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LAND SUPPORT

An extended transfer function model for the prediction of nonpoint-source pollutant travel times

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Presentation outline

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2. The scope of the work
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    c. Comparison TFM-ext –Hydrus 1D
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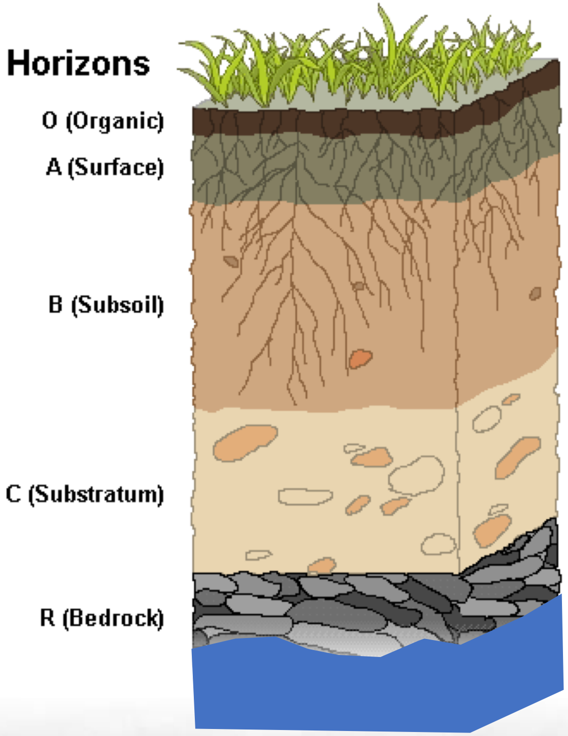
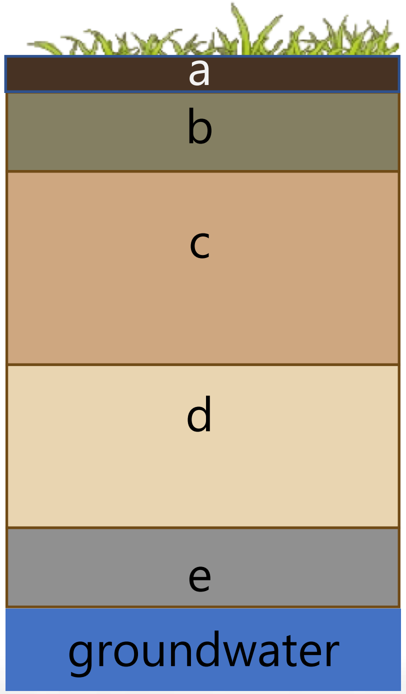
The solute transport problem (1/2)

Water quality is continuously threatened in most rural areas, in both low- and high-income countries. Agriculture, in fact, is one of the biggest sources of pollutants, such as pesticides, fertilizers, irrigation wastewater and manure, which are the most common Non-Point Source (NPS) chemical contaminants.

The solute transport problem (2/2)

Let's consider a soil profile, representative of a soil unit, which is discretized in a sequence of horizon, with well defined hydrological characteristics.





