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SoilWater2 Model Component

PD 3.2.3

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General information

Task(s) and Activity code(s):	Task 3.2, activity 3.2.3
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Executive summary

The SoilWater2 component represents in detail the water dynamics within the soil profile and its hydrostructural state at any time and depth. It differs from SoilWater mostly in that it accounts for preferential water flow in the soil profile. The soil structure is a matrix of solid phase holding water and air on several smaller scales. The module simulates dynamics of both soil structure and soil-water interacting together. The profile consists of a surface layer and underlying horizons. The impact of technical practices, like tillage or effect of a soil surface crust, is on water infiltration and evaporation. Surface hydraulic conductivity, layer thickness and maximum surface storage are the three principal modified factors. Each horizon is considered as a homogeneous zone in term of structure and organization of particles such that it is characterized by the same set of hydrostructural parameters everywhere within it. Soil horizons are discretized into layers. The equation used allows the uniformity of the layer's depth in each horizon and differences between horizons.

Since the paradigm of soil hydrostructural characterization and modelling in which this soil water component was built is new, as well as many of the functional equations, variables and parameters that belong to it, and even if most of those are yet published, a synthetic explanation of the theory is given in the document.

The document presents the basic principles of the new paradigm, the soil hydrostructural functioning model Kamel® from which the SoilWater 2 component has been adapted to work as a module of APES.

Specific part

1 Introduction

Soil physics literature describes soil hydraulic properties independent from the hierarchical organization of the soil medium and its hydro-structural functioning. The natural organisation of the soil medium and its organizational state variables are still ignored in bio-physical processes happening in the soil medium This leads to a double deadlock in agro-environmental sciences: 1) an empirical approach can only be used for characterizing and modelling the internal soil hydro-structural properties (soil shrinkage, water potential, field capacity, available water, hydraulic conductivity) so that neither bio-physical process in the soil medium can be physically described at the local scale of its emergence; 2) the transfer of scale, from the soil characterisation in laboratory to the modelling at field scale and more cannot actually be physically controlled. To face this situation, Braudeau and Mohtar (2009) proposed a new paradigm in soil sciences that bridges the gap between pedology and soil physics and allows for a physically-based hydro-structural characterization and modelling of any organized soil system.

A computer model for the vadoze zone water dynamics and storage was first developed with Simile® development tool as a prototype of the soil-water component of APES able to take into account the soil structure and its changes under cultivation according to this new paradigm. This prototype, Kamel® (Braudeau, 2006, Martin et al. 2007) was partly funded by SEAMLESS (with IRD and Purdue University). It characterizes and simulates the hydrostructural functioning of the pedon and both structure and water dynamics at each level of the internal soil organization (surface layer, pedon, horizons, pedostructural layers, and primary peds). It has been implemented after that to become the SoilWater2 component of APES.

Since the paradigm used for the soil structure and water characterization and modelling is new, as well as many of the functional equations, variables and parameters that belong to it, and even if most of those are yet published, a synthetic explanation of the theory is given hereafter.

The document presents i) the basic principles of Kamel® along with the hydrostructural state variables used; ii) the functional equations and parameters used for characterizing the soil system and modelling its dynamic, iii) the way for providing the required hydrostructural parameters of Kamel® starting from texture and soil organic matter data; and iv) the coupling of Kamel® with the WEPP model soil component (Alberts et al. 1995) for taking into account the changes in hydrostructural properties of the surface layer under cultivation.

2 Theoretical Development

2.1 Basic principles of the new soil physics paradigm

2.1.1 Using both notions of REV and SREV of the soil medium for the transfer of scale)

Braudeau and Mohtar (2009) present the new notion of "Structure Representative Elementary Volume" (SREV) as follows: Similar to the well know "Representative Elementary Volume" (REV) used in soil physics and hydrology in order to apply equations of the continuous porous media theory, a SREV represents a homogeneous medium and do not have any physical boundary; but unlike REV, SREV is virtually delimited by an enclosure which is permeable to air, water, or salts fluxes but not to solids that compose the structure. This description defines any SREV as a volume V comprised of a fixed mass of solids, m_s, such that its specific volume, defined as $\overline{V} = V/m_S$, depends only on the change in content of its mobile phases. That gives to SREVs the following properties:

- A given SREV encloses a constant structural mass, m_s, and its descriptive variables refer to this structural mass instead of the volume. This mass corresponds to the classical oven dried mass of the sample at 105°C.
- The SREV delineation is linked to the structured solid phase. Once defined or recognized at the discretization of the pedon into layers for the modeling purpose (Figure 1), these SREV (layers) are positioned in the 3-D space relative to the spatial organization of the medium (soil horizons) of which it belongs. Adding solids into a SREV, and thus increasing the structural mass (m_S) independently of the structural volume, is not allowed because such operation should change the structure of the SREV and its hydrostructural properties. The only possible change of m_s without any changes to the structure and hydrostructural properties would consist of a change of delineation within the same structured medium.

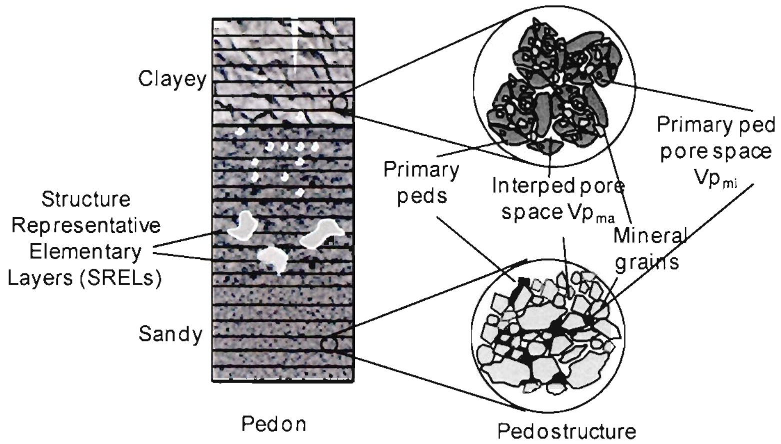

Figure 1. Soil medium organization modelled by Kamel (Braudeau et al., 2009)

Organizational variables of an SREV can be nested with respect to the hierarchical organization of the medium. Relationships between these variables at different levels of scale can be established in regard to the organization and functionality of the SREV. An example is given Table 1 by the organizational variables of the pedostructure which was defined by Braudeau et al. (2004a) as the SREV of the soil fabric in a soil horizon.

Table 1. Pedostructure state variables. Subscripts *mi* and *ma*, *hor, fiss*, and *s*; refer to as micro and macro, horizon, fissures and solids; ip, st, bs and re, refer to as the name of the corresponding shrinkage phase of the shrinkage curve: interpedal, structural, basic and residual.

Volume of concern	Specific volume (dm³/kg)	Specific pore volume (dm³/kg)	Specific water content (kg w./kg soil)	Non swelling water (kg w./kg soil)	Swelling water (kg w./kg soil)	Suction pressure (kPa)	Conduc-tivity (dm/s)
Horizon	$\overline{V_{hor}}$	Vp_{fiss}	W_{hor}				
Pedostructure	$\overline{V}$		W			h	k
Interpedal porosity		Vp_{ma}	W_{ma}	w_{st}	w_{ip}	h_{ma}	k_{ma}
Primary peds	$\overline{V_{mi}}$	Vp_{mi}	W_{mi}	w_{re}	w_{bs}	h_{mi}	k_{mi}
Primary particles	$\overline{V_s}$						

Kamel® uses the specific SREV variables (like W and $\overline{V}$) for modelling **all processes at their local scale in the soil medium** and the volumetric REV variables (like θ, ratio to a soil volume that is not linked to the structure) for providing as outputs integrated soil variables at the macroscopic field level. In fact, REV variables are macroscopic integrated or averaged variables and should not be used for describing processes at their local scale of emergence (Braudeau and Mohtar, 2009).

