WATERAGRI

FACTSHEET

WATER RETENTION CHARACTERISTICS MODEL

Key information

The Water Retention Curve Model represents a new type of soil water retention curve model based on interfacial physics. It describes the relationship between soil water content and soil suction for unsaturated soil conditions. The presented model provides the subsurface hydrology modeler with a reliable and convenient tool and the end user with an accurate assessment of the water retention effect on the soil water retention capacity.

Target audience: Scientists, modelers.

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A. Brief Introduction:

A number of mathematical models have been proposed and adopted to describe and represent the water retention curve of soils. However, to date, most of these models are either purely empirical or too complicated and ineffective to be used to evaluate water retenting agents and directly quantify their influence on soil water retention capacity in wide range of water saturation degree, such as from fully saturated to nearly dry. The water retention properties model adopted for WATERAGRI aims to address these challenges. The model is developed based on the concept of interfacial physics.

B. Design concept and experimental set up:

Soil water retention characteristic depends on the soil nature and pore structure. Using the water retention characteristic model above to assess the effect of water retainer agent usage added into either soil or water directly, the model has been modified to integrate a standalone function, which is to quantify the water retainer effect. The modified model is in the form below:

$$P_c = e^{\gamma C_{WR}}\left(\lambda\left[\frac{1}{\alpha}(\exp(\alpha S_w) - 1) - \frac{1}{\beta}(\exp(\beta(1 - S_w)) - 1)\right] - m(1 - S_w)^n\right), \qquad \text{(Eq.1)}$$

where γ is a constant and C_{WR} stands for the usage (concentration) of the water retainer.

The mathematical formula can be directly used to fit the measurement water retention curves of soils, which use or are applied with the water retaining agents.

Theory:

There are three different water phases co-exists in unsaturated soils, they are the bulk water in fully occupied pore space, the water vapor in the empty pore space and the water film on the empty pore walls, as illustrated in the Fig. 1 below. The model describes and assess the three phases in terms of their respective states using classic physical interfacial theory. It gives out an explicit mathematical expression for the state of the three phases, so establishes a state equation for the soil water retention characteristics at different water contents or pore water saturation, from fully dry to fully wet. The state equation is further modified to evaluate the effect of the use of water retaining agent on soil retention curve.

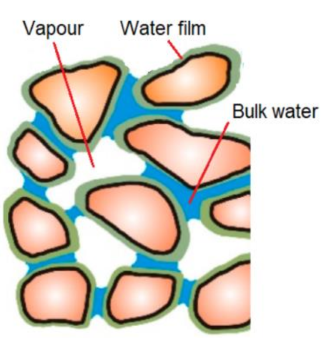

Fig. 1. Three respective water phases, i.e., bulk water, vapour and water film, which are coexists in the pores of unsaturated soils.

The three water phases in soil have their respective pressures at a certain state of water saturation degree, which can be described as below:

- For the bulk water phase

$$P_w = \frac{\lambda}{\alpha}(\exp(\alpha S_w) - 1),$$

Where P_w is the pore water pressure, S_w is the pore water saturation, α is a constant relating to the water interaction with soil particles at their interface, λ is a constant relating to the initial water film when bulk water starts to accumulate in pore space due to capillary condensation.

- For the vapour phase

$$P_v = \frac{\lambda}{\beta}(\exp(\beta(1 - S_w)) - 1),$$

where P_v is the pore vapour pressure, β is a constant relating to the vapour interaction with soil particles at their interface.

- For the water film [1]

$$P_f = m(1 - S_w)^n,$$

P_f is the pressure of water film on empty pore walls, m and n are two constant parameters.

Soils under unsaturated states displays a suction on free water outside, known as the soil metric suction or capillary pressure P_c, which can be defined mechanically as below:

$$P_c = P_w - (P_v + P_f).$$

Substituting the phases' pressure above generates:

$$P_c = \lambda\left[\frac{1}{\alpha}(\exp(\alpha S_w) - 1) - \frac{1}{\beta}(\exp(\beta(1 - S_w)) - 1)\right] - m(1 - S_w)^n \qquad \text{(Eq. 2)}$$

The Eq. (2) defines the soil water retention characteristic and represents the water retention curve.

