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Impacts of various scenarios of agricultural management on the hydrological behaviour of a farmed catchment during flood events

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Abstract Field limits, tillage practices and ditch networks constitute man-made hydrological discontinuities in farmed catchments, and are expected to influence hydrological response during flood events. The spatially distributed hydrological model MHYDAS was especially developed to take into account these hydrological discontinuities. MHYDAS is a flood simulation model based on a subdivision of the basin into hydrological units linked to the channel network. For each hydrological unit, MHYDAS offers to the modeller the choice between eight production functions based on one-dimensional infiltration laws or a full resolution of the Richards three-dimensional equations. Runoff is then routed through the channel network using the diffusive wave model. The role of tillage was studied by comparing hypothetical scenarios. Results show the importance of the role of these hydrological discontinuities on the form of the hydrograph, the lag time, the runoff volume and the peak discharge.

Key words ephemeral channel system; farmed basins; flood; hydrological processes; infiltration; land use change; Mediterranean zone; runoff-channel routing; spatially distributed hydrological modelling

INTRODUCTION

Runoff processes have mainly been modelled in natural catchments (Grayson *et al.*, 1992). However, on farmed catchments, processes differ since the agricultural land use, the division of the landscape into fields, and the ditch network, are significant factors in controlling flood generation (Gallart *et al.*, 1994). Agricultural operations like tillage have greatly influenced the local surface runoff, infiltration and surface storage by altering soil hydrological properties and soil surface roughness (Mwendera & Feyen, 1993). Tillage generally increases infiltration by increasing soil porosity and breaking up crusts. Also, the ditch networks influence the water transfer from the fields to the catchment outlet (Hughes & Sami, 1992). In contrast to natural drainage networks, they modify water transfer from fields to the catchment outlet in two ways. First, since the ditches follow the field boundaries, water flow does not necessarily follow the steepest slope of the catchment surface topography. Second, since the ditches are excavations in the soil, they influence largely the flow exchange processes between the surface and the groundwater.

With the increase of environmental concerns about the occurrence of severe flood events and the pollution of surface waters by agricultural compounds like nitrates and pesticides, the question arises as to how much agricultural management of the land influences the flow of water and materials at the catchment scale? In this paper, we address this question by a simulation approach that uses a recently developed hydrological model MHYDAS (Modélisation HYdrologique Distribuée des AgroSystèmes—distributed hydrological modelling of agrosystems) (Moussa *et al.*, 2002), that attempts to take into account the main characteristics of farmed catchments.

THE STUDY AREA

The Roujan basin is an experimental catchment operated by the French National Institute for Agricultural Research (INRA). Located in southern France, 60 km west of Montpellier, the 0.91 km catchment has a Mediterranean climate. The soils of the catchment developed from marine, lacustrine or fluvial sediments. The catchment is mainly covered by vineyards (0.71 km^2) and is divided into 237 fields (Fig. 1). A survey identified two main soil treatments for weeding. In one, herbicides are applied over the whole field without any tillage. In the other, the soil is tilled with a rotovator, between the vine rows, one to three times during the growing period between March and July. On the Roujan catchment, the soil surface features of parts of vine fields were classified into two types: non-tilled field and tilled field. The drainage network is formed by man-made ditches and generally follows agricultural field boundaries (Fig. 1). Their density is variable. Typically, they are 0.7 to 1.2 m wide and 0.8 to 1.4 m deep. The total length of the ditch network is 11 069 m.

The basic instrumentation design, set up in May 1992, consists of a raingauges, stream flow recorders and soil water monitoring (tensiometer plus neutron probe measurement) sites. In an attempt to describe the spatial variability of runoff, discharge is measured at three gauging stations using a Venturi channel: the main station monitors runoff at the outlet of the basin (0.91 km^2), whereas the two others control runoff at the outlet of the two fields: a non-tilled field (1200 m^2) and a tilled field (3240 m^2), both located on the terraces.

