Methodology to assess the hydrological impact of weed control practices with a view to management of Mediterranean vinegrowing catchments

Anne Biarnès, François Colin

Anne Biarnès, François Colin. Methodology to assess the hydrological impact of weed control practices with a view to management of Mediterranean vinegrowing catchments. International Journal of Sustainable Development, 2006, 9 (2), pp.161-179. hal-02657348

Published in Int. J. Sustainable Development, Vol. 9, No. 2, 161-179, 2006

Methodology to assess the hydrological impact of weed control practices with a view to management of Mediterranean winegrowing catchments

Biarnès Anne* and Colin François**
* IRD, UMR LISAH
** Agro M, UMR LISAH
UMR LISAH, 2 place Viala, 34060 Montpellier

Abstract:

This paper proposes a methodology to assist water resources managers in assessing the hydrological impact of weed control practices in Mediterranean winegrowing catchments. The methodology is based on a spatial representation of practices and its integration in a distributed hydrologic model. The representation is based on the search for indicators that can be used to attribute a distribution of practices to each hydrological unit of the model and a classification of practices according to their effect on soil surface hydraulic conductivity. The observed diversity is integrated in the hydrologic modelling running an existing physical hydrologic model on an elementary experimental catchment.

Key words: vineyard, weed control practices, soil surface characteristics, hydrological modelling, catchment, parameterisation

Biographical notes:

Anne Biarnès is an agronomist. She has been working for IRD since 1985. Her fields of study are farmers' practices and farm management in France and in developing countries. After one year in Côte d'Ivoire and six years in Mexico, she returned to France where she took part in research on modelling decision-making processes for crop-management on farms. She is now working in the Laboratory on the Interactions between Soils, Agrosystems and Hydrosystems (LISAH) in Montpellier, France. In this laboratory, she focuses on the analysis of spatial and temporal organisation of the agricultural activities that are involved in the processes of runoff, erosion and pollution.

François Colin is a hydrologist. Since 2001, he has been working as lecturer and scientist at the School of Agronomy of Montpellier and is a member of the LISAH team. His fields of study are hydrological modelling and spatial analysis of environmental risks.

Published in Int. J. Sustainable Development, Vol. 9, No. 2, 161-179, 2006

Methodology to assess the hydrological impact of weed control practices with a view to management of Mediterranean winegrowing catchments

1. Introduction

Assessment of the risks of non-point water pollution associated with cropping practices is a topic of current concern in many countries owing to the increased use of pesticides and fertilizers since the 1950s (Katerji et al., 2002; Novotny, 1999). In France, pesticide contamination is over European drinking water standards at many water quality monitoring sites. According to the French Institute of the Environment, in 1999 and 2000, only 56% of samples of surface water for drinking water were of sufficiently high quality to be distributed without prior treatment (IFEN, 2002). In southern France, regional water quality inventories conducted by the Rhône-Mediterranean-Corsica water authority over the same period showed that 65% of surface water and 80% of groundwater sources are contaminated by pesticides (A*gence de l'eau RMC*, 2000 and 2002). More than 50% of the active substances identified are herbicides. Studies of water contamination processes indicate that this pollution should be seen in relationship to the importance of winegrowing and the high risks of herbicide leaching in a Mediterranean climate (Lennartz *et al*., 1997; Louchard *et al.*, 1999; Louchard *et al*., 2001). The studies showed that the water surface pollution was related to the transport of the active matter by runoff during heavy rainfall events. The authors pointed to a crucial role by the weed control practices used in vineyards.

One requirement for addressing these concerns is to evaluate the efficacy of public policy instruments for pollutant emission control based on technical proposals and/or economic mechanisms such as taxes, pollution rights, etc. Within this perspective, there is a need to assist water resources managers to assess the environmental impact of agricultural practices and to define pertinent corrective actions. As the legislation does not explicitly define an authorized catchment management authority, managers may be farmers' organizations, mayors, river basin authorities, etc., freely chosen or imposed. Corrective actions may concern the catchment considered as a whole. As recommended by the CORPEN (French Advisory Comity for Environment-friendly Practices), corrective actions can also be focused on priority zones of action selected according to their particular characteristics (e.g. geomorphological characteristics or user's action on the environment) and their contribution to transfers of the pollutant (CORPEN, 2003). The latter option is particularly relevant in Mediterranean winegrowing regions because of the heterogeneity and the high number of holdings, which makes the choice of pertinent actions difficult. However, the choice of such an option should be based on a credible representation of the hydrological functioning of the local environments and a good representation of user's actions on the usable environment concerned:

- risk diagnosis should be implemented to enable identification of priority zones
- the environmental impact of realistic scenarios of changes in practices should be simulated.

When dealing with water resources, the spatial field is a catchment area: a surface catchment area for direct intake of drinking water from a river, or the catchment area of the aquifer. The aim is thus to construct representations of a spatial field ranging from 100 to 1000 square kilometers.

Distributed hydrologic models are available at this scale. Most of them require catchment segmentation based on subcatchments, also called Hydrologic Response Units (Uhlenbrook et al., 2004). Research into changes of scale in hydrology suggest using subcatchments of about 1 to 5 km² (Wood et al., 1988; Woods et al., 1995). The hydrological behaviour of these subcatchments is then globally defined with respect to relief, soil types and land use, as described in Soil and Water Assessment Tools (Arnold et al., 1993). River reaches interconnect subcatchments to simulate the whole catchment behaviour. Such models are used to evaluate hydrologic modifications linked with evolutions such as global change. As they are spatially distributed, users can run them to define priority zones of action within a water resources catchment. But difficulties still exist when these models are to be used in the context of a vineyard, one being the impossibility to account for the impact of the range of different weed control practices that are used within the subcatchments, whereas according to Moussa *et al.* (2000 and 2002), this diversity is one determining factor of hydrological functioning. Weed control practices are based on three main methods: chemical weeding, mechanical weeding and grass cover. These methods results in changes on the soil surface characteristics, on which the soil surface hydraulic conductivity and the volume of runoff water at the field outlet depend. They also determine the concentration of herbicides in the runoff water.

