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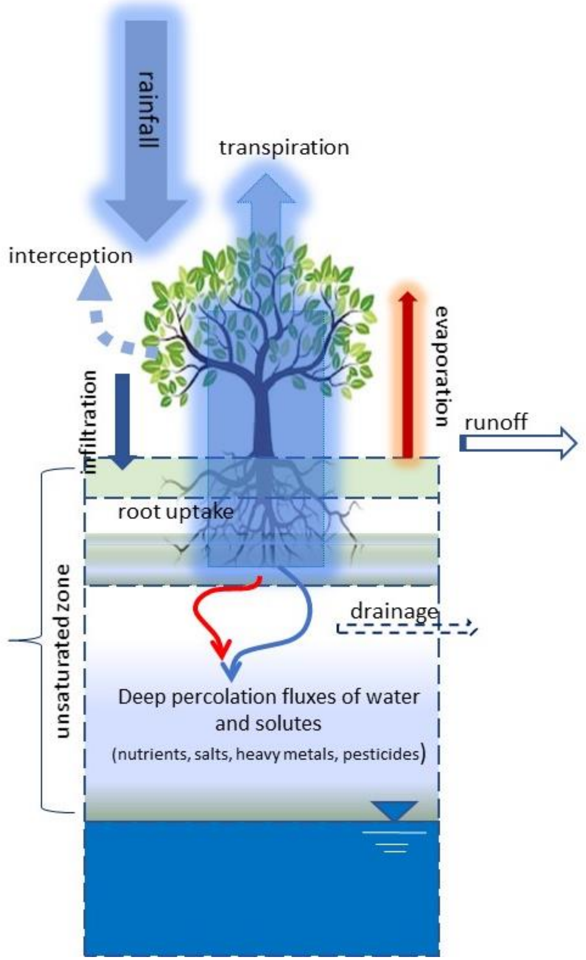
FLOWS Agrohydrological Model

Theoretical basis

The model

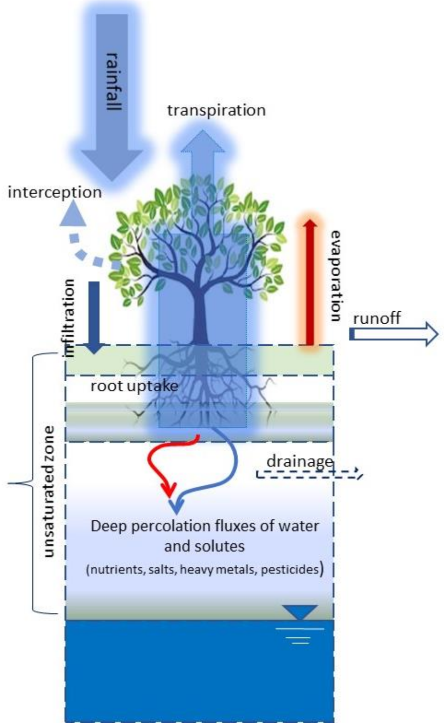
- It is a physically-based model to simulate water flow and solute transport (and transformations) in the soil in the presence of vegetation.

- In the scope of NPP-SOL project: it is the agro-hydrological model to evaluate water and nutrient fluxes under different scenarios.



The model produces, node by node, information on the time evolution of (among many other outputs):

- Soil water contents and pressure potentials in the soil profile;
- Solute (tracers, adsorbed and reactive solutes) concentrations in the soil profile. The model also allows for nitrogen transport simulations by solving the ADE twice, once for N-NH4 and once for N-NO3, with appropriate exchange terms;
- Water and solute uptake and actual evapotranspiration for simulated crops;
- Deep percolation water fluxes
- Deep percolation solute fluxes;
- Root uptake of water and solutes;
- Water and solute fluxes to runoff;
- Drainage water fluxes and related solute fluxes.
- Irrigation fluxes computed by the model;
- Temperature in the soil profile



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Water flow equation

- Richards Equation for 1-D soil water flow:

$$C(h)\frac{\partial h}{\partial t} = \frac{\partial}{\partial z}\left(K(h)\frac{\partial h}{\partial z} - K(h)\right) - S_w$$

where C(h)=dθ/dh [L^{-1}] is the soil water capacity, h [L] is the soil water pressure head, t [T] is time, z [L] is the vertical coordinate being positive upward, *K*(h) [L T^{-1}] the hydraulic conductivity and S_w [T^{-1}] is a sink term describing water uptake by plant roots, S_r, and/or lateral water drainage, S_{dr}, so that $S_w = S_r + S_{dr}$.

