Use of tracer infiltration patterns for the parameterization of macropore flow

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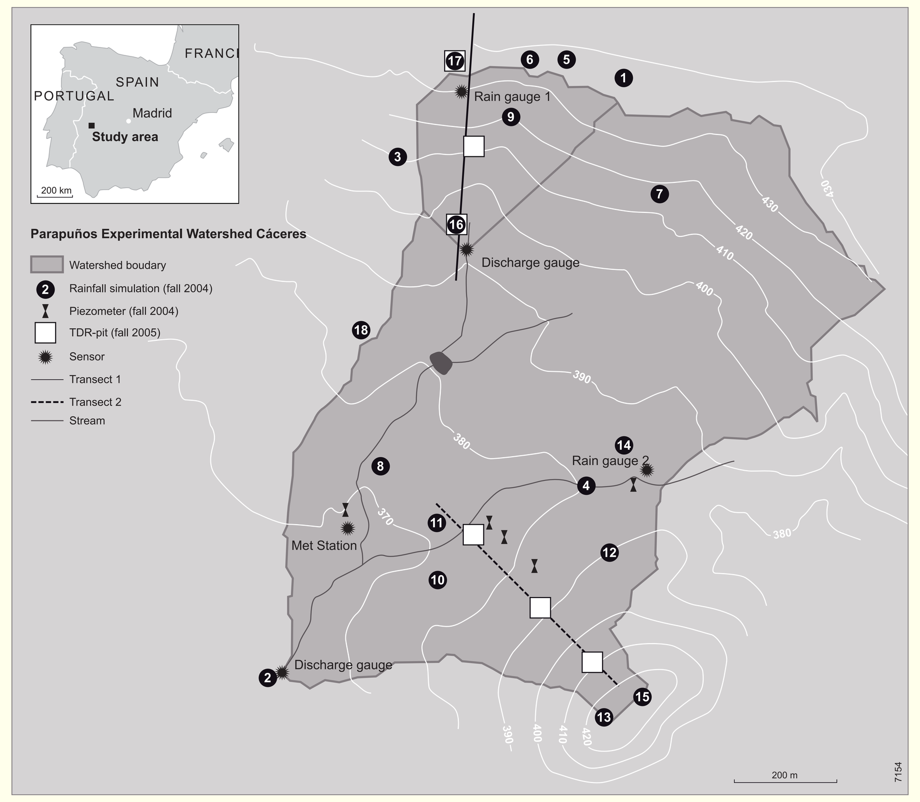
Study area

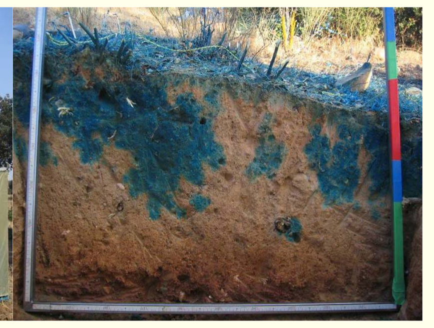
The area chosen for the fieldwork is the Parapuños catchment (approx. 99 ha) in Spain, near the city of Cáceres, Extremadura. The area is part of the Dehesas, a semi-natural landscape, which is typical for a large part of the south western Iberian Peninsula.

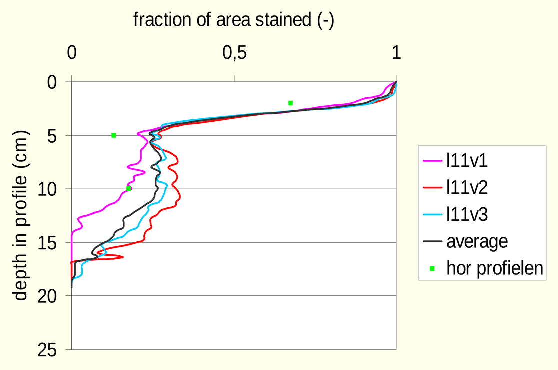


Catchment characteristics:
- agro-silvo-pastoral landuse;
- mediterranean, semi-arid climate;
- poor soils (shallow, acid, low organic matter content).