2.1.2 The notion of primary ped

Brewer (1964) introduced the following concepts of *primary ped* and *S-matrix*:

"A ped is an individual natural soil aggregate consisting of a cluster of primary particles and separated from adjoining peds by surfaces of weakness which are recognizable as natural voids or by occurrence of cutans."

"Primary peds are thus the simplest peds occurring in a soil material. They cannot be divided into smaller peds, but they may be packed together to form compound peds of higher level of organization. The S-matrix of a soil material is the material within the simplest (primary) peds, or composing apedal soil materials, in which the pedological features occur; it consists of plasma, skeleton grains, and voids that do not occur in pedological features other than plasma separations."

"It is apparent from the definitions of the levels of structure and from the nature of soil materials that structure analysis is concerned with units with very different hydraulic properties: plasma, skeleton grains, peds, voids..."

Braudeau et al. (2004a) complete this morphological definition with a functional definition based on the determination of the air entry point of the S-matrix on the continuously measured shrinkage curve. This definition allowed the physical characterization of the hydrostructural properties of primary peds and of their assembly, the pedostructure, SREV of a soil horizon (Braudeau and Mohtar, 2009).

Therefore variables and parameters are defined for both distinct media of the pedostructure: inside and outside of the primary peds: V_{mi}, Vp_{mi}, W_{mi}, h_{mi}, k_{mi}, Vp_{ma}, W_{ma}, h_{ma}, k_{ma} (Table 1).

2.1.3 The four types of water pools in the structured soil medium

For interpreting the shrinkage curve (SC) Braudeau et al. (2004a) define two pools of water in the two pore systems, inside and outside primary peds: swelling water, w_{sw}, and condensed water or non swelling, w_{cn}. Swelling water occupies a pore space acquired by the spacing of particles or aggregates under the effect of osmotic pressure. Its removal from the sample causes shrinkage of the concerned pore system. Condensed water, on the other hand, occupies an interstitial pore space and is replaced by air (or water vapor at saturation pressure) when it leaves the pore; its loss causes little or no shrinkage. During drying, each linear phase of the shrinkage curve is caused by the predominant departure of only one pool of water, w_{sw} or w_{cn}, from either the micro- or the macro-pore system (Figure2). In general there are four water pools that evaporate successively from a soil sample initially saturated: they were called in reference to the corresponding shrinkage phase, interpedal, structural, basic and residual: w_{ip}, w_{st}, w_{bs}, w_{re}.

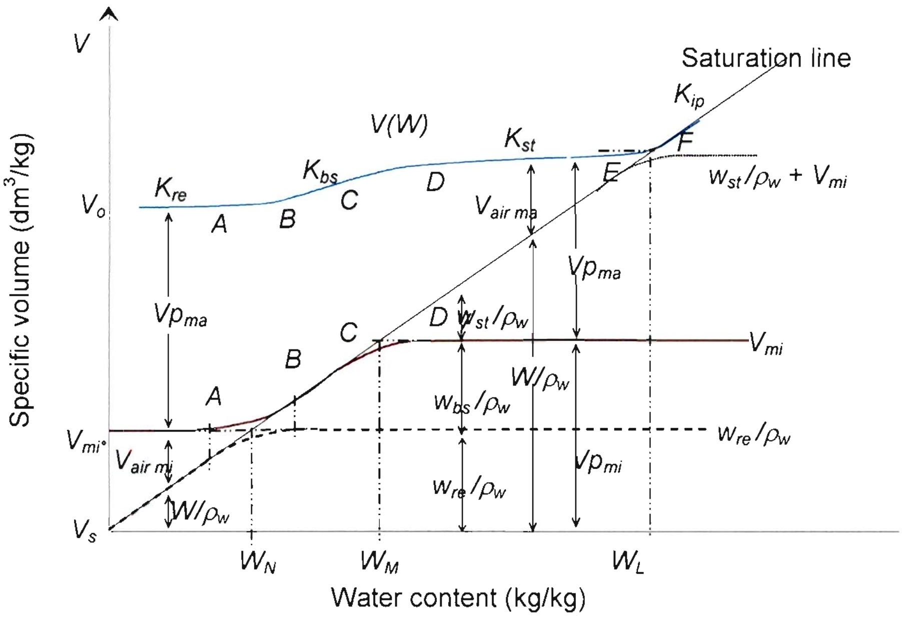

Figure 2. Graphical representation of the specific volumes of the pedostructure (V, in blue) and primary peds (V_{mi}, in brown), the specific pore volumes (Vp_{mi} and Vp_{ma}), the air contents (V_{airmi} and V_{airma}) and the water pools (W, w_{re}, w_{bs}, w_{st}, and w_{ip}) of the pedostructure starting from a measured SC. V_{mi} is equal to (Vp_{mi} + V_s) = (max(w_{re}) + w_{bs} + V_s) .

2.1.4 Hydration forces of interaction between solids surface and water

The usual approach for modeling soil water potential emphasizes the geometrical aspect of the structure, restricting the matrix water potential to the interfacial tension of the air-water meniscus in a capillary. Its curvature determines the potential according to Laplace-Kelvin's law and is assimilated to the pore radius r_c for which all pore segments with sides shorter than $2r_c$ are filled with water. This approach does not make reference to any swelling pressure, due to osmotic or hydration force of interaction between solid surfaces and water.

Braudeau and Mohtar (2004) showed that, in contrast to the usual approach, the physico-chemical approach of Low (1987), Voronin (1980) and Berezin (1983) calls for other notions than the interfacial meniscus curvature. According to Low (1987), water is arranged in layers at the surface of the particles and a swelling pressure is observed depending on the thickness of the water film (τ) and the specific surface area of the soil particles. In this approach, the thickness t of the film of water at the surface of the unsaturated pores is used as the variable. The difference with the Laplace-Kelvin approach is that the change of water is simply related to τ by $dW = Sd\tau$ where S is the specific surface area of the solids. The geometry of the structure is less important in this approach than the knowledge of the nested organization up into swelling aggregates which defines different levels of surface area (for example the surfaces outside, relatively to inside, of the primary peds).

2.2 Equations of hydrostructural states and dynamics for a layer, SREV of a soil horizon

2.2.1 Water pools in the pedostructure at equilibrium

The shrinkage curve measured in the laboratory according to Braudeau et al. (1999) as well as the soil water potential curve can be considered as a succession of equilibrium states of the pedostructure. Braudeau et al. 2004a showed that, at equilibrium at given water content W, equations of the water pools in term of the total water content W are:

$$w_{ip}^{eq} = \frac{1}{k_L}\ln[1+\exp(k_L(W-W_L))] \tag{1}$$

$$w_{st}^{eq} = -\frac{1}{k_M}\ln[1+\exp(-k_M(W-W_M))] - w_{ip}^{eq} \tag{2}$$

$$w_{bs}^{eq} = \frac{1}{k_N}\ln[1+\exp(k_N(W-W_N))] + \frac{1}{k_M}\ln(1+\exp(-k_M(W-W_M)); \tag{3}$$

$$w_{re}^{eq} = -\frac{1}{k_N}\ln[1+\exp(k_N(W-W_N))] + W \tag{4}$$

Parameters W_N, W_M, W_L are the water content at the intersection points N', M', L' of the tangent lines extending the quasi-linear shrinkage regions of the shrinkage curve (Figure 2). Their value represents characteristic pore volumes of the pedostructure with ρ_w being the water density in kg dm^{-3}:

$W_N = \max(w_{re}) = \rho_w \min(Vp_{mi})$, the pore specific volume of primary peds at dry state (5)

$W_M = \max(w_{re}) + \max(w_{bs}) = \rho_w \max(Vp_{mi})$, the maximum pore specific volume of saturated primary peds; and

W_L - $W_M = \max(w_{st}) \approx \rho_w\ Vp_{ip}$, the interpedal pore specific volume in the structural linear region of the shrinkage curve (D-E).

