Runoff simulations using a physically based hydrological model for a semi-arid catchment in the Spanish Dehesas

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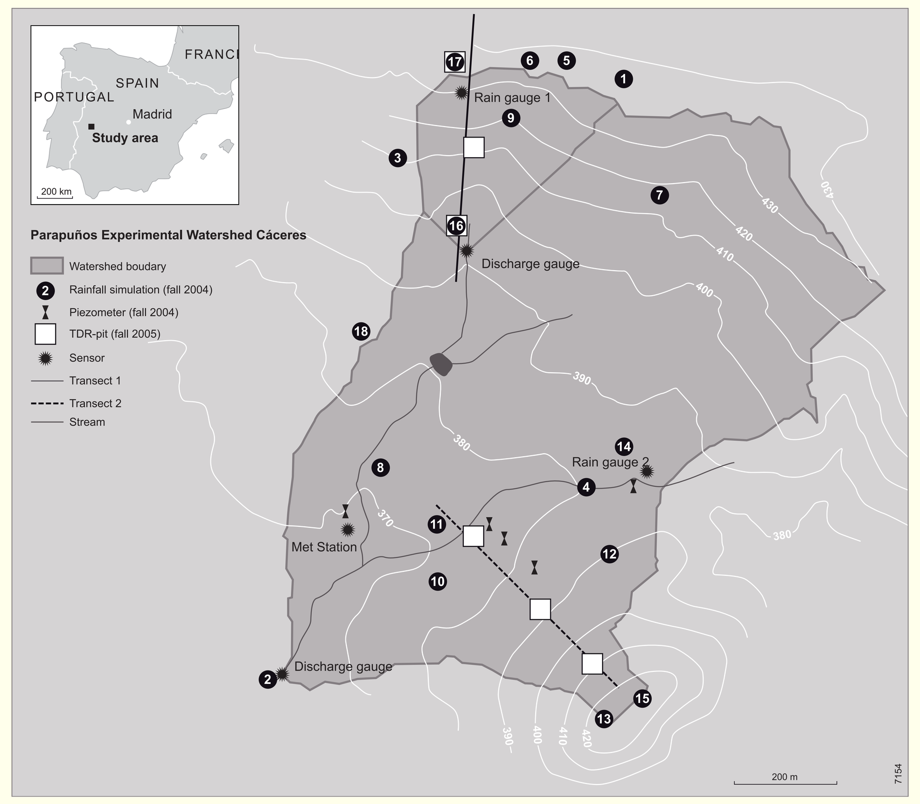
Study area

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.

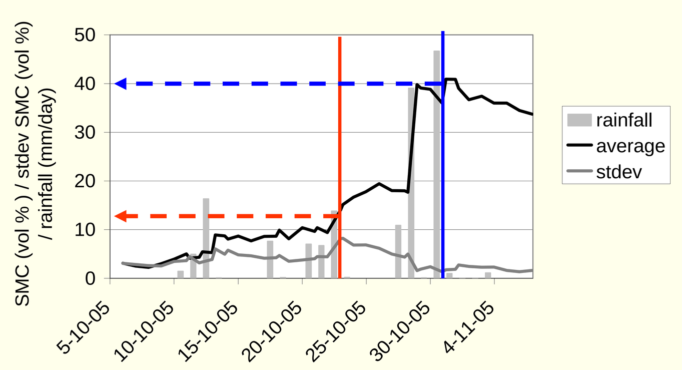


Catchment characteristics:
- agro-silvo-pastoral landuse;
- mediterranean, semi-arid climate;
- poor soils (shallow, acid, low organic matter content).

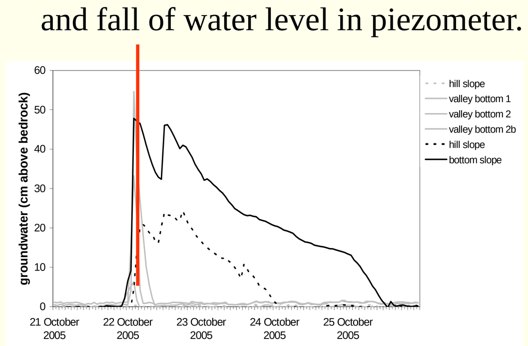
Measurements

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 experimenents, soil pits with TDR-sensors and piezometer measurements.