The scope of the work

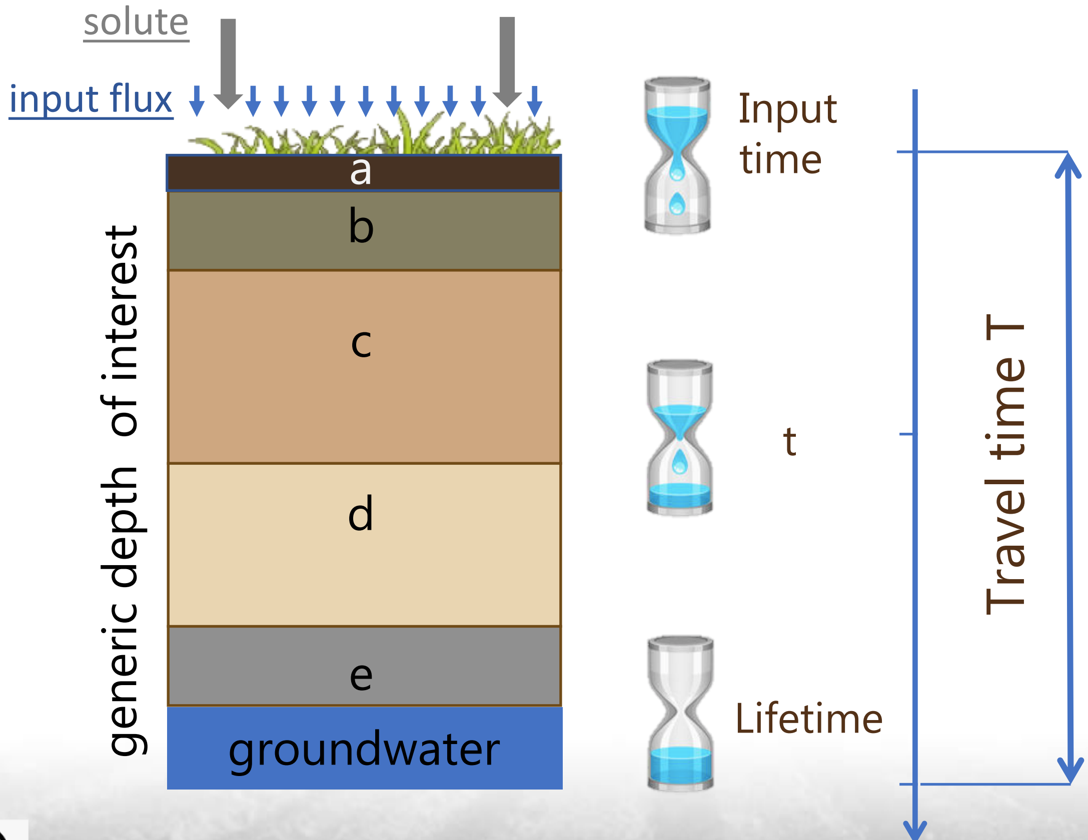
The scope of this work is to present

an extended transfer function model (TFM-ext),

which simulates the spatio-temporal distribution of non-point-source solutes along the unsaturated zone at large scales.

The transfer function model (1/5)

This approach is based on the definition of a probability density function for the *travel times* of a solute particles moving in a field soil, (Jury, 1982) .



The transfer function model (2/5)

According to this model, the output concentration at the investigated depth is:

$$C_z(z,t) = \int_0^T C_o(t) f_f(z,t)\,dt$$

Output concentration at a reference depth

Input concentration

Travel times pdf

The transfer function model (3/5)

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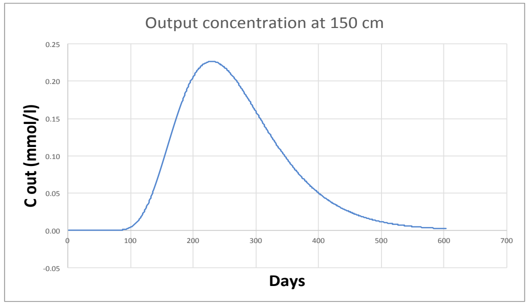

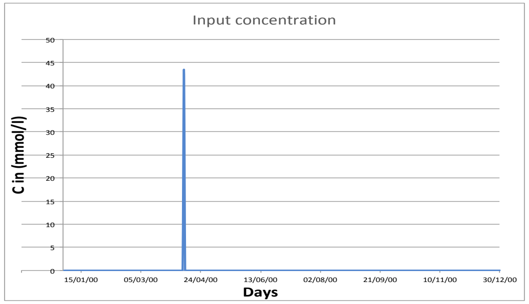

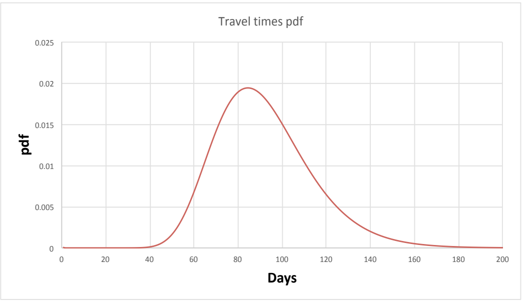

The transfer function model (4/5)

The transfer functions for each soil horizon are derived from the soil hydraulic properties, according to *Scotter and Ross, 1994*.

$$\boxed{f_f(z,t)} = -\frac{1}{\boxed{q}}\frac{d\boxed{K(\theta)}}{dt}$$

Travel times pdf

Input flux (i.e. net precipitation)

Relationship between hydraulic conductivity and water content

The transfer function model (5/5)

The transfer functions for each soil horizon are derived from the soil hydraulic properties, according to *Scotter and Ross, 1994*.

