A general BEST method predicting soil hydraulic parameters for any water retention and hydraulic conductivity curves.

Manaaki Whenua
Landcare Research

Jesús Fernández-Gálvez[1, 2], Joseph A.P. Pollacco[1*], Laurent Lassabatere[3], Rafael Angulo-Jaramillo R.[3], Sam Carrick[1]

Introduction

- To predict water storage and transport in soil, hydrological models require a description of the soil water retention, $\theta(h)$, and the hydraulic conductivity, $K(h)$, functions. These functions are highly variable, as well as costly and time consuming to measure.
- The hydraulic parameters can be derived faster and cheaper in situ from infiltration tests, such as by using the popular Beerkan estimation of soil transfer parameters (BEST method) [Lassabatere et al., 2006; Angulo-Jaramillo et al., 2016; 2019]. The BEST approach involves measuring: (a) initial soil water content, θ_{ini}; (b) soil bulk density, ρ_b, which is used to derive the saturated soil water content, θ_s; (c) Particle Size Distribution (PSD); and (d) cumulative infiltration through a single ring under a near-zero pressure head [Fig. 1 & Fig. 2].
- Some of the drawbacks of the traditional BEST method are that:
  - It only works with the van Genuchten model for water retention function combined with the Brooks and Corey model for the unsaturated hydraulic conductivity function;
  - It requires knowledge of the PSD;
  - It uses approximate expansions to describe the infiltration process that are valid only over restricted ranges of time for either the transient or the steady states.

Objectives

Solve the mentioned drawbacks by:

- Generalizing the BEST method to predict hydraulic parameters by using the Kosugi [1999] functions that are expected to be more physically sound and more representative for most soils;
- Avoiding the need for PSD data when deriving the soil hydraulic parameters from infiltration measurements by taking advantage of a relationship between the Kosugi [1999] hydraulic parameters;
- Incorporating in the optimization a description of the infiltration that is valid for all ranges of time.

Methods

The novel method to derive soil hydraulic parameters from infiltration measurements include two alternative methods [Fernández-Gálvez et al., 2019]:

- The use of the analytical quasi-exact implicit (QEI) model developed by Haverkamp et al. [1994] for 1D infiltration and extended to 3D infiltration by Smettem et al. [1994];
- A new, simplified analytical approximation ($BEST_{SA}$) based on a two-term approximation of the QEI model that is defined for all times [Haverkamp et al., 1994] and that combines the approximations originally developed for either transient or steady state.

When the Kosugi hydraulic model is used it is possible to reduce non-uniqueness by relating two of the hydraulic parameters as proposed by Pollacco et al. [2013] as described in Fig. 3. This constraint allows derivation of the full set of hydraulic parameters without PSD data.

Results

The proposed method was validated against numerically generated data for several synthetic soils. The new methodologies compare satisfactorily to simulated data using HYDRUS-3D for a set of contrasting soils as shown in Table 1 and Fig. 4.

Table 1 shows the accuracy of fits (Nash–Sutcliffe efficiency coefficient, NSE_i), estimates for sorptivity (relative error, $Er(S)$), saturated hydraulic conductivity (relative error, $Er(K_s)$), and agreement between estimated and target $\theta(h)$ and $K(\theta)$ functions (NSE_{θ_K}). Shaded rows correspond to less accurate matches.

Fig. 4 shows target and estimated $\theta(h)$ and $K(\theta)$ functions by $BEST_{QEI}$ and $BEST_{SA}$ methods. Soil type and corresponding σ values for the selected soils are indicated for each row in the right-hand panel.

Conclusions

- The BEST method is generalized to predict water retention and hydraulic conductivity curves for any functions, making use of the Kosugi functions;
- The new BEST methods are valid for all times and always manage to provide estimates, without failure;
- Estimates of all the hydraulic parameters can be obtained without PSD data by using a relationship between the two Kosugi hydraulic parameters.

Future Work

- The model has been tested with numerically generated data, and we are further testing the model with data derived from the laboratory. The development of easy-to-use equipment (automatic infiltrometers operated by smartphone) and user-friendly software such as the open-source Soil-Water-Toolbox [contact for program], will allow widespread use of the methodology;
- Physically based analytical development of the parameters used in the 1D and 3D infiltration models.

