Intercomparison of the SCS-CN and Green & Ampt Methods for Runoff Generation in three small Experimental Watersheds in Southern Bavaria

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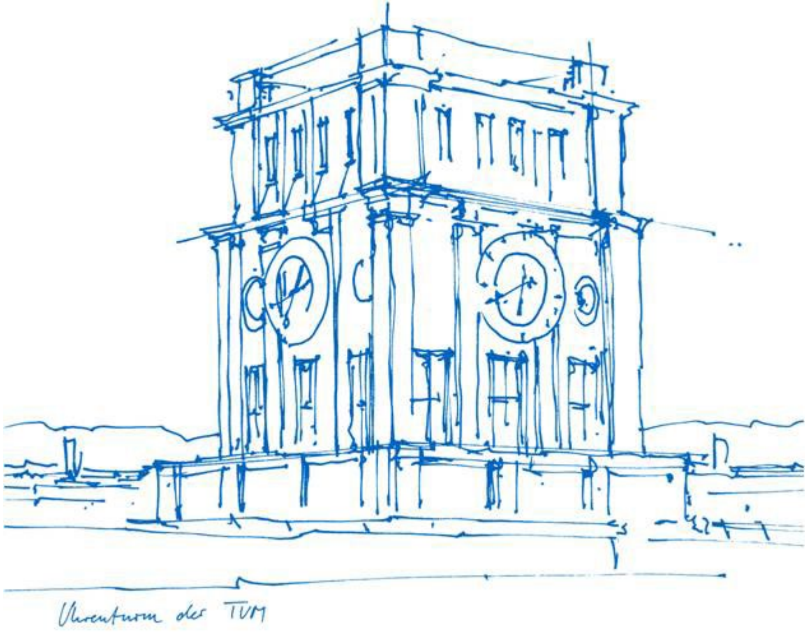
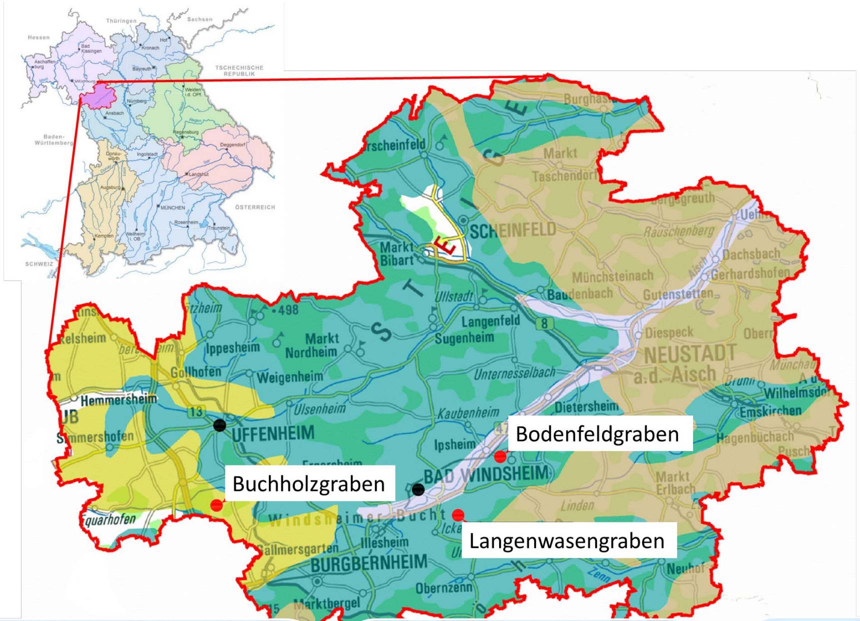


Motivation and Background

Motivation

Project Grüne Gräben (green diches)

- Enhance water retention in “GrüneGräben” using controllable weirs
- Investigate spatial and temporal infiltration capacity along ditches
- Assess transferability of measures across Bavaria



Buchholzgraben bei Vorderpfeilach

- Geological main unit Loess/Loess Loam
- Inpoundment lenght: ca. 100 m
- Inpoundment volume: ca. 56 m^3
- Inpoundment height: ca. 0,75 m
- Catchment area: ca. 0,17 km^2

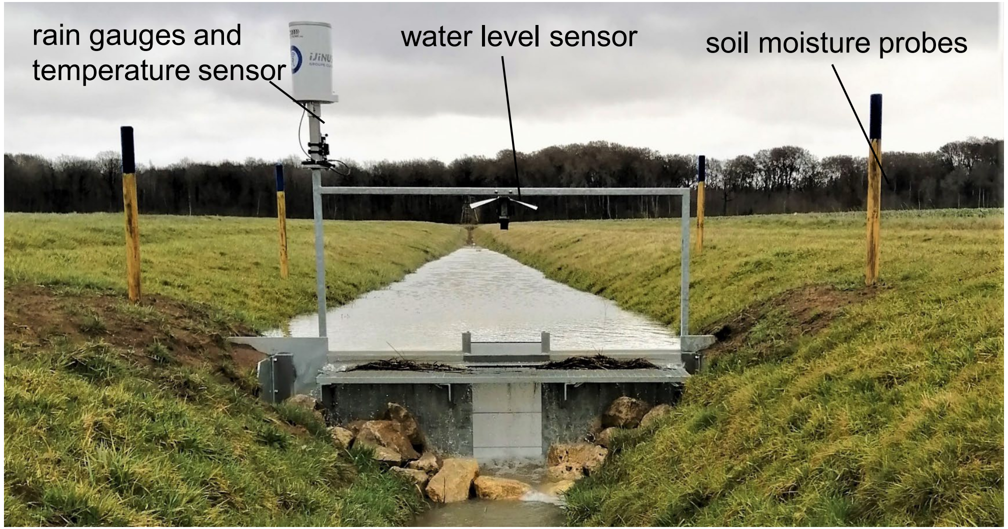
Langenwasengraben bei Ickelheim

- Geological main unit: Gypsum Keuper
- Inpoundment lenght : ca. 36 m
- Inpoundment volume : ca. 10 m^3
- Inpoundment height : ca. 0,6 m
- Catchment area : ca. 1,88 km^2

Bodenfeldgraben Bei Oberndorf

- Geological main unit: Gypsum Keuper
- Inpoundment lenght : ca. 65 m
- Inpoundment volume : ca. 19 m^3
- Inpoundment height : ca. 0,55 m
- Catchment area : ca. 0,34 km^2