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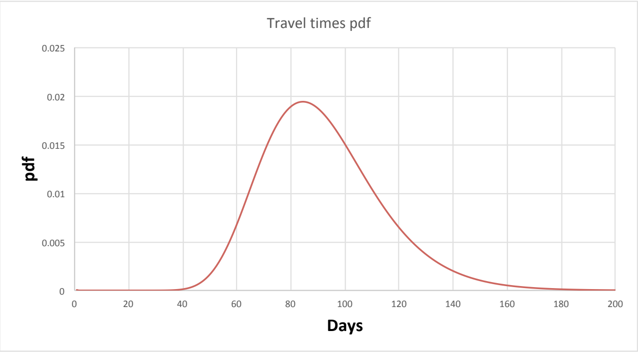
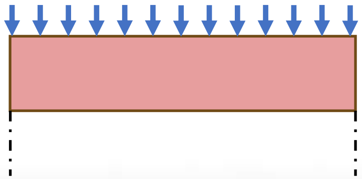
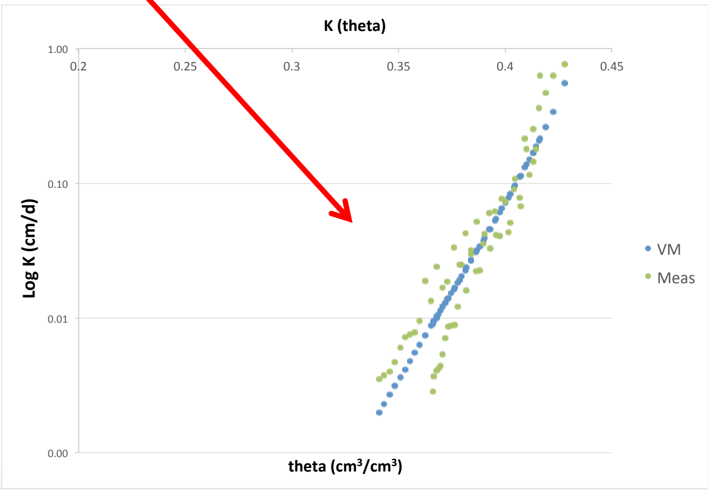
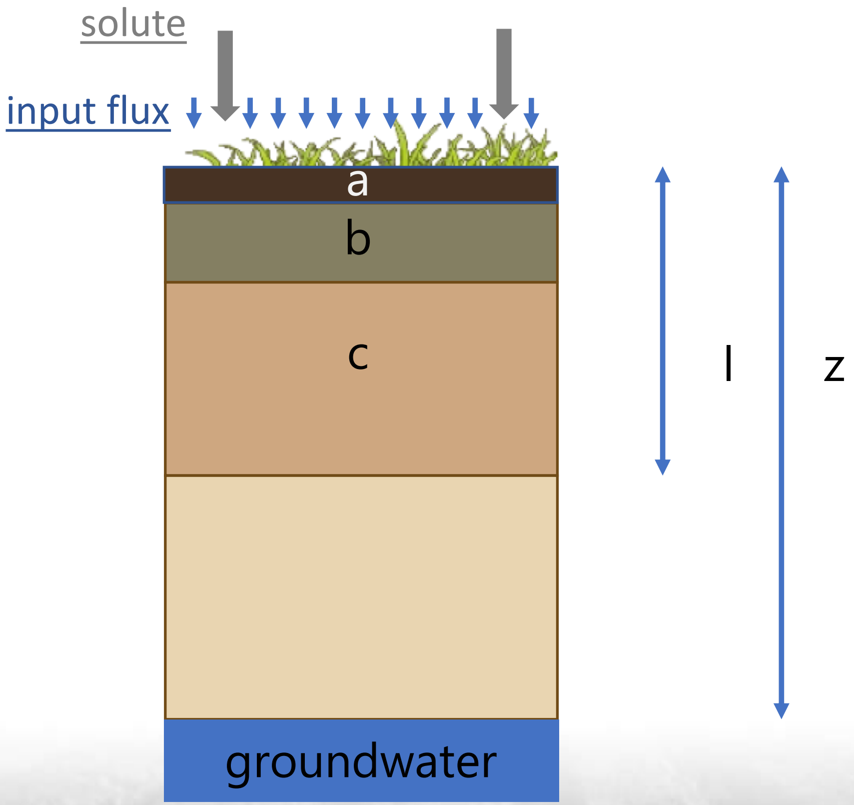






The extended transfer function model (1/2)

Let's assume that we are interested in transport to depths greater than the soil depth l, for which the TFM-ext has been developed, e.g., below the soil profile till the groundwater table level z, where z is greater then l.



The extended transfer function model (2/2)

To extend the process till z, we used the Generalized Transfer Function (GTF) proposed by R. Zhang, 2000, according to which the travel time moments scale with the ratio *z/l*, while the travel times distribution has a lognormal form.

$$\frac{E_z(z,t)}{E_l(l,t)} = \left(\frac{z}{l}\right)^{\tau_1}$$

$$\frac{Var(z,t)}{Var(l,t)} = \left(\frac{z}{l}\right)^{2\tau_2}$$

$$\frac{CV(z,t)^2}{CV(l,t)^2} = \left(\frac{z^2}{l^2}\right)^{2(\tau_1-\tau_2)}$$

$$f_f(z,t) = \frac{1}{(2\pi)^{0.5}\sigma_z t} exp\left(-\frac{(ln(t)-\mu_z)^2}{2\sigma_z^2}\right)$$

Input data

- Meteorological forcings (mean daily precipitation, actual evapotranspiration);
- Hydraulic properties of each layer (unsaturated hydraulic conductivity K(θ) → van Genucthen-Mualem equation);
- Water table depth;
- Solute input concentration;
- Decay and retardation factors for reactive solutes.