Parameters k_N, k_M, and k_L represent the y-distance between these intersection points and the shrinkage curve (as for example: k_M/Log2 = $(K_{bs}-K_{st})/(V_M-V_{M'})$). They are constants under experimental conditions, but they depend on the load and overburden pressure under field conditions.

2.2.2 Shrinkage curve

The specific volume of the pedostructure is dependent of the types of water such as:

$$d\overline{V} = K_{bs}dw_{bs} + K_{ip}dw_{ip} \tag{6}$$

where K_{bs} and K_{ip} = 1 dm^3/kg are the slopes of the linear basic and interpedal shrinkage phases (parallel to the saturation line), respectively (see Figure 2). They represent the pedostructure volume change caused by the change of the *swelling* water pools w_{bs} and w_{ip}. The slopes are considered as structural parameters of the pedostructure, linking the macroscopic assembly level to the water pools levels. As an example:

$$K_{bs} = \partial\overline{V}/\partial w_{bs} = \partial\overline{V}/\partial\overline{V}_{mi}$$

where $\overline{V}_{mi}$ is the specific volume of primary peds, including primary particles $\overline{V}_s$ (Table 1):

$$\overline{V} = \overline{V}_{mi} + \overline{V}p_{ma} \text{ and } \overline{V}_{mi} = \overline{V}p_{mi} + \overline{V}_s \quad (7)$$

2.2.3 Soil water suction pressure

The water suction pressure intra and extra primary peds, h_{mi} and h_{ma}, are expressed according to Braudeau and Mohtar (2004) in terms of W_{mi} and W_{ma} such as:

$$h_{ma} = Ps_{ma} - Ps^{o}_{ma} = \rho_w E_{ma}\left(1/(W_{ma}+\sigma) - 1/(W_{sat} - W_M + \sigma)\right) \quad (8)$$

$$h_{mi} = Ps_{mi} - Ps^{o}_{mi} = \rho_w E_{mi}\left(1/(W_{mi}-W_N) - 1/(W_M - W_N)\right) \quad (9)$$

where ρ_w is the water bulk density (kg/dm^3); Ps_{mi} and Ps_{ma} are the swelling pressure (kPa) inside and outside the primary peds (Fig. 3), E_{mi} and E_{ma} are the potential energies of the solid phase resulting from the external surface charge of clay particles, inside and outside the primary peds (joules/kg of solids) respectively; and σ is a part of the micropore water (kg/kg) at interface with interpedal water. Both terms $Ps_{mi°}$ and $Ps_{ma°}$ represent the swelling pressure at saturation, inside and outside of the primary peds, respectively, when $W_{ma} = W_{sat}$-W_M; and $W_{mi} = \max(W_{mi}) = W_M$.

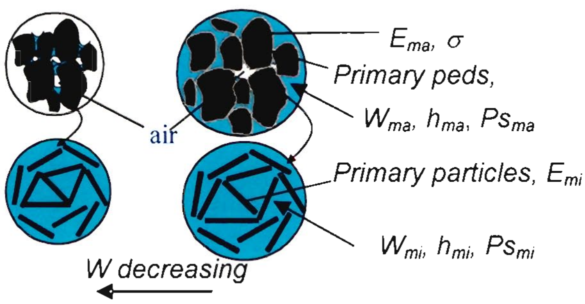

Figure 3. Representation of the variables of state in the pedostructure

2.2.4 Dynamics of the pedostructure volumes

The two opposite dynamics, swelling and shrinking, are supposed to be governed by the same conceptual process that is the water exchange between the primary peds and the interped pore space. Braudeau and Mohtar (2006) validated in a particular case (aggregates immersed in water) the following equation where the water exchange between the two media is proportional to the difference in their suction pressure:

$$\frac{dw_{bs}}{dt} = k_{mi}\left(h_{mi} - h_{ma}\right) \quad (10)$$

In this equation, k_{mi} is the transfer rate coefficient (kg$_{micro\ water}$ kg$^{-1}_{soil}$ kPa^{-1}s^{-1}) for the absorption-desorption of the interped water by the primary peds. This coefficient expresses the velocity of the last layer of water on the surface of the clay particles entering or leaving the primary peds. This transfer rate coefficient k_{mi} is assumed to be constant, in the considered range of water content (W_B – W_{sat} Braudeau and Mohtar (2006) showed that the micro-macro water exchange, k_{mi}, can be calculated by

$$k_{\mathrm{mi}} = \frac{(W_{\mathrm{M}} - W_{\mathrm{N}})^2}{\rho_{\mathrm{w}} E_{\mathrm{mi}}} \frac{0.1931}{t_{1/2}} \quad (11)$$

where $t_{1/2}$ is the time of half swelling in seconds at $w_{\mathrm{bs}} = \max(w_{\mathrm{bs}})/2 = (W_{\mathrm{M}} - W_{\mathrm{N}})/2$. This time of half swelling seems to be a characteristic of the kind of clay in the soil and is easily determined in laboratory using the measurement of the swelling in time of aggregates immersed in water.

Assuming that Equation 10 is valid at any hydrostructural state of the pedostructure and using Equation 6, one can calculate the dynamic of the shrinkage ($dw_{\mathrm{bs}}/dt < 0$) as well as the swelling ($dw_{\mathrm{bs}}/dt > 0$) of the pedostructure. The knowledge of the water pools then W_{mi} ($w_{bs}+w_{re}$) and W_{ma} ($w_{st}+w_{ip}$) at each time of the simulation allows the calculation of all the state variables listed in Table 1, including the fissures and cracks specific volumes (Vp_{fiss}) appearing with the shrinkage.

2.2.5 Dynamic of the micro and macro water contents of a layer

Kamel® distinguishes two types of transport: (1) a local transport within the pedostructure of the layer (SREV of the horizon) that corresponds to the water exchange between the both pore spaces inside and outside primary peds according to Equation 10; and (2) a transport through the layer that concerns only the interped water, W_{ma}, and obeys the Darcy law. The Richards equation must be re-written such as (Braudeau and Mohtar, 2009):

$$\frac{dW_{ma}}{dt} = \rho_w \overline{V}_{layer} \frac{\partial}{\partial z}\left(k_{ma}\left(-\frac{dh_{ma}}{dz} + 1\right)\right) - \frac{dW_{mi}}{dt} \quad (12)$$

and $\frac{dW_{mi}}{dt} = k_{mi}(h_{mi} - h_{ma})$

where $\overline{V}_{layer}$ (dm^3/kg solids) is the specific volume of the thin layer that is considered as a SREV (of which all variables have the same unique value everywhere in the SREV and the mass of the solids belonging to the soil structure is constant); z is the layer depth (dm) (positive upward), h_{ma} and h_{mi} are expressed in high of water (dm); and k_{ma} the hydraulic conductivity though the interpedal pore space (dm/s).

Concerning the latter, Braudeau et al. (2009) showed that, according to the literature, one can assume that the conductivity curve is an exponential function of W_{ma} for the high and low ranges of W_{ma} with parameters of the exponential function different for the two ranges of moisture content. Keeping the distinction between both ranges of conductivities defined by the shrinkage curve (W_{sat} to W_M and W_M to W_C) the two exponential equations were combined in the same logistic equation such that:

$$k_{ma} = \frac{k_{maM} \exp(\alpha_o W_{ma})}{k_{maM} / k_{ma}^o + \exp((\alpha_o - \alpha_M) W_{ma})} \quad (13)$$

This equation represents the conductivity curve for the pedostructure model and has four parameters: k_{maM}, α_M, k_{ma^o}, and α_o that can be measured in the laboratory or estimated with pedotransfer functions.

2.3 Estimation of pedostructure parameters using classical soil data

A complete soil physical characterization requires the measurement in laboratory of the 4 characteristic curves mentioned above: shrinkage curve, water potential curve, conductivity curve and the time dependant swelling curve.

Pedostructure parameters obtained from the measurement of these curves are not available in soil data bases but can be estimated using pedotransfer functions (Braudeau et al. 2004b) from basic information like soil texture, soil bulk density, field capacity etc.