Furthermore, acquiring data on cropping practices to run a model on a large area is difficult since costly exhaustive surveys cannot be envisaged. This explains researchers' use of averaged data based on the literature, on experts' evaluations or on technical recommendations (Giupponi et al., 1999; Bioteau *et al.*, 2002; Mignolet *et al.*, 2004) or the use of scenarios of uniformly distributed agricultural practices (Knox *et al.*, 1996; Hartkamp et al., 2004) to assess the impact of agricultural practices. Such indirect means cannot be used in our case since the focus is on the range of different weed control practices used within vineyards. Remote sensing has long proven its value for acquiring spatialized data on land use. More recently, it has also been used for mapping tillage practices in intensive agricultural regions of the United States (van Deventer et al., 1997; Gowda et al., 2001; South et al., 2004), using Landsat images. However, in the case of winegrowing catchments in southern France, Wassenar et al. (2001) and Corban (ongoing research) showed that different weed control practices cannot be distinguished even with high spatial resolution images (less than 1 m spatial resolution). The results obtained proved to inaccurate in the majority of cases. Moreover, tools of this kind can only provide partial knowledge of practices because some technical options, particularly those involving the use of pesticides, cannot be detected through remote sensing. No other method for mapping agricultural practices over large areas is mentioned in the literature.

After this state of the art, it was clear that to assist water resources managers manage a vineyard catchment, it would be necessary to develop a modelling approach able to account for the diversity of practices. On the other hand, no relevant method was available to obtain precise information over large areas on cropping practices. This paper thus proposes a methodology based on an integrated approach to the water resources catchment to create a spatialized representation of the weed control practices and to integrate it in a distributed hydrologic model. The methodology presented here only concerns water fluxes. First we describe some specifications for an integrated modelling approach and the resulting methodological choices. We then apply the proposed methodology to the case of a Mediterranean catchment in the department of Hérault in southern France. Our results are discussed in the last section.

2. Methodological approach

2.1. Specifications for an integrated modelling methodology

With a view to reducing non-point pollution in Mediterranean winegrowing catchments, we assumed that water resources managers need a methodology for spatial and temporal evaluation of water quality. In order to be useful for managers, the specifications for the methodology need to be detailed.

Such a methodology must be able to predict the impact of alternative scenarios. The selected hydrological model must be sensitive to the diversity of soil surface hydraulic conductivity created by the range of weed control practices at the subcatchment level. This implies first constructing a representation of these practices based on a functional classification of practices and on being able to provide plausible distributions of values of soil surface hydraulic conductivity for areas which fullfill the hydrological modelling need. Finally, the number of parameters must be limited to easy available variables.

For this first integrated approach we chose to work at the flood event scale. This decision was justified because the most important water management problems occur at this temporal scale in Mediterranean winegrowing catchments.

2.2. Resulting methodological choices

2.2.1. Distribution of weed control practices and of resulting soil surface hydraulic conductivity within the hydrological units of the model

The method proposed to characterize weed control practices and the resulting soil surface hydraulic conductivity is based on:

(i) an inventory of the range of the different practices used in the study area and the classification of these practices according to their effect on changes in soil surface characteristics and consequently on changes in hydraulic conductivity;

(ii) the search for spatialized or spatializable indicators of the practices that can be used to attribute a distribution of types of practices in each hydrological unit;

(iii) the calculation of plausible distributions of values of soil surface hydraulic conductivity at any given date.

To this end, spatially explicit data on the practices and the factors that may explain their distribution must be collected in the study area. As existing agricultural censuses do not provide these data, they have to be gathered through surveys. The selection of potential indicators of practices should be based on a review of the literature and on knowledge of the specific situation in the study area, so as to take different levels of organisation into account. In the case of winegrowing catchments, a previous work (Biarnes *et al.*, 2004) showed that a minimum of three possible levels have to be considered: the field, the holding and the commune of location of the field, which roughly corresponds to a cooperative winery's supply basin. In the Languedoc Region of southern France, the winery supply basin roughly covers the vineyards of one commune or two neighbouring communes. The first two levels are intended to take into account the specific constraints of the field and the operating constraints of the holding, which limit the technical options. The third is intended to take into account the growers' socio-professional environment, including relations between neighbours and the influence of the cooperative wineries in the organization of the industry.

Winegrowers have three main methods available to control the development of weeds in theirs fields: chemical weeding, mechanical weeding, which consists in repeated surface tillage during the year, and grass cover. These different methods may be combined in different ways in the same field : the rows of vines may be treated differently to the alleys and some alleys may be treated differently to others, leading to a wide range of possible types of weed control practices depending on the percentage of area of individual field that can be attributed to each method.

A review of the literature and ongoing research in winegrowing catchments in southern France showed that changes in soil surface characteristics and in the resulting soil surface hydraulic conductivity depends on the methods used (Leonard and Andrieux, 1998, Hébrard et al., 2006, Andrieux, 2006). Thus the spatial distribution of weed control methods within a field determines the percentage of area that can be attributed to soil surface characteristics that may correspond to eachmethod.

To obtain a spatial representation of weed control practices, the data are processed by multivariate analysis. The aim is to highlight the variables and modalities of variables that best explain the choice between the different types of practices, in order to use them as pertinent keys to represent the spatial distribution of the practices and to attribute a percentage distribution of the different types of practices to each hydrological unit of the model.

In order to allow this representation to be coupled with the hydrological model, these percentage distributions of types of practices are then converted into percentage distributions of weed control methods from which, on the basis of experts' evaluations, plausible percentage distributions of types of soil surface characteristics can be deduced for a given date. Each type of soil surface characteristic is then attributed to a value of hydraulic conductivity deduced from the literature.

2.2.2. Hydrological modelling structure

The selected hydrological model is a distributed model based on a functional spatial segmentation of the catchment in terms of both hydrological functioning and land management. The segmentation procedure is based on the division of the catchment into subcatchments of about 1 to 5 km² as recommended by Wood *et al.*, (1988) and Woods *et al.* (1995). A Geographical Information System can be used to obtain these hydrologic spatial units from morphologic (relief and hydrography) and soil layers.