Fig. 2 below shows the results using the Eq. (2) to represent the water retention curve measurements of three kinds of soil, they are sand (S100), clayey sand I (70% sand & 30% clay), and clayey sand II (50% sand & 50% clay), when they were applied different usages of an assessed water retainer (WR), which were 0%, 1%, 2%, 3%, and 5% by the ratio of WR to soil pore water weight at fully saturated state. Fig. 3 shows the results using the popular van Genuchten model [2] to represent the same measurements. The comparison between the Fig. (2) and Fig. (3) demonstrates the outperformance of the proposed unsaturated soil water retention characteristic model, the Eq. (2), which not only presents a reliable accuracy but also well represents the shape of the water retention curves in wide range of water content variation from fully saturated to nearly dry states.

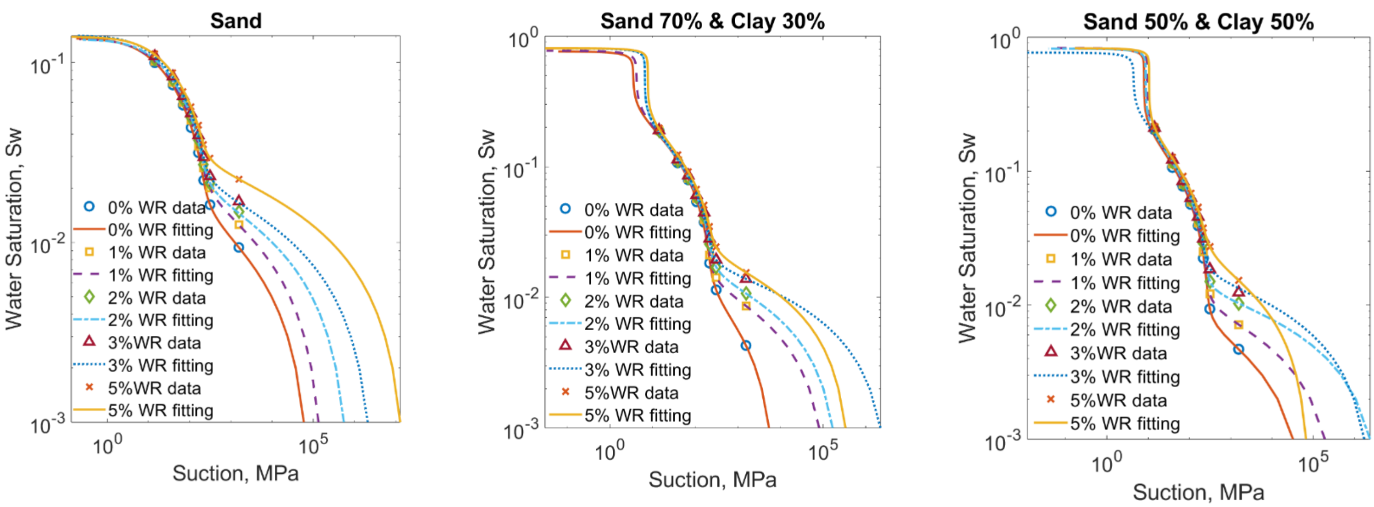

Fig. 2. Modelling results of Eq. (2) for the soil water retention curves

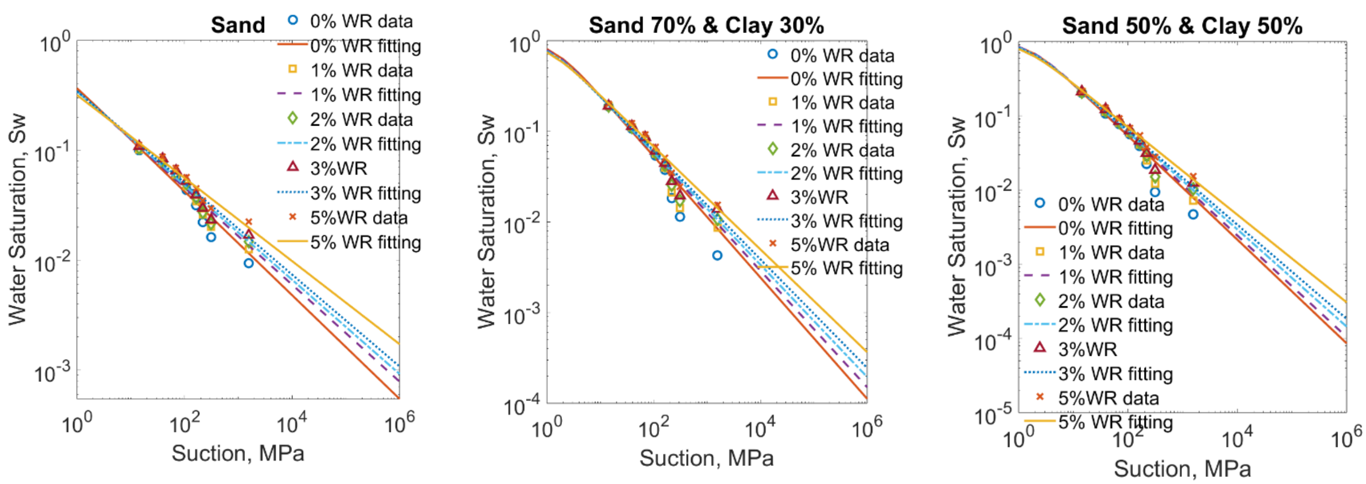

Fig. 3. Modelling results of van Genuchten model [2] for the soil water retention curves

Both the experimental measurements and the modelling display that the tested water retaining agent, the water retainer (WR), has little effect on static soil water retention in wide soil saturation range ($S_w > 5\%$), but only shows effect at relatively dry states. This may be explained by the mechanism that the water retainer has little influence on water surface tension at high water content because of a low concentration in water, however it largely enhances the water adsorption on soil particles when soil water content is significantly small when the concentration largely increases. This characteristic can be effectively represented by the water film term in the Eq. (2).

The little effect of the water retainer at high soil water content states has been further confirmed by the experiment in the same study in this project, using the instrument, HYPROP-2 [5], as shown in Fig. 4. Fig. 5. gives out the HYPROP-2 measurements, which shows that the water retention curves of the three soils at three different water retainer concentration states, i.e., 0%, 3% and 5%, have little difference in the low suction range, pF < 4 hPa, which corresponds high water content. A comparison of Fig. 2 against Fig. 5 shows that the shape of water retention curves represented by Eq. (2) agrees with the measurement of the HYPROP-2 test.