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Solute Transport Equation

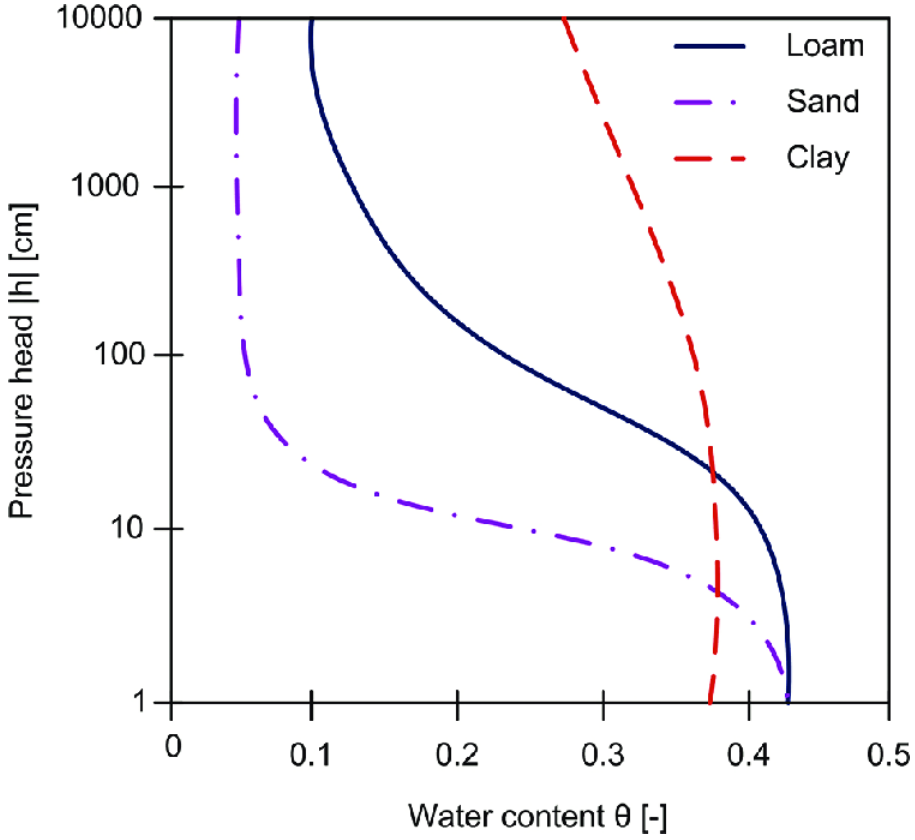
- The 1-D form of the Advection-Dispersion Equation:

$$\frac{\partial \theta C}{\partial t} + \rho_b \frac{\partial C_s}{\partial t} + \frac{\partial \theta_g C_g}{\partial t} = -\frac{\partial qC}{\partial z} + \frac{\partial}{\partial z}\left(\theta D_h \frac{\partial C}{\partial z}\right) + \frac{\partial}{\partial z}\left(\theta_g D_g^s K_H \frac{\partial C}{\partial z}\right) - S_s$$