Sensitivity analysis (1/4)

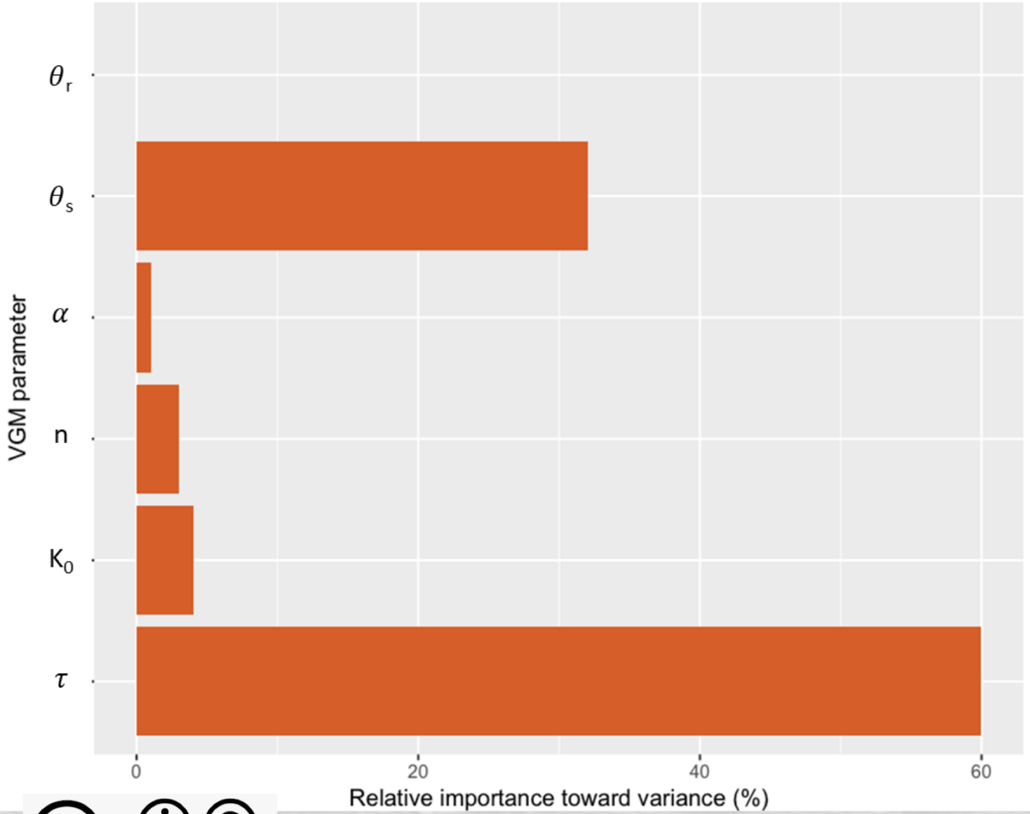
In order to evaluate **the relative importance of each parameter of the hydraulic conductivity curve** on the TFM-ext output,

- N random sets were generated for a Monte Carlo (MC) procedure,
- using 46 soil profiles data.

Moreover, the sensitivity of the model was also tested against flux variations.

Sensitivity analysis towards the parameters (2/4)

Results of the MC shown that θ_s **and** τ are responsible for **60 % and 32%** of the travel times variance, respectively, and therefore, those are the most sensitive parameters in the model.