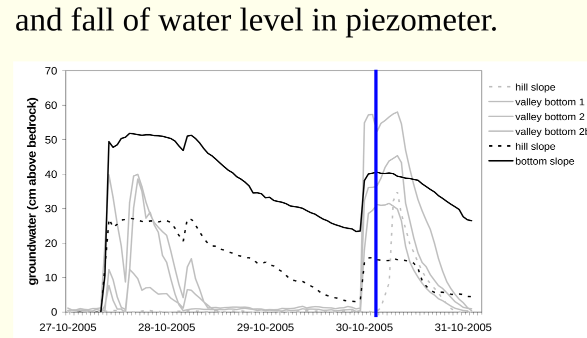
Soil moisture content, average value of 5 TDR's in a horizontal layer at 20 cm depth



Dry catchment conditions, rapid rise and fall of water level in piezometer.



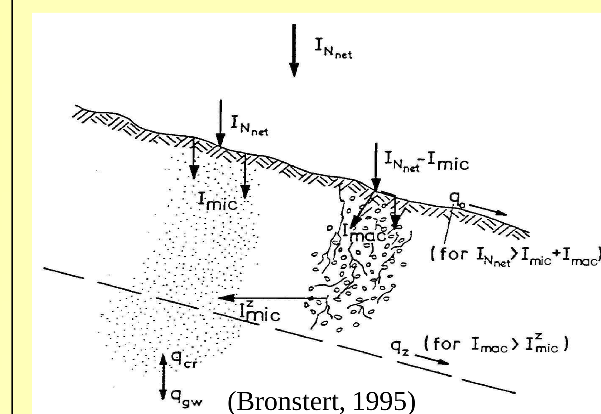
Wet catchment conditions, rapid rise and fall of water level in piezometer.



The analysis of soil moisture contents, piezometer water levels and discharge pointed out that a significant part of catchment scale discharge may be produced by subsurface macropore flow, instead of surface runoff. A large connected macropore network is thought to exist, which can transport water laterally regardless of the soil moisture content of the matrix. Under dry conditions the macropores loose a lot of water to the matrix, but can also transport water as subsurface stormflow. Under near saturated conditions there is little infiltration to the matrix and most of the water will become subsurface stormflow.

Hillflow 3D model

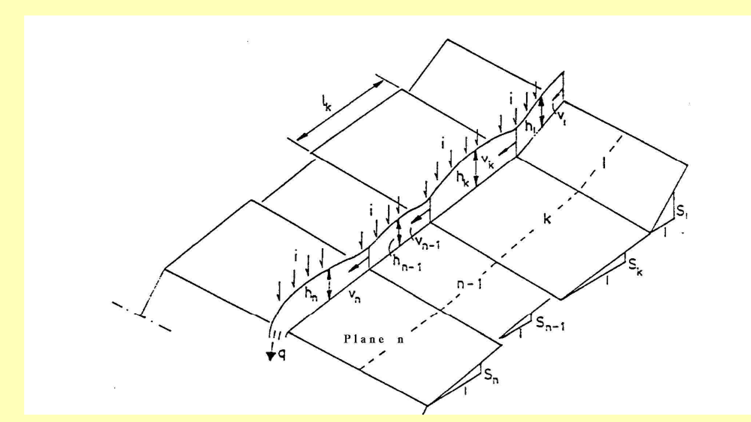
Hillflow 3D (Bronstert, 1995) treats matrix and macropore domains as separate volumes, which can rapidly transport water laterally regardless of the matrix moisture content. The interaction between the macropores and the matrix is dependent on matrix moisture content.



(Bronstert, 1995)

Infiltration to macropores starts once matrix infiltration capacity is exceeded. As soon as the macropores are also filled up, surface runoff starts.

The infiltration from macropores to matrix in Hillflow 3D was adapted slightly in order to be applicable in the extremely dry circumstances of the semi-arid catchment. As under the extremely dry situations the infiltration calculated using the Darcy equation is limited by the low unsaturated conductivities, sorptivity was included in the model. Under dry circumstances the sorptivity was used to calculate infiltration in stead of the Darcian flux.



Surface runoff and subsurface stormflow are both calculated using a simplified form of the St. Venant equations:

Simplified momentum calculation: $S_f + \frac{\partial h}{\partial x} = S_0$

Surface runoff: $v_0 = \sqrt{S_0} k_{st} h_0^{5/3}$

Macropore flow: $v_z = S_0 k_z$

The model input for the simulations:

- distributed maps of soil and vegetation
- six soil layers were used and for the shallow soil catchment areas the deeper layers were made impermeable
- precipitation and evapotranspiration data for october 2005
- surface runoff strickler coefficient: 4.0 $m^{1/3}/s$
- volume percent of macropores 0.1 vol % (very low, but necessary due to model limitations => no surface runoff occurs until the preferential flow volume is full)
- subsurface stormflow coefficient: 1.5 m/s

Bronstert, A., 1995. User manual for the HILLFLOW-3D Catchment Modelling System. Potsdam Institute for Climate Impact Research. Potsdam, Germany.