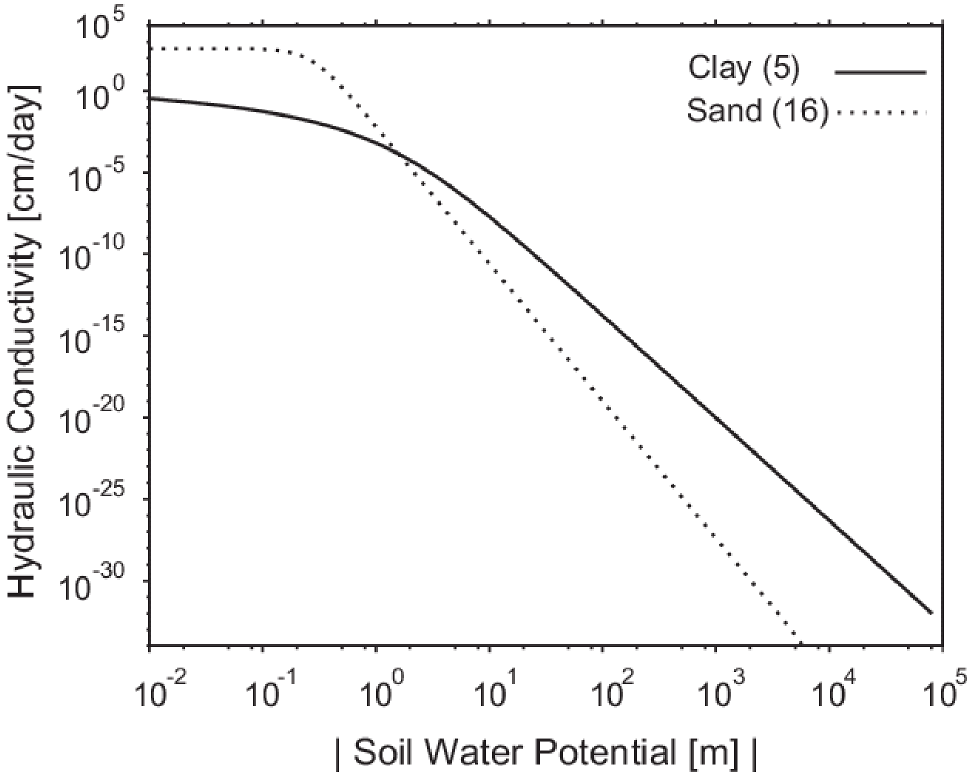
In the equation, C [M L^{-3}], C_s [M M^{-1}] and C_g [M L^{-3}], are the amount of solute in the liquid, adsorbed and gaseous phases, respectively, q [L T^{-1}] is the darcian water flux, ρ_b [M L^{-3}] is the bulk density, D_h [L^2 T^{-1}] the hydrodynamic dispersion coefficient, D_g^s is the dispersion coefficient in the gaseous phases [L^2 T^{-1}], θ_g is the volumetric air content in soil, S_s [ML^{-3}T^{-1}] is a source-sink term for solutes, K_H is the dimensionless Henry constant.

Richards Equation Requirements: Soil Hydraulic Properties (SHP)

- Water Retention Curve, θ(h)



- Hydraulic Conductivity Curve, K(h)



SHP Models Available in FLOWS

FLOWS requires the SHP for each soil horizon. The soil hydraulic parameters that can be used are those of:

- Unimodal van Genuchten – Mualem model;
- Unimodal Gardner & Russo;
- Bimodal Durner – Mualem model; or
- Bimodal Ross & Smettem

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Example: van Genuchten – Mualem

van Genuchten (1981) water retention $S_e = \frac{\theta - \theta_r}{\theta_s - \theta_r} = \left[1 + \left|\alpha_{VG} h\right|^n\right]^{-m}$

Mualem (1976) hydraulic conductivity $K_r(S_e) = \frac{K(S_e)}{K_0} = S_e^{\tau}\left[1 - \left(1 - S_e^{1/m}\right)^m\right]^2$

Root Uptake, root distribution and ET

(macroscopic approach)

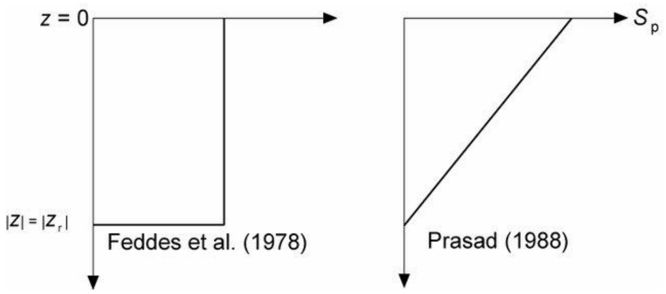
$ETr\ \&\ Kc \rightarrow ETp \rightarrow LAI \rightarrow Ep + Tp$