Measurements



Controllable weir with measuring instruments at the Buchholzgraben

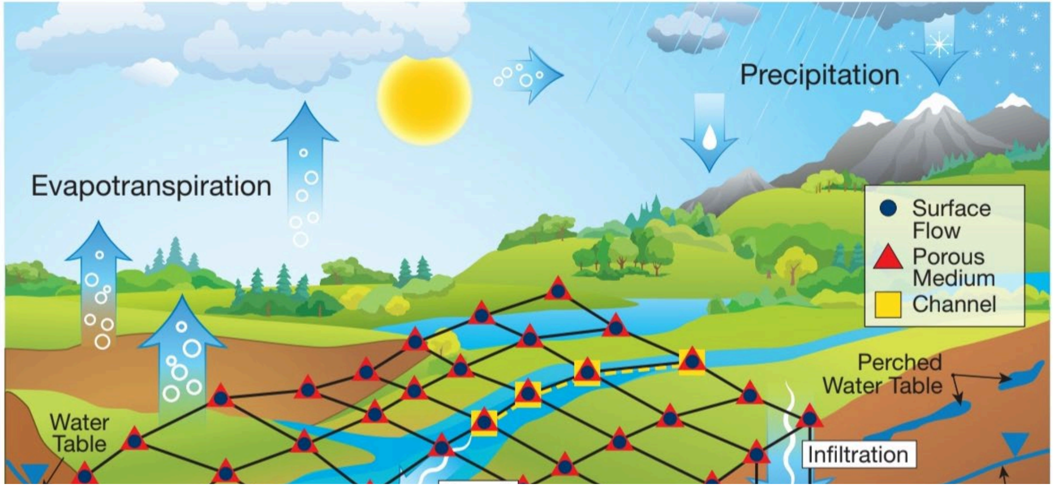
Infiltrometer

Soil probes

$$Q = \frac{2}{3} * \mu * B * \sqrt{2 * g} * h_{ü}^{3/2}$$

Drone measurements for high resolution DTM

Benchmark Model HydroGeoSphere (HGS)



- Soil water movement governed by Richards' Equation in 3-dimensional transient subsurface flow.
- Surface flow governed by 2-dimensional Saint-Venant shallow water equations
- Macropore flow (preferential flow)
- Flexible Meshing and implicit time

Richards' Equation (3D)

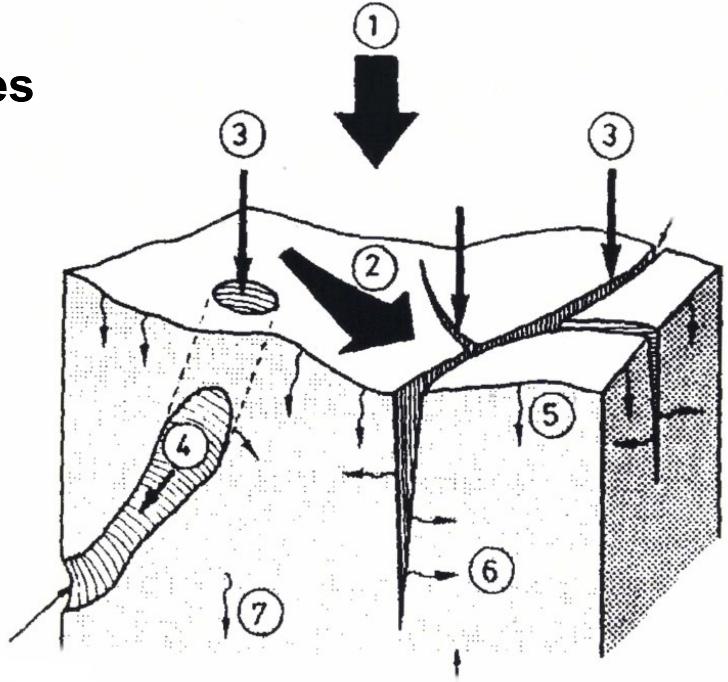
$$-\nabla \cdot (w_m \mathbf{q}) + \sum \Gamma_{\text{ex}} \pm Q = w_m \frac{\partial}{\partial t}(\theta_s S_w)$$

$$\mathbf{q} = -\mathbf{K} \cdot k_r \nabla(\psi + z) \qquad S_w = \frac{\theta}{\theta_s}$$

$$\mathbf{K} = \frac{\rho g}{\mu} k$$

SWAT infiltration methods / bypass flow / interflow

Hydrologic processes during infiltration



① Precipitation

② Surface runoff

③ Percolation into macropores

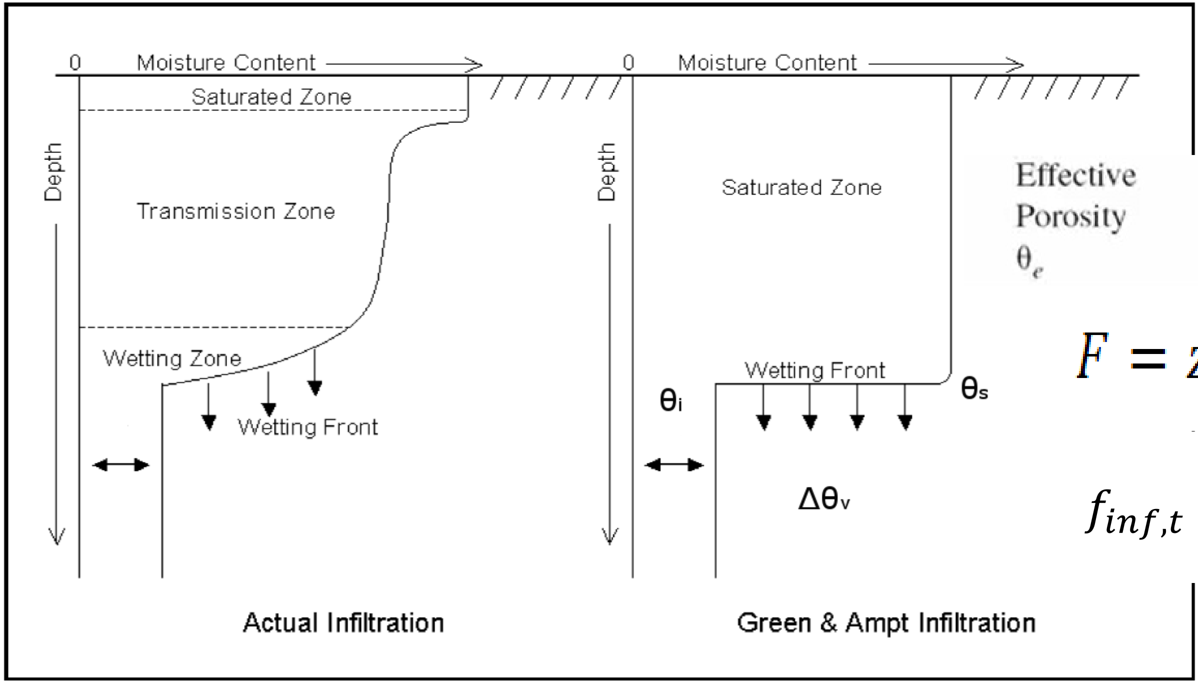
④ Percolation within macropores

⑤ Percolation into micropores through the soil surface

⑥ Percolation from macropores to micropores

⑦ Percolation within micropores

Green & Ampt Method



Effective Porosity θ_e	Wetting Front Soil Suction Head ψ (cm)	Hydraulic Conductivity K (cm/h)