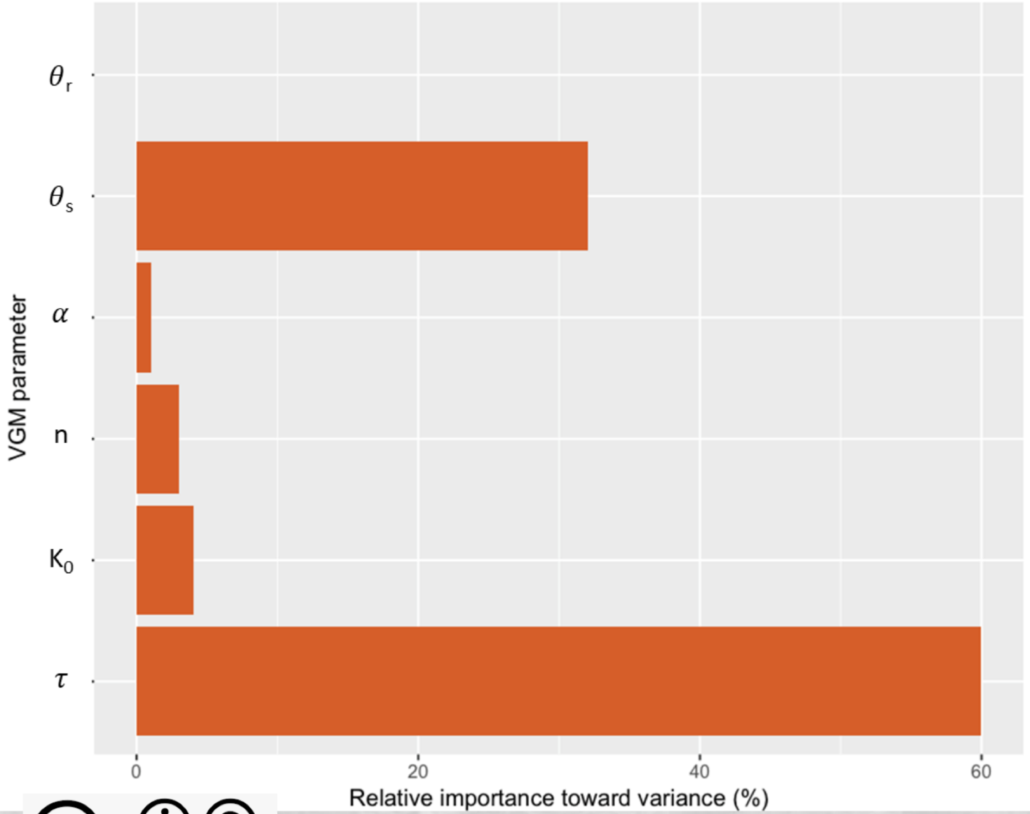


Relative importance index toward variance

$$RI_p^{\sigma^2_{T_p}} = \frac{\sigma^2_{T_p}}{\sum_{p=1}^{P} \sigma^2_{T_p}}$$

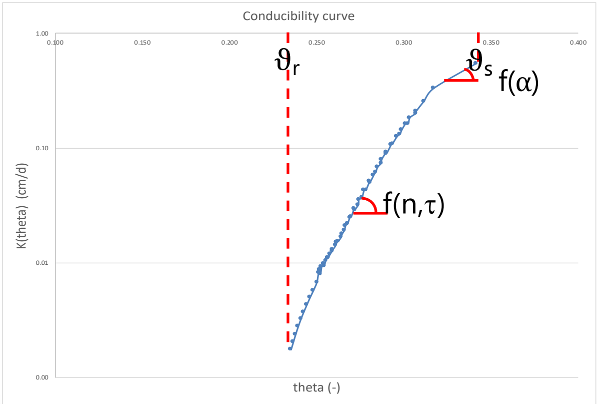
Sensitivity analysis towards the parameters (3/4)

The high relative importance of θ_s is explained by its great influence on the flow and transport processes, while the parameter τ controls the slope of the hydraulic conductivity curve and thus, its derivative.



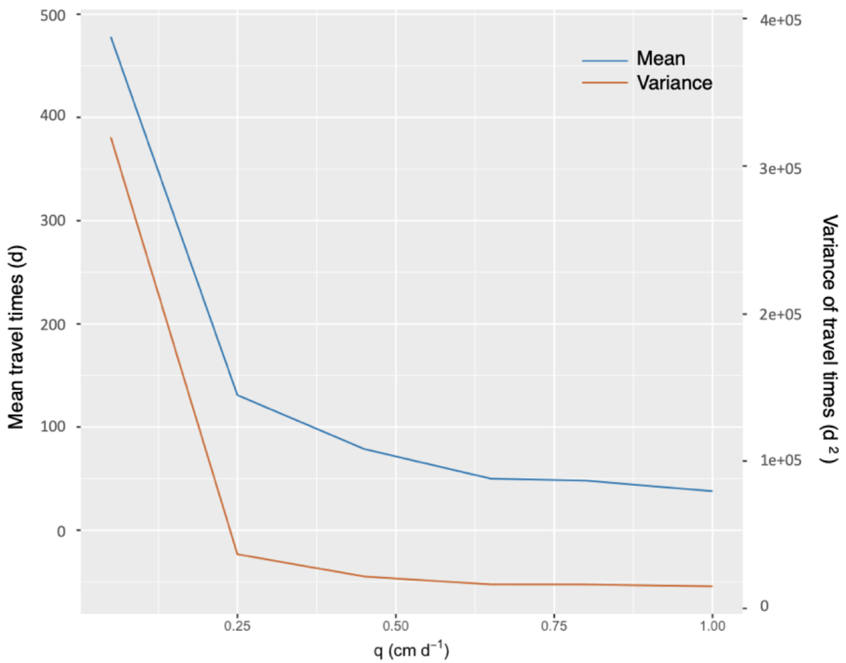
$$S_e(h) = \frac{\theta(h) - \theta_r}{\theta_s - \theta_r} = \frac{1}{\left(1 + |\alpha_{VG} h|^n\right)^m}$$