$$S_{r,p}(z) = g(z)T_p$$

$$T_p = \int_0^{Dr} S_{r,p}(z)\, dz$$

$g(z)$

1. Feddes (uniform)
2. Prasad (triangular)
3. Vrugt
4. Logistic



Water Uptake reduction coming from both water and osmotic

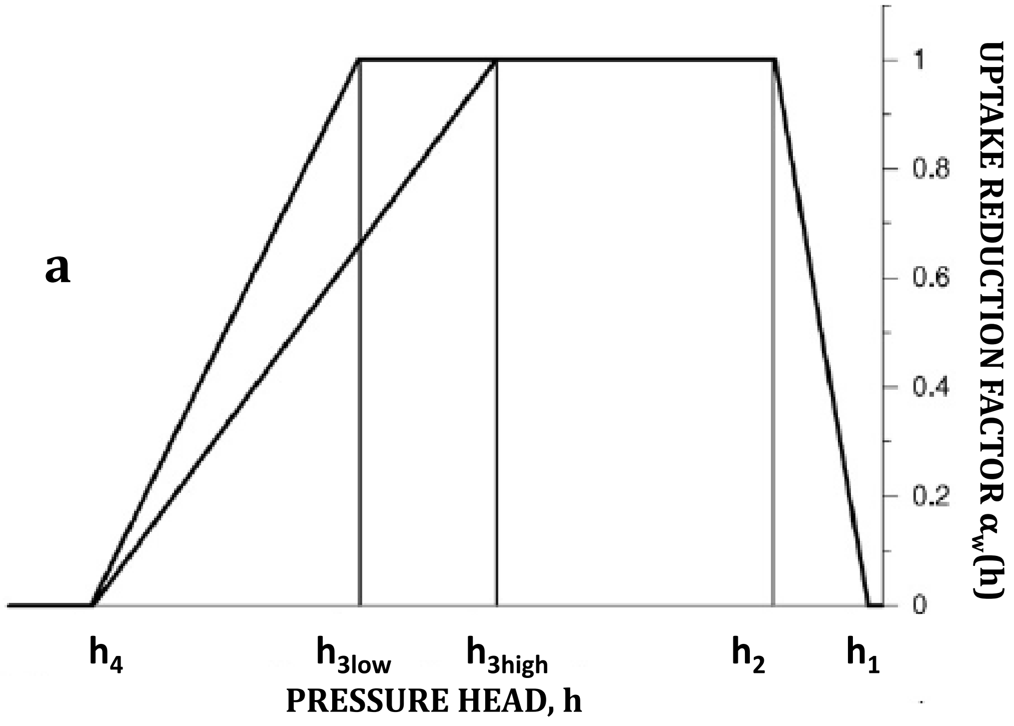
$$S_{r,a} = \alpha_w(h)\alpha_s(h_{os})S_p = \alpha_w(h)\alpha_s(h_{os})g(z)T_p$$