$$F = z_f \cdot (\theta_s - \theta_i) = z_f \cdot \Delta\theta_v$$

$$f_{inf,t} = K_e \cdot \left(1 + \frac{|\psi_f| \cdot \Delta\theta_v}{F_{inf,t}}\right)$$

$$F_{inf,t} = F_{inf,t-1} + K_e \cdot \Delta t + |\psi_f| \cdot \Delta\theta_v \cdot \ln\left[\frac{F_{inf,t} + |\psi_f| \cdot \Delta\theta_v}{F_{inf,t-1} + |\psi_f| \cdot \Delta\theta_v}\right]$$

CN Method

Using the relationship of $F = P_e - Q$ *into*

$$\frac{F}{S} = \frac{Q}{P_e}$$

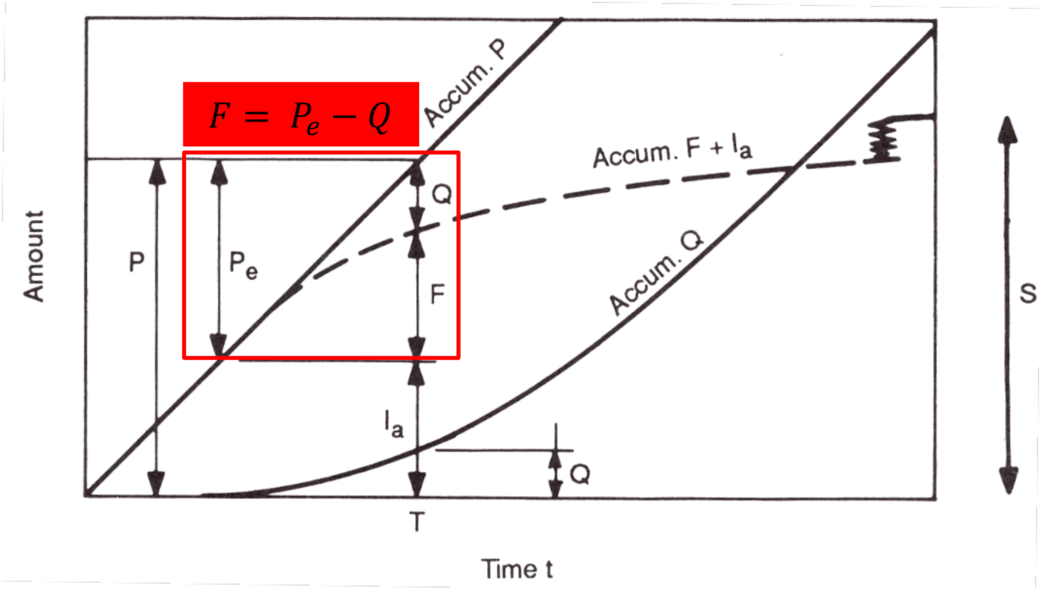
yields the basic SCS equation

$$Q = \frac{{P_e}^2}{P_e + S} = \frac{(P - I_a)^2}{P - I_a + S}$$

The empirical relation $I_a = 0.2 \cdot S$ was adopted as the best approximation from observed data, so that

$$P_e = P - 0.2 \cdot S$$

And therefore



$$Q = \frac{(P - 0.2 \cdot S)^2}{P + 0.8 \cdot S} \; for\ P > 0.2 \cdot S$$

$$S = 25.4 \cdot \left(\frac{1000}{CN} - 10\right) (in\ mm)$$

Bypass flow

To accurately predict surface runoff and infiltration in areas dominated by soils that have Vertisol properties, the temporal change in soil volume must be quantified, as traditional models of infiltration are applicable to soils in which cracks have been closed by swelling and the soil acts as a relatively homogenous porous medium.

Dry vertisol with huge cracks (www.geography.hunter.cuny.edu)

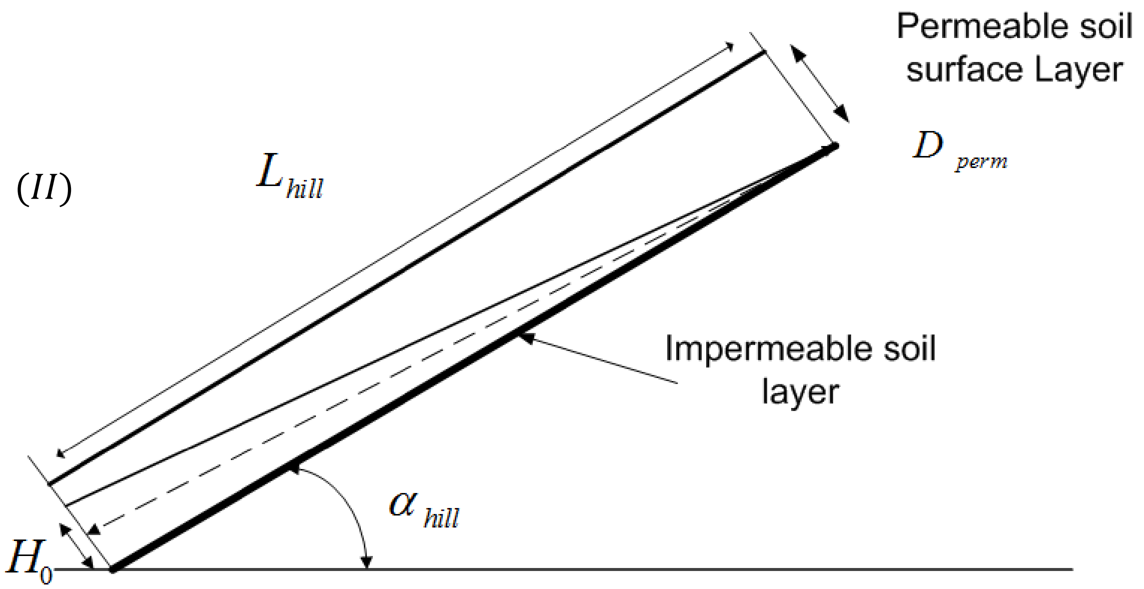
$$crk_{ly,i} = crk_{max,ly} \cdot \frac{coef_{crk} \cdot FC_{ly} - SW_{ly}}{coef_{crk} \cdot FC_{ly}}$$

