Co-constructing with stakeholders a role-playing game to initiate collective management of erosive runoff risks at the watershed scale

Véronique Souchère a,*, Laurent Millair a, Javier Echeverria a, François Bousquet b, Christophe Le Page c, Michel Etienne d

a UMR SADAPT, B. P. 1, 78850 Thiverval Grignon, France
b CIRAD Green, TA 60/15 Campus de Baillarguet, 34398 Montpellier Cedex 5, France
c CIRAD Green, Dpt. of Biology, Chulalongkorn University, 254 Phayathai Road, Pathumwan, Bangkok 10330, Thailand
d INRA SAD – Unité Ecodéveloppement, Site Agroparc, 84914 Avignon Cedex 9, France

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A B S T R A C T

Erosive runoff is a recurring problem and is a source of sometimes deadly muddy floods in the Pays de Caux (France). The risk results from a conjunction of natural factors and human activity. Efficient actions against runoff in agricultural watersheds are well known. However they are still difficult to implement as they require co-operation between stakeholders. Local actors thus need tools to help them understand the collective consequences of their individual decisions and help to initiate a process of negotiation between them. We decided to use a participatory approach called companion modelling (ComMod), and, in close collaboration with one of the first group of local stakeholders, to create a role-playing game (RPG) to facilitate negotiations on the future management of erosive runoff. This paper describes and discusses the development of the RPG and its use with other groups of local stakeholders within the framework of two game sessions organized by two different watershed management committees. During the joint construction step, stakeholders shared their viewpoints about the environment, agents, rules, and how to model runoff in preparation for the creation of the RPG. During the RPG sessions, two groups of eight players, including farmers, mayors and watershed advisors, were confronted with disastrous runoff in a fictive agricultural watershed. Results showed that they managed to reduce runoff by 20–50% by engaging a dialogue about grass strips, storage ponds and management of the intercrop period. However, further progress is still needed to better control runoff through the implementation of better agricultural practices because, during the RPG sessions, the watershed advisors did not encourage farmers to do so. Because of the complexity of management problems, results of jointly constructing the game and the RPG sessions showed that modelling and simulation can be a very useful way of accompanying the collective learning process. This new way of working was welcomed by the participants who expressed their interest in organizing further RPG sessions.

1. Introduction

The Pays de Caux is a very productive agricultural area in Upper Normandy (France) with a large number of areas with erosive phenomena. From a socio-economic point of view, erosive damage affects both agricultural and non-agricultural land, off-site damage being the most dramatic with muddy floods sometimes leading to the death of people. After the construction of storm basins to solve the problem, it appeared necessary to combine a remedial approach with a preventive process to reduce runoff from agricultural land. Various studies have shown that agricultural practices have a marked influence on the hydrographic structure of cultivated watersheds (Auzet et al., 1995; Souchère et al., 1998, 2003; Govers et al., 2000; Takken et al., 2001). Indeed, interactions between meteorological conditions, farming operations and the texture of the topsoil can lead to rapid and significant changes in the hydraulic properties of silty topsoil (often less than 15% clay). Rainfall causes a sedimentary crust to appear on the soil surface, which reduces infiltration capacity from 50 to 60 mm h⁻¹ for seedbeds to only 1–2 mm h⁻¹ for the sedimentary crust (Boiffin et al., 1988). Even low intensity rainfall (under 10 mm h⁻¹) is enough to lead to degradation of the soil surface. At the same time, soil surface roughness is also altered, which reduces depression...
storage (Govers et al., 2000). Agricultural practices can lead to varying rates of spatial and temporal degradation of the soil surface.

To reduce damage, runoff has to be controlled not only in the field (i.e. where runoff is produced), but also at the scale of the watershed (i.e. where runoff concentrates and accumulates). As runoff flows down a slope and does not respect the limits of fields and farms, the actions that need to be undertaken require cooperation between stakeholders. But designing collective management of agricultural land is all the more difficult because the economic context means that farmers focus primarily on productive and individual strategies. As producers, they only take damage into account insofar as it affects their own crops. As individuals, their management of space is limited to the land that makes up their farm, and they consequently do not consider the continuity of the physical phenomena concerned. To design collective management of a watershed is a real challenge especially since environmental management, is controlled by natural processes, meaning that actors are not free to choose how they wish to cooperate in a given watershed. Further complexity is also due to the heterogeneity of the environment and the diversity of interactions between different natural and human entities.