The hydrological model works with a production function dividing rainfall into infiltration and surface runoff, a transfer function and an exchange function (Figure 1).

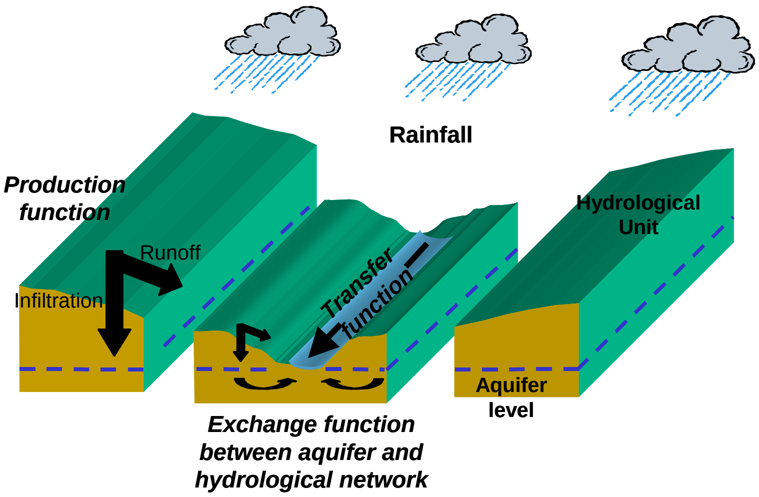


Figure 1: Schematic hydrological modelling structure

For each subcatchment, the production function operates as a reservoir whose filling depends on the depth of the superficial aquifer, the hydrological network (including manmade ditches) and the diversity of surface hydraulic conductivity due to the impact on the soil surface characteristics of land use and, in the case of a vineyard, of the different weed control practices. This diversity of surface hydraulic conductivity is represented using a single parameter that we called Kuh and whose value varied throughout the year. The transfer function carries water through the hydrological units to their outlets and from there to the outlet of the main drainage basin. This function requires only measurable variables such as lengh, depth, slope and bank roughness of the stream reaches. The exchange function allows the representation of the fluxes between stream reaches and aquifer compartments according to a Darcian flow hypothesis. This is a quite simple function which uses two conceptual parameters: permeability between the aquifer and the network and permeability between the network and the aquifer. The value parameters have to be fixed during the calibration phase.

2.2.3. Parameterisation of the hydrological units and coupling with the spatial representation of practices

The coupling of the hydrological model with the spatial representation of practices and the resulting distributions of soil surface hydraulic conductivities for a given date is based on the calculation of the values of the Kuh parameter. These values must be calculated for each hydrological unit before simulating the impact of a rainfall event. We propose a 2-step procedure to parameterise the resource catchment hydrologic model and on this basis, to calculate the required values of Kuh for each simulated event:

- in the first step, hydrological units are classified according to a functionnal typology;
- in the second step, nomogram systems are performed, which enable the value of the parameter Kuh to be calculated for each hydrological unit type according to a given percentage area distribution of soil surface hydraulic conductivities.

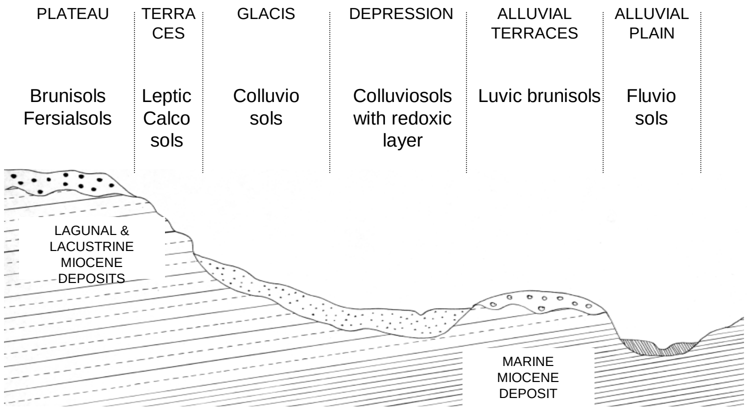
Pedological expertise enables subcatchments to be classified according to the probability of the presence of a superficial aquifer. This criterion is particularly important because it determines the exchange conditions between the hydrographic network and the aquifer. Consequently, we propose that three subcatchments types : type (a) with a temporary suspended aquifer; type (b) without an aquifer; and type (c) with a permanent superficial aquifer.

The second step is based on existing experimental references for each type of subcatchment in an elementary representative catchment, and on the use of a physically elementary catchment model, the MHYDAS model (Moussa et al., 2002) which is a powerful tool to simulate streamflows for Mediterranean catchments affected by agricultural activities. For each subcatchment type within the experimental catchment, streamflows are simulated with the MHYDAS model considering various possible distributions of values of soil surface hydraulic conductivity induced by land use and practices and, when a superficial aquifer exists (types a and b subcatchments), by a range of different initial depths of the aquifer. Next, streamflows at the subcatchment outlet are simulated using the reservoir production function for various possible values of the Kuh parameter. Finally, on this basis, we associate a Kuh value with the distribution of hydraulic conductivities which enables calculation of the same streamflows for a subcatchment type and for the initial depth of the aquifer.

3. Case study

3.1. Study site

The catchment used for our study was the Peyne river basin in the mid Hérault valley. It is 75 km² in area, about the same size as catchments in the region that are used for water resources. It was chosen with a view to developing an integrated modelling methodology that can be used in comparable situations. The Peyne river basin presents a succession of clearly differentiated geomorphological units which, according to Bonfils (1993), strongly determine the distribution of soils within the landscape (Figure 2). Altitude ranges from 20 m to 340 m. There are sharp contrasts in landscape between the northwest – rugged and mainly scrub-covered, with little arable land – and the rest of the valley, which has gentler landforms and is almost entirely under vines. This catchment includes an experimental elementary catchment (the Roujan catchment), established in 1992 and which is 91 ha in area. It was chosen because it is made of the main geomorphological units found in the Peyne catchment (Figure 3).