Interflow

$$H_0 = \frac{2 \cdot SW_{ly,excess}}{1000 \cdot \phi_d \cdot L_{hill}} \quad (I)$$

$$v_{lat} = K_{sat} \cdot \tan(\alpha_{hill}) = K_{sat} \cdot slp \quad (II)$$

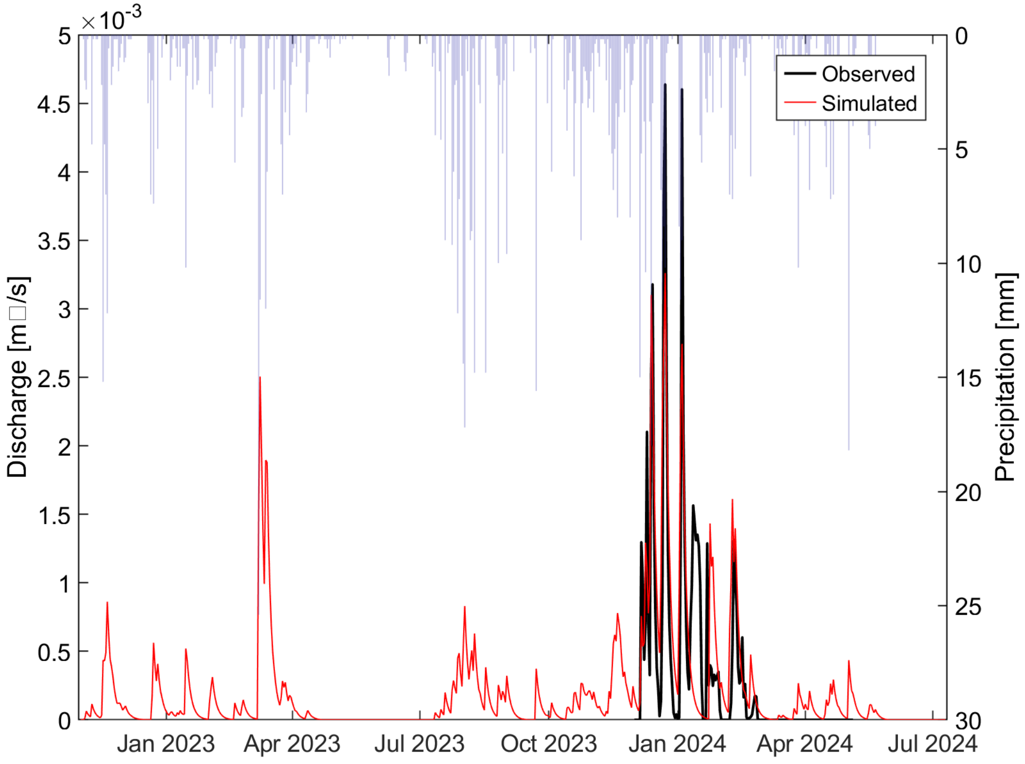
$$Q_{lat} = 24 \cdot H_0 \cdot v_{lat} \quad (III)$$



$$Q_{lat} = 0.024 \left(\frac{2 \cdot SW_{ly,excess} \cdot K_{sat} \cdot slp}{\phi_d \cdot L_{hill}} \right)$$

SWAT model results Buchholzgraben

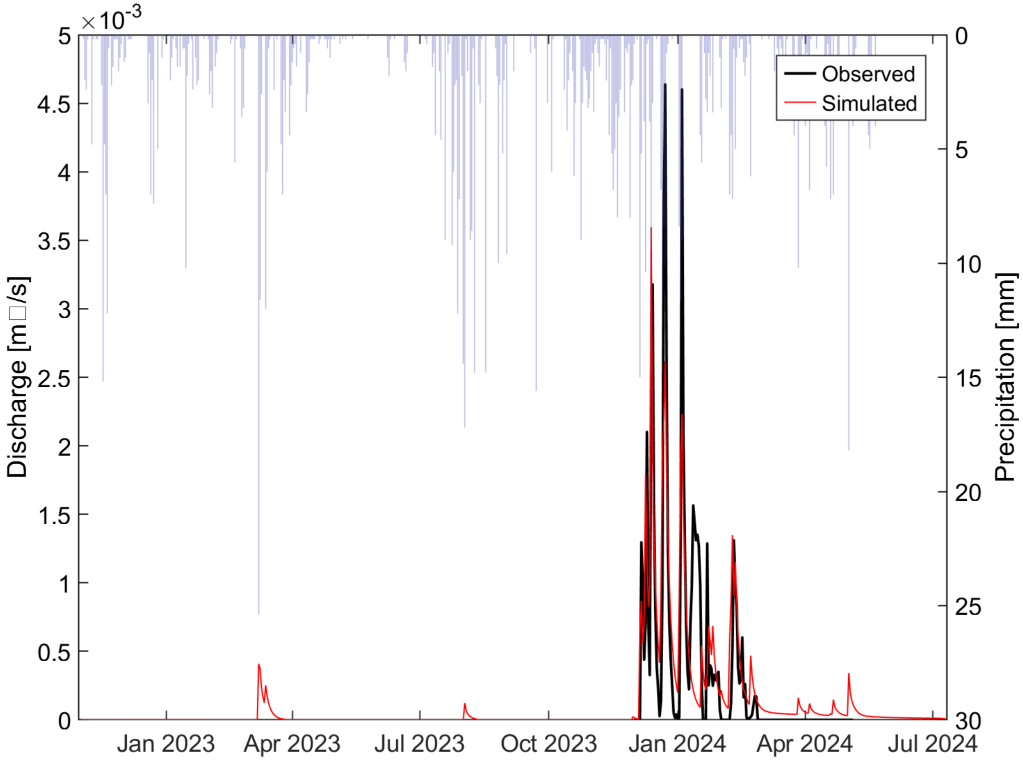
Simulation Discharge with CN Method (without cracks)



Parameters:	
CN2	54.9
ESCO	0.9
EPCO	0.1
SOL_AWC	0.5
SOL_BD	1.2
SOL_K	85.7
HRU_SLP	1.0

NSE = 0.64
KGE = 0.70
PBIAS = -17.8

Simulation Discharge with CN Method (with cracks)



Parameters:

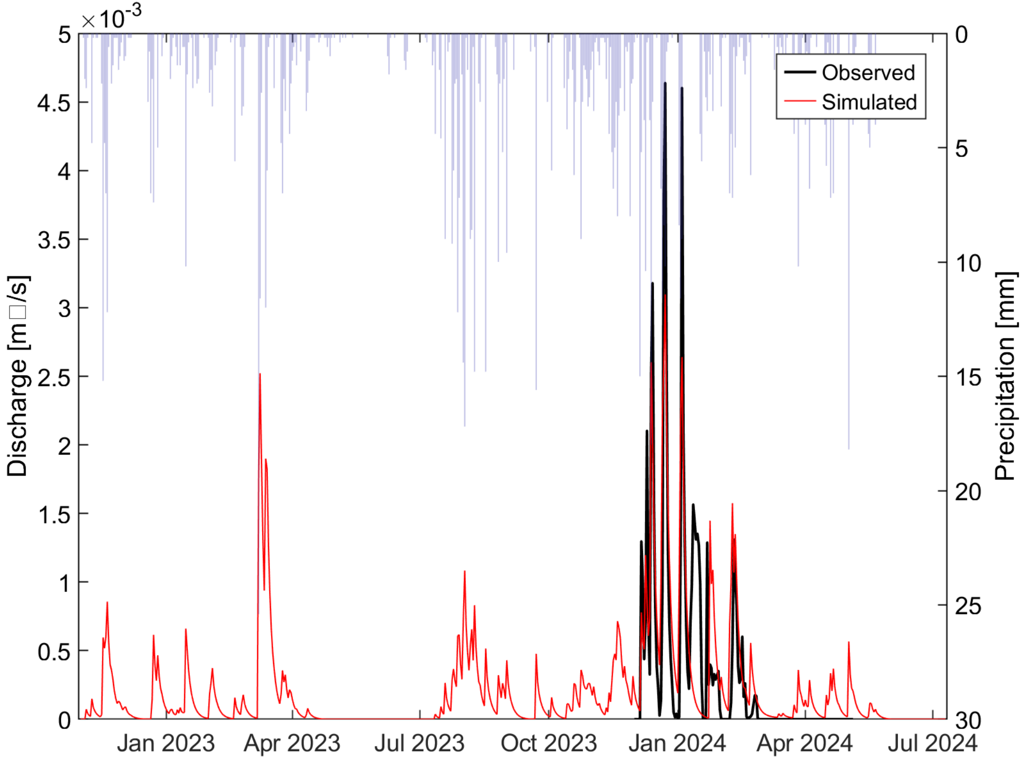
CN2	67.0
ESCO	0.9
EPCO	0.5
SOL_AWC	0.5
SOL_BD	0.9
SOL_K	69.3
HRU_SLP	1.1
SOL_CRK	0.09

NSE = 0.63

KGE = 0.66

PBIAS = -4.4

Simulation Discharge with Green&Ampt Method (without cracks)

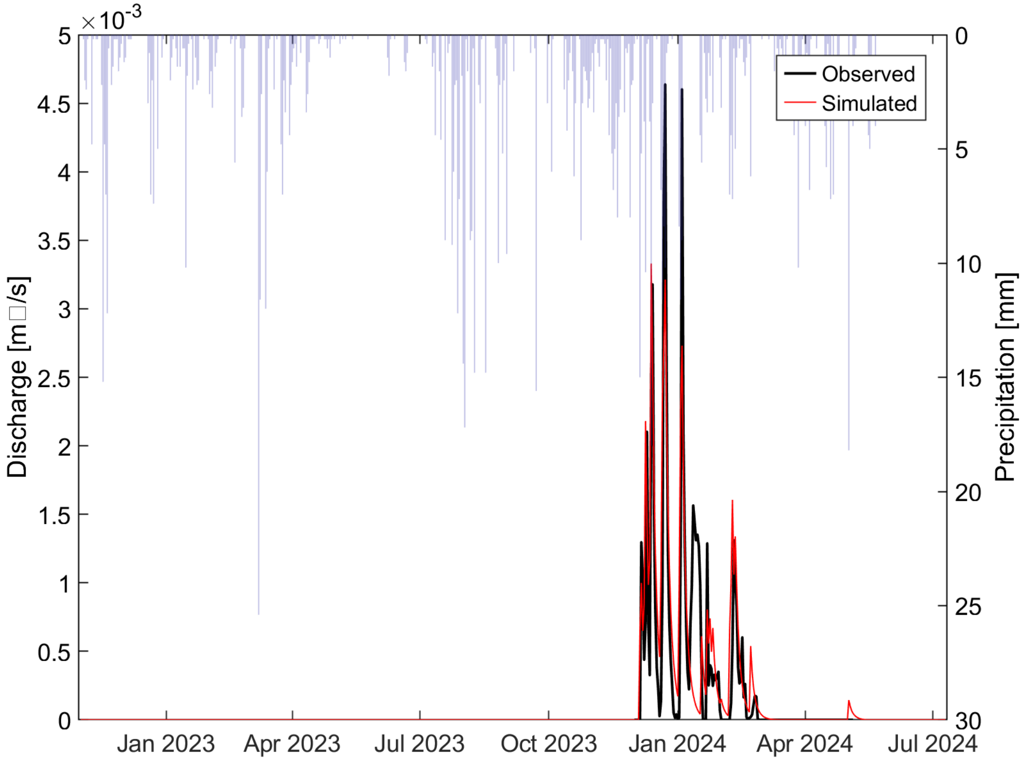


Parameters:

ESCO	1.0
EPCO	0.3
SOL_AWC	0.4
SOL_BD	1.2
SOL_K	69.3
HRU_SLP	1.0

NSE = 0.63
KGE = 0.67
PBIAS = -12.5

Simulation Discharge with Green&Ampt Method (with cracks)