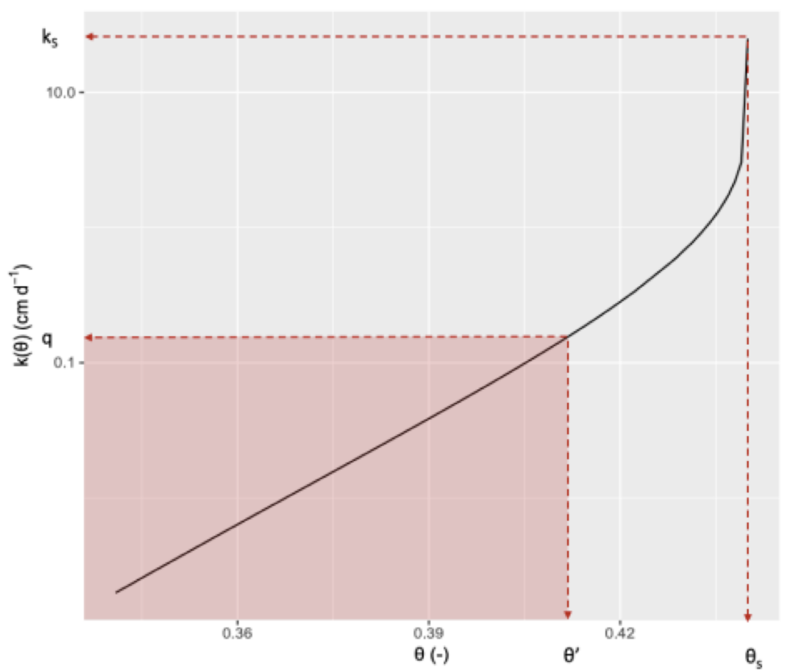
$$K(\theta) = K_s S_e^{\tau}\left[1 - \left(1 - S_e^{1/m}\right)^m\right]^2$$



Sensitivity analysis toward the fluxes (4/4)

As regards the flux variations, both the mean and the variance showed the same behavior: they decreased sharply till a certain value and then tended to an asymptotic value. As soon as q increases, more pores contribute to the flow and reduces indeed the mean travel times to reach the fixed depth till a certain value. After this value, all the porous space is involved in the flow process till the upper limit of complete saturation ($\theta_0 = \theta_s$).



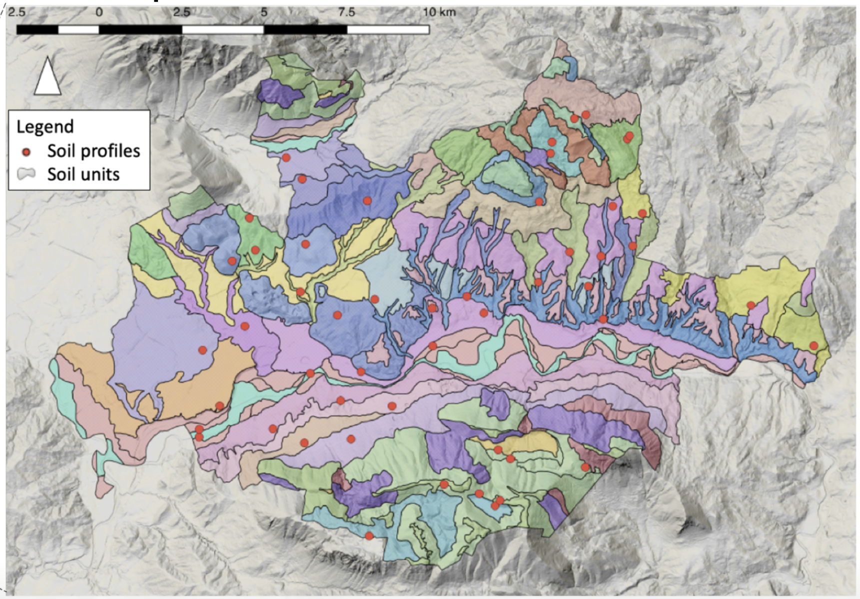


Comparison TFM-ext - Hydrus 1D (1/3)

Hypothesis:

1. Constant flux boundary conditions (constant net precipitation)
2. Passive solute
3. Constant depth at 150 cm

46 soil profiles in Valle Telesina (200 km^2)