NB: The upper Peyne basin, not shown in the figure, has shallow, gravelly to stony soils on quartzic substratum or basalt flows.

Figure 2: Geomorphological and soil units of the lower Peyne valley (from Lagacherie et al. (2001), adapted by Bonfils (1993))

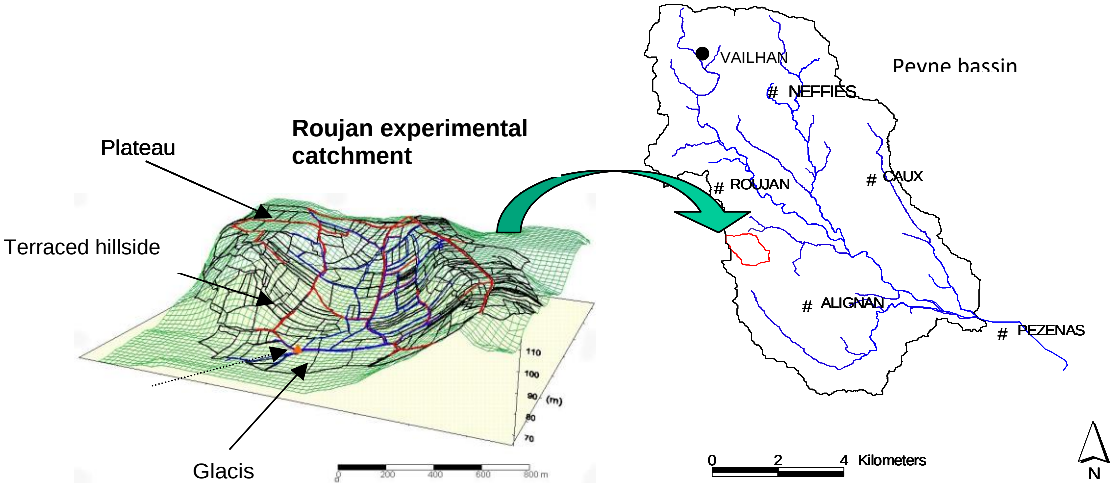


Figure 3: Peyne river basin and Roujan experimental catchment

The region's climate is sub-humid Mediterranean with a long dry season. Annual rainfall is about 700 mm, but varies widely from year to year. There are sharp seasonal contrasts, with rainy autumns and springs and hot, dry summers with heavy downpours. Potential evapotranspiration is high, with an average of 1000 mm, owing to high temperatures, strong sunshine and often strong winds.

The Peyne basin incorporates most of the territory of six different communes and is farmed by some 800 winegrowers. According to the data from the last farm census carried out in 2000 by the Regional Direction of Agriculture and Forestry, 93% of these holdings supply their grapes to cooperative wineries, the remainder supplying private wineries. Four commune-based cooperative wineries collect most of the output.

3.2. Spatial distribution of weed control practices

3.2.1. Data collection

The required data were gathered by a survey of a sample of 64 holdings cultivating 1004 fields in the Peyne basin which represented 1017 ha, i.e. about 20% of the area under vines within the basin (Gal, 2004; Boissieux, 2005). The holdings covered by the survey were selected by drawing fields by lot along seven transects perpendicular to the river Peyne, spread so as to traverse the toposequence, the range of soil types and the communes. It was assumed that the appropriate selection of fields would imply the correct selection of holdings to provide a sample of fields that were representative of the range of practices and the proportionate use of each.

The survey questionnaire was in two complementary parts. The first part focused on the weed control practices used and their distribution among the holding's vineyard fields, which were precisely located on the land register map. The second part was designed to provide data for the variables assumed to explain the choice of practices, identifying

- the physical characteristics of the fields on which each practice was implemented,
- the commune the vineyard field belonged to,

- the holdings' structural characteristics and their production priorities.

Locating the vineyard field on the land register map made it possible to add information such as the commune in which the field was located, soil type and slope class, which were taken, respectively, from the land register, the 1:100,000 soil map by Bonfils (1993) and the digital terrain model (DTM) based on the IGN (French Institute of Geography) topographical database with a spatial resolution of 50 m.

The data were processed by correspondence discriminant analysis and a classification tree. To this end, the values taken by each explanatory variable were divided into classes using thresholds that took into account our hypotheses on the determinants of the practices while ensuring a sufficient number of fields per class. Within each set of explanatory variables, correspondence discriminant analysis was used to select those best correlated with the choice of weed control practices. The selected variables were then used in a classification tree to establish a hierarchy between the discriminant variables and to evaluate their discrimination power.

