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Defining HYSS Based Response Units (HYSSBRU) for hydrological modelling in a semi-arid environment

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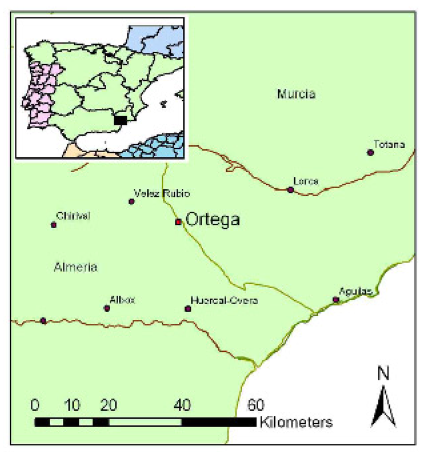
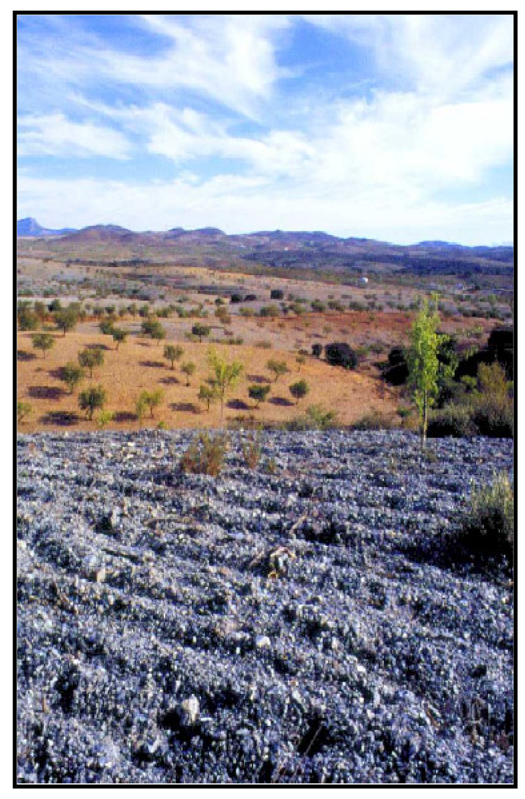
Overview

The aim of this work is to identify hydrological response units based on hydrologically similar surfaces (HYSS) for the Ortega catchment, a 2 km^2 sub-catchment of the Rambla de Nogalte, SE Spain. These units are then used in a hydrological model to investigate the generation of overland flow and the connectivity of runoff pathways at the sub-catchment scale. HYSS are areas with a similar hydrological response defined by their distribution of storage and infiltration values. These are associated with land use, surface characteristics, lithology and soil properties. HYSS are defined by vertical exchanges and are independent of topography. For the Ortega catchment two predominant HYSS were identified: tree crops (almond and olive) with frequently ploughed soils and semi-natural scrubland (matorral). A series of infiltration experiments were conducted using rainfall simulation and minidisk infiltrometry techniques. This information was then used to derive the infiltration distribution within each HYSS.

A HYSS describes the runoff generation characteristics at a point while a HYSS Based Response Unit (HYSSBRU) describes the response over a spatial unit. The effect of this change in scale is that the HYSSBRU integrates the local (HYSS) response over the topography of the response unit. These modelling units therefore reflect the complexity of nature both in terms of the hydrological characteristics of the surface and the topography. HYSSBRU were defined for the Ortega catchment using detailed maps of land use and a high resolution DEM.

Study Catchment





The Ortega catchment is a sub-catchment of the Rambla de Nogalte, Spain (37° 35' N, 01° 56' W). The geology is dominated by red mica shists and local outcrops of blue mica shists. The main land covers are almond and olive cropping and scrub. The scrub is composed of anthyllis, grasses, rosemary and thyme.

Infiltration Experiments

The selection of sites in the field was based upon a stratified random scheme using land use, geology and slope as the defining criteria. At the scrub sites, both vegetated and bare plots were investigated. The geology was divided into two main categories, red and blue shists. Both sloping and flat sites were investigated.

Two experimental techniques were used: rainfall simulation and minidisk infiltrometry. The rainfall simulation has the advantage of more closely replicated natural conditions but requires the installation of a plot to capture the generated runoff. This plot breaks up the soil surface and hence can cause infiltration rates to be higher. The minidisk infiltration experiments do not require the surface to be broken but only sample a small surface area (3.1 cm^2) and do not take into account the affects of macropores.