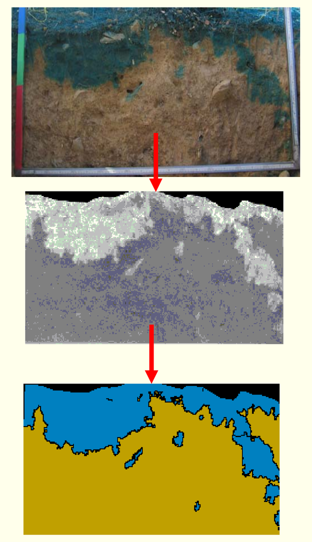
Measurements

In the Parapuños watershed meteorological data (temperature, humidity, net radiance, global radiance, wind speed and –direction), rainfall, catchment discharge and sediment transport are measured every 5 minutes as part of an ongoing measurement campaign. Further measurements for this study existed of dye-tracer infiltration experiments, soil pits with TDR-sensors and piezometer measurements.





Measurements were used in two steps:
1) infiltration patterns are used for the inverse parameterisation of the physically based macropore parameters in SWAP
2) TDR-measurements and yearly water balance are used for evaluation of model performance under natural circumstances

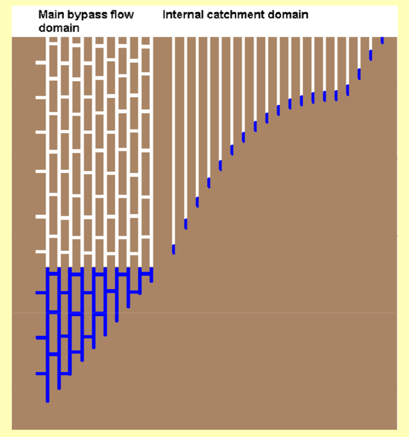


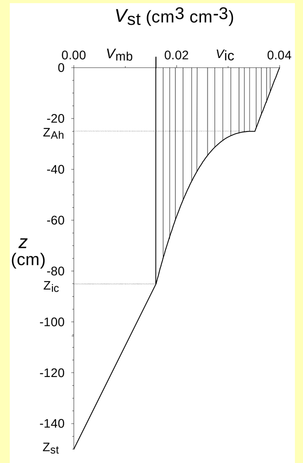
SWAP- model

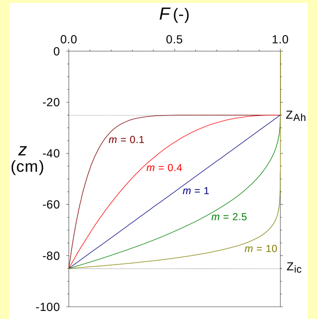
The variably saturated water flow in the soil matrix is based on the Richards equation, including terms for root water uptake and macropore exchange. The soil hydraulic relationships are described according to van Genuchten. The top-boundary conditions are determined by precipitation, irrigation and evapotranspiration.

Macropore concept:

The predominant feature of macropore flow is that precipitation and irrigation water with solutes are routed into macropores at the soil surface, bypassing the reactive unsaturated soil. This water is transported rapidly downwards and distributed over different depths in the soil or the groundwater. The macropore volume is characterised according to two properties:
- continuity: internal catchment macropores versus main bypass macropores;
- persistency: static macropores versus dynamic (cracks).





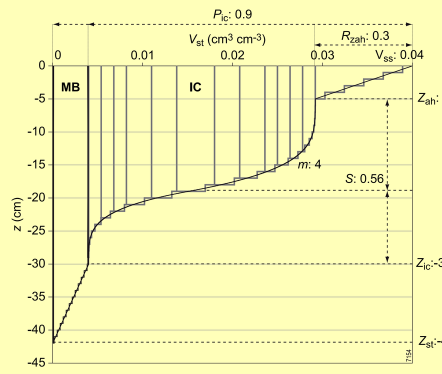


$$F = 1 - S$$

$$S = S_{Z_{Ah}} \cdot \frac{z}{Z_{Ah}}$$

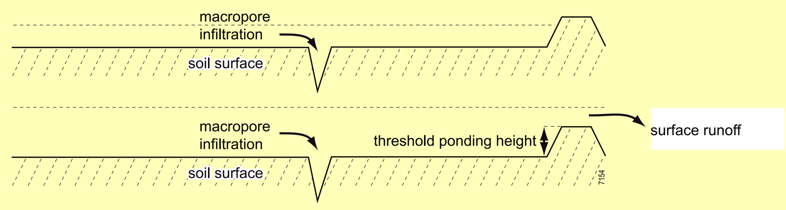
$$S = S_{Z_{Ah}} + \left(1 - S_{Z_{Ah}}\right) \cdot \left(\frac{Z_{Ah} - z}{Z_{Ah} - Z_{ic}}\right)^m$$