Water stress Uptake reduction function

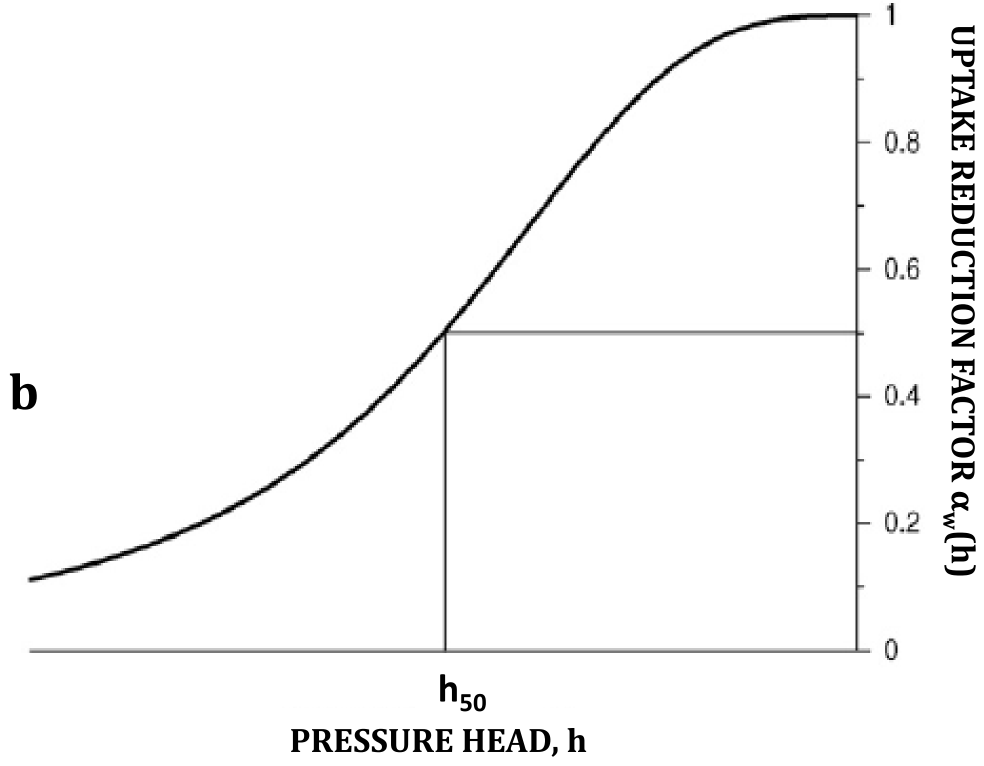
$$\alpha(h) = \begin{cases} \frac{h-h_4}{h_3-h_4}, & h_3 > h > h_4 \\ 1, & h_2 \geq h \geq h_3 \\ \frac{h-h_1}{h_2-h_1}, & h_1 > h > h_2 \\ 0, & h \leq h_4 \; or \; h \geq h_1 \end{cases}$$

$$\alpha(h) = \frac{1}{1+\left(\frac{h}{h_{50}}\right)^{p_1}}$$

Feddes Uptake reduction factor



van Genuchten Uptake reduction factor



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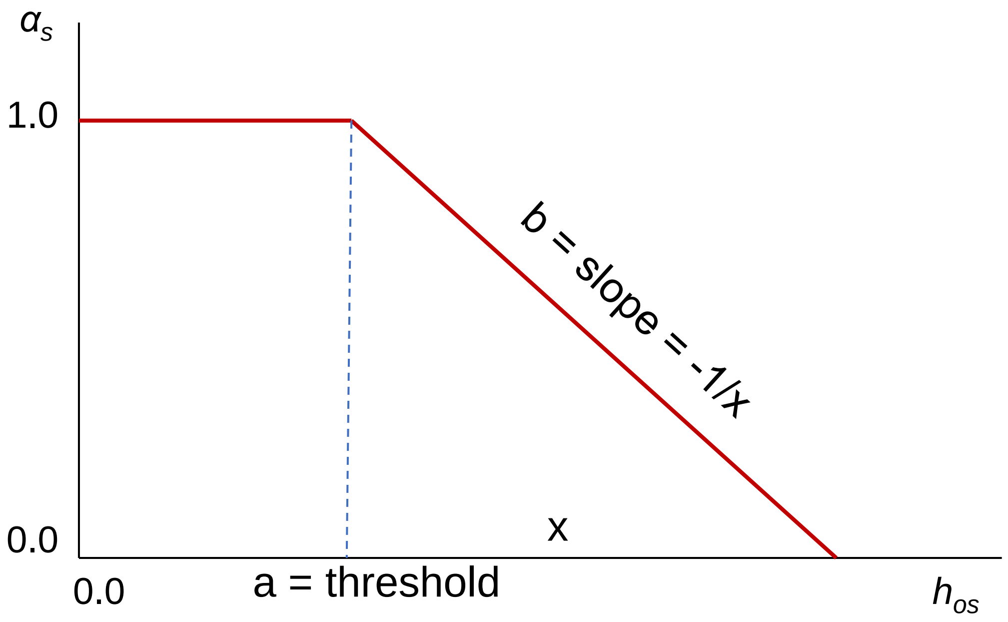
Salinity stress Uptake reduction function

$$\alpha_s(h_{os}) = \begin{cases} 1, & a \le h_{os} \le 0 \\ 1 + b(h_{os} - a), & a > h_{os} > a - \frac{1}{b} \\ 0, & h_{os} \le a - \frac{1}{b} \end{cases}$$