Two successive steps are considered in the Kamel® parameters estimation:

1st, estimation of the hydrostructural soil parameters provided by both equations of state of the pedostructure: the shrinkage curve and the potential curve, and

2nd, estimation of the dynamical parameters: of the hydraulic conductivity inter-aggregates (k_{maM}, $k_{ma°}$, α_M and $\alpha°$); and of the swelling of the clayey plasma: k_{mi}

2.3.1 Hydro-structural state parameters

These are all provided by the shrinkage curve and the water potential curve, from saturation up to the dry state. Concerning the water potential measurement, the methods of reference in laboratory that will be considered valid are the tensiometer method, from saturation to 60 kPa, and the Richards apparatus for suctions of 100 kPa and more.

There are two cases: 1) Ideal case, the shrinkage curve and the water potential curve have been measured and 2) general (SEAMLESS) case, the shrinkage curve and water potential curve parameters are estimated using pedotransfer functions.

1- Measured parameters

The two curves were measured on a same undisturbed sample (or on two separate repetitions) and all the shrinkage phases are clearly distinguished on the shrinkage curve. The following parameters for the micro pore system (V_N, k_N, W_N), and the interpedal pore system(K_{bs}, k_M, W_M, k_L, W_L), respectively, are determined on the measured ShC. The water potential curve can be used for determining E_{ma}, E_{mi}, σ and W_{sat}, the water content at saturation (zero suction) by fitting equations of h_{mi} and h_{ma} (Equations 8 and 9) on the measured curve: $h(W)$, were W_{mi} and W_{ma} are calculated in terms of W using parameters of the ShC

However, depending on the soil type or on the sample preparation (disturbed structure), it happens frequently that only the micro parameters: V_N, k_N, W_N, and K_{bs} can be determined or are valid using the S_hC. The tensiometric curve is used, thus, for getting the rest: W_M, k_M, W_{sat} (may be different from W_L), E_{ma}, E_{mi} and σ.

In fact, a computer module of Kamel, KamelSoil®, was developed for determining this last set of 6 macropore system parameters by fitting the two equations of h_{mi} and h_{ma} (Eqs 8 and 9) together on the measured tensiometer curve $h(W)$ in the range of 0 to 60 kPa.

2- Parameters estimated using the pedotransfer functions

Since it has been decided in SEAMLESS that the soil characteristics inputs will be only the soil texture and the organic matter content by horizon, the pedostructure parameters of Kamel will be deduced from these both characteristics using the set of pedotransfer functions presented by Saxton and Rawls (2006). In the following equations hereafter, variables with asterisk are variables estimated using this set of pedotransfer functions.

a) *VD, the specific volume of the pedostructure at humid state.*

We neglect in this work the swelling contribution of wip in equation 6 such that we make the following approximation: Vsat = VD, the pedostructure specific volume at point D of the shrinkage curve, beginning of the shrinkage of primary peds, identified as the point at field capacity.

The soil bulk density BD (kg/dm^3) corresponding to VL, is estimated via the volumetric water content at saturation, θ_{sat}* (m^3/m^3), and the density of the solid phase supposed equal to 2.65, according to the following equation:

$$VD = 1/BD = 1/2.65 + W_{sat}/\rho_w = 1/2.65 + \theta_{sat}{}^*/BD \qquad (14)$$

where W_{sat} is the gravimetric water content at saturation, in kg water/kg solids, and ρ_w is the water density (1 kg/dm^3).

b) *W_N and k_N , parameters of Equations 3, 4 and 9.*

The wilting point W_{1500} (soil moisture at 1500 kPa) is used for estimating W_N and k_N assuming that this point W_{1500} corresponds to the air entry point W_B on the ShC (Braudeau et al. 2005). The equations used are:

$$1500 = E_{mi}/(W_{1500} - W_N) - E_{mi}/(W_M - W_N) \qquad (15)$$

according to Equation 9 where h_{mi} = 1500 kPa; and the following relationship (Eq. 16) given by Braudeau et al. (2004a) where W_B has been replaced by the estimated wilting point, W_{1500}:

$$k_N = 3.46\ \mathrm{Ln}(2)\ /(W_{1500} - W_N) \qquad (16)$$

In general, the wilting point is measured in kg/kg and is available in soil data bases. For APES W_{1500} is estimated via $\theta_{1500}{}^* = BD\ W_{1500}/\ \rho_w$, using the pedotransfer functions of Saxton and Rawls (2006). We have to note that the required bulk density in the previous relationship should have been the dry bulk density instead of BD. This distinction between dry and moist bulk density cannot be neglected in the case of swelling soils but has been never considered in the making of pedotransfer functions.

c) The soil water potential curve estimation and the corresponding parameters

Soil moistures at 100 kPa (1 bar), W_{100} and at 33 kPa: W_{33} are two soil characteristics that are generally measured and found in the soil data bases, in kg/kg. Like W_{1500}, they are estimated in KamelSoil® via θ_{100}* and θ_{33}* (divided by BD) using pedotransfer functions of Saxton and Rawls (2006). With W_{1500}, and W_{33}, one can calculate the two parameters A and B of the equation (26) used by Saxton and Rawls (2006) for representing the tension segment of 1500 to 33 kPa:

$$h_{(1500\text{-}33)} = A W^{B} \qquad (17)$$

In KamelSoil® this equation is used to fit h_{mi} on these three points (W_{1500}, W_{100} and W_{33}) and simultaneously on h_{ma} between 70 kPa to saturation (0 kPa). The assumption here is that h_{mi} and h_{ma} are equal from 70 kPa up to saturation. Thus, the segment between 33 kPa and saturation which was taken as a straight line by Saxton and Rawls (2006) is actually modelled by h_{ma} and h_{mi} under this assumption.

This fitting procedure, under the constraints of Equations 1 to 4, 8, 9, 15 and 16, provides W_M, k_M, W_{sat}, E_{ma} , σ, E_{mi}, W_N, and k_N.

d) *K_{bs}, slope of the basic shrinkage curve.*

The standard COLE index (NRCS, 1995) may be used for calculating $\Delta V = V_{M'} - V_{N'}$ then K_{bs}, the slope of the basic shrinkage phase of the shrinkage curve, according to the relationship $K_{bs} = \left(\overline{V}_{M'} - \overline{V}_{N'}\right)/\left(W_M - W_N\right)$ (see Figure 2). The COLE denotes the fractional change in the clod dimension from a dry to a moist state at 33 kPa. It can be expressed such as:

$$\mathrm{COLE} = \left(\overline{V}_{33}/\overline{V}_{Dry}\right)^{1/3} - 1 \approx \left(\overline{V}_{33} - \overline{V}_{Dry}\right)/\left(3\overline{V}_{Dry}\right) \quad (18)$$

Assuming that $\overline{V}_{33}$ is a good approximation of $\overline{V}_{M'}$ for all types of ShC and that $\overline{V}_{dry} = \overline{V}_{N'} = \overline{V}_{A}$, we can then calculate K_{bs} as:

$$K_{bs} = \left(3\mathrm{COLE}\,\overline{V}_{D}/(3\mathrm{COLE}+1)\right)/\left(W_M - W_N\right) \quad (19)$$

If the COLE index is not available, a relationship between K_{bs} and the contents in clay, silt and sand (kg/kg) can be sought (Braudeau et al. 2004b, Boivin et al. 2004). In KamelSoil® for APES the following Equation 20 is used waiting for more investigations:

If (Clay + 0.25 Silt) > 0.5 kg/kg then K_{bs} = 1.1 else K_{bs} = 2(Clay + 0.25Silt) (20)

where Clay and Silt are in kg/kg of solids.

e) V_A, the specific volume of the pedostructure at dry state.

$$V_A = V_D - K_{bs}\,(W_M - W_N) \quad (21)$$

2.3.2 Estimation of the dynamic parameters

Parameters of $k_{ma}(W_{ma})$ in Equation 13 are estimated by fitting this equation to the conductivity curve $k(\theta)$ simulated by Brooks and Corey equation (1964):

$k(\theta) = k_{sat}*((\theta - \theta r) / (\varphi - \theta r))^\wedge n$
(22)

where parameters θr, and n are determined by PTFs from clay %, sand % and porosity (volume fraction) according to Saxton and Rawls (2006). The conductivity at saturation k_{sat} is calculated by the Saxton and Rawls (2006) procedure according the following relationship:

$k_{sat} = 1930(\theta_{sat} - \theta_{33})^{(3 - 1/B)}$
(23)

where B is the parameter of Equation 26 calculated with points (W_{1500}, 1500) and (W_{33}, 33).