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Fig. 1 Single ring infiltrometer

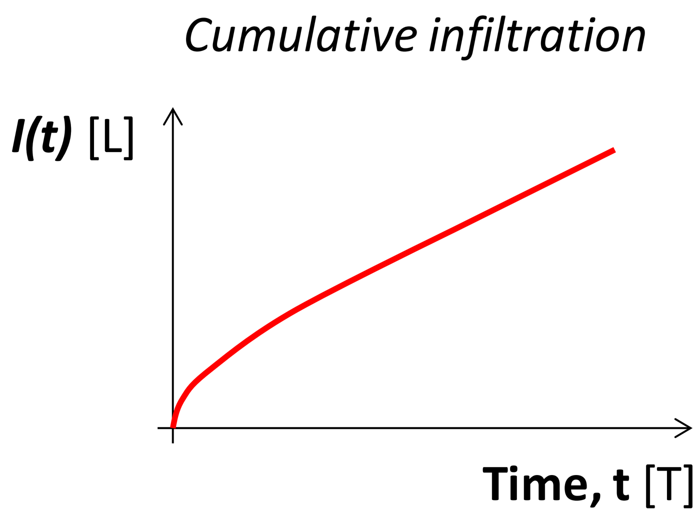


Fig. 2 Cumulative infiltration curve as a function of time

Table 1 Accuracy of fits (Nash–Sutcliffe efficiency coefficient, NSE_i), estimates for sorptivity (relative error, Er(S)), saturated hydraulic conductivity (relative error, $Er(K_S)$), and agreement between estimated and target θ(h) and K(θ) functions (NSE_{θ_K}). Shaded rows correspond to less accurate matches [Fernández-Gálvez et al., 2019].

		$BEST_{QEI}$ (constrained relating σ to h_{kg})				$BEST_{QEI}$ (unconstrained)			$BEST_{SA}$ (constrained relating σ to h_{kg})			
ID	Soil type	NSE_i	Er(S)	$Er(K_S)$	NSE_{θ_K}	NSE_{θ_K}	Er(S)	$Er(K_S)$	NSE_i	Er(S)	$Er(K_S)$	NSE_{θ_K}
1	Loam 1	1.00	1.00	0.64	-1.81	-6.07	1.00	0.64	1.00	0.99	0.64	-1.84
2	Loam 2	1.00	0.99	0.73	0.66	0.58	0.99	0.73	1.00	0.98	0.74	0.66
3	Silty Clay Loam	1.00	0.86	0.94	0.93	-0.75	0.86	0.94	1.00	0.88	0.97	0.93
4	Sandy Loam	0.96	0.90	0.88	0.98	-5.16	0.90	0.88	1.00	0.96	0.88	0.97
5	Silt	1.00	0.99	0.34	0.92	0.63	0.99	0.34	1.00	0.98	0.24	0.84
6	Silty Loam	1.00	0.76	0.69	-0.05	-1.63	0.76	0.69	1.00	0.79	0.71	-0.02
Average		0.99	0.92	0.70	0.27	-2.07	0.92	0.70	1.00	0.93	0.70	0.26