Multiplicative water and osmotic stress Uptake reduction function

$$\alpha(h, h_{os}) = \frac{1}{1 + \left(\frac{h}{h_{50}}\right)^{p_1}} \frac{1}{1 + \left(\frac{h_{os}}{h_{os,50}}\right)^{p_2}}$$

Flow Chart of the Processes Calculations

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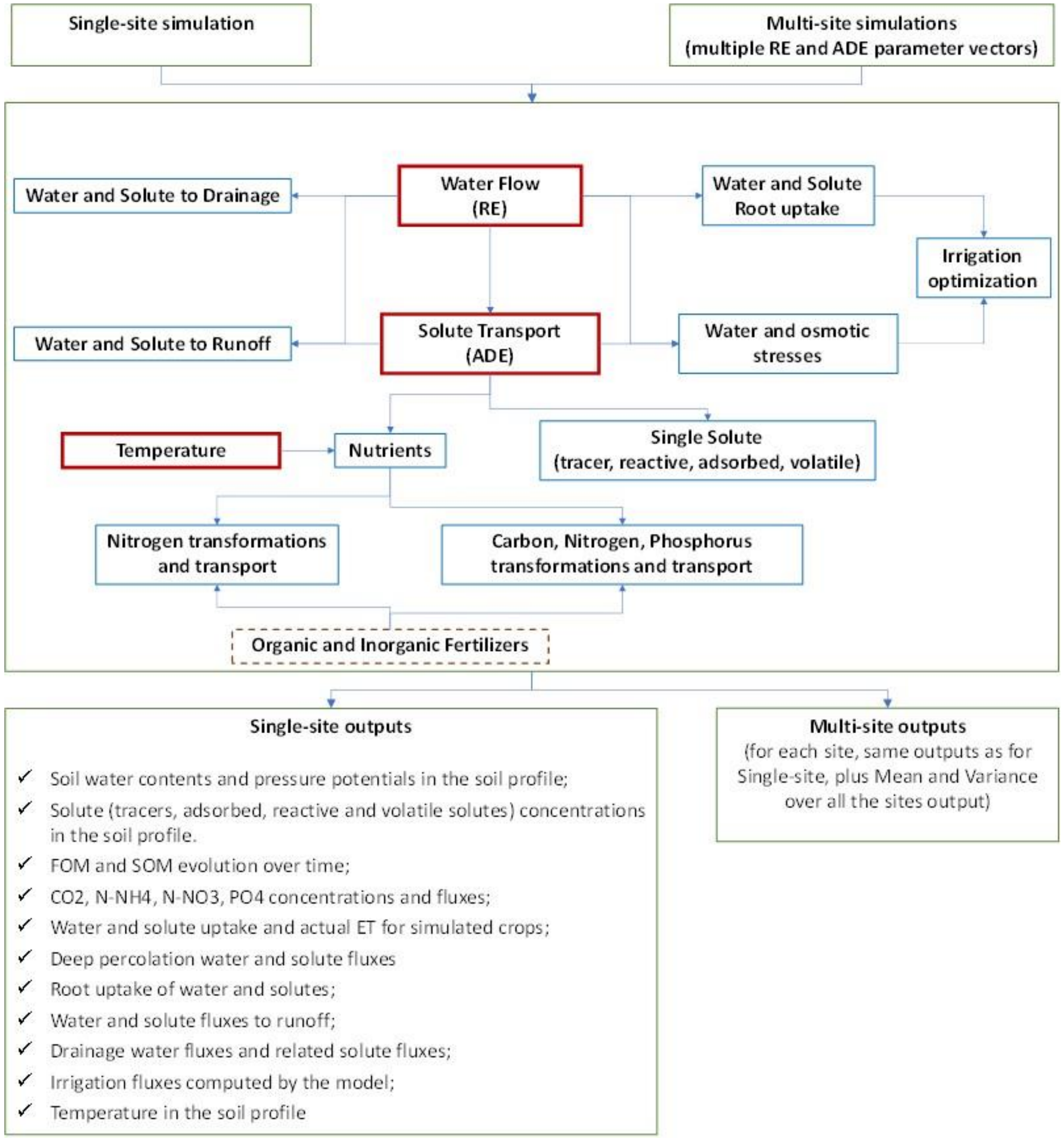