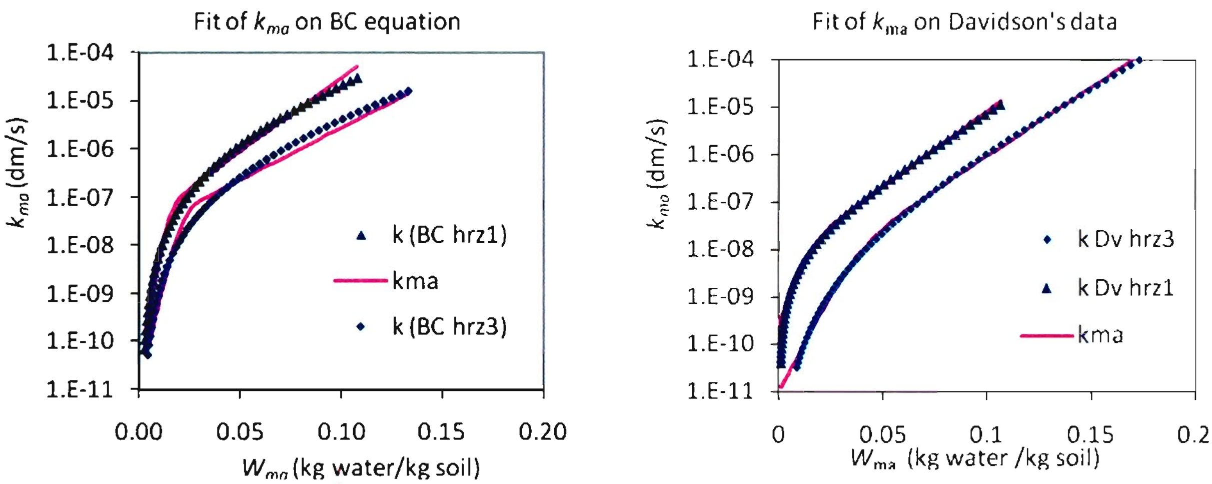

Figure 4. Hydraulic conductivity parameters obtained by optimizing the fit of the exponential logistic equation of k_{ma} on: a) the estimated Brooks and Corey's equation of the conductivity k for horizons 1 and 3 of the Yolo loam Soil using KamelSoil®; and b) on the measured exponential equation of the conductivity for the same horizons (Davidson et al. 1969).

The conductivity equation of Kamel® (Equation 13) is then adjusted to the conductivity curve of Brooks and Corey (1964) (Equation 22) using the solver function of Excel® after initialization of the Kamel® parameters as:

$$\alpha_M = n/(W_{sat} - W_N);\ k_{mao} = k(\theta_C)\ ;\ k_{maM} = k(\theta_M) \qquad (24)$$

and α_o given by equation 13 at $W=W_M$ ($k_{ma}=k_{maM}$ and $W_{maM} = w_{st}(W_M) = -\text{Ln}(2)/k_M$ from Equation 2 of w_{st} in annexes).

An example is presented on Figure 4a showing the fit of the logistic equation of k_{ma} on the conductivity curve (Equation 22) estimated using PTFs from the texture for two horizons of the Yolo loam soil studied by Davidson et al. 1969. For comparison, we put on Figure 4b the measured corresponding data of hydraulic conductivity (Davidson et al. 1969) fitted also by the logistic equation of k_{ma}. A better result is obtained with the logistic equation of k_{ma} (Equation 13).

Concerning the absorption rate of water by the swelling plasma of primary peds, k_{mi}, this rate was rarely measured. The time of half charge, $t_{1/2}$, which is chosen as parameter for representing k_{mi} via Equation 11, depends on the soil plasma and its degree of division in the structure. It was fixed at 30 minutes, waiting for more future investigations.

Table 2 is an example coming from Braudeau et al. (2009) of the set of input pedostructure parameters for Kamel® calculated to simulate the hydostructural functioning of the Yolo loam soil studied by Davidson et al. (1969).

3 Taking into account the tillage

3.1 Surface layer definition in Kamel®

This layer has a particular status relatively to the other layers underneath belonging to the pedon modeled. In the modeling point of view, the soil surface layer is a module that makes the interface between external events (rainfall, irrigation, tillage …) and the internal hydrostructural dynamic of the pedon. In the Kamel model and SoilWater2 component the hydrostructural characteristics of the pedostructure composing this layer are considered as the same of the horizon A underneath. One assumes that what is changing in the surface layer after tillage, then under the action of rainfall and weathering, is only the bulk density of the layer and not its pedostructure that stays representative of clods and aggregates composing the layer. Tillage induces a macroscopic inter clods specific volume equal to $\left(\overline{V}_{Surflayer} - \overline{V}_{pedostructure}\right)$, which will be decreasing during the cropping cycle until reaching zero at the end of the cycle.

Therefore, the only variables of state that are needed in order to take into account this tillage effect on the hydrostructural functioning of the surface layer are its bulk density, ρ_t, and its thickness. These both variables will be estimated for the SoilWater2 component using the WEPP model as described on the next section.

The soil water potential and hydraulic conductivity curves of the surface layer, functions of the macroscopic (interpedal) water content of the layer W_{maSurf}, keep the same expression and parameters before and after tillage, independent from ρ_t. The only difference is that their ranges of values extend to values corresponding to values of W_{maSurf} higher than W_{maSat} which stays unchanged as one characteristic of the pedostructure (Equations 8 and 24).

3.2 Soil bulk density of the surface layer predicted by WEPP model

The WEPP model (1995) is used to predict the bulk density of the surface layer after tillage, ρ_t, needed as input to SoilWater 2 component. Documentation on Wepp model can be fund and downloaded at

http://topsoil.nserl.purdue.edu/nserlweb/weppmain/docs/readme.htm

The chapter 7 (Alberts et al., 1995) "provides the WEPP user with background information on the soil and soil-related variables currently predicted in the WEPP model." In the section 7.7 about the soil bulk density, one can find all equations used for predicting soil bulk density after tillage, ρ_{t0}, ii) its consolidation due to the rainfall and iii) due to the weathering during the cropping cycle.

i) Tillage effect

The equation used to predict soil bulk density just after tillage is (Williams et al. 1984):

$$\rho_{t0} = \rho_{t-1} - [\rho_{t-1} - 0.667\rho_c]T_{ds} \quad (25)$$

where ρ_{t0} is the bulk density just after tillage (kg.m−3), ρ_{t-1} is the bulk density before tillage (kg.m−3), ρ_c s he consolidated soil bulk density (kg.m−3) at 0.033 MPa of tension, and Tds is the fraction of the soil surface disturbed by the tillage implement (0-1). T_{ds} is a WEPP parameter of which values between 0 and 1 are listed for 78 tillage implements in the Table 7.5.1 of the chapter (see Appendices).

For adapting this equation to our assumptions in APES, ρ_{t-1} will be taken equal to ρ_c with $\rho_c=BD=1/V_D$. That leads to

$$\rho_{t0} = \rho_c(1 - 0.33T_{ds}) \quad (26)$$

ii) Rainfall consolidation

"Soil bulk density increases by rainfall are predicted from (Onstad et al., 1984):

$$\rho_d = \rho_t + \Delta\rho_{rf} \quad (27)$$

where ρ_d is the bulk density after rainfall (kg.m−3), ρ_t is the bulk density after tillage (kg.m−3), and $\Delta\rho_{rf}$ is the bulk density increase due to consolidation by rainfall (kg.m−3).