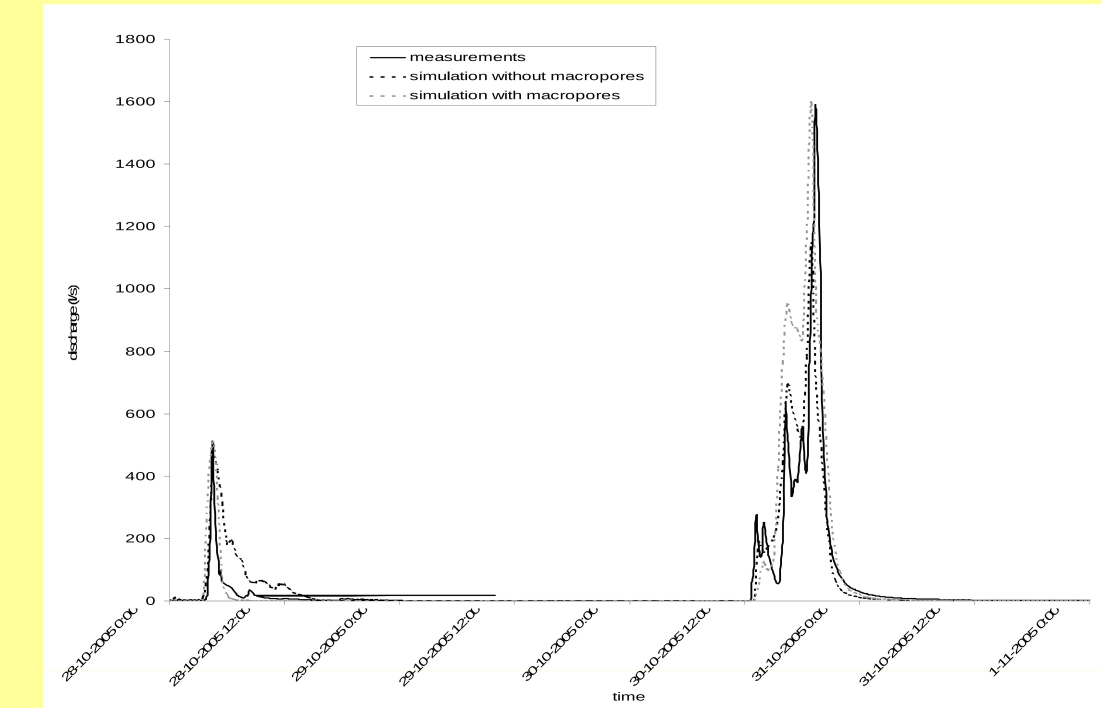
Parameterisation with and without macropore flow

For the model simulations the Mualem van Genuchten parameters were derived from Multi Step Outflow (MSO) experiments. The fitted saturated conductivity of the MSO experiments was used for the matrix in the simulations with macropores, while the simulations without were done with measured saturated conductivities (ponded water layer). Simulations with and without including macropores in the modelling show slightly different runoff patterns, both perform reasonably well, but deviate from the measured discharge in different ways.

The Hillflow3D model concept does fit the concept of the hydrological behaviour in the research catchment. There are however some limitation to what is possible in Hillflow3D:

-the macropores have to be completely filled before surface runoff starts. In reality surface runoff starts well before the macropores are filled and both infiltration to macropores as well of surface runoff will increase simulataneously. Once the macropore infiltration capacity is reached the increase in surface runoff will become very large;

-the soil depth and the interflow depth are both homogeneous for the whole catchment and though the macropore volume can be varied spatially, the distribution in depth is homogeneous.



