_{obs}^{min}}$$

where y_{sim} and y_{obs} denote respectively the simulated and observed output and $t = 1, ..., T$.
The objective is to find the parameter combinations which minimize $nRMSD$ during periods of interest. These periods of interest are defined following sensitivity index dynamics and correspond to wet period (e.g. 0 to 2000 h), drying period (e.g. 3560 to 4045 h) and when it rains during drying periods (e.g. 2800 h). The $nRMSD$ is computed for each period and each model evaluation (generated for GSA). The optimal parameter combination is presented in red on Figure 2. The absolute error between the simulated and measured VWC is plotted at the bottom of the figure.

4. DISCUSSIONS AND PERSPECTIVES

In this paper, a calibration approach based on GSA is applied to a GR model in order to reproduce a real configuration. GSA highlights the influence of the parameter uncertainties over time on the model output (Figure 1). The uncertainty interval of the model parameter have been reduced and nominal values have been proposed to reproduce the specific green roof configuration. The simulated data for nominal values are close to the observed data, however some errors are persistent (Figure 2). These differences can be caused by several reasons. For instance, the assumption of constant vegetation parameters could have impacted the simulated soil drying. The time-variations of vegetation parameters can be investigated but raise difficulties for sample generation. Moreover, these differences can also highlight the limits of the models and Hydrus-1D©. All green roof phenomena may not be exactly reproducible by simulation.

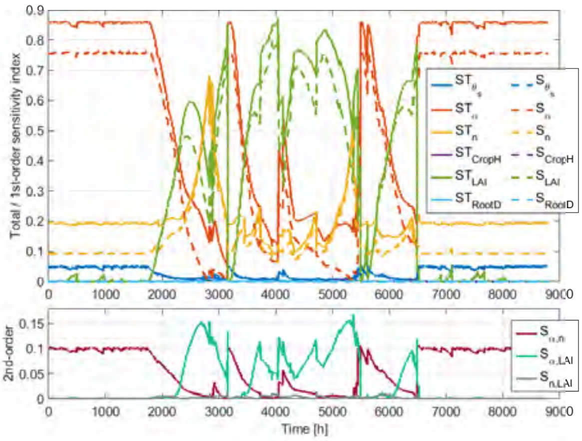

Fig. 1. Sensitivity indices applied to quantify parameter effects on VWC. At the top, total index with solid line and first-order index with dashed line and at the bottom, second-order index.

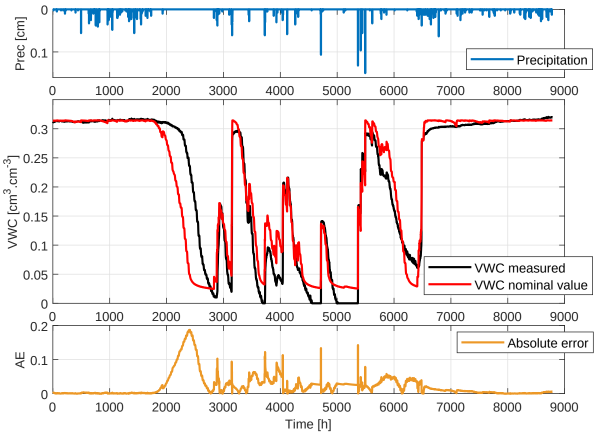

Fig. 2. Comparison of the simulated (red) and measured (black) VWC, absolute error (orange) between the simulated and measured VWC and rainfall (blue).

REFERENCES

Hégo, A., Collin, F., Garnier, H., and Claverie, R. (2021). Approaches for green roof dynamic model analysis using gsa. *IFAC-PapersOnLine*, 54(7), 613–618.

Li, Y. and Badcock Jr, R. (2014). Green roof hydrologic performance and modeling: a review. *Water Science & Technology*, 69(4), 727–738.

Simunek, J., Sejna, M., Saito, H., Sakai, M., and van Genuchten., M. (2008). *The HYDRUS-1D software package for simulating one-dimensional movement of water, heat, and multiple solutes in variably saturated media.* Department of Environmental Sciences University of California Riverside, Riverside, California.