The increase in soil bulk density from rainfall consolidation ($\Delta\rho_{rf}$) is calculated from:

$$\Delta\rho_{rf} = \Delta\rho_{mx}\frac{R_c}{0.01 + R_c} \quad (28)$$

where $\Delta\rho_{mx}$ is the maximum increase in soil bulk density with rainfall and R_c is the cumulative rainfall since tillage (m).

The maximum increase in soil bulk density with rainfall is predicted from:

$$\Delta\rho_{mx} = 1650 - 2900\,clay + 3000\,clay^2 - 0.92\,\rho_t \quad (29)$$

and if $\Delta\rho_{mx}$ is ≤0.0, then $\Delta\rho_{mx}$= 0.0.

The upper boundary for soil bulk density change with rainfall is reached after a freshly-tilled soil

receives 0.1 m of rainfall."

iii) Weathering consolidation

Consolidated soil bulk density (ρc) is assumed to be the upper boundary to which a soil naturally tends to consolidate.

The difference between the naturally consolidated bulk density and the bulk density after 0.1 m of

rainfall is:

$$\Delta\rho_c = \rho_c - \rho_t \quad (31)$$

where $\Delta\rho_c$ is the difference in soil bulk density between a soil that is naturally consolidated and one that has received 0.1 m of rainfall. ρ_t is soil bulk density on the day cumulative rainfall since tillage equals 0.1 m.

The adjustment for increasing bulk density due to weathering and longer-term soil consolidation is

computed from:

$$\Delta\rho_{wt} = \Delta\rho_c\, F_{dc} \quad (32)$$

where $\Delta\rho_{wt}$ is the daily increase in soil bulk density (kg.m−3) after 0.1 m of rainfall, and F_{dc} is the daily consolidation factor.

The daily bulk density consolidation factor is predicted from:

$$Fdc = 1 - e^{-0.005\ daycnt} \quad (33)$$

where *daycnt* is a counter to keep track of the number of days since the last tillage operation.

Soil bulk density changes following tillage are predicted from:

$$\rho_t = \rho_{t0} + \Delta\rho_{rf} + \Delta\rho_{wt} \quad (34)$$

where the tillage occurred the previous day t0 and the variables have been previously described.

3.3 Coupling WEPP and Kamel® models

The thickness of the surface layer in WEPP model is fixed to 0.2 m. It can be chosen in Kamel® model. It will be fixed to 0.15 m by default for APES, knowing that the first horizon of the pedon just under the surface layer has the same pedostructure characteristics and that its thickness can be also chosen (0.05m by default).

In order to connect values of ρ_t calculated by WEPP (Equation 34) to the specific volume of the surface layer $V_{surfLayer}$ and to the specific volume of its pedostructure, V (changing with the water content), the variable parameter *CoefTill* has been defined such as:

$$CoefTill = (V_{SurfLayer} - V_D)/V_D \quad (35)$$

where $V_{SurfLcyer} = 1/\rho_t$ is the specific volume of the surface layer in Kamel and $V_D = 1/BD = 1/\rho_c$ the pedostructure specific volume at moist state (field capacity) of the first horizon. Thus,

$$CoefTill = (BD/\rho_t - 1) \quad (36)$$

In contrary with the other layers of the pedon, the surface layer is considered as a fixed volume (of height $H_{surfLayer}$ = 0.15 m). The change of height of water ($H_{WaterSurf}$) with time in this compartment is the sum of the water fluxes crossing the upper and lower sides of the surface layer. The water content W_{surf} is then calculated as:

$$W_{surf} = H_{WaterSurf} \cdot V_{surflayer} / H_{surfLayer} \,. \quad (37)$$

Then, W_{maSurf} which is the independent variables of the hydrostructural functions of the surface layer (h_{ma} and k_{ma}) is calculated according to equation 2 in terms of W_{surf}:

$$W_{maSurf} = w_{st}^{eq} + w_{ip}^{eq} = -\frac{1}{k_M}\ln\left[1 + \exp\left(-k_M\left(W_{surf} - W_M\right)\right)\right] \qquad (38)$$

Note that parameters of the pedostructure functions do not change with the change of bulk density due to tillage, so the parameter W_{sat} in equation 8 of h_{ma} is the water content at saturation of the pedostructure, lower than the water content at saturation of the surface layer $W_{layerSat}$. Therefore, if $W_{maSurf} > W_{maSat}$ of the pedostructure (where $W_{maSat} = W_{sat}$-W_M) then h_{ma} is negative in the surface layer, which cannot currently happen in the layers underneath in the pedon. This excess of water out of the pedostructure acts like a height of water (h_{ma}) on the first layer of the horizon A of the pedon.

4 Summary and conclusions

The SoilWater 2 component of APES is an adaptation of Kamel® and though at the present stage it has been restricted to the use of pedotransfer functions and classic agronomic outputs (see the Table of E/S in Appendices), it has potentially the specific properties of Kamel®.

As a soil-structure water model, Kamel® has the following features:

1. It represents the soil organizational characteristics and variables for each hydrostructural state at any soil depth.
2. It simulates the water flow in this organization (the vadoze zone) in response to external factors such as rain, ETP (inducing water uptake by roots), and structural change of the surface layer.
3. It generates outputs which keep the link between the internal physical state variables (referred to the structural mass of solids and used for describing processes at their local scale) with the classical volumetric averaged variables used in agriculture to generalize at larger scales (units in dm/dm or kg/ha). The model therefore solves the scaling problem among measurements in laboratory, estimation from soil databases, and modeling at the field scale.
4. It allows as a framework to integrate biogeochemical processes that act at the pedostructure level.

Because Kamel® is entirely founded on physical equations describing the soil-water interaction, and on significant and measurable parameters, it can be adapted to all types of soil and situations (simulation of experiments in the laboratory or in the field). In particular, it is able to provide the same macroscopic information (volumetric variables) as that commonly sought after using existing soil-water models and the characteristics inputs of these models, which are often estimated by pedotransfer functions. But, at the same time, it also describes the internal functioning of the corresponding pedon as if it was characterized by the 15 pedostructure parameters. For this, it relies on a program associated to Kamel®, KamelSoil, which transforms common information generally used today to characterize soils (texture, pF4,2, apparent density, ...) into the set of hydrostructural parameters needed for Kamel using pedotransfer functions.

It is important to note that if these parameters have been measured in laboratory, then in theory the model does not need to be calibrated because the 4 basic functions of a soil horizon (shrinkage curve, soil water potential curve, hydraulic conductivity curve and the time dependent swelling curve) would have already been determined.

If only the texture is known, then KamelSoil® estimates the 15 characteristic parameters of the soil with a degree of approximation depending on the pedotransfer functions used. Hence, the result of the simulation will be coherent but approximate; and modeling by Kamel® may require calibration with field data like other soil-water models. Nevertheless, for Kamel®, knowledge of the physical significance of the parameters describing the four characteristic functions of the pedostructure simplifies this calibration step, which no longer requires a long and difficult sensitivity analysis as in the case of other models.

For all these reasons the SoilWater2 component can be used as a standard reference to evaluate other soil-water models and also pedotransfer functions at a given location or agronomical situation.

