321-9: Effective Hydraulic Parameters for Sloping Heterogeneous Soil Formations

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Introduction

- Infiltration in sloping layered soils is common under field conditions. It is an important factor in many hydrological processes.
- Green-Ampt model is a widely used representation of infiltration process due to its physically-based with simplicity and accuracy. Modifications and improvements of this method are needed for implementation in sloping layered soils.
- The effective hydraulic conductivity value K_e in Green-Ampt equation is equal to a factor *c* multiples the saturated hydraulic conductivity K_s. The factor *c* is set to 0.5 in most research. Will these values be the same for sloping layered soils?
- To integrate Green-Ampt model in large–scale hydrologic and land-atmosphere simulations, effective parameters of the model for sloping layered soils need to be investigated.

Objectives

1. Develop a modified Green-Ampt infiltration model for Sloping Layered Soils (GASLS).
2. Investigate the factor *c* for GASLS under various scenarios.
3. Determine effective parameters of GASLS model for upscaling.

Methods

❖ GASLS Model

✓ For the Richards' equation for sloping surface in the x* and z* coordinates :

$$\frac{\partial\theta}{\partial t}=\frac{\partial}{\partial z^*}\left(D\frac{\partial\theta}{\partial z^*}\right)-\frac{dk}{d\theta}\frac{\partial\theta}{\partial z^*}cos\gamma$$

✓ The gravity normal to the surface direction is changed by cosγ. Similar modification is applied to Green-Ampt model.

✓ For the wetting front in the first layer in z* direction, i.e. $Z_f \le Z_1$

$$i=K_{e,1}\frac{Z_f cos\gamma+h_{s,1}+h_p}{Z_f}$$

where i is infiltration rate, Z_f is wetting front depth, effective hydraulic conductivity in layer 1 $K_{e,1}=cK_{s,1}$, ponding head $h_p=H_d cos\gamma$, $h_{s,1}$ is the suction head

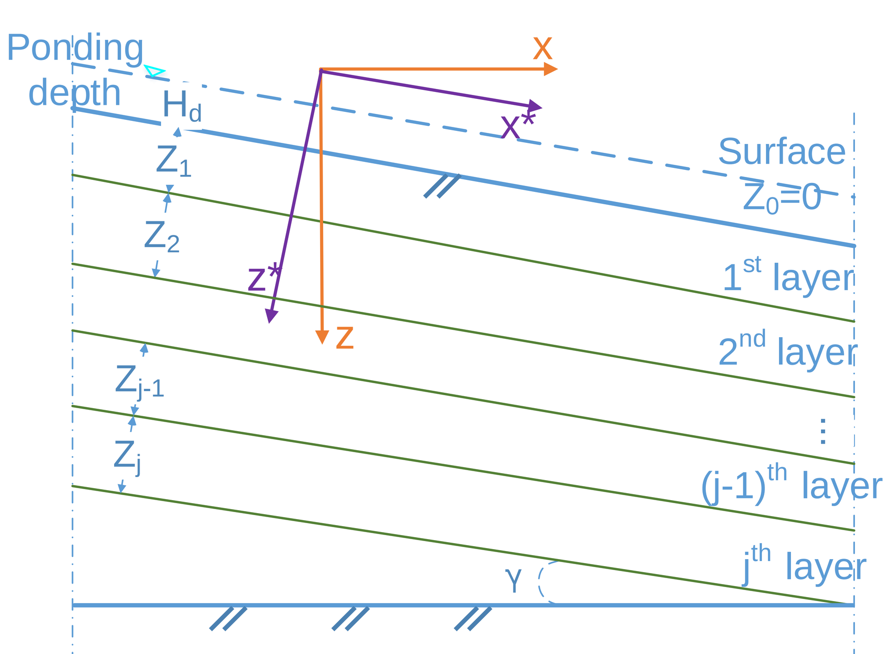
$$h_{s,j}=\frac{1}{K_{s,j}-K_{i,j}}\int_{-\infty}^{0}K(h)\,dh$$

Cumulative infiltration depth I:

$$I=(\theta_{s,1}-\theta_{i,1})Z_f$$

Time:

$$t=\frac{\theta_{s,1}-\theta_{i,1}}{K_{e,1}cos\gamma}\left[Z_f-\frac{h_s+h_p}{cos\gamma}ln\frac{Z_f cos\gamma+h_{s,1}+h_p}{h_{s,1}+h_p}\right]$$



Schematic of sloping layered soils.