MODEL DESCRIPTION

MHYDAS, the hydrological model used here was extensively described by Moussa *et al.* (2002). The model subdivides the basin into "hydrological units" taking into

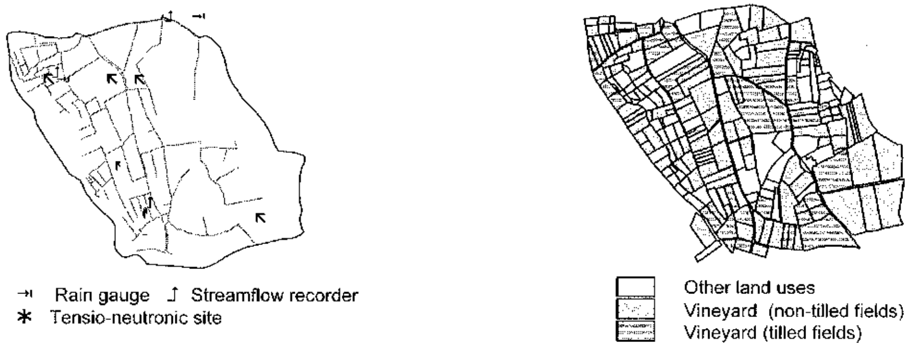

Fig. 1 The Roujan catchment: (a) location of equipment and channel network, and (b) land use.

account the hydrological discontinuities encountered in agricultural catchments. The procedure consists of overlaying geographical information such as ditch networks, field limits, subcatchments, soil maps, land use, etc. According to the objectives of the study, some limits or contours can be eliminated, for instance those that define very small areas. After this, all units of the remaining discretization contour are considered as hydrological units.

For each hydrological unit, MHYDAS gives the modeller the choice between eight simplified one-dimensional (1-D) infiltration laws or the general Richards three-dimensional (3-D) equations. The simplified 1-D infiltration laws offered are based on physical hypotheses in the form of the equations of Richards, Parlange and Haverkamp, Green and Ampt or the Morel-Seytoux simplification, Philip, or Corradini *et al.*, conceptual approaches such as Horton's or Diskin and Nazimov's models, or the empirical SCS (US Soil Conservation Service) model. The flow exchange between the ditch network and the groundwater is calculated using a simple Darcian relation. The second type of infiltration model uses the complete resolution of the Richards 3-D equations (Simunek *et al.*, 1995). MHYDAS uses the diffusive wave equation for discharge routing through the ditch network. Over each reach, the two parameters of the diffusive wave model, celerity and diffusivity, are calculated using topographic data such as the length of the reach, its slope, the Manning coefficient and the cross-sectional width. The cross sectional shape of each reach is an input of the model.

MHYDAS requires the knowledge of the spatial distribution of parameters of the hydrological units, reaches, and groundwater units. Three kinds of parameters can be distinguished: those extracted from DEMs, those obtained from field observations and those calibrated. In this application, the Morel-Seytoux production function was used and the parameters that we calibrated were the hydraulic conductivities of the hydrological units, the exchange coefficients between the reaches and the groundwater, and the average value of the Manning coefficient for the ditch network. The calibration was performed for each flood event by iteratively seeking the values of the parameters that enabled the most accurate simulations of the observed hydrographs at the outlets of experimental fields and of the catchment (example in Fig. 2).

DISCUSSION OF THE IMPACT OF AGRICULTURAL PRACTICES ON FLOOD EVENTS

MHYDAS was used to study the influence of agricultural management practices on runoff generation during typical hydrological situations in Roujan. Three hypothetical scenarios were defined and compared to the reference simulation. These scenarios are termed A1, A2 and A3:

A1 All vineyard fields are non tilled. For each flood event, saturated hydraulic conductivity on vineyards is considered equal to the value calibrated for the non-tilled field.

A2 All vineyard fields are tilled, and surface features are similar to those of the measured tilled field. For each flood event, saturated hydraulic conductivity on vineyards is considered equal to the value calibrated for the tilled field.

A3 All fields, vineyards and other land uses, are considered freshly tilled. The saturated hydraulic conductivity for the whole catchment is considered constant.