The macropore geometry is described using a limited number of physical and shape parameters:
- Z_{ah}: Depth bottom A-horizon
- Z_{st}: Depth bottom Internal Catchment domain
- Z_{st}: Depth bottom Static macropores
- V_{st}: Volume Static Macropores at Soil Surface
- P_{ic}: Proportion of IC domain at Soil Surface
- m: Power m for distribution curve IC domain
- R_{zah}: Fraction macropores ended at bottom A-horizon
- S: Symmetry Point for freq. distr. curve



Rainfall distribution to matrix, macropores and surface runoff:

As long as precipitation intensity is lower than matrix infiltration capacity, the precipitation is distributed over matrix and macropores equal to the ratio of their surface areas. Once matrix infiltration capacity is exceeded the precipitation excess will flow into the macropores and runoff starts. A slight delay in the infiltration to macropores occurs due to a resistance to inflow, which depends on the macropore width. This resistance is very low and usually a threshold ponding height must be exceeded before regular runoff to surface waters starts. Therefore runoff into macropores is favored over regular runoff.

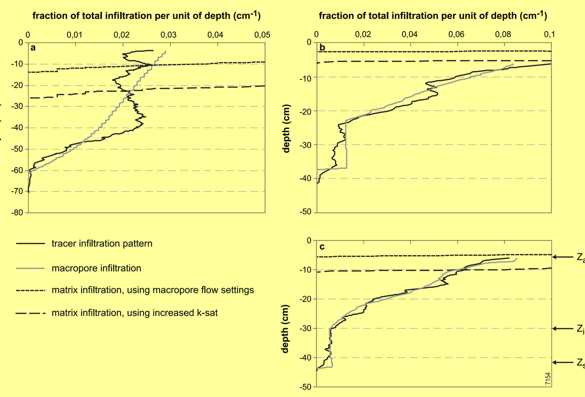


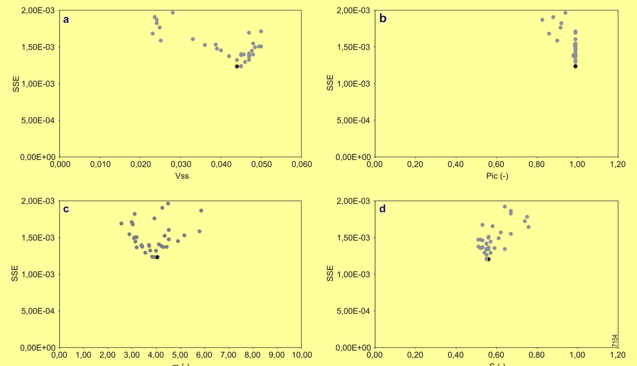
Parameterisation

The macropore parameters were calibrated using the tracer infiltration profiles, by minimizing the difference between the measured and simulated curves of infiltration with depth. The Mualem van Genuchten parameters for the soil matrix characterisation were obtained from Multi Step Outflow experiments. In the case of simulations with macropore flow the fitted saturated conductivity of the MSO experiments was used. For the simulations without macropore flow the much higher measured saturated conductivity was used, this was measured using a ponded water layer on the soil samples.

100 Pest runs show a small area with the best optimizations, with almost similar parameter sets, indicating that a unique set of best parameters can be obtained using the infiltration patterns for the optimisation.