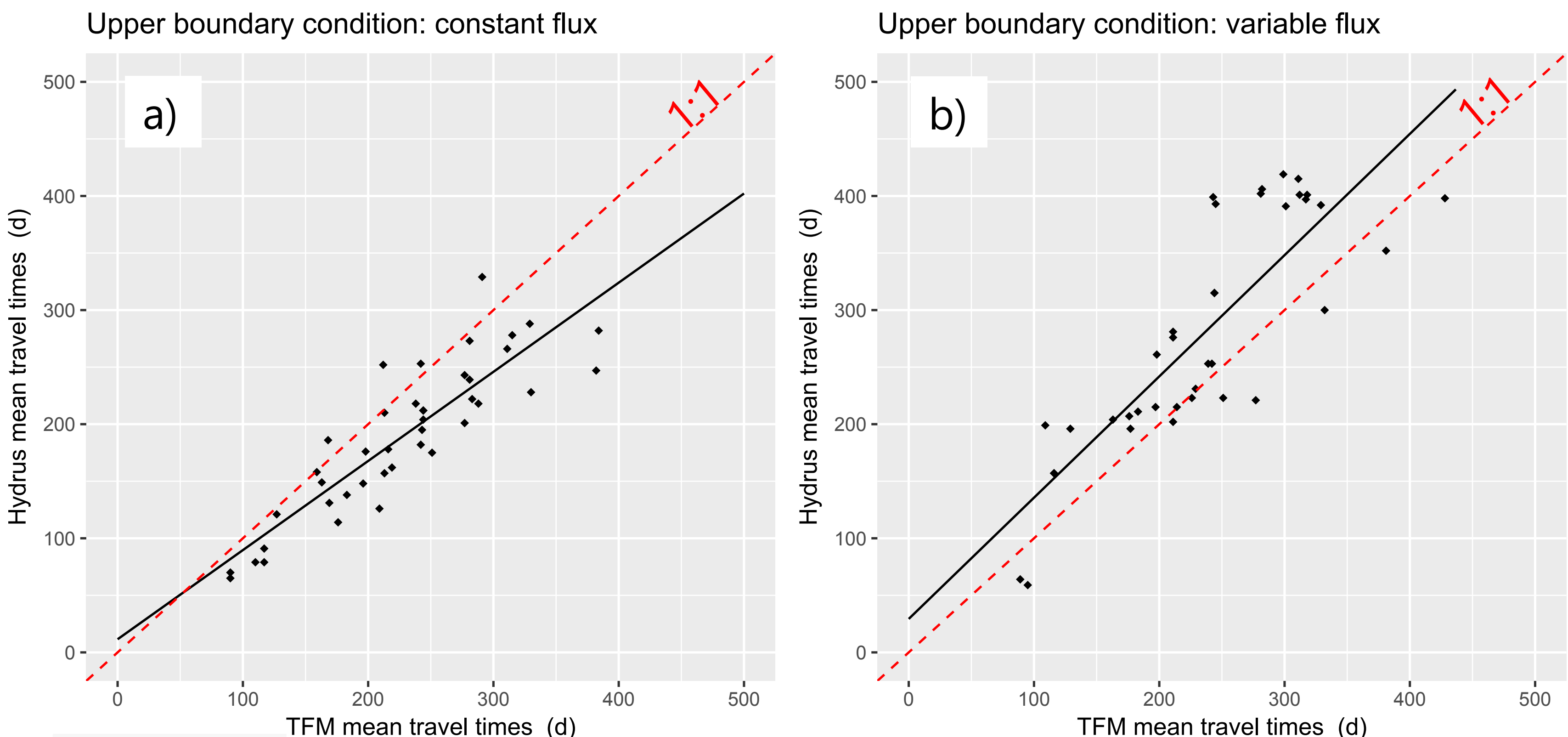
Comparison TFM-ext - Hydrus 1D (2/3)

The mean TT estimated with TFM-ext were then compared with those obtained from the physically-based model Hydrus 1D. Two distinct applications were performed, as detailed described in the following Table.

	TFM-ext		Hydrus 1D	
	Vegetation	Upper BC	Vegetation	Upper BC
1^o application	bare soil	constant in space and time	bare soil	constant in space and time
2^o application	pasture	variable in space and constant in time	pasture	variable in space and time

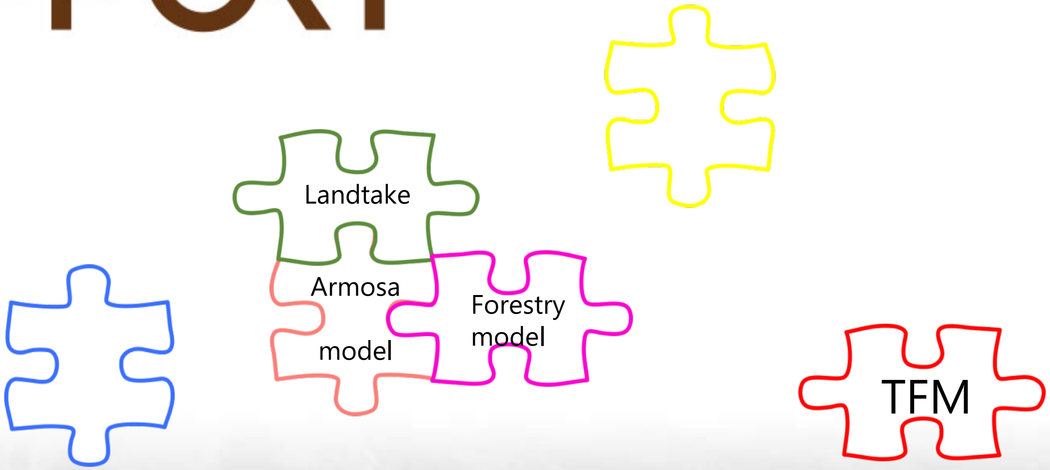
Comparison TFM-ext - Hydrus 1D (3/3)