3.2.2. Diversity of weed control practices in the Peyne valley

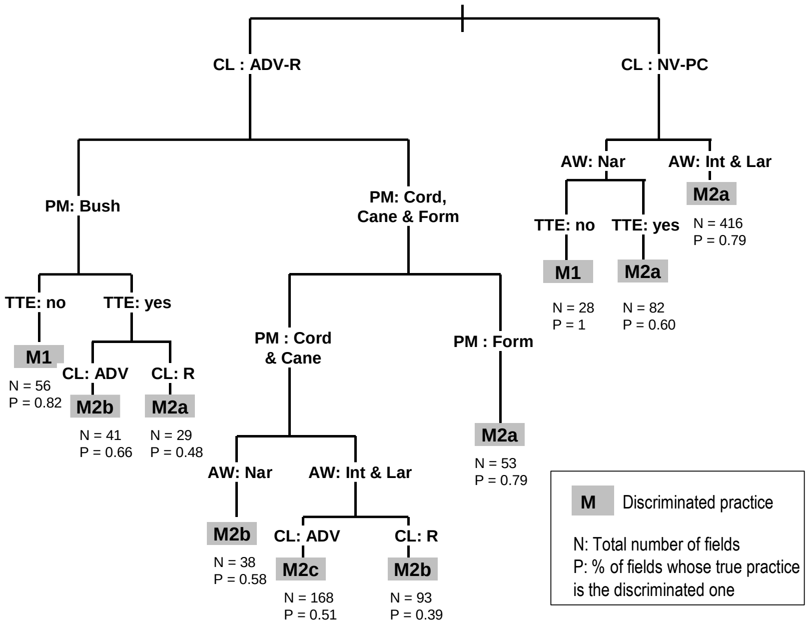
Four types of weed control practice were differentiated: M1, M2a, M2b and M2c. Practice M1 was based on chemical weeding in the rows of vines and alleys alike. The other three practices also used chemical weeding in the rows, but differed in the methods used for the alleys. In practice M2a, the alleys were repeatedly shallow-tilled. Practices M2b and M2c both managed some alleys by tillage but alternated these at regular intervals within the field with alleys managed using a different method. In practice M2b, tillage alternated with chemical herbicide, and in M2c, tillage alternated with alleys under permanent grass, natural or sown, and controlled by mower or rotary cutter. In both M2b and M2c, the untilled alleys were those where the tractor passed to spray the crop in spring and summer; the reason for not tilling was to ensure a good load-bearing capacity. The corresponding repartition of weed control methods is shown in Table 1.

Table 1: Average percentage distribution of each weed control method as a function of the type of practice

Type of practice	% of area of field under each weed control method		
	Chemical weeding	Mechanical weeding	Permanent grass cover
M1	100	0	0
M2a	30	70	0
M2b	65	35	0
M2c	30	35	35

3.2.3. Indicators of practices

The classification tree presented in Figure 4 summarizes the results of the data analysis. Only four variables (Commune of location, Alley width, Pruning method, Availability of tillage and traction equipment for closely spaced rows) were necessary to reach a satisfactory performance in classifying the practices. With these variables, 68 % of the parcels were assigned to their true practice. This percentage reached 77% when practices M2b and M2c, whose discrimination was not good, were combined. However, the most striking result revealed the importance of the variable "Commune of location", which roughly corresponded to the supply basin of a winery cooperative, as first discriminant variable.



Discriminant variables	Modalities
CL (Commune of Location)	ADV (Alignan-Tourbes); R (Roujan); NV (Neffiès-Vailhan), PC (Pezenas-Caux)
AW (Alley Width)	Nar (narrow); Int (intermediate); Lar (large)
PM (Pruning Method)	Bush, Cord (bilateral cordon), Cane (cane pruned), Form (Formation: pruning method not yet defined)
TTE (Tillage and Traction Equipment for closely spaced rows)	yes, no

Figure 4: Classification tree

3.2.4. Spatial distribution of practices

On the basis of these results, we chose "Commune of location" as a single key to spatialize the practices. Assuming that the distributions of practices can be considered as homogeneous within a commune, distribution of the types of weed control practice were calculated per commune by extrapolating from the data survey. This choice resulted from

- high fragmentation and dispersion of the land of the farm holdings in the sample of holdings
- the lack of preferential localization of the determining factors of practices within the communes.

These results are shown in Table 2. They underline the contrast between the communes of Alignan-du-Vent and Roujan, where M2b and M2c were predominant practices, and the communes of Caux-Pezenas and Neffiès-Vailhan, where the main method was tillage (M2a).

Table 2: Distribution of practices between communes

Commune	% area per type of practice			
	M1	M2a	M2b	M2c

Roujan	15	30	30	25
Alignan-du-vent	6	20	36	39
Caux-Pezenas	17	74	8	1
Neffiès-Vailhan	24	66	7	4

3.3. Hydrological segmentation and subcatchment typology

A preliminary division into surface drainage subcatchments was obtained from the relief (the DTM) and the hydrographic network. For groundwater, we assumed that soil types were indicative of homogeneous aquifer conditions (Tassinari, 1998). From the 1:100,000 soil map data (Bonfils, 1993), we grouped soil units according a groundwater criterion:

1. molasse soils with a temporary shallow aquifer, soils
2. limestone plateau, basalt soils, molasse soils and urban areas with no groundwater, soils
3. soils on alluvial terraces, recent soils and alluvia with stream-connected groundwater with a shallow aquifer.

The divisions into surface subcatchments and units with homogeneous groundwater features were then superimposed to define the hydrological units for the resource-catchment as shown in Figure 5.

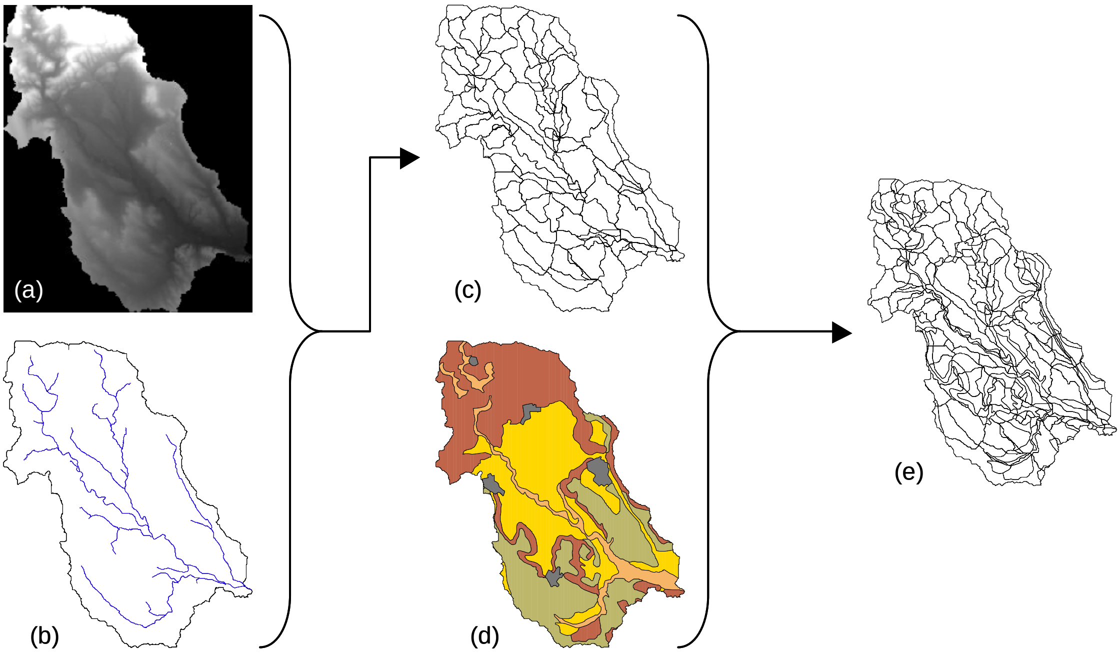


Figure 5: Construction of hydrological units: (a) Digital Elevation Model, (b) hydrographic network, (c) topographical subcatchments, (d) soil map, (e) final hydrological units