The simulations of separate matrix and macropore flow with model parameters based on soil physical measurements and the infiltration patterns results in a much better prediction of measured distribution of infiltration with depth as compared to simulations without macropore flow

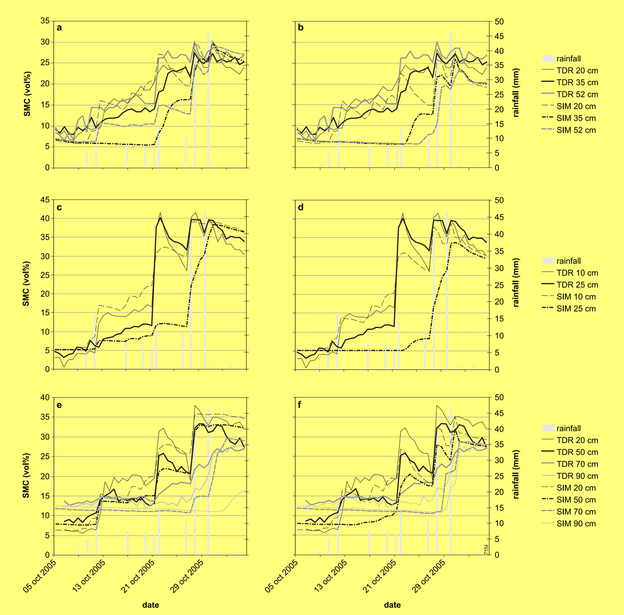




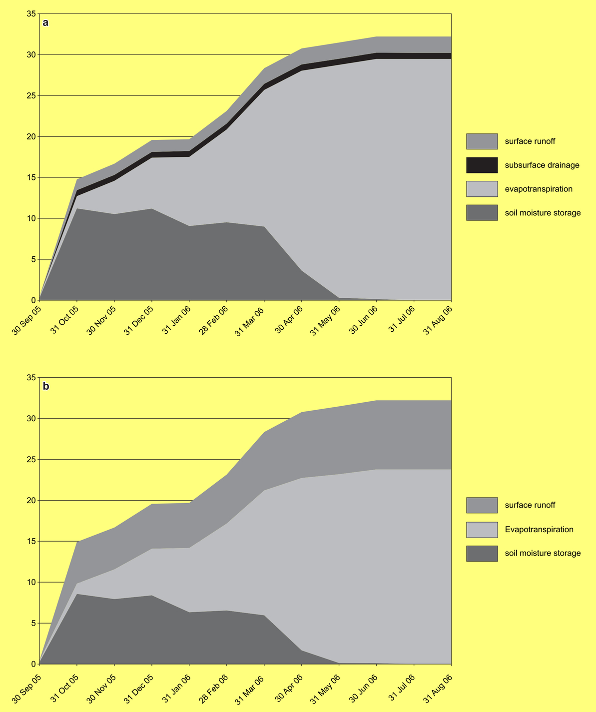
Optimized parameters (with 95% uncertainty bounds)				
Volume of macropores at soil surface, V_{ss} (cm^3/cm^3)	0.04 (±0.004)	0.048 (±0.001)	0.04 (±0.003)	0.01 - 0.0
Fraction of internal catchment at soil surface, P_{ic} (-)	0.90 (±0.03)	0.98 (±0.002)	0.99 (±0.001)	0.01 - 0.9
Power –m, m (-)	10.0 (±0.97)	1.69 (±0.061)	4,01 (±0.21)	0.1 - 10.0
Relative depth of S-parameter, S (-)	1.0 (±0.06)	0.37 (±0.013)	0.56 (±0.023)	0.0 - 1.0

Soil moisture content and water balance simulations under natural circumstances

For both soil moisture content as well as water balance, the simulations with macropores show better results the than simulations without macropores. The soil moisture content simulations of the topsoil yield better results using the macropore model. The sudden jumps in soil moisture content after rainfall are reproduced well with both methods. In simulations without macropores, the high saturated conductivity values which are needed to ensure enough infiltration result in rapid percolation from the topsoil to deeper layers. Therefore in the simulations without macropores the top soils do not easily reach or maintain the high water contents, which according to the measurements do occur in the top soils.



Wetting of the deeper layers is too slow for both the simulations with and without macropores. This indicates that there is more preferential flow to the deeper layers than is calculated using the parameterization based on the dye-tracer infiltration profiles. Runoff amounts are well simulated with macropores, but strongly overestimated in the simulations without macropores, even though these simulations were performed with the very high, measured k-sat values.



Conclusions

- macropore parameterisation based on infiltration profiles works well
- fitted parameters underestimate rapid infiltration to deeper layers
- runoff and drainage is better simulated using the macropore concept

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