Sensitivity Analysis on a green roof hydrological model
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Context

Urban imperviousness is a major urban issue during rainfall events. Solution → Green Roofs
• lower the peak flow rate in water system by 22% to 93%  
• delay the peak flow by 0 to 30 min

Green Roofs hydrologic modeling

• Rainfall data and real water content measured in a green roof of the CRERMA of Nancy  
• Simulation of the water infiltration into the layers using Richards equation (1) implemented in Hydrus-1D software

\[
\frac{\partial h}{\partial t} = \frac{\partial}{\partial x}\left(K(\theta)\frac{\partial h}{\partial x}\right) - \frac{1}{\theta_s} \left(h - h_n\right) \tag{1}
\]

\[
\theta_i = \frac{\theta_i - \theta_s}{1 + \left|\frac{h}{K_i}\right|^m} - \theta_s \quad \text{with} \quad m = 1 - \frac{1}{n} \tag{2}
\]

\[
K(S_i) = K(S_i^0) \left(1 - (1 - S_i^0)^m\right)^2 \quad \text{with} \quad S_i(\theta) = \frac{\theta_i - \theta_s}{\theta_i - \theta_s} \tag{3}
\]

Problem statement

• Input : Rainfall  
• Output : Water content \(\theta(t)\) or \(VWC(t)\) in (ii)  
• \(k = 6\) uncertain parameters : \(\theta_s, \theta_r, K_s, l, n\) and \(\alpha\)

GSA method

Method based on PCE:

\[
Y(t) = G(X, t) = \sum_{i=1}^{N} a_i(t)\psi_i(X_1, \ldots, X_l) \tag{4}
\]

Method applied at each time instant:
1. Define the distribution of uncertain parameters to compose \(\psi_i\)
   Uniform distribution → Legendre Polynomials
2. Define \(p\), the maximum development order of \(\psi_i\)
3. Estimate the PC coefficients \(a_i(t)\) by solving a least square problem
4. Estimate sensitivity index (SI) with:
   First order SI:

\[
S_i(t) \approx \sum_{l=1}^{L_i} a_l^2(t) E[Y_i(X_l)] \tag{5}
\]
   where \(L_i\) is polynomial order of \(\psi_i\) which depends only on \(X_l\)

Total SI:

\[
S_T(t) \approx \sum_{l=1}^{L_i} a_l^2(t) E[Y_i(X_l)] \tag{6}
\]
   where \(L_i\) is polynomial order of \(\psi_i\) which depends only on \(X_l\) and all its interactions.

Results on Green Roofs

• Variations whatever \(VWC(t)\) evolution  
  \(\Delta S_i = S_{fi} - S_{al}\) for no interaction between parameters  
  3 influential parameters : saturated water content \(\theta_s\), pressure head fitting parameter \(\alpha\) and porosity \(n\) distribution  
  \(S_{fi}\) follows \(VWC(t)\) i.e \(\geq \) when it rains  
  \(S_{al}\) inversely follows \(VWC(t)\) i.e \(\leq \) when it rains  
  \(S_{al}\) varies slightly following \(VWC(t)\)  
  The other parameters are not influential

• No variation when \(VWC(t)\) is saturated  
  As for the variation of substrate parameters, we have:  
  \(S_{fi} = S_{al}\)  
  Same 3 influential parameters and the other parameters uninfluential  
  Same dynamics for \(S_{fi}, S_{al}\) and \(S_{al}\) but with more intensity

For the green roof model, 500 samples from Sobol sequence (QMC) to generate \(Y(t)\) and a development order \(p = 3\) to obtain indices is adapted

Conclusion and Prospect

• 3 influential parameters, saturated water content \(\theta_s\), pressure head fitting parameter \(\alpha\) and porosity \(n\) and different influences depending on the layer  
• Prospects : analyse the outflow and include meteorological uncertainties

References