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Appendices

Example of set of pedostructure parameters

Table 2. Kamel® parameters calculated from the measured data of Davidson et al. (1969) (extracted from Braudeau et al., 2009)

n°	Parameters	horizon1	horizon2	horizon3	horizon4	Units
1	K_{bs}	0.6	0.5	0.5	0.5	dm^3/kg water
2	V_A	0.735	0.855	0.847	0.855	dm^3/kg soil
3	W_N	0.128	0.082	0.072	0.083	kg w./kg soil
4	W_M	0.219	0.250	0.240	0.249	kg w./kg soil
5	W_{Sat}	0.319	0.426	0.417	0.426	kg w./kg soil
6	k_N	410	184	86	71	kg soil/kg w.
7	k_M	-37	-20	-19	-19	kg soil/kg w.
8	E_{ma}	0.4	1.0	1.6	1.7	Joule/kg soil
9	α_M	75.0	68.6	66.7	68.7	kg soil/kg w.
10	σ	0.0001	0.0001	0.0001	0.0001	kg w./kg soil
11	k_{ma°	1.7E-10	8.8E-12	1.0E-11	8.5E-12	dm/s
12	α°	278	238	194	238	kg soil/kg w.
13	E_{mi}	6.8	13.8	21.2	23.7	Joule/kg soil
14	$t_{1\,2}$	30	30	30	30	minutes
15	k_{sat}	9.0E-06	2.6E-04	1.6E-04	2.6E-04	dm/s

Table of WEPP soil T_{ds} parameter for 78 tillage implements (Alberts et al. 1995)

Tillage Implements CODE and description	T_{ds}
ANHYDISK - anhydrous applicator with closing disks	0.25
ANHYDROS - anhydrous applicator	0.15
BEDDER - bedders, lister and hippers	1
CHISCOST - chisel plow with coulters and straight chisel spikes	1
CHISCOSW - chisel plow with coulters and sweeps	1
CHISCOTW - chisel plow with coulters and twisted points or shovels	1
CHISELSW - chisel plow with sweeps	1
CHISSTSP - chisel plow, straight with spike points	1
CHISTPSH - chisel plow, twisted points or shovels	1
COMBDISK - combination tools with disks, shanks and leveling atchmnts	1
COMBSPRG - combination tools with spring teeth and rolling basket	1
CRNTFRR - drill, no-till in flat residues-ripple or bubble coulters	0.5
CULTFW - cultivator, row finger wheels	0.95
CULTMUSW - cultivator, row, multiple sweeps per row	0.85
CULTRD - cultivator, row, rolling disks	0.9
CULTRT - cultivator, row, ridge till	0.9
CULTSW - cultivator, row, single sweep per row	0.85
DI1WA12+ - disk, one-way with 12-16" blades	1
DI1WA18+ - disk, one-way with 18-30" blades	1
DICHSP - disk chisel plow with straight chisel spike pts	1
DICHSW - disk chisel plow with sweeps	1
DICHTW - disk chisel plow with twisted points or shovels	1
DIOFF10 - disk, offset-heavy plow > 10" spacing	1
DIOFF9 - disk, offset-primary cutting > 9" spacing	1
DIOFFFIN - disk, offset, finishing 7-9" spacing	1
DIPLOW - disk plow	1
DISGANG - disk, single gang	1
DITAF19 - disk, tandem-finishing 7-9" spacing	1
DITAHP10 - disk, tandem-heavy plowing > 10" spacing	1
DITALIAH - disk, tandem-light after harvest, before other tillage	1
DITAPR9 - disk, tandem-primary cutting > 9" spacing	1
DRDDO - drill with double disk opener	0.85
DRDF12- drill, deep furrow with 12" spacing	0.9
DRHOE - drill, hoe opener	0.8
DRNTFLSC - drill, no-till in flat residues-smooth coulters	0.4
DRNTFRFC - drill, no-till in flat residues-fluted coulters	0.6
DRNTSRFC - drill, no-till in standing stubble-fluted coulters	0.6

DRNTSRRI - drill, no-till in standing stubble-ripple or bubble coulters	0.5
DRNTSRSC - drill, no-till in standing stubble-smooth coulters	0.4
DRSDFP7+ - drill, semi-deep furrow or press 7-12" spacing	0.9
DRSDO - drill, single disk opener (conventional)	0.85
FCPTDP - field cultivator, primary tillage-duckfoot points	1
FCPTS12+ - field cultivator, primary tillage-sweeps 12-20"	1
FCPTSW6+ - field cultivator, primary tillage-sweeps or shovels 6-12"	1
FCSTACDP - field cultivator, secondary tillage, after duckfoot points	1
FCSTACDS - field cultivator, secondary tillage, sweeps 12-20"	1
FCSTACSH - field cultivator, secondary tillage, swp or shov 6-12"	1
FURROWD - furrow diker	0.7
HAFTT - harrow-flex-tine tooth	1
HAPR - harrow-packer roller	1
HARHCP - harrow-roller harrow (cultipacker)	1
HASP - harrow-spike tooth	1
HASPTCT - harrow-springtooth (coil tine)	1
MANUAPPL - applicator, subsurface manure	0.4
MOPL - plow, moldboard, 8"	0.1
MOPLUF - plow, moldboard with uphill furrow (Pacific NW only)	1
MULCHT - mulch treader	1
PARAPLOW - paratill/paraplow	0.3
PLDDO - planter, double disk openers	0.15
PLNTFC - planter, no-till with fluted coulters	0.15
PLNTRC - planter, no-till with ripple coulters	0.15
PLNTSC - planter, no-till with smooth coulters	0.15
PLRO - planter, runner openers	0.2
PLRT - planter, ridge-till	0.4
PLSDDO - planter, staggered double disk openers	0.15
PLST2C - planter, strip-till with 2 or 3 fluted coulters	0.3
PLSTRC - planter, strip-till with row cleaning devices (8-14" wide)	0.4
RORRP - rodweeder, plain rotary rod	1
RORRSC - rodweeder, rotary rod with semi-chisels or shovels	1
ROTHOE - rotary hoe	1
ROTILPO - rotary tiller-primary operation 6" deep	1
ROTILSO - rotary tiller-secondary operation 3" deep	1
ROTILST - rotary tiller, strip tillage - 12" tilled on 40" rows	0.3
SUBCC - subsoil-chisel, combination chisel	1
SUBCD - subsoiler, combination disk	1
SUBVRIP - subsoiler, V ripper 20" spacing	0.2
UNSMWBL - undercutter, stubble-mulch sweep (20-30"wide) or blade	1
UNSMWBP - undercutter, stubble-mulch sweep or blade plows > 30" wide	1

4.1 Table of E/S for the SoilWater2 component

#region model options	
[ModelOption("SoilWater2 model option", "Soil discretization in layers", "", new string[] { "All Uniform", "15 cm-Uniform" })] [Input("SoilLayerDiscretization", "Modcom.SoilWater2.dll,SoilWater2Wrapper_ModcomVarInfo")] string soilLayerDiscretization = "All Uniform";	
[ModelOption("SoilWater2 model option", "Drainage intensity", "", new string[] { "None", "X-Small", "Small", "Medium", "Large", "X-Large", "XX-Large" })] [Input("DrainageIntensity", "Modcom.SoilWater2.dll,SoilWater2Wrapper_ModcomVarInfo")] string drainageIntensity = "X-Small";	
#region Static inputs	
[Input("TestPrePostConditions", "Modcom.SoilWater2.dll,SoilWater2Wrapper_ModcomVarInfo")]	int TestPrePostConditions = 0;
[Input("HorizonThickness", "Modcom.SoilWater2.dll,SoilWater2Wrapper_ModcomVarInfo")]	IFloatArray HorizonThickness = null;
[Input("NumberOfLayersInit", "Modcom.SoilWater2.dll,SoilWater2Wrapper_ModcomVarInfo")]	int totalNumberOfLayers = DEFAULT_LAYERS_NUMBER;
[Input("LayerThicknessForLayering", "Modcom.SoilWater2.dll,SoilWater2Wrapper_ModcomVarInfo")]	IFloatArray layerThicknessByHor = null;
[Input("ClayHor", "Modcom.SoilWater2.dll,SoilWater2Wrapper_ModcomVarInfo")]	IFloatArray clayHor = null;
[Input("SandHor", "Modcom.SoilWater2.dll,SoilWater2Wrapper_ModcomVarInfo")]	IFloatArray sandHor = null;
[Input("OrganicCarbonHor", "Modcom.SoilWater2.dll,SoilWater2Wrapper_ModcomVarInfo")]	IFloatArray OrganicCarbonHor = null;
[Input("WaterTableDepth", "Modcom.SoilWater2.dll,SoilWater2Wrapper_ModcomVarInfo")]	double waterTableDepth = 0;
[Input("InitialWaterContentHorizon", "Modcom.SoilWater2.dll,SoilWater2Wrapper_ModcomVarInfo")]	IFloatArray InitialWaterContentHorizon = null;
#region Dynamic inputs	
[Input("InfiltrationDaily", "Modcom.SoilWater2.dll,SoilWater 2Wrapper_ModcomVarInfo")]	double InfiltrationDaily = 0;//new FloatArraySimData(new double[TIME_DISCRETIZATICN_HALF_HOURLY]);
[Input("TranspirationPotentialDailyByLayers", "Modcom.SoilWater2.dll,SoilWater2Wrapper_ModcomVarInfo")]	IFloatArray TranspirationPotentialDailyByLayers = null;
[Input("ReferenceEvapoTranspirationDaily", "Modcom.SoilWater2.dll,SoilWater2Wrapper_ModcomVarInfo")]	double ReferenceEvapotTanspirationDaily = 0;
[Input("SoilFractionInterception", "Modcom.SoilWater2.dll,SoilWater2Wrapper_ModcomVarInfo")]	double SoilFractionInterception = 0;