Three types of hydrological units were defined according the groundwater criterion:

- type a with a temporary suspended aquifer on soils (1),
- type b without an aquifer on soils (2),
- type c with a permanent superficial aquifer on soils (3).

3.4. Nomogram system used to parameterise the hydrologic model

For each of the three hydrological unit types, an average ditch network density was adopted based on observations made in the Peyne Valley. The hydrological impact of the distribution of the different weed control practices was simulated by running the MHYDAS model in the experimental Roujan catchment.

For the study area, several studies describe the diversity of soil surface characteristics (0-10 cm) that are induced by different weed control methods (Leonard and Andrieux, 1998, Hébrard et al., 2006, Andrieux, 2006). For each set of soil surface characteristics and different type of soil, the authors measured hydraulic conductivity using rainfall simulation. They showed that hydraulic conductivity was more influenced by soil surface characteristics than by soil type. They consequently proposed a typology of soil surface characteristics in association with hydraulic conductivity. We selected three types of soil surface characteristics that we assumed were representative of the scope of impact of weed control methods in vinegrowing fields (Table 3). Each of these three types corresponds to a specific value of soil surface hydraulic conductivity which was measured. Moreover, we attributed the same value of soil surface hydraulic conductivity to land-use areas other than vineyard (forest, scrub cover, fallow land and cereal), the value we selected is the one that was measured with a grass cover.

Table 3: Types of soil surface characteristics and corresponding hydraulic conductivity values as a function of weed control methods

Type of soil surface feature	Average value of hydraulic conductivity (mm/h)	Weed control methods
Csd	12	Chemical weeding or mechanical weeding (not recently tilled field)
T	28	Mechanical weeding (recently tilled field)
Vst	35	Permanent grass cover

On this basis, to test the methodology, nomogram systems were constructed for each type of hydrological unit (Figure 6). This nomogram system enabled calculation of the values of the Kuh parameter according to a wide range of possible distributions of the three selected types of soil surface characteristics. The procedure was based on the calculation of the values of the runoff coefficient ratio which is the ratio between the total depth of runoff at the catchment outlet and the total depth of rainfall. This was done using the rainfall event of the 20th October 2002. The runoff coefficient simulated by the MHYDAS model is given for 11 distributions of the three values of hydraulic conductivity as a function of the initial depth of the aquifer (Figure 6, sub-figure I). In Figure 6 sub-figure II, the runoff coefficient simulated by the reservoir production function is given for various Kuh values as a function of the initial depth of the aquifer. Finally, in Figure 6 sub-figure III, Kuh is given for the selected distributions of hydraulic conductivity as a function of the initial depth of the aquifer.

3.5. Hydrological simulations for the Peyne basin

To conclude the methodology, we ran the model on the Peyne basin for two rainfall events, 20th October 2002 and 1st October 2003.

3.5.1. Distributions of soil surface hydraulic conductivity at the dates of the two simulated events

Percentage distributions of the values of soil surface hydraulic conductivity at the dates of the two simulated events were first calculated for each commune of the Peyne valley. To this end, the average distribution of the different types of land use was calculated on the basis of the last agricultural census. We then attributed to the area under vine the corresponding percentage distribution of weed control practices (see Table 2) and, consequently, of the three available methods. Assuming that at the dates of the two simulated events all the area under mechanical weeding had have recently been tilled, the percentage distribution of each of the three values of soil surface hydraulic conductivity within each commune was deduced on the basis of Table 3. Finally, the average percentage distribution of hydraulic conductivity found in a given commune was attributed to each hydrological unit located within that commune.

3.5.2. Simulations

For the two simulated rainfall events, a piezometric survey provided the initial depth of the aquifer. Using the nomogram system (Figure 6) and the previously calculated distributions of soil surface characteristics, we set the infiltration capacity parameter Kuh for each hydrological unit.

The parameters of the Peyne basin's hydrographic network were partly measured (cross-sections, slopes, roughness) and partly fitted (coefficients of flood wave celerity and diffusivity, groundwater-river exchange coefficients) from the rainfall event of 20th October 2002. These parameters were kept for validation by the rainfall event of 1st October 2003. The rainfall measured at the Roujan catchment weather station was assumed to be uniform across the Peyne basin. The results of the simulations were compared with the outflows measured at the basin outlet (Figure 7). These two simulations (calibration and validation) showed that the model reproduced autumn flood events satisfactorily using the parameterisation approach adopted for the two different rainfall events.

4. Discussion - conclusion

We initiated this study under the assumption that integrated tools were not available to manage non-point pollution at the scale of water resources, particularly in winegrowing catchments. Needs require diagnosis and forecasting tools. Diagnostic approaches aim to simulate the catchment’s current situation to highlight either the areas whose contributions to the transfer of the pollutants are the greatest, or areas resulting in the same contributions but with very different geomorphological characteristics or agricultural practices. Forecasting focuses on the evaluation of the impacts of plausible alternative scenarios of practices. Within theses perspectives, our goal was to develop a methodology enabling the diversity of weed control practices to be taken into account in order to parameterise a distributed hydrological model that would work at the flood event scale. To this end, we constructed a hydrologic model that is sensitive to hydraulic conductivity which, in vineyard catchments, is mainly controlled by the weed control practices. Developing such a methodology is a long and exacting task which requires a good knowledge of the biophysical processes and of the decisional ones leading to the selection of practices by the farmers. The results presented here only concern stream flows, but research is currently underway to enable us to add a pesticide module. These results are based on the winegrowing Peyne catchment in the department of Hérault in Southern France. They underline the advantages of simultaneously developing a model representing the practices and the hydrological model that allows assessment of the environmental impact of these practices. However, at this stage, they represent a first approach which will continue to be developed.