For wetting front located in layer j, i.e.,$Z_{j-1}<Z_f\le Z_j$

$$i=\frac{Z_f cos\gamma+h_{s,j}+h_p}{\frac{Z_j-Z_{j-1}}{K_{e,j}}+\sum_{m=1}^{j-1}\frac{Z_m-Z_{m-1}}{K_{e,m}}}$$

$$I=(Z_j-Z_{j-1})(\theta_{s,j}-\theta_{i,j})+\sum_{m=1}^{j-1}(Z_m-Z_{m-1})(\theta_{s,m}-\theta_{i,m})$$

$$t_{Z_f}=t_{j-1}+\frac{(\theta_{s,j}-\theta_{i,j})(Z_f-Z_{j-1})}{K_{e,j}cos\gamma}+(\theta_{s,j}-\theta_{i,j})*\left[\sum_{m=1}^{j-1}\frac{Z_m}{cos\gamma}\left(\frac{1}{K_{e,m}}-\frac{1}{K_{e,m+1}}\right)-\frac{h_p+h_{s,j}}{K_{e,j}cos^2\gamma}\right]*ln\left(\frac{Z_f cos\gamma+h_{s,j}+h_p}{Z_{j-1}cos\gamma+h_{s,j}+h_p}\right)$$

where t_{j-1} is the time when wetting front passed layer j-1.

✓ Note that i and I are in z* direction.

❖ Factor *c*

✓ Simulate infiltration with ponding water in sloping layered soil using Hydrus-1D.

✓ Simulate infiltration process with identical soil profile using GASLS model.

✓ Employ Shuffled Complex Evolution (SCE-UA) method to optimum the factor *c* that can reconcile the time of saturating whole profile with Hydrus and GASLS.

❖ Effective Parameters of GASLS model

✓ Determine effective parameters(K_s, h_s) with an equivalent homogeneous soil profile with optimal factor *c*.

✓ Effective parameters are evaluated using SCE-UA method to minimize objective function of saturation time difference between equivalent homogeneous and layered soils.

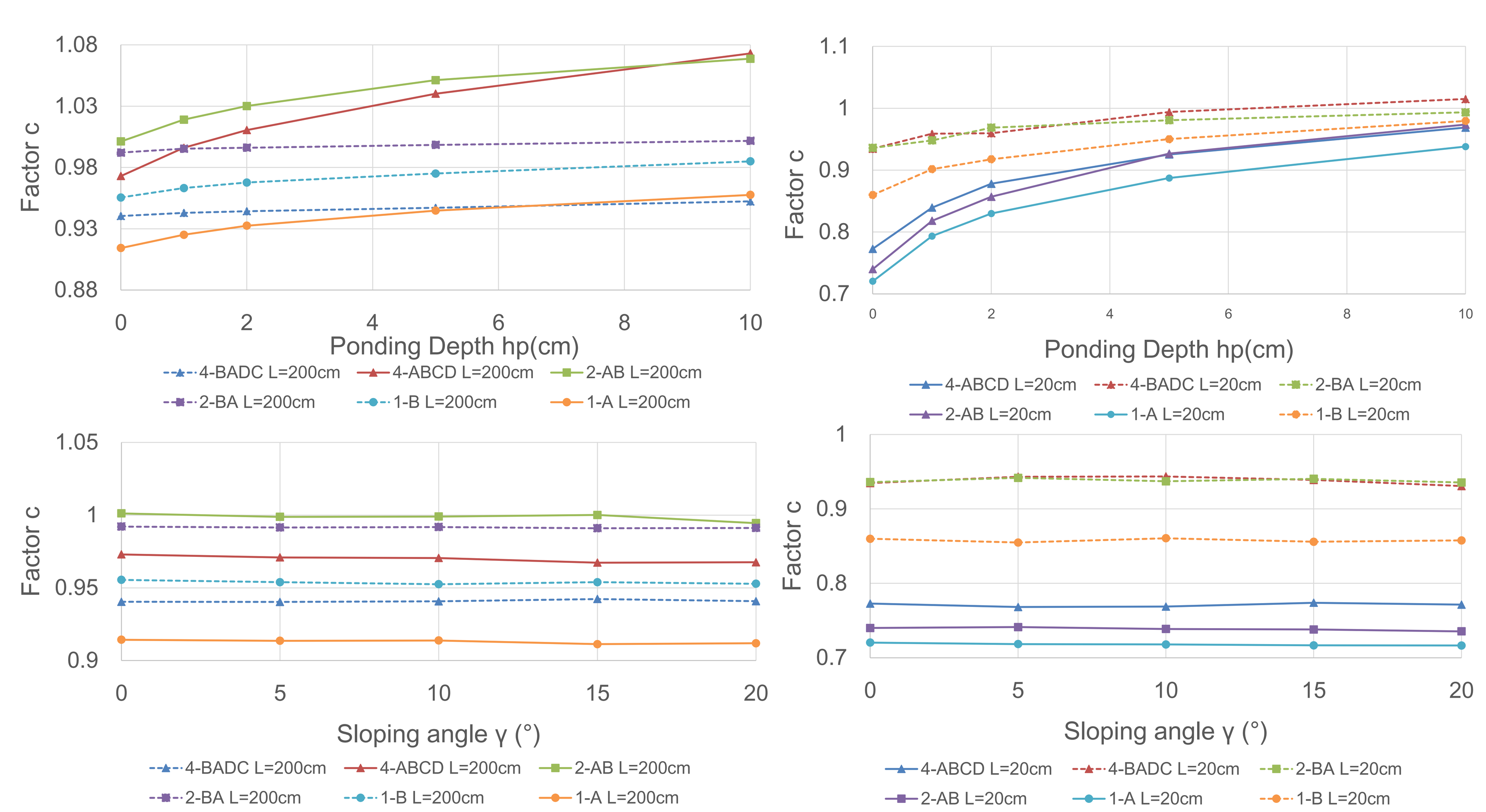
✓ Power mean *p* is used to represent effective parameters of all soil layers

