Modeling the establishment of preferential flow during infiltration in a heterogeneous glaciofluvial deposit

Erij Ben Slimene[1,2]*, Laurent Lassabatere[1], Thierry Winiarski[1], Remy Gourdon[2]

EGU2015-5503

1 – Context and objectives

Due to its rapid movement, preferential flow in the vadose zone allows much faster contaminant transport and creates significant consequences for ground-water quality.

⇒ This study deals with flow modeling during the infiltration phase in a strongly heterogeneous glaciofluvial deposit underneath an infiltration basin. In particular, we want to point out numerically the worst conditions with regards to preferential flow as a function of entering flow rates.

2 – Profile: sedimentological and schematic description

The study site is located on the glaciofluvial deposit of the east of Lyon, France, underneath Django Reinhardt infiltration basin for runoff water. The sedimentological heterogeneity of the deposit was characterized and implemented into a numerical model:

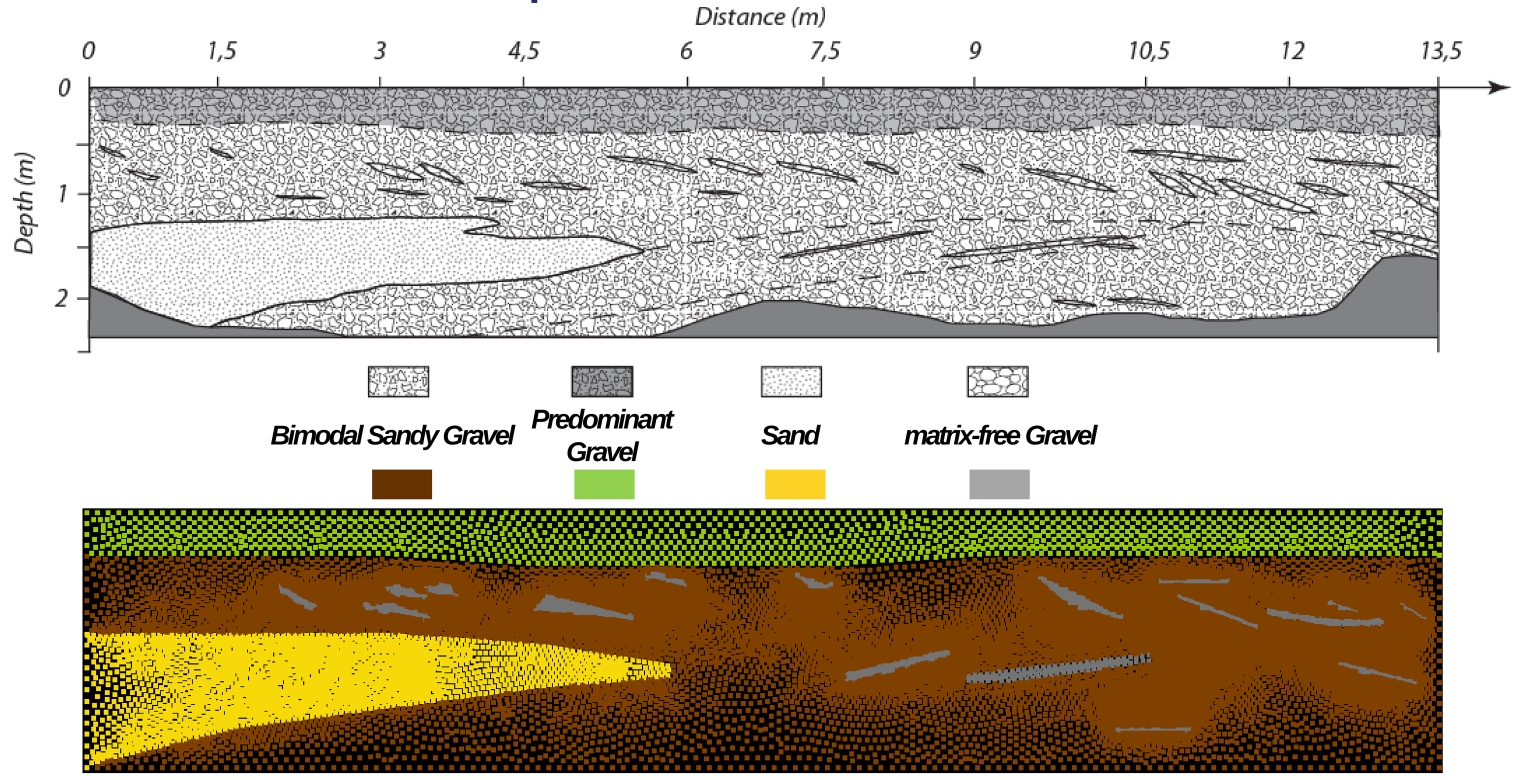

Fig. 1. Lithofacies description (up) and Material distribution in HYDRUS (down).