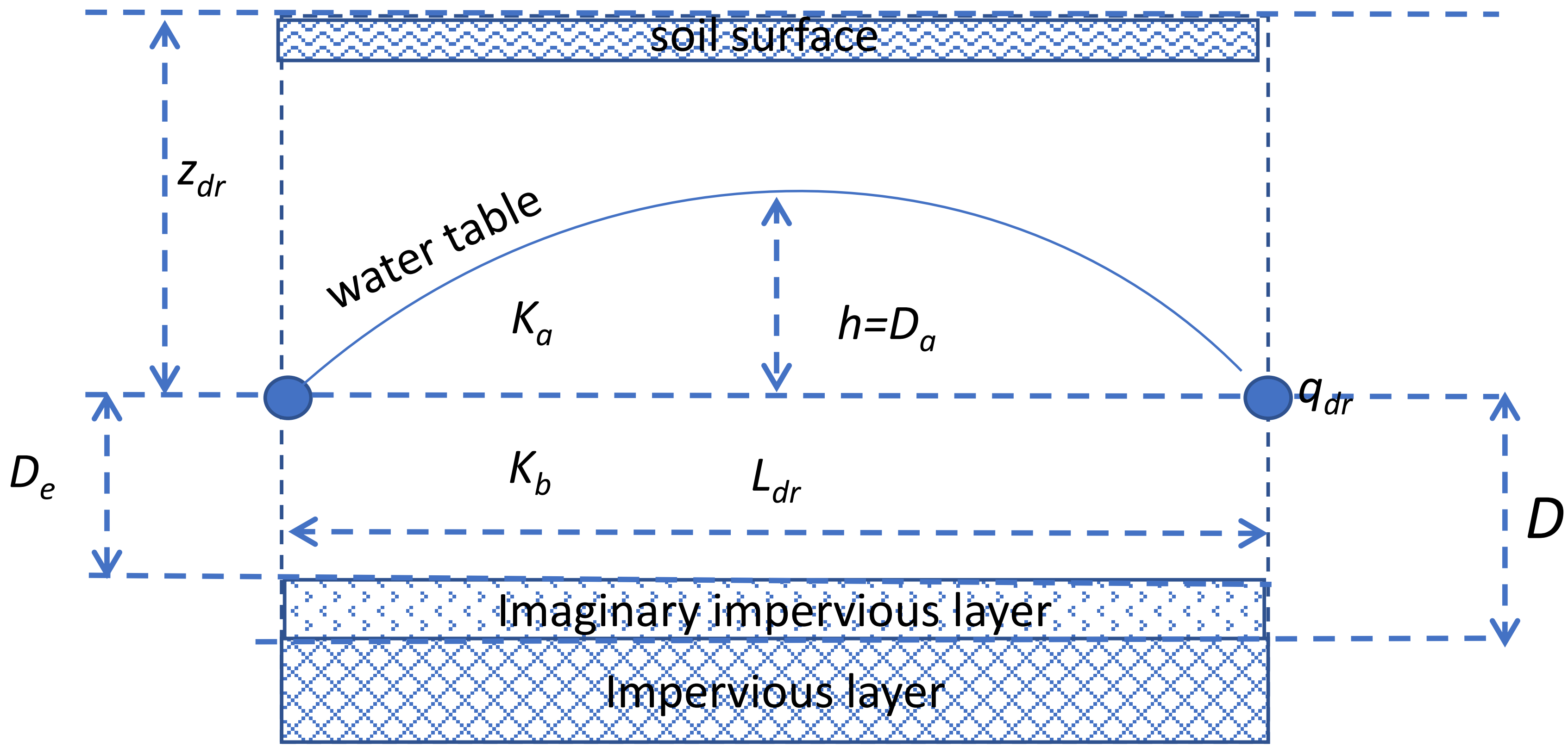
HOOGHOUDT'S DRAINAGE EQUATION

ADJUSTED FOR ENTRANCE RESISTANCE

$$q_{dr} = \frac{8K_b D_{eq} D_a + 4K_a D_a^2}{L_{dr}^2}$$

S_{dr}= fraction of q_{dr} in the i^{th} node

Ss_{dr}= $S_{dr} \cdot C$ = solute flux to the drainage



Irrigation computed by the model - Irrigation criterion

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