The results of the comparisons were very good, with high correlation coefficients **(r > 0.8)**, mean absolute errors of 30 and 40 days and percent **bias of 20% and -16%,** in the constant and variable flux cases, respectively.



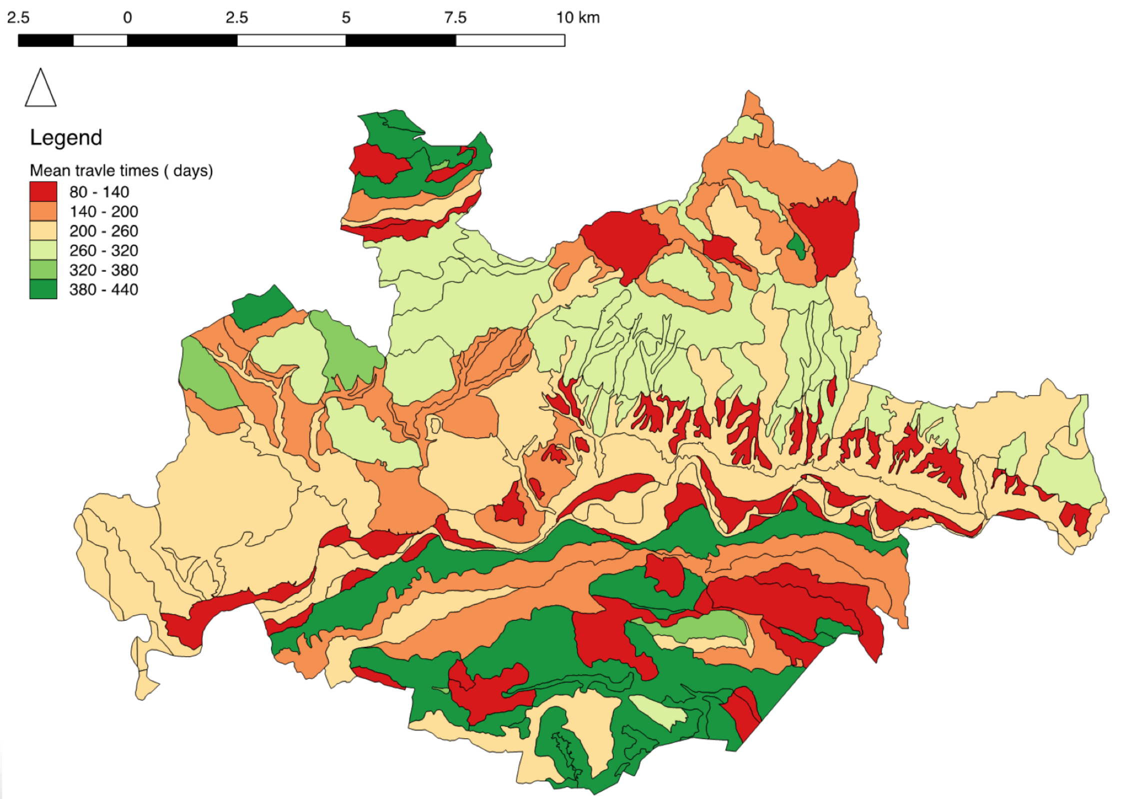
Preliminary application: Valle Telesina (1/2)

The model was implemented as a Java application within the GeoSpatial Decision Support System LandSupport (https://www.landsupport.eu).



Preliminary application: Valle Telesina (2/2)

The Figure shows the results obtained for the spatial application to the Valle Telesina. The mean travel times are categorized in six intervals from 80 (red) to 440 (green) days.



Conclusions

- The Extended Transfer Function Model is easy to implement and to interpret;
- The model requires few input data and parameters, therefore it could be used at large scales;
- Good results were obtained for the Valle Telesina (IT) compared to a physically based approach (Hydrus)
- The model is easily expandable, considering different types of solutes
- The model is going to be used for the territorial scope for vulnerable areas.

Principal references

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