The results presented here highlight the importance of spatial coupling of the representation of weed control practices and hydrological modelling. As far as the practices are concerned, the results of our case study show that these were not evenly distributed, and that consequently the question of spatialisation of practices is relevant. The diversity of soil surface hydraulic conductivity which results from the spatial distribution of practices within each hydrological unit was integrated in the hydrologic model through a nomogram system. This nomogram system allowed calculation of the simulated rainfall events as the value of a parameter we called Kuh, which represents the hydraulic conductivity of each hydrological unit. It was run in an existing physical hydrologic model on an elementary experimental catchment that is representative of the observed diversity of hydrological units in the study area.

In the case study presented here, the proposed grid to spatialize the practices was coarse grain as it was based on the administrative boundaries of the neighbouring communes which roughly correspond to the supply basin of a same winery cooperative. The same distribution of practices was thus attributed to each of the hydrological units located in the same commune or group of communes. To couple it with the hydrological model, a finer grain to spatialize the practices was considered unnecessary because of the very probable homogeneous distribution of practices within the communes. However, such a choice will probably not be valid in situations where other determining factors of practices than the commune exist. Further studies are thus required to be able to produce distributions of practices on a fine grid when necessary.

In the same way, further efforts are needed to take better account of temporal aspects in the representation of the practices and of their impact on soil surface hydraulic conductivity. This is particularly important when a more precise diagnosis is required. In the case study presented here, we assumed that, for the simulation dates, only one given distribution of soil surface hydraulic conductivity could be attributed to a given distribution of weed control practices. In so doing, we did not account for possible staggering of the dates of cultivation operations for a given method and its effect on changes in soil surface characteristics and consequently in hydraulic conductivity. Further studies should associate the distribution of weed control practices with different probable distributions of values of soil surface hydraulic conductivity. Taking this uncertainty into account in the hydrological modelling will enable us to build fuzzy nomogram systems.

To be useful for water resources managers, the hydrological modelling approach should be applicable at different temporal and spatial scales. In the Mediterranean context, we proposed the flood event scale as the most pertinent temporal scale to manage crisis situations. In the results presented here, the simulated events concerned two autumn rainfall events. Tests remain to be done: similar simulations should be extended to different typical rainfall events during the year. Other nomogram systems should be calculated for different climatic conditions to parameterise the hydrologic model. In this way, we will obtain nomogram systems for several types of climatic conditions. Extrapolation of the modelling approach to any water resource catchments of the Languedoc winegrowing plain (which represents 297.118 ha, equal to 33% of total French vineyards) is partially possible on the basis of the representativeness of the elementary experimental Roujan catchment and of the typology of subcatchments chosen. However, this typology will probably have to be extended. To obtain a nomogram system suitable for other types of subcachement, new experimental experiments will thus be necessary.

The use of the proposed methodology by water resources managers will always require a considerable financial investment given the amount of data needed on practices and hydrological behaviour even if the investment will always be much lower than that required for integral physical modelling like the SHE model (Abbott, 1986). The quality of the results of the hydrological simulations depends on the investment in the collection of the necessary data. Therefore, it may be that the water resources managers will have to decide on the level of quality they expect from the simulations and, consequently, how much money to spend on data collection. Finally, as suggested by Power (1993), such an application by managers would provide global validation of the methodology by its use.

Acknowledgements:

This work was partly supported by the French INRA programme PSDR (*Pour et Sur le Développement Régional*) and was originally presented at the INRA symposium "*Territoires et Enjeux du Développement Régional*", Lyon, France, 9-11 March 2005.

5. References

Abbott, M.B., Bathurst, J.C., Cunge, J.A., O'Connell, P.E., Rasmussen, J., (1986). An Introduction to the European Hydrological System – "SHE". *Journal of Hydrology* **87**, 45-59.

Agence de l'eau RMC (2000). "Composés phytosanitaires dans les eaux superficielles et souterraines du bassin Rhône-Méditerranée-Corse: campagne août 1999 juillet 2000." Agence de l'eau Rhône-Mediterranée-Corse, Lyon, http://www.eaurmc.fr

Agence de l'eau RMC (2002). "Pesticides dans les eaux superficielles et souterraines du bassin Rhône-Méditerranée-Corse: campagne août 1999 décembre 2001." Agence de l'eau Rhône-Mediterranée-Corse, Lyon, http://www.eaurmc.fr

Andrieux, P., (2006). Soil surface characteristics and infiltration in Mediterranean cultivated areas. 14th Conference of International Soil Conservation Organization (ISCO), 14-19 may 2006, Marrakech, Morocco.

Arnold, J. G., Allen, P. M., and Bernhardt, G. (1993). A comprehensive surface-groundwater flow model. *Journal of Hydrology* **142**, 47-69.

Biarnès, A., Rio, P., and Hocheux, A. (2004). Analysing the determinants of spatial distribution of weed control practices in a Languedoc vineyard catchment. *Agronomie* **24**, 187-196.

Bioteau, T., Bordenave, P., Laurent, F., and Ruelland, D. (2002). Evaluation des risques de pollution diffuse par l'azote d'origine agricole à l'échelle de bassins versants : intérêts d'une approche par modélisation avec SWAT®. *E A T* **32**, 3-12.

Boissieux, Y. (2005). Analyse de la variabilité spatiale des pratique d'entretien du sol dans un bassin versant viticole du sud de la France. Rapport de fin d'étude d'ingénieur en agriculture, ESITPA.