3 – Modeling : Parameters and numerical options

Generalized Richards Equation:

$$\frac{\partial \theta}{\partial t} = \nabla . (K(\theta)\, \nabla H)$$

$$H = z + h$$

θ: volumetric water content at pressure head h, t: time, and K: unsaturated hydraulic conductivity tensor.

Van Genuchten - Mualem Model:

$$S_e(h) = \frac{\theta(h) - \theta_r}{\theta_s - \theta_r} = \left(1 + \left(\frac{h}{h_g}\right)^n\right)^{-m}$$

$$K(S_e) = K_s S_e^l \left(1 - \left(1 - S_e^{\frac{1}{m}}\right)^m\right)^2 ; m = 1 - \frac{1}{n}$$

The model was built using the 2D representation of the lithofacies:

- ✓ **Mesh: Triangular elements; Max. number of nodes: 200000;**
- ✓ **Boundary conditions: Bottom BC: Free drainage; Top BC: Atmospheric Boundary with constant flux;**
- ✓ **Initial conditions: A pre-drainage phase of 168h following full water saturation;**
- ✓ **The hydrodynamic parameters of each hydrofacies (Tab.1) were implemented in HYDRUS 2D.**

Tab. 1. Hydrodynamic parameters for Van Genuchten - Mualem Model.

Material	θr (m^3m^{-3})	θs (m^3m^{-3})	α =1/hg (m^{-1})	n (-)	Ks ($m\ h^{-1}$)
Sand	0.013	0.337	20.5	2.92	3.52
Predominant Gravel	0.037	0.274	4.74	2.40	0.551
Bimodal Gravel	0.032	0.226	0.840	2.71	0.0432
matrix-free Gravel	0.020	0.360	111.6	2.70	360

θ_r and θ_s [$L^{-3}L^3$] denote the residual and saturated water contents, respectively; K_s [LT^{-1}] is the saturated hydraulic conductivity; α [L^{-1}], n [-] and l are empirical coefficients affecting the shape of the hydraulic functions (l=0.5).

4 – Results: Influence of material heterogeneity and entering flux on preferential flow