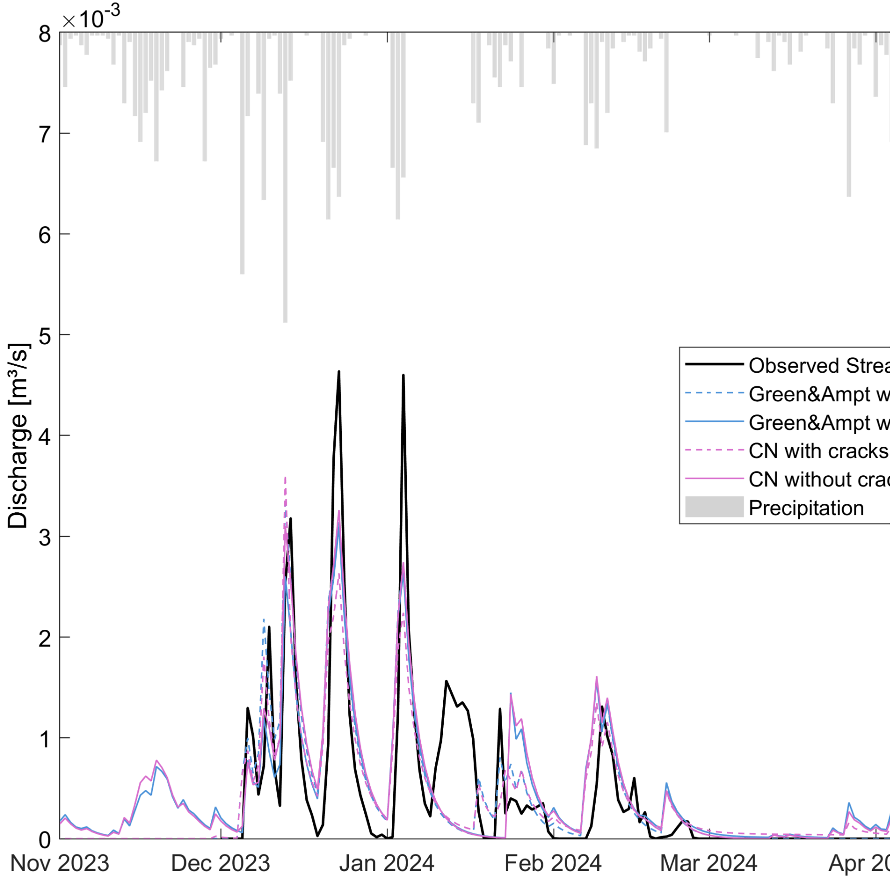


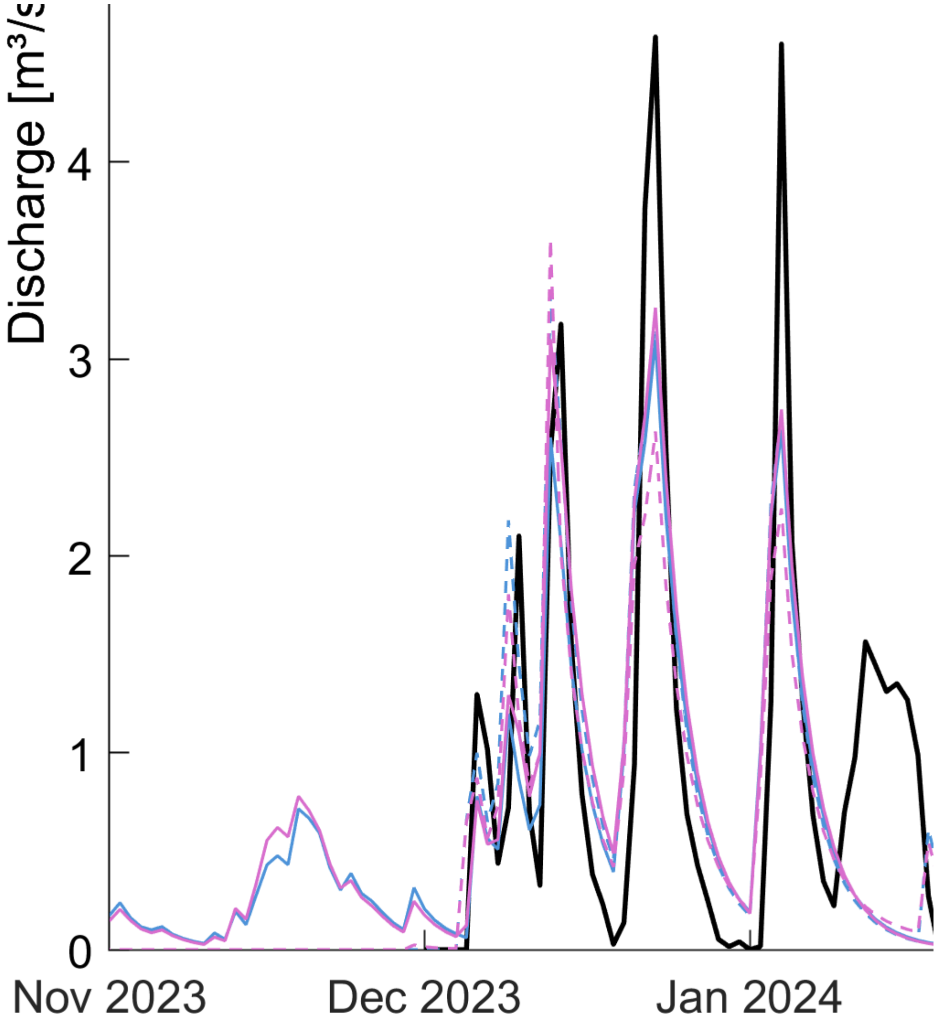
Parameters:

ESCO	0.9
EPCO	0.6
SOL_AWC	0.5
SOL_BD	0.8
SOL_K	79.7
HRU_SLP	1.3
SOL_CRK	0.27

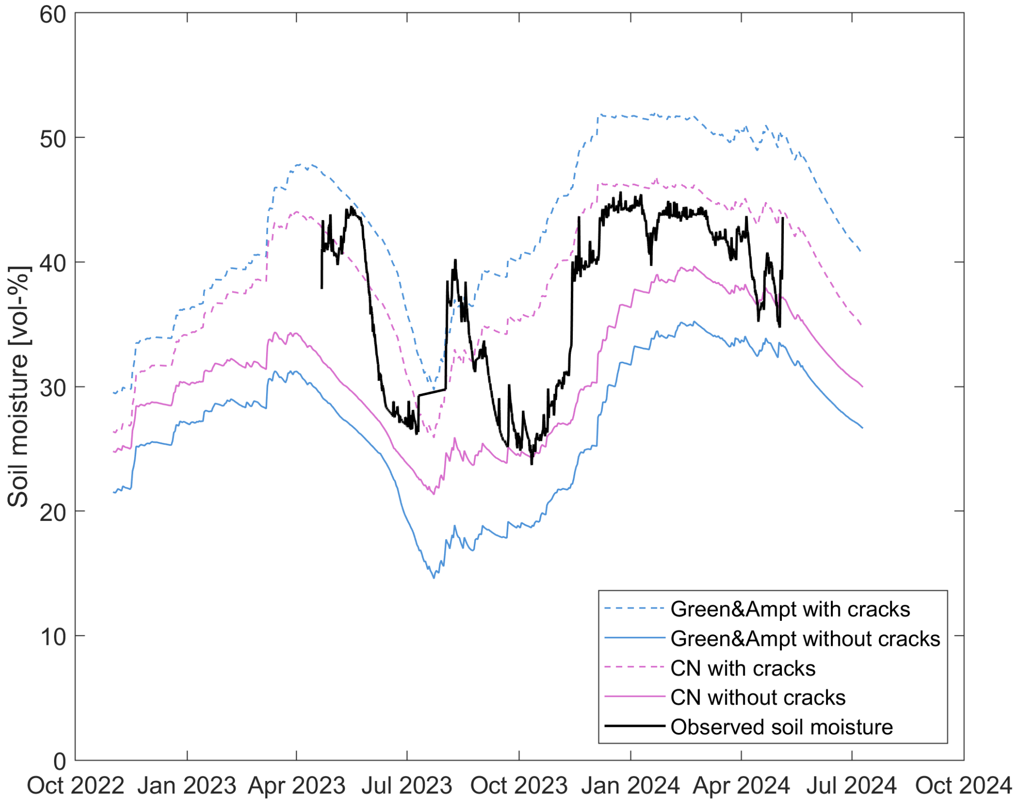
NSE = 0.67
KGE = 0.76
PBIAS = -9.2

Comparison Discharge



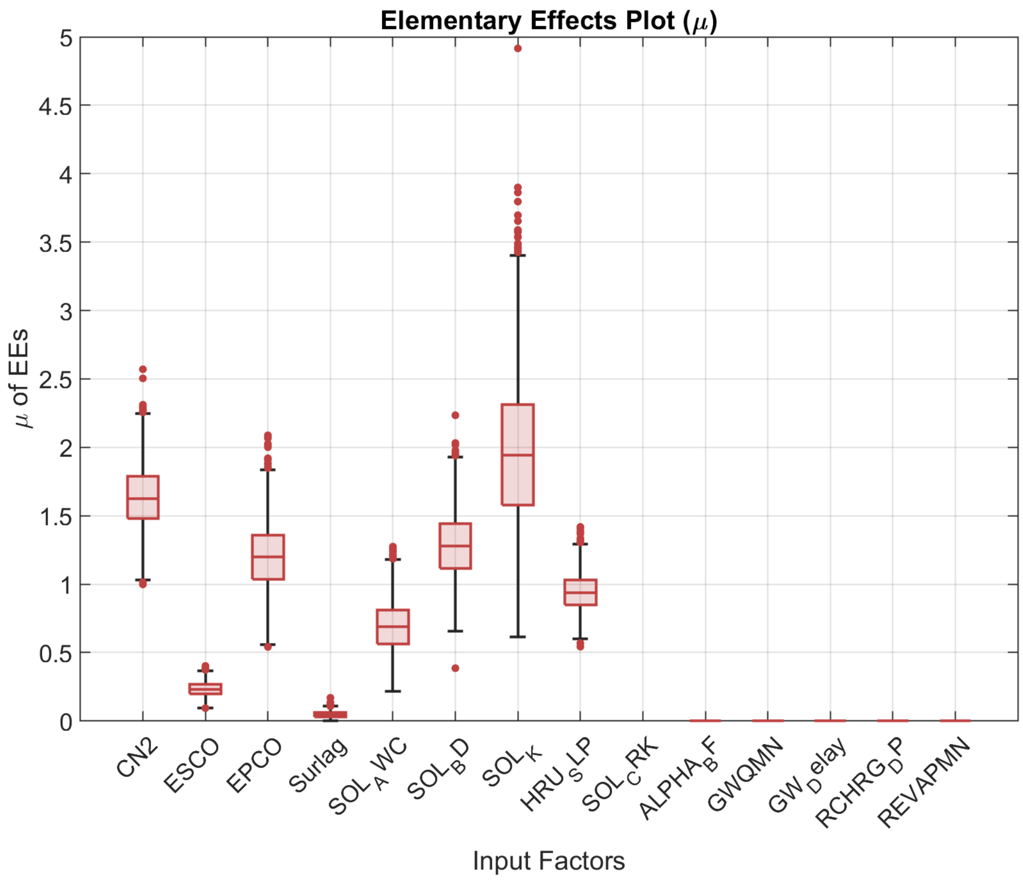


Comparison Soil Moisture

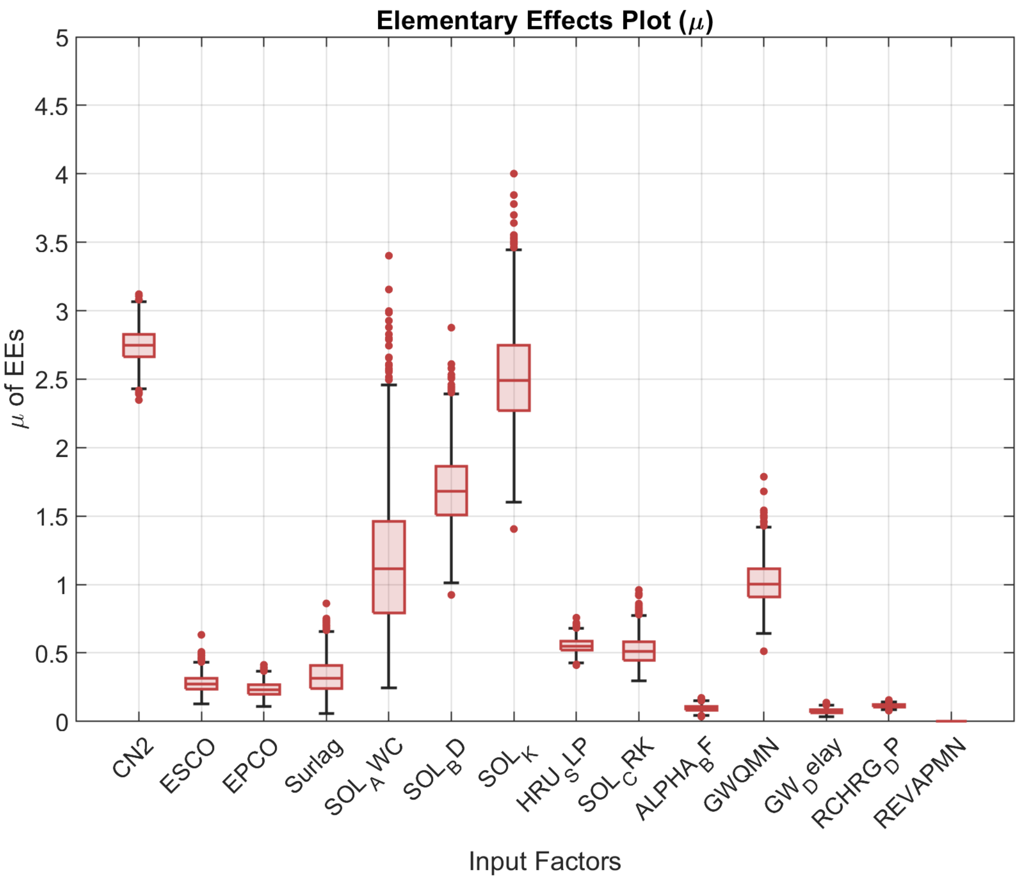


Parameter Sensitivities

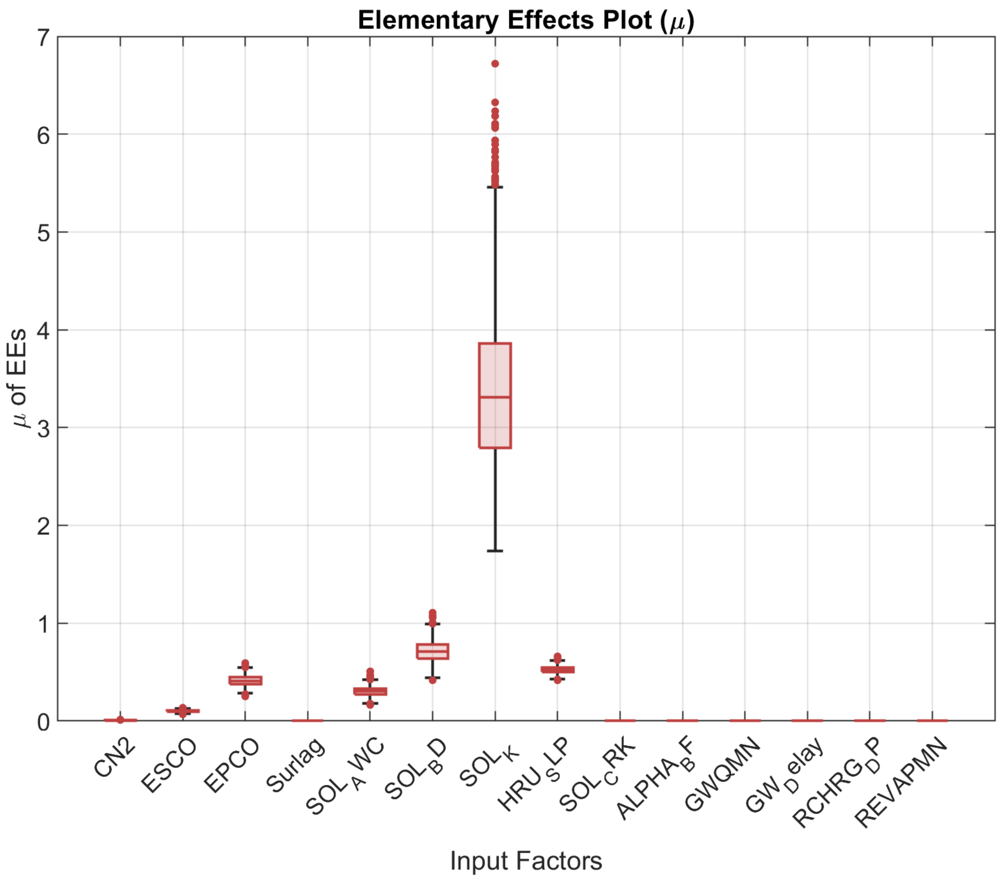
Parameter Sensitivity CN Method (without cracks)



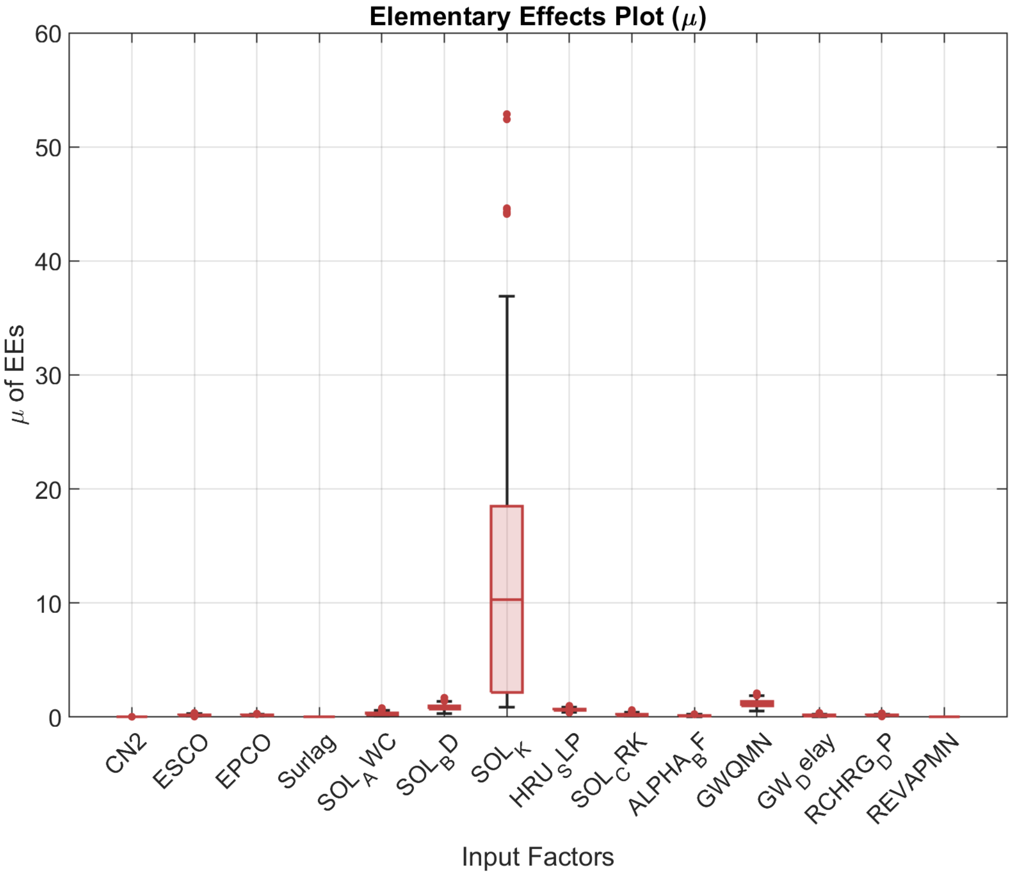
Parameter Sensitivity CN Method (with cracks)



Parameter Sensitivity Green&Ampt Method (without cracks)



Parameter Sensitivity Green&Ampt Method (with cracks)



Conclusions and Outlook

Conclusions

- CN- and Green&Ampt methods generally able to simulate discharge to ditches in small agricultural basins
- Soil crack introduction important to improve interflow modelling of shrinking and swelling soils
- Different k_{sat} values for horizontal and vertical soil water flow needed
- Green&Ampt model superior to the CN method (process representation)

Outlook

- Improvement of Interflow simulation (new parametrization):

  k_s(lat) and drainage density d_r

  $$q_{ifl} = k_s(\Theta_m) \cdot \Delta z \cdot d_r \cdot \tan \beta$$

- Improvement of Crack simulation:

  a) precipitation intensity threshold

  b) definition of macropore depth

  c) infiltration from full macropores towards soil matrix

- Systematic evaluation of Green&Ampt model for hourly time steps
- Green&Ampt for layered soils down to groundwater level and coupling with gwflow

Thank you for your attention!