The rainfall simulator design is based on Cerda *et al.* (1997) with a single nozzle mounted 1.7 m above the plot. Each rainfall simulation experiment was run for 25 minutes at an intensity of ~73 mm hr^{-1}. Two experiments were undertaken at each plot, one with dry initial conditions and one after one hour of the first experiment with wet initial conditions. The runoff generated was recorded every minute during the storm and for five minutes after the cessation of rainfall.

At each site, a series of minidisk infiltrometry experiments were conducted. The rate of infiltration over five minutes was recorded and the infiltration rate was calculated.

Analysis of Experimental Data

In order to assess the differences in the runoff generation characteristics on different surfaces, statistical analysis of the results was undertaken. Factors from both the rainfall simulation and the minidisk infiltration experiments were considered. The rainfall simulation factors considered were the mean and peak runoff coefficients, the depth of precipitation needed to generate runoff and the slopes of the rising and falling limbs of the hydrograph. The affects of the geology, land use and the initial conditions were investigated.

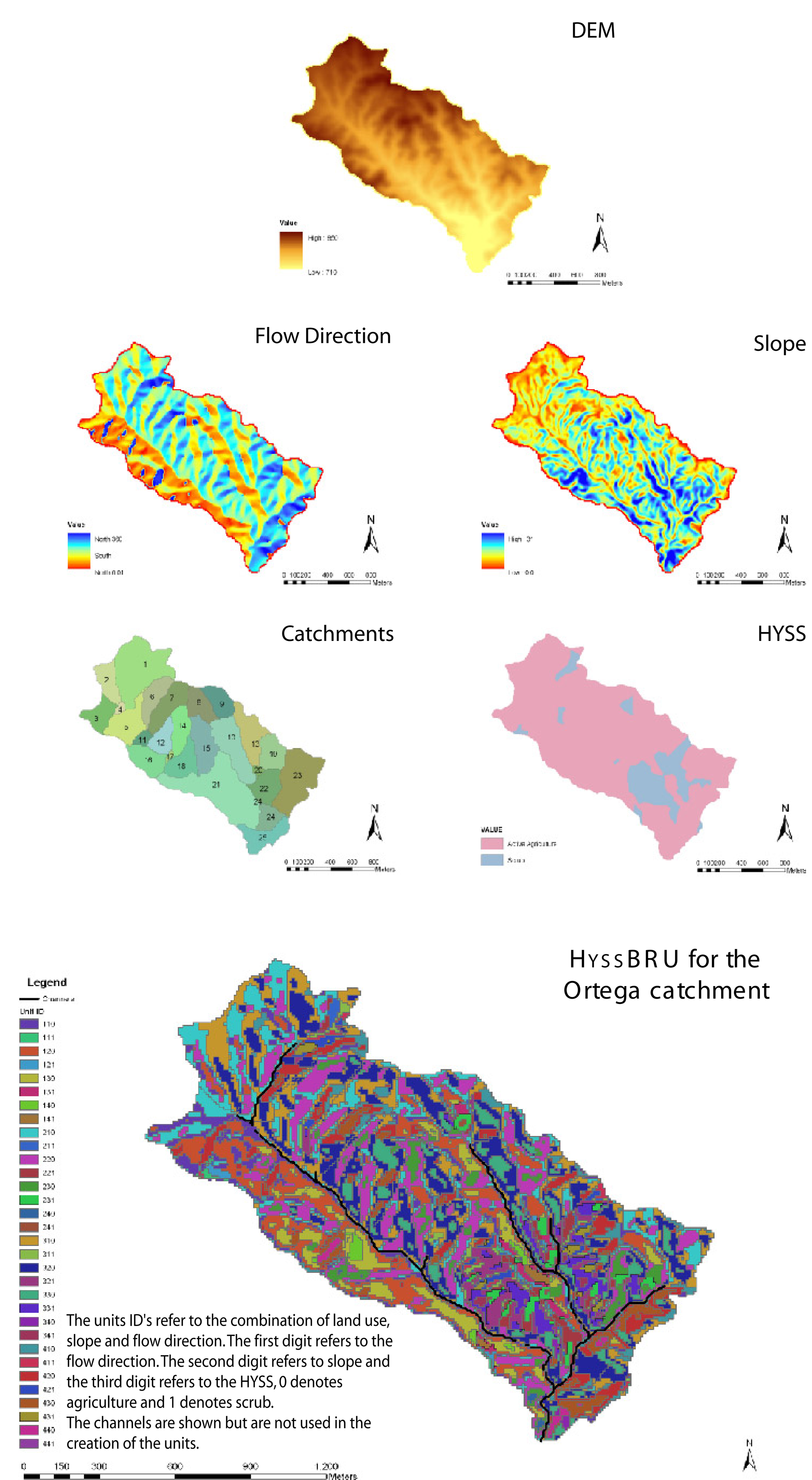
The runoff coefficient data are non-normally distributed and hence the non-parametric Mann-Whitney U test was used. The results are shown in the tables and the significant results are highlighted.