We believe that collective management can be addressed by enabling stakeholders to discover different points of view. Their shared perceptions can then be used to facilitate stakeholder coordination and negotiation mechanisms. The challenge is therefore to supply local actors with tools to help them to see the collective consequences of their individual decisions and to initiate a process of negotiation between them with the final aim of creating integrated management of the watershed. In the process, simulation tools can be used to define, simulate, and discuss different options to facilitate the emergence of socially, economically and ecologically acceptable courses of action through improved stakeholder interactions (Roling, 1996; Ferreyra and Beard, 2007; Ahrends et al., 2008). To achieve this goal, user consultation during the design and implementation stages of the system is essential (Lam et al., 2004; Liu et al., 2008; Martinez-Santos et al., 2008). Companion Modelling (ComMod) is a community-based scientific approach that emerged in the 1990s to facilitate collective action (Collectif ComMod, 2006). It combines Multi-Agent Systems (MAS) and role-playing games (RPG) to facilitate dialogue between the different stakeholders concerned by a given local issue of natural resource management (Bousquet et al., 1999). Several field experiments have demonstrated the effectiveness of such an approach to facilitate dialogue, shared learning, negotiation, and collective decision making among multiple stakeholders (Etienne et al., 2003; Barreteau et al., 2007; Bousquet et al., 2007; Mathevet et al., 2007; Becu et al., 2008). This can be done through the collective construction of a common artificial world leading to the emergence of a shared representation of the complex system and problem.

In 2006, a project to measure the effects of the application of ComMod approach in different countries was proposed to the French National Research Agency as part of the “Agriculture and Sustainable Development” Programme. The objective of this project, which was based on the comparison of about twenty case studies, was to propose and test a method to assess the ComMod approach on collective decision making, the implication of researchers and stakeholders in the process, its impact on the social networks, and sustainability. This article focuses on the Pays de Caux case study where the ComMod approach was tested with stakeholders in the framework of the above-mentioned project. The paper describes and discusses the development of the ComMod approach. The first part identifies the main questions involved in this approach and describes the process of collective construction of the conceptual model of the RPG. The second part is devoted to the RPG called “CauxOpération” and describes the representation of environment in the form of a game board, the erosive runoff model, and the agents involved. The third part describes how stakeholders played the game. Before concluding, we discuss the interest of such an approach based on the results of the first two RPG sessions held.

2. Collective construction of the conceptual model for the role-playing game

At the beginning of 2006, we proposed to local stakeholders concerned by erosive runoff to use a ComMod approach to design a role-playing game called “CauxOpération” to promote collective watershed management of erosive runoff. As the stakeholders needed tools to help them initiate a process of co-operation between themselves, they were happy to play an active role in constructing the RPG and testing it with other local stakeholders. They also agreed to participate on a voluntary basis because they already had previous experience of working with the scientists in charge of this study. So, this initiative, which originated entirely within the scientific community, resulted in the creation of a group about 15 people (researchers and stakeholders) who worked together for two years. The participants selected by the scientists belonged to the extension services who manage runoff problems in the field (Regional association for soil preservation, Farmers’ association, watershed management committees), institutions that finance the remedial or preventive measures (Water Agency, District Council and Regional Council). Other participants (farmers) were also invited because their practices can have a direct impact on erosive runoff. Lastly, mayors were also invited to take part because they are responsible for cleaning up and repairing their villages and roads after a muddy flood. Thanks to their local experience, all the participants were able to speak on behalf of all the stakeholders with whom they came into contact. Fig. 1 shows the main stages in the study which are based on back and forth steps between the model and the field. Changes in the timeline and in the stakeholders involved in the ComMod process are also specified.