Influence of high intensity rainfall events on runoff production, modelled with and without macropore flow

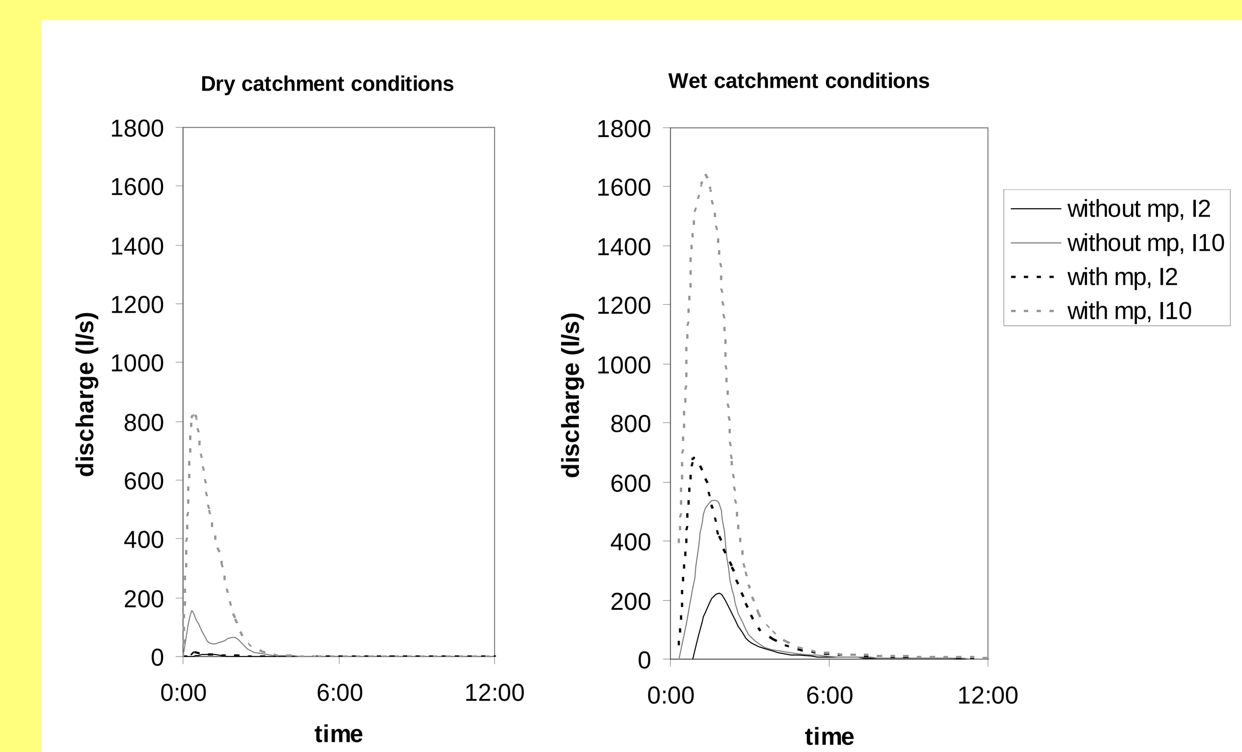
Comparing the produced runoff for 30 minute maximum intensity rainfall events, with a return period of 2, 10 and 50 years respectively, we see that the produced total runoff and the peak flow are much larger for the simulations with macropore flow. This is consistent with what might be expected as the soil matrix conductivity is very low, but the macropores allow for a high total infiltration into the soil. The macropores can produce subsurface stormflow, but this is slower than the surface runoff. Once the macropore network fills up completely, the infiltration capacity will decrease rapidly and surface runoff will increase.

Runoff simulations with macropores

30 min event	Xn 2	Xn 10	Xn 50
total rainfall(mm)	13,3	20,9	27,8
total discharge (mm)	0,07	1,47	12,20
peak discharge (l/s)	16	821	2400
RO coeff (%)	0,5	7,0	43,9
total discharge (mm)	5,07	11,79	17,75
peak discharge (l/s)	674	1642	2898
RO coeff (%)	38,1	56,4	63,8

Runoff simulations without macropores

30 min event	Xn 2	Xn 10	Xn 50
total rainfall(mm)	13,3	20,9	27,8
total discharge (mm)	0,03	0,88	4,82
peak discharge (l/s)	7	151	1087
RO coeff (%)	0,2	4,2	17,3
total discharge (mm)	1,4	3,34	6,1
peak discharge (l/s)	223	528	1121
RO coeff (%)	10,5	16,0	21,9



Conclusions

- Present day rainfall-discharge production is simulated well using the Hillflow 3D model, which fits the concept of the hydrological behaviour in the research catchment.
- Preferential flow is usually not included in catchment scale modelling and present day simulations may be calibrated to fit the catchment hydrographs, using very high matrix conductivities. However including macropore flow in hydrological models has a large impact on the predictions of discharge production for high intensity rainfall events (both peak flow as well as total discharge).

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