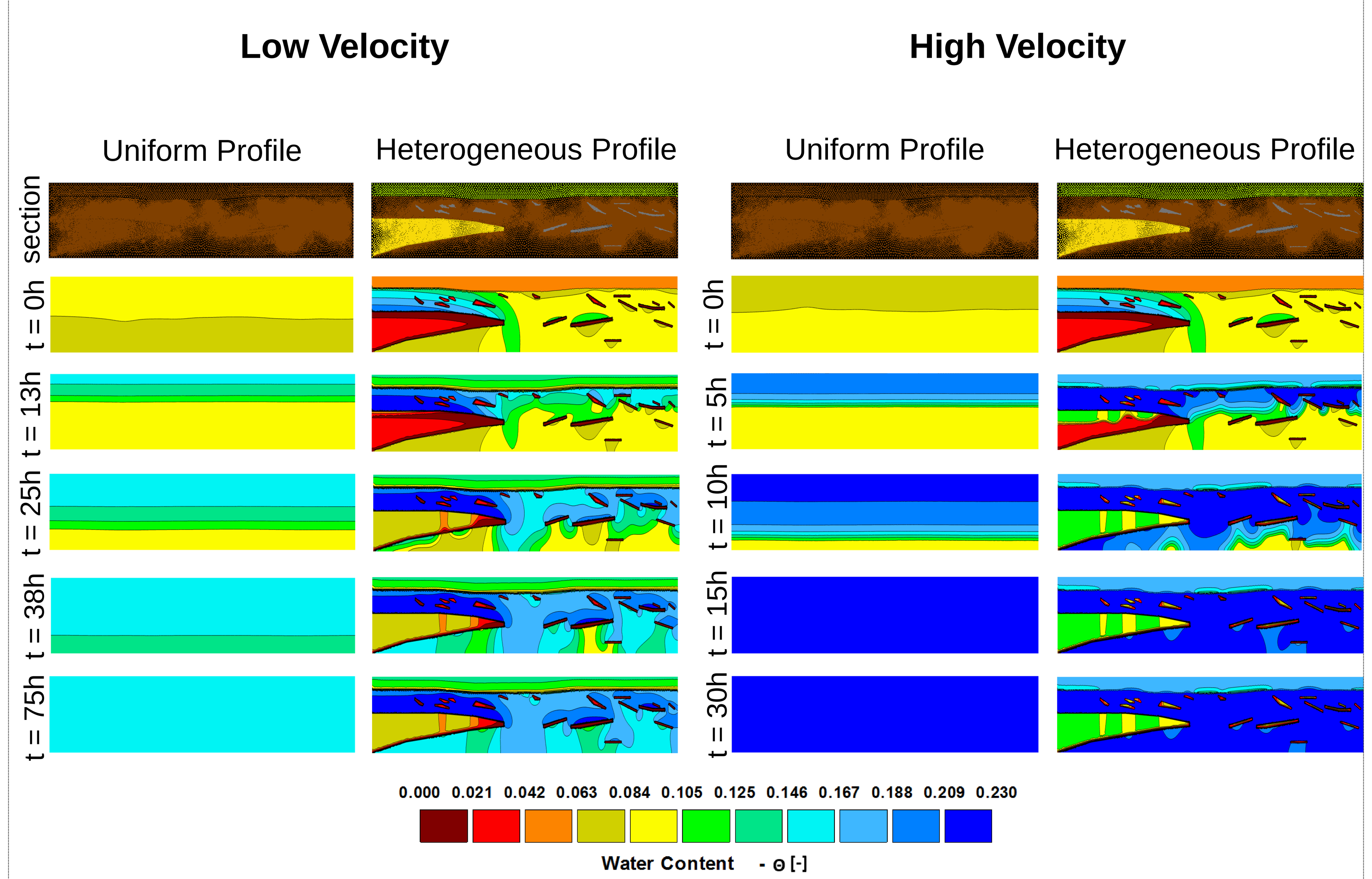

Fig. 2. Evolution of the volumetric water content as a function of time, calculated with HYDRUS for 2 imposed surface fluxes 5 mm/h (a) and 25 mm/h (b).