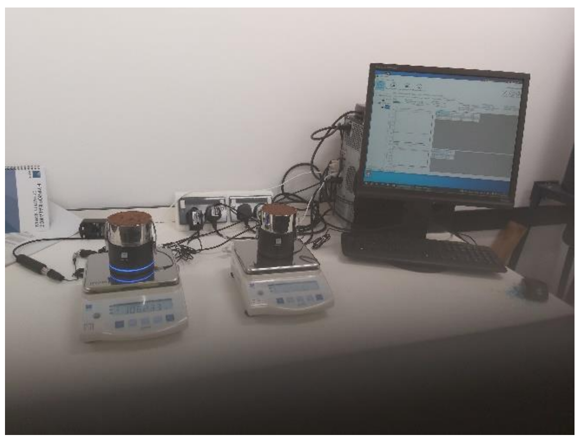

Fig. 4. HYPROP-2 test

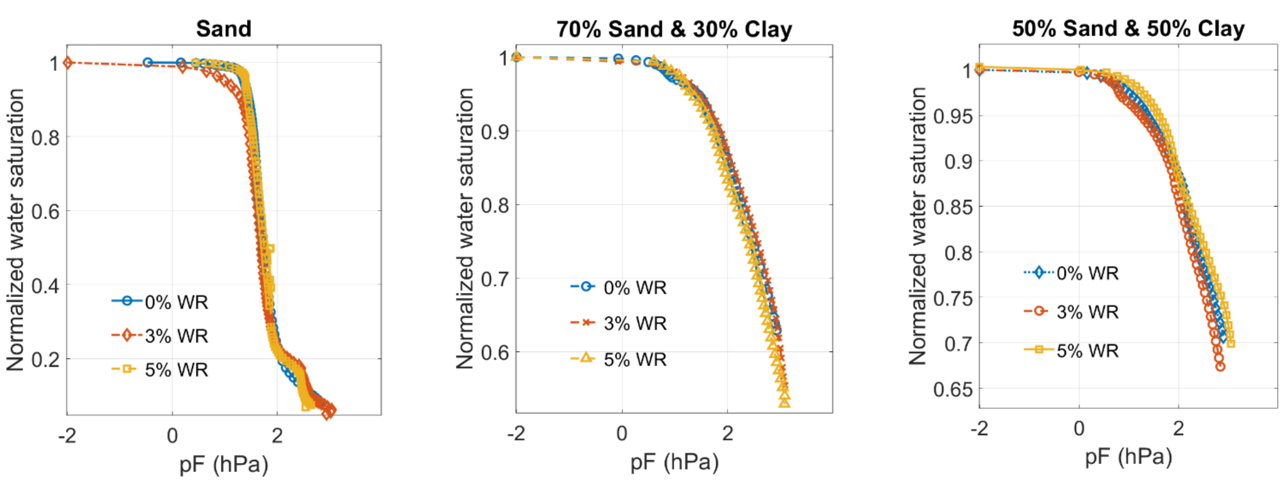

Fig. 5. HYPROP-2 measurements

At last, we can use the modified form, Eq. (1), which is established on the Eq. (2), to represent the water retainer effect on soil water retention curve in 3D space. The use the Eq. (1) is more convenient in practice to estimate the usage of the assessed water retaining agent compared to parametric characterization of the Eq. (2) on the individual water retention curves presented in the Fig. 2. The 3D representation demonstrates a good accuracy in term of the relative error at 7 measurement points at different WR usages.