[Input("Albedo", "Modcom.SoilWater2.dll,SoilWater2Wrapper_ModcomVarInfo")]	double Albedo = 0;
#region Output	
[Output("Erosion", "Modcom.SoilWater2.dll,SoilWater2Wrapper_ModcomVarInfo")]	double erosion = 0;
[Output("BypassCoefficient", "Modcom.SoilWater2.dll,SoilWater2Wrapper_ModcomVarInfo")]	IFloatArray byPassCoefficient = new FloatArraySimData(new double[0]);
[Output("NumberOfSoilLayers", "Modcom.SoilWater2.dll,SoilWater2Wrapper_ModcomVarInfo")]	int Output_NumberOfSoilLayers = 0;
[Output("LayerThickness", "Modcom.SoilWater2.dll,SoilWater2Wrapper_ModcomVarInfo")]	IFloatArray Output_LayerThickness = new FloatArraySimData(new double[0]);
[Output("Clay", "Modcom.SoilWater2.dll,SoilWater2Wrapper_ModcomVarInfo")]	IFloatArray Output_Clay = new FloatArraySimData(new double[0]); // clay content for each layer of soil (%)
[Output("Sand", "Modcom.SoilWater2.dll,SoilWater2Wrapper_ModcomVarInfo")]	IFloatArray Output_Sand = new FloatArraySimData(new double[0]); // Sand content for each layer of soil (%)
[Output("Silt", "Modcom.SoilWater2.dll,SoilWater2Wrapper_ModcomVarInfo")]	IFloatArray Output_Silt = new FloatArraySimData(new double[0]); // Silt content for each layer of soil (%)
[Output("BottomDepth", "Modcom.SoilWater2.dll,SoilWater2Wrapper_ModcomVarInfo")]	IFloatArray Output_BottomDepth = new FloatArraySimData(new double[0]); // bottom depth for each layer of soil (m)
[Output("BulkDensity", "Modcom.SoilWater2.dll,SoilWater2Wrapper_ModcomVarInfo")]	IFloatArray Output_BulkDensity = new FloatArraySimData(new double[0]); // Wet bulk density for each layer of soil (t m-3)
[Output("Ksat", "Modcom.SoilWater2.dll,SoilWater2Wrapper_ModcomVarInfo")]	IFloatArray Output_Ksat = new FloatArraySimData(new double[0]); // hydraulic conductivity at saturation for each layer of soil (mm h-1)
[Output("VolumetricFieldCapacity", "Modcom.SoilWater2.dll,SoilWater2Wrapper_ModcomVarInfo")]	IFloatArray Output_VolumetricFieldCapacity = new FloatArraySimData(new double[0]); // Field capacity for each layer of soil (m3 m-3)
[Output("VolumetricWaterContentAtSaturation", "Modcom.SoilWater2.dll,SoilWater2Wrapper_ModcomVarInfo")]	IFloatArray Output_VolumetricWaterContentAtSaturation = new FloatArraySimData(new double[0]); // Soil water content at saturation for each layer of soil (m3 m-3)
[Output("VolumetricWiltingPoint", "Modcom.SoilWater2.dll,SoilWater2Wrapper_ModcomVarInfo")]	IFloatArray Output_VolumetricWiltingPoint = new FloatArraySimData(new double[0]); // Soil wilting point for each layer of soil (m3 m-3)
[Output("OrganicCarbon", "Modcom.SoilWater2.dll,SoilWater2Wrapper_ModcomVarInfo")]	IFloatArray OrganicCarbon = new FloatArraySimData(new double[0]); // organic carbon for each layer of soil (%)
[Output("VanGenuchtenAlpha", "Modcom.SoilWater2.dll,SoilWater2Wrapper_ModcomVarInfo")]	IFloatArray Output_VanGenuchtenAlpha = new FloatArraySimData(new double[0]); // Alpha variable of VanGenuchten hydraulic retention function (cm-1)
[Output("VanGenuchtenN", "Modcom.SoilWater2.dll,SoilWater2Wrapper_ModcomVarInfo")]	IFloatArray Output_VanGenuchtenN = new FloatArraySimData(new double[0]); // N variable of VanGenuchten hydraulic retention function (unitless)
[Output("Runoff", "Modcom.SoilWater2.dll,SoilWater2Wrapper_ModcomVarInfo")]	double Output_Runoff = 0; // daily runOff mm d-1
[Output("Infiltration", "Modcom.SoilWater2.dll,SoilWater2Wrapper_ModcomVarInfo")]	double Output_Infiltration = 0; // daily infiltration mm d-1

[Output("Percolation", "Modcom.SoilWater2.dll,SoilWater2Wrapper_ModcomVarInfo")]	double Output_Percolation = 0; // daily percolation mm d-1
[Output("EvaporationLimited", "Modcom.SoilWater2.dll,SoilWater2Wrapper_ModcomVarInfo")]	double Output_EvaporationLimited = 0; // actual evaporation from the soil mm d-1
[Output("EvaporationPotential", "Modcom.SoilWater2.dll,SoilWater2Wrapper_ModcomVarInfo")]	double Output_EvaporationPotential = 0; // actual evaporation from the soil mm d-1
[Output("RootWaterUptake", "Modcom.SoilWater2.dll,SoilWater2Wrapper_ModcomVarInfo")]	double Output_RootWaterUptake = 0; // actual transpiration from soil mm d-1
[Output("VolumetricWaterContent", "Modcom.SoilWater2.dll,SoilWater2Wrapper_ModcomVarInfo")]	IFloatArray Output_VolumetricWaterContent = new FloatArraySimData(new double[0]); // Soil water content for each layer of soil (m3 m-3)
[Output("WaterPotential", "Modcom.SoilWater2.dll,SoilWater2Wrapper_ModcomVarInfo")]	IFloatArray Output_WaterPotential = new FloatArraySimData(new double[0]); //
[Output("WaterFlux", "Modcom.SoilWater2.dll,SoilWater2Wrapper_ModcomVarInfo")]	IFloatArray Output_WaterFlux = new FloatArraySimData(new double[0]); // daily flux of water from a layer to another just below; it is positive downwards (mm d-1)
[Output("RootWaterUptakeByLayers", "Modcom.SoilWater2.dll,SoilWater2Wrapper_ModcomVarInfo")]	IFloatArray Output_RootWaterUptakeByLayers = new FloatArraySimData(new double[0]); // actual transpiration in each layer mm d-1