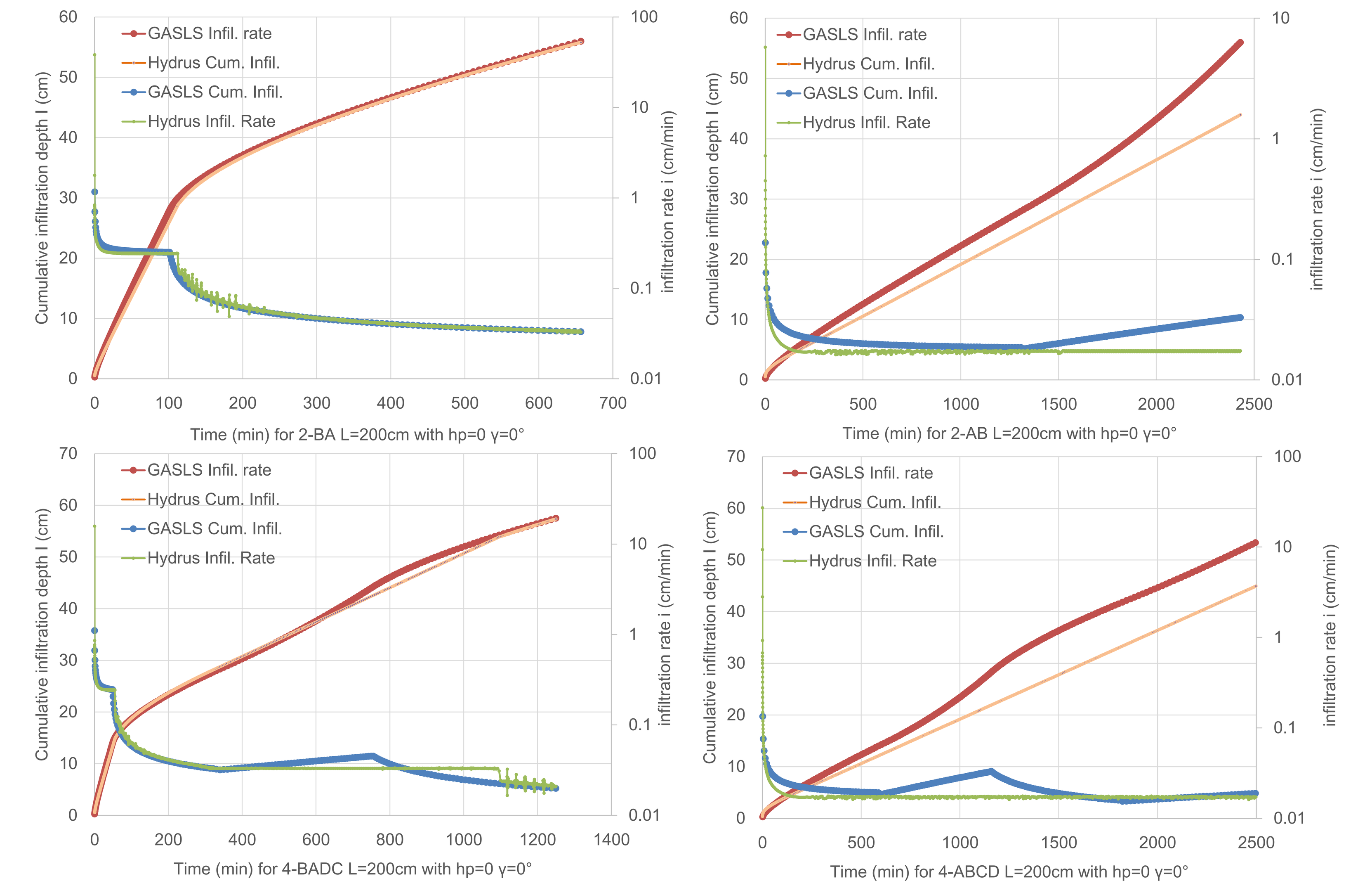
Results

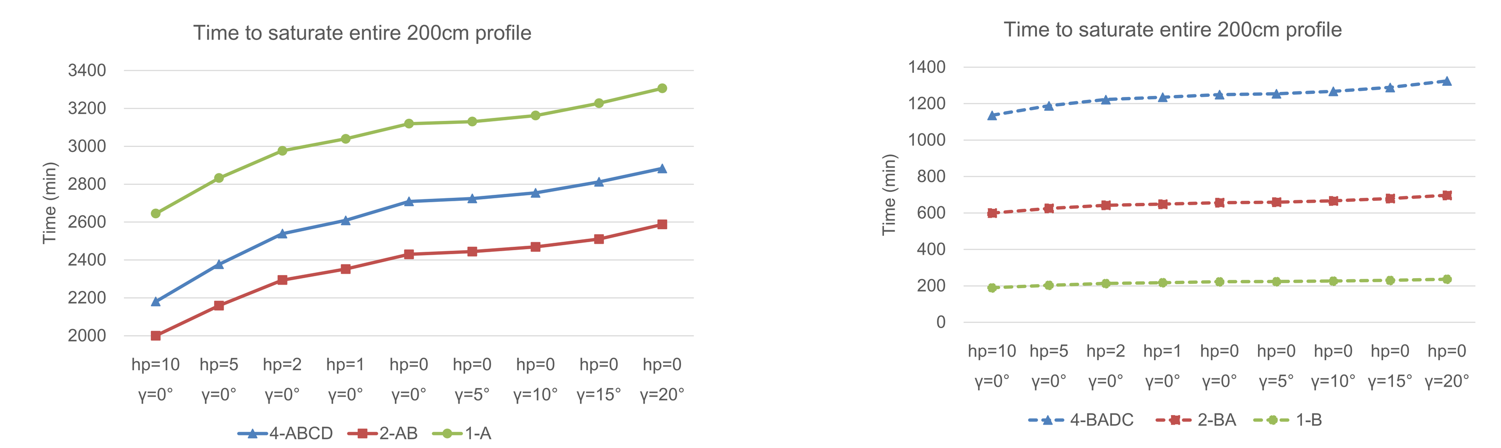
van Genuchten parameters of soils in this study

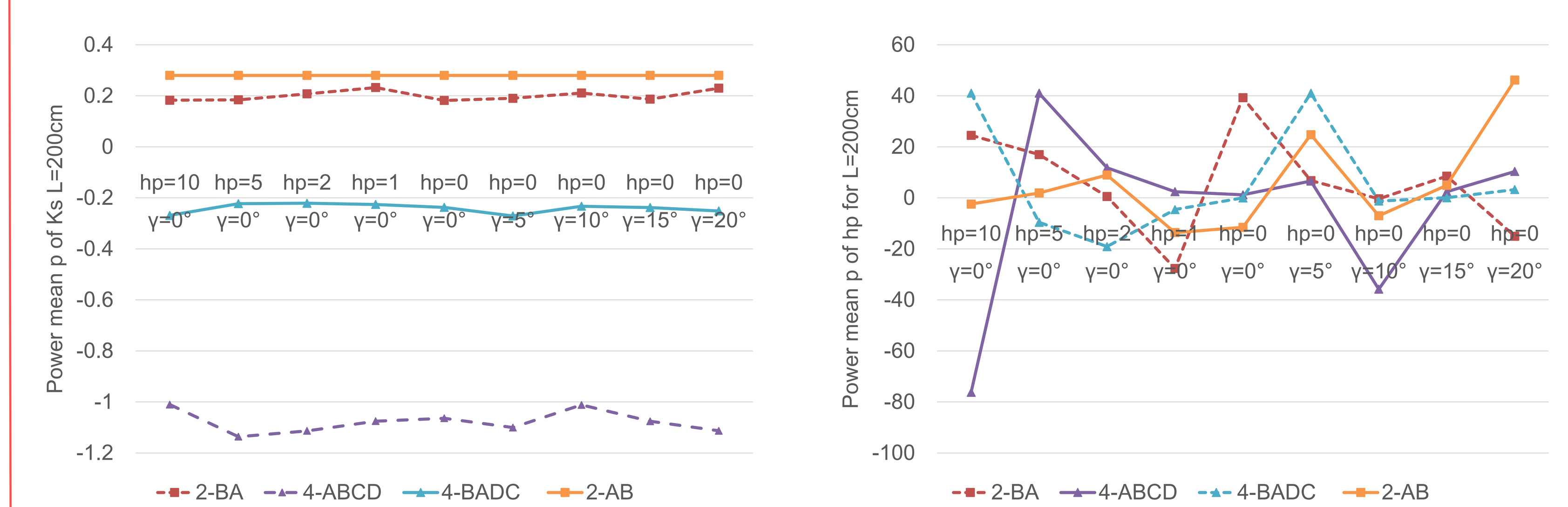
ID	Soil	θ_r	θ_s	θ_i	α (1/cm)	n	K_s (cm/hr)	h_s (cm)
A	Loam	0.078	0.43	0.15	0.036	1.56	1.04	6.941
B	Loamy sand	0.057	0.41	0.13	0.124	2.28	14.592	3.838
C	Silt loam	0.067	0.45	0.18	0.02	1.41	0.45	8.995
D	Sand	0.045	0.43	0.11	0.145	2.68	29.7	3.807