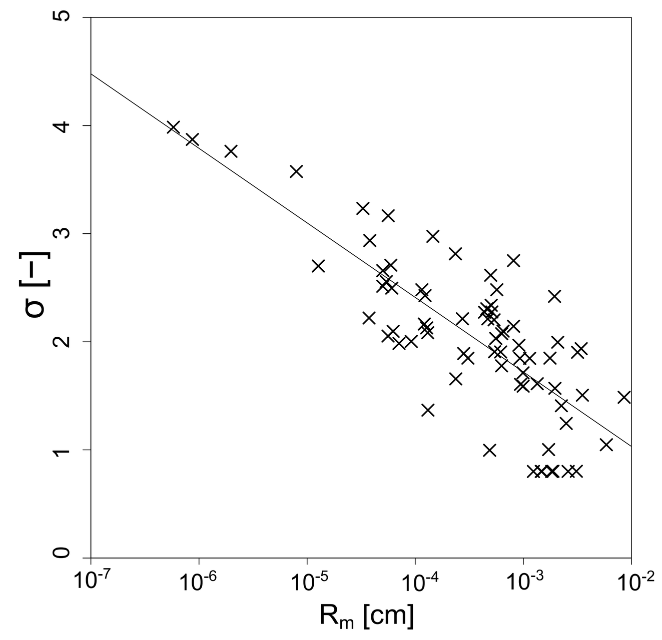
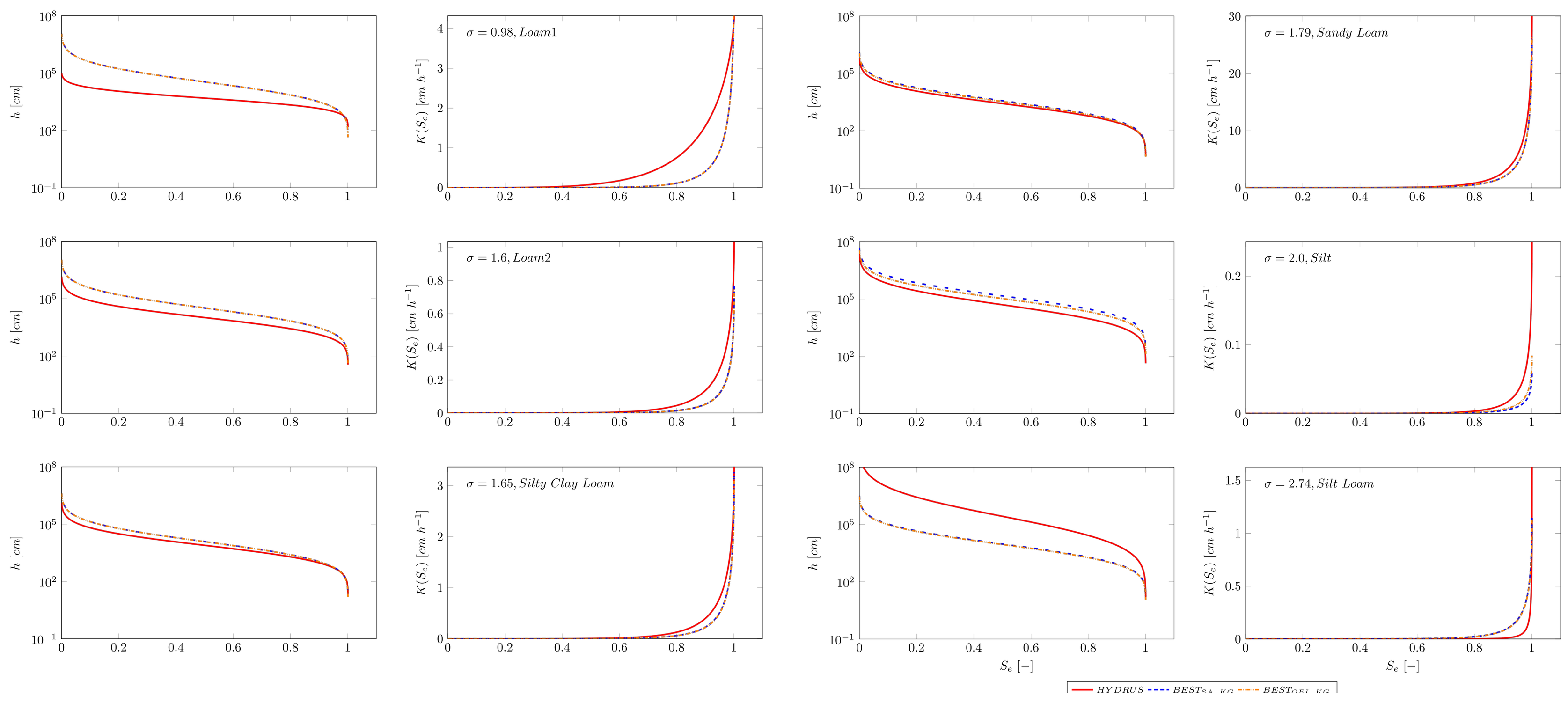


Fig. 3 Linear relationship between the standard deviation of log-transformed h, σ, and the $\log_{10}$ median pore-radius R_m (= Cst / h_m Young-Laplace equation). [Pollacco et al. 2013].



$$h = h_{kg}\exp[\mathrm{erfc}^{-1}(2\,S_e)\,\sigma\sqrt{2}]$$

$$K(S_e) = K_s\,\sqrt{S_e}\left\{\frac{1}{2}\,\mathrm{erfc}\left[\mathrm{erfc}^{-1}\{2\,S_e\} + \frac{\sigma}{\sqrt{2}}\right]\right\}^2$$

Fig. 4 Predicted versus target water retention and hydraulic conductivity curves for different soil types. Equations show the Kosugi hydraulic model [Fernández-Gálvez et al., 2019].

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Contact

Joseph Pollacco
PollaccoJ@landcareresearch.co.nz

[1] Manaaki Whenua – Landcare Research, Lincoln, New Zealand
[2] Dept. of Regional Geographic Analysis and Physical Geography, University of Granada, Spain
[3] Univ Lyon, Université Claude Bernard Lyon 1, CNRS, ENTPE, UMR 5023 LEHNA, F-69518, Vaulx-en-Velin, France

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