		Runoff Coefficient	Peak Runoff coefficient	Precipitation needed to generate runoff	Slope of hydrograph rising limb	Slope of hydrograph receding limb
Land Use	U value	12	18.5	25	23	4
	Significance	0.001	0.001	0.335	0.013	0.5
Geology	U value	47	47	30	42	8
	Significance	0.418	0.228	0.479	0.251	0.905
Initial Conditions	U value	54	58.5	22	51	8
	Significance	0.699	0.898	0.122	0.562	0.562

		Minidisk infiltration rate
Land Use	U value	293.5
	Significance	6.5109e-005
Geology	U value	679
	Significance	0.881

It is clear that the only factor, which gives significant differences in the form of the runoff hydrograph is land use. This is true for both the rainfall simulation and minidisk experiments. Therefore, land use is used as the basis for defining HYSS.

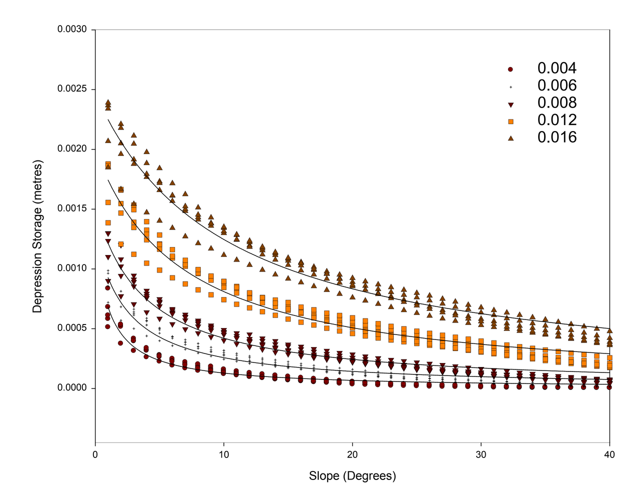
HYSSBRU Data Layers



Scrub Slope Results

The overall trend is for a decrease in depression storage with an increase in slope. As the roughness increases, the amount of depression storage also increases. Hyperbolic decay curves have been fitted to the data series using the equation:

$$dp = \frac{ab}{b\beta}$$



Where *a* and *b* are coefficients and beta is the slope of the surface in degrees.

The a and b coefficients can be determined from:

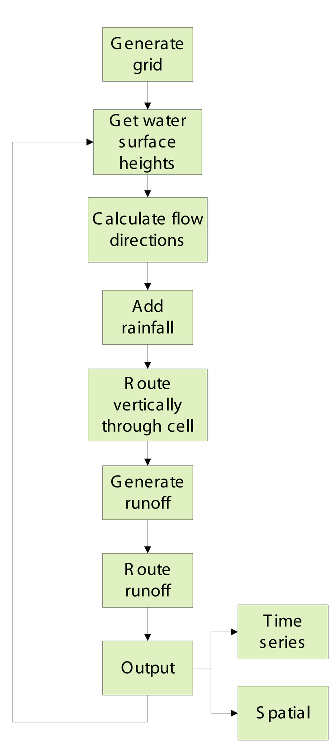
a = 0.1039a + 0.0008 (R^2 = 0.975)
b = - 757.24a - 2.0932 (R^2 = 0.998)

This equation may be used for the calculation of depression storage for any given combination of slope and roughness.