During the first half-day workshop in January 2006, we identified the main questions involved in implementing the approach. The 15 stakeholders agreed on two main questions that the computer tool would have to take into account:

- How to engage and support a dialogue between stakeholders about the management of erosive runoff that would include the implementation of both better agricultural practices and landscape structures.
- How to simultaneously account for production issues and environmental stakes.

Then, during two other one-day workshops in May and June 2006, we worked with the group to build the conceptual model of the role-playing game based on the ARDI method (Etienne et al., 2008). Our objective was to collectively identify the main stakeholder concerns about the erosion issue, the entities they manage and the main dynamics and interactions at play according to different temporal and spatial scales. We asked the group four successive questions (Etienne et al., 2008):

1. Who are the main stakeholders who play a decisive role in managing runoff in this territory?
2. What are the main resources of the territory?
3. What are the main ecological dynamics at stake, and how are they impacted by stakeholders? How does each stakeholder use the desired resources and modify the runoff processes?
4. The answers to these questions were then represented in four simple diagrams (diagram of stakeholders and management entities, diagram of resources, diagram of dynamics and diagram of interactions). They were
designed to be easily translated into computer language. The diagrams were elaborated on the basis of the information supplied by the group in several rounds to allow speaking time to be fairly distributed among the participants. The diagrams were then displayed on a screen and completed according to proposals made by participants, which were discussed and validated by all the participants. The exercise had a time limit (about one half-day per question). Fig. 2 shows an extract of the diagram of interactions built during this step. The interactions between stakeholders and resources or among stakeholders are symbolized by arrows associated with verbs that describe the type of action. This diagram served as a support for implementing the model.

At the end of the workshops, we had obtained all the elements we needed to begin implementing the role-playing game called “CauxOpération” i.e. a set of relationships between stakeholders, a time frame and space, and a range of possible actions. Between June 2006 and June 2007, we alternated periods of implementing the RPG and meetings with the group to validate the tool built with their collaboration. At these meetings, we proposed a set of proposals and their alternatives. In return, the participants helped us to clarify or eliminate some of the proposals. They also suggested new proposals. Step by step, the RPG was built starting with the points on which all the participants agreed. During this period, over a hundred proposals were submitted for discussion before we managed to build the first version of the “CauxOpération” RPG described below.

3. Description of “CauxOpération”

The co-constructed conceptual model was implemented by the research team in an agent-based model under the Cormas platform (Common-pool Resources and Multi-Agent Systems) which is designed to understand and simulate complex resource management systems (Bousquet et al., 1998). Cormas provides a framework to represent the different components of the decisions made by agents and, as a result, to estimate runoff flow and agents’ incomes at each round of the RPG. Fig. 3 shows the class diagram of “CauxOpération” with entities, attributes, methods, and their relationships. As four points were discussed in some detail during working meetings, we chose to focus the description of “CauxOpération” on these points i.e. representation of environment, erosive runoff modelling, agents, and the temporal and climate scenario of the game.

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3.1. Representations of the environment used as the game board

During the workshops, participants from the extension services that manage erosive runoff persuaded all the other participants that the field scale is the most appropriate scale to control erosive runoff. So the participants decided together that the game board must be made up of juxtaposed fields. But to represent components of actors’ decisions, all the participants agreed that this would not be sufficient. Farm and watershed scales were also essential. The farm scale represents the farmer’s decision while the watershed scale is the most appropriate to visualize the spatial interdependence of fields and to be aware of off-site environmental impacts. The discussions between participants led us to progressively elaborate a map of the watershed, which was used to represent the environment in “CauxOpération”. To allow the players to make relatively realistic decisions during the RPG sessions, the participants chose to create a virtual but nevertheless realistic watershed. As the objective was to organize several RPG sessions with different local actors, participants preferred to build a more general watershed map as it would be easier to compare the results of all the RPG sessions if the same map was used by players all over the Pays de Caux. To draw the map of the watershed, the group discussed the positions of the road and the village as well as the location and the ratio of grasslands and woodlands to arable land. Grassland was located on slopes of more than 10% as is the case in real life. The size of the fields varied to give the farmers maximum choice of cropping patterns. Fig. 4 shows the game board derived from a real watershed which