Bonfils, P. (1993). "Carte pédologique de France au 1/100°000 ; feuille de Lodève," SESCPF INRA.

CORPEN (2003). "Mesures réglementaires concernant les produits phytosanitaires, leurs utilisateurs et leur incidence sur l'environnement." Comité d'Orientation pour des pratiques respectueuses de l'environnement, Ministère de l'Ecologie et du Développement Durable.

Gal, M. (2004). Analyse des déterminants de la diversité et de la localisation des pratiques d'entretien du sol en vue de la spatialisation de ces pratiques dans un bassin versant viticole. Mémoire de fin d'étude d'ingénieur, ESITPA, Rouen.

Giupponi, C., Eiselt, B., and Ghetti, P. F. (1999). A multicriteria approach for mapping risks of agricultural pollution for water ressources: The Venice Lagoon watershed case study. *Journal of Environmental Management* **56**, 259-269.

Gowda, P. H., Dalzell, B. J., Mulla, D. J., and Kollman, F. (2001). Mapping tillage practices with landstat thematic mapper based logistic regression models. *Journal of Soil and Water Conservation Ankeny* **56**, 91-96.

Hartkamp, A. D., White, J. W., Rossing, W. A. H., van Ittersum, M. K., Bakker, E. J., and Rabbinge, R. (2004). Regional application of a cropping systems simulation model: crop residue retention in maize production systems of Jalisco, Mexico. *Agricultural Systems*, Vol. 81, pp.117-138.

Hébrard, O., Voltz, M., Andrieux, P., Moussa R. (2006). Spatio-temporal distribution of soil surface moisture in a heterogeneously farmed Mediterranean catchment. *Journal of Hydrology*, In Press, corrected proof available online.

IFEN (2002). "Bilan annuel 2002," IFEN.

Katerji, N., Bruckler, L., and Debaeke, P. (2002). L'eau, l'agriculture et l'environnement : analyse introductive à une réflexion sur la contribution de la recherche agronomique. *Courrier de l'environnement de l'INRA* **46**, 39-50.

Knox, J. W., Weatherhead, E. K., and Bradley, R. I. (1996). Mapping the spatial distribution of volumetric irrigation water requirements for maincrop potatoes in England and Wales. *Agricultural Water Management* **31**, 1-15.

Lagacherie, P., C. Collin-Bellier, and Goma-Fortin, N. (2001). Evaluation et analyse de la variabilité spatiale de la mortalité des ceps dans un vignoble languedocien à partir de photographies aériennes à haute résolution. *J. Int. Sci. Vigne Vin (Journal International des sciences de la vigne et du vin)* , Vol 35(3), pp. 141-148.

Lennartz, B., Louchard, X., Voltz, M., and Andrieux, P. (1997). Diuron and simazine losses to runoff water in mediterranean vineyards. *Journal of Environmental Quality* **26**, 1493-1502.

Leonard, J., Andrieux, P., (1998). Infiltration characteristics of soils in Mediterranean vineyards in Southern France. *Catena*, 32, 209-223.

Louchart, X., Voltz, M., and Andrieux, P. (1999). Herbicides Run-off from Field to Catchment Scale in a Mediterranean Area. *In* "24e Congrès EGS", Vol. 1, pp. 281.

Louchart, X., Voltz, M., Andrieux, P., and Moussa, R. (2001). Herbicide Transport to Surface Waters at Field and Watershed Scales in a Mediterranean Vineyard Area. *Journal of Environmental Quality* **30**, 982-991.

Mignolet, C., Schott, C., and Benoît , M. (2004). Spatial dynamics of agricultural practices on a basin territory: a retrospective study to simulate nitrate flow. The case of the Seine basin. *Agronomie* **24**, 219-236.

Moussa, R., Voltz, M., Andrieux, P. and Lagacherie, P. (2000). "Hydrological modelling of flood events in a farmed Mediterranean catchment," in Claps, P., and Sicardi, F. (Eds): *Mediterranean storms*, Editoriale Bios, Cosenza, Italy, 377-386.

Moussa, R., Voltz, M., and Andrieux, P. (2002). Effects of the spatial organization of agricultural management on the hydrological behavior of a farmed catchment during flood events. *Hydrological Processes.* **16**, 393-412.

Novotny, V. (1999). Diffuse pollution from agriculture - a worldwide outlook. *Water Science and Technology* **39**, 1-13.

Power, M. (1993). Predictive validation of ecological and environmental models. *Ecological Modelling* **68**, 33-50.

South, S., Qi, J., and Lusch, D. P. (2004). Optimal classification methods for mapping agricultural tillage practices. *Remote sensing of Environment* **91**, 90-97.

Tassinari, C., (1998). Contribution à l'étude de sols méditerranéens (Languedoc-France). Caractérisation de leurs nappes et des indicateurs morphologiques associés. Thèse. Ecole Nationale Supérieure Agronomique.155 p.

Uhlenbrook, S., Roser, S., and Tilch, N. (2004). Hydrological process representation at the meso-scale : the potential of a distributed, conceptual catchment model. *Journal of Hydrology* **291**, 278-296.

van Deventer, A. P., Ward, A. D., Gowda, P. H., and Lyon, J. G. (1997). Using thematic mapper data to identify contrasting soil plains and tillage practices. *Photogrammetric Engineerin and Remote Sensing* **63**, 87-93.

Wassenar, T., Baret, F., Robbez-Masson, J.-M., and Andrieux, P. (2001). Sunlit soil surface extraction from remotely sensed imagery of perennial, discontinuous crop areas; the case of Mediterranean vineyards. *Agronomie* **21**, 235-245.

Wood, E. F., Sivapalan, M., Beven, K., and Band, L. (1988). Effects of spatial variability and scale with implications to hydrologic modelling. *Journal of Hydrology* **102,** 29-47.

Woods, R., Sivapalan, M., and Duncan M. (1995). Investigating the representative elementary area concept: an approach based on field data. *Hydrological Processes* **9**, 291-312.