Modelling

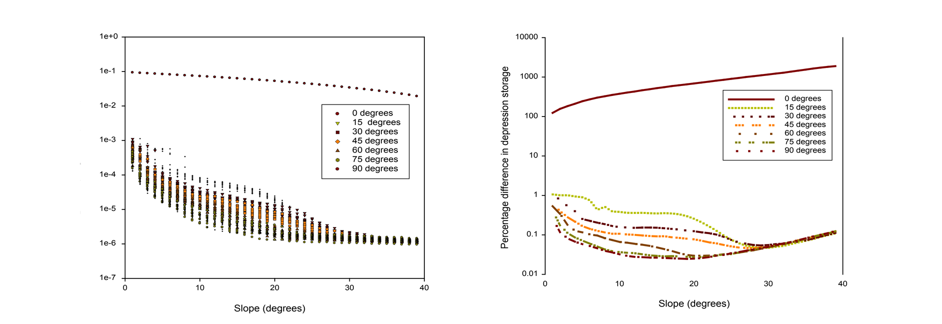
The amount of water which can be stored in the depression store is strongly related to slope (Onstad 1984). To investigate the nature of this relationship, a distributed hydrological model was developed. The model using a multiple flow direction routing algorithm, FD8 (Quinn *et al.* 1993), to model the movement of water over a stochastically generated surface. Rainfall is applied at a constant rate until the depression store is full. The main model loop is shown in the figure.

Both scrub and ploughed fields were investigated. The surface roughness on scrub fields was generated using independent random heights drawn from an exponential distribution and a separate slope component. The furrows in the ploughed field sites were simulated using a sine wave parameterised from field measurements and a seperate roughness component.



Main model routine

Ploughed Field Results

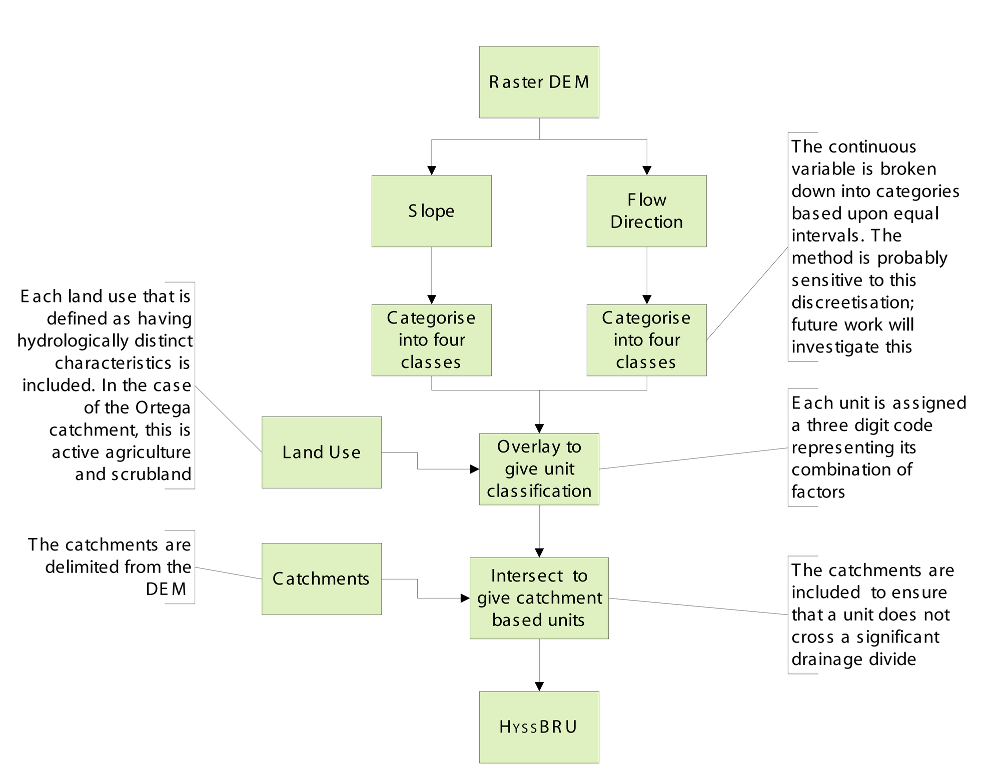


At low slope angles the roughness component is dominant in controlling the depth of depression storage, as shown by the large amount of scatter. As the slope increases, this effect decreases. The greater the angle between the furrow and the contours, the steeper the decrease in depression storage with slope.