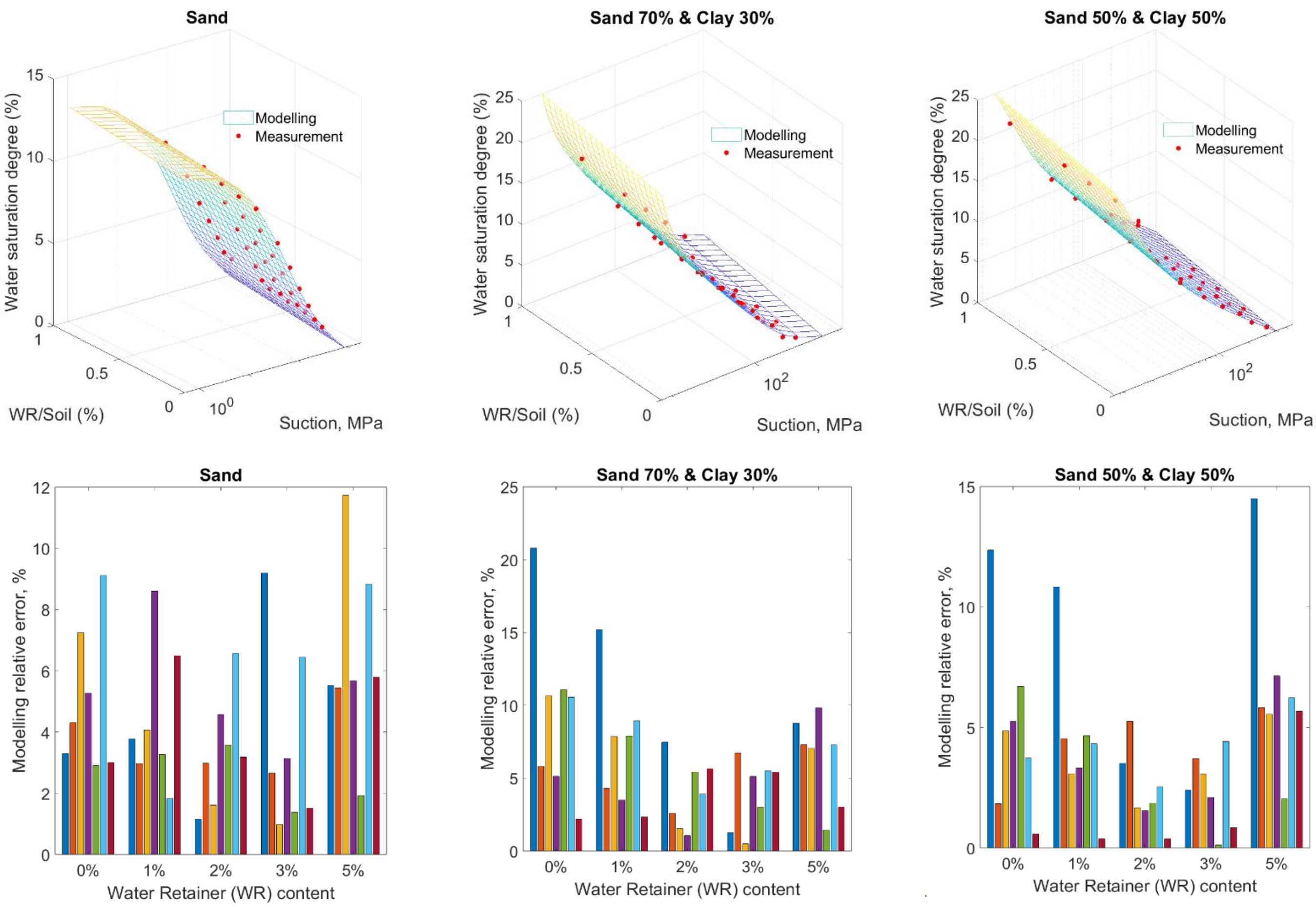

Fig. 6. 3D representative, the Eq. 1, for the water retention characteristic at different suction and water retainer percentage and the modelling error

C. Costs and Benefits:

The model can be easily used by any researchers of fundamental knowledge of unsaturated soil physics and curve fitting.

D. Challenges and opportunities:

Wider test and implementation will help for further development for both the underlying theory for the unsaturated soil physics and hydrology modelling for real world challenges.

E. Reference and demonstration:

[1]. Yu Wang, Yirong Leng, Miklas Scholz, Nora Hatvani, Bjørn Kløve, Vincent Uzomah, 2023, *Assessment of water retainer effect on soil water retention and characteristic modelling for the change of water retention curves*, paper under review.

[2]. MT van Genuchten, 1980, *A closed-form equation for predicting the hydraulic conductivity of unsaturated soils*, Soil Sci. Soc. Am. J. **44** (5): 892-898.

[3]. Yu Wang, S.M. Grove, M.G. Anderson, 2008, *A physical-chemical model for the static water retention characteristic of unsaturated porous media*, Advances in Water Resources, **31**: 723-735.

[4]. Yu Wang, X.Y. Wang, M. Scholz, D.K. Ross, 2012, *A physico-chemical model for the water vapour sorption isotherm of hardened cementitious materials*, Construction and Building Materials, **35**: 941–946.

[5]. https://www.metergroup.com/en/meter-environment/products/hyprop-2-soil-moisture-release-curves

The description for the current three phase water-vapour sorption isotherm and water retention characteristics (WVSI-WRC) model can be found on:
https://www.youtube.com/watch?v=tyYyK9TYdXQ

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