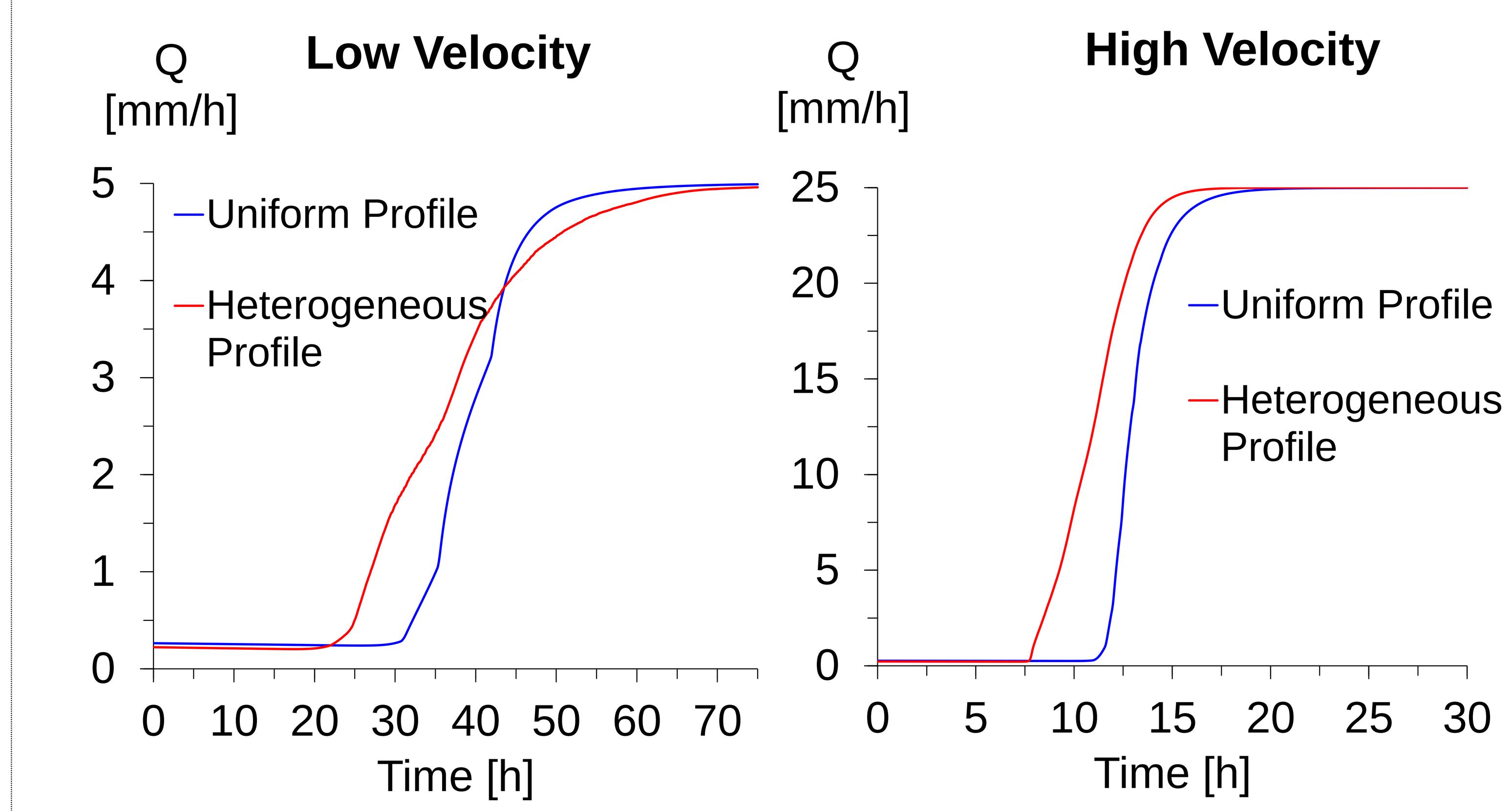

Fig. 3. Flow rate at 2.5 m depth (groundwater recharge) for an imposed surface flux of 5 mm/h (left) and 25 mm/h (right); data for the uniform profile (blue line) and for the heterogeneous profile (red line).

⇒ In both cases, earlier arrival of wetting fronts due to heterogeneity.
For lower infiltration rate, more dispersion around the wetting front due to preferential flow.

Fig. 4. Velocity vector distribution at steady state: 75h (a) and 30h (b), calculated with HYDRUS for Uniform profile and Heterogeneous profile.

- ❑ **Low surface flux (5 mm/h): Water content and wetting fronts impacted by section heterogeneity. For steady state: heterogeneous distribution of velocity vector in the heterogeneous section.**
- ❑ **High surface flux (25 mm/h): the wetting front can be assimilated to a plug flow. When the steady state is established, the velocity vector field is uniform for both profiles.**

⇒ At low velocity, water contents remain low, especially in the most draining materials (Sand and matrix-free Gravel) due to low water retention capacities ⇒ lower permeability ⇒ Flow deviations at their interfaces with the predominant bimodal Gravel ⇒ significant regionalization of flow.

5 – Conclusions

Numerical modeling permitted pointing out the existence of preferential flow paths associated with the sedimentary heterogeneity of the glaciofluvial deposit. For lower surface fluxes, Sand lens and matrix-free Gravel were the sources of capillary barrier effects, leading to a funnelled flow and strongly heterogeneous flow field. Lithological heterogeneity impacted also the recharge of groundwater with earlier and more dispersed wetting fronts.

*Corresponding author : erij.benslimene@entpe.fr - (1) University of Lyon, LEHNA UMR 5023 CNRS ENTPE UCBL, Lyon, France; (2) University of Lyon, LGCIE INSA Lyon, France

ACKNOWLEDGEMENTS: the field observatory for urban water management (OTHU), the Greater Lyon, the Rhone-Mediterranean and Corsica water agency, the Rhone-Alpes Region and the French Ministry of Ecology (GESSOL research program)