The very low levels of depression storage are related to the decrease in storage area from the furrows and to the concentration of flow in the furrow bottoms. This concentration enables the flow to overcome the micro-roughness and connect with the plot outflow. The greater organisation in the surface leads to greater connectivity of overland flow.

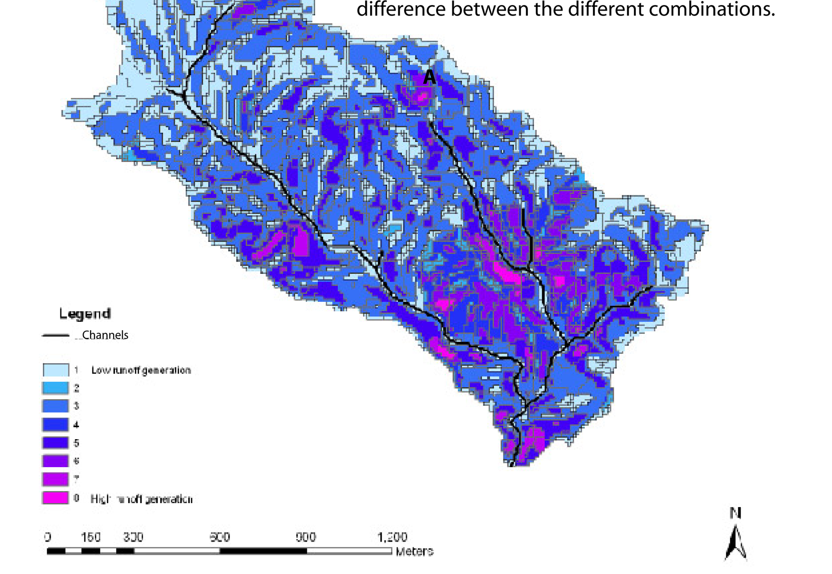
The amount of depression storage is less on a ploughed field then on an equivalent mattoral surface. This set of curves enables the depression storage of a ploughed field to be related to the depression storage of an equivalent mattoral surface.

Process of Defining HYSSBRU



Relative Runoff Generation

The different combinations of factors that make up the individual units have been classified in order according to the amount of runoff generation. It is assumed that steep scrub units will produce the most amount of water, that flat ploughed fields will produce the least and that a low slope scrub unit will produce more runoff than a steep ploughed field. Future work will look at the amount of difference between the different combinations.



Conclusions

The process of defining HYSS based response units (HYSSBRU) is a valuable tool for understanding the spatial pattern of runoff generation. From the application of the method to the semi-arid Ortega catchment it can be seen that only a small fraction of the catchment produces significant amounts of runoff. Many of these areas are located away from the main channels, such as the zone at point A. Since runoff producing storm events have short duration, the travel distance of overland flow is also short. Therefore, much of the generated runoff may not reach the main channel network. The mosaic pattern of units is important since if a high runoff generating unit is located above a low runoff generating unit, the lower unit may act as a runoff sink, thus removing the connection to the channel. Future work will consider these issues both at the hillslope and small catchment scale.

From the modelling of the depression storage on scrub slopes and ploughed fields, consistent relationships have been found. The amount of depression storage is inversely related to slope and positively related to roughness. A family of hyperbolic decay curves can be used to predict this key relationship. This enables the prediction of this key runoff generating parameter. Ploughed fields are also very sensitive to the relationship between the plough line direction and the contours. If the plough lines are slightly off the contour, flow concentration occurs resulting in far greater discharge from the base of the slope. These relationships can be used to modify the HYSS response based upon the characteristics of the HYSSBRU.

Cerda A., Ibanez S. and Calva A. 1997: Design and operation of a small and portable rainfall simulator for rugged terrain; *Soil Technology* vol. 11 pp 163 - 170.
Onstad C. 1984: Depressional storage on tilled soil surfaces; *Transactions of the ASAE*; paper number 83 – 2050
Quinn, P., K. Beven, P. Chevallier, and O. Planchon 1991: The prediction of hillslope flow paths for distributed hydrolgical modelling using digital terrain models; *Hydrological Processes*, vol. 5, pp 59 - 79

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