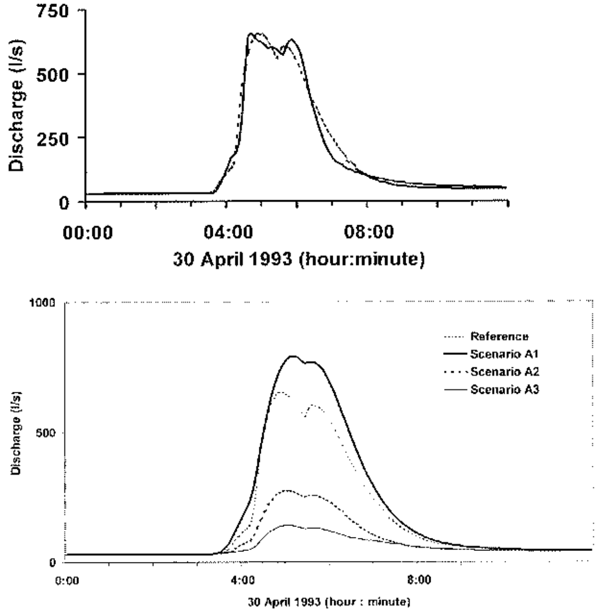

Fig. 2 Example of MHYDAS simulations at the Roujan outlet. Comparison between calculated (reference) and measured hydrograph (top), and comparison between the simulated discharge corresponding to the three scenarios A1, A2 and A3 (below).

Figure 2 shows an example of application case on the flood event of 30 April 1993. These tests were made on nine flood events corresponding to various spatial distributions of tillage practices and various initial water content conditions. The scenario A1 produces the highest runoff values at the field and at the catchment scale, while scenario A3 produces the lowest values. In effect, A1 corresponds to all vineyard fields non-tilled and A3 to all vineyards fields freshly tilled.

The most sensitive parameter in MHYDAS is the saturated hydraulic conductivity *Ks*, which varies in space and in time according to tillage practices. These results point out that it is essential to take into account the influence of soil treatment when simulating hydrological processes at the scale of farmed catchments. However, two main modelling difficulties were noted when using MHYDAS. First, the calibration of *Ks* to field runoff data revealed that after tillage, *Ks* decreases with time due to rain drop impact on the soil surface. But in its present version, MHYDAS considers *Ks* as constant during a rainfall event, while many studies revealed that *Ks* can decrease significantly during a single rainfall event due to aggregate breakdown, erosion and deposition. Second, it is difficult to know the spatial distribution of tilled and non-tilled fields for all flood events, because farmers change their soil treatment practices within and between years.

Moving from the field to the catchment scale, the area on which runoff occurs is extended because of the inter-field ditch network. The simulations show two main results. First, the ditch network accelerates runoff by concentrating flow and avoiding natural obstacles. The second result deals with the role of ditch networks in the flow exchange between surface and groundwater. When the water table is below the bed of the ditch, most of the runoff produced at the field scale infiltrates through the ditch network. One difficulty in simulating flow in the ditch network is related to the assumption that the parameters characterizing the ditches are constant and spatially uniform. This assumption is a gross approximation. The exchange coefficients between the ditches and the groundwater depend on the infiltration properties of the ditch network, which are generally unknown, and should be measured at different locations of the ditch network.

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REFERENCES

Gallart, F., Llorens, P. & Latron, J. (1994) Studying the role of old agricultural terraces on runoff generation in a small Mediterranean mountainous basin. *J. Hydrol.* **159**, 291–303.

Grayson, R. B., Moore, I. D. & McMahon, T. A. (1992) Physically based hydrologic modeling. I. A Terrain-based model for investigative purposes. *Water Resour. Res.* **28**(10), 2639–2658.

Hughes, D. A. & Sami, K. (1992) Transmission losses to alluvium and associated moisture dynamics in a semiarid ephemeral channel system in Southern Africa. *Hydrol. Processes* **6**, 45–53.

Moussa, R., Voltz, M. & Andrieux P. (2002) Effects of the spatial organization of agricultural management on the hydrological behaviour of a farmed catchment during flood events. *Hydrol. Processes* **16**, 393–412.

Mwendera, E. J. & Feyen, J. (1993) Predicting tillage effects on infiltration. *Soil Sci.* **155**, 229–235.

Simunek, K., Huang, K. & Van Genuchten, M. T. (1995) The SWMS_3D code for simulating water flow and solute transport in three-dimensional variably-saturated media. Research report no. 139, version 1.0. USDA, US Salinity Laboratory, Riverside, California, USA.