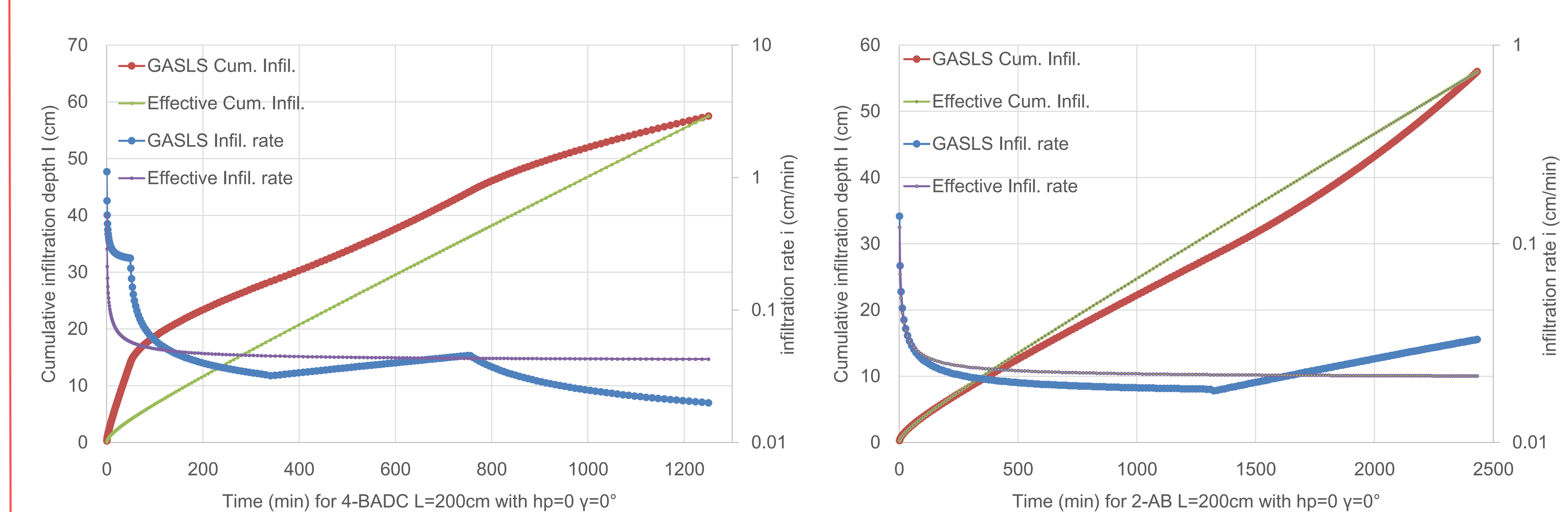
- For simplicity, abbreviations are used. Such as, 4-BADC L=200cm means the four layers with equal length 50cm loamy sand, loam, sand, and silt loam from top down in a 200cm soil profile.











Summary

❖ We developed a modified Green-Ampt infiltration model for Sloping Layered Soils (GASLS). It can describe infiltration process.

❖ Factor *c* approaches 1 along increasing soil profile length and ponding depth. Arrangements of soil layers highly influences factor *c*.

❖ Power mean *p* of effective parameters is affected by layer formation. Constant power mean of K_s can be assumed when upscaling, while *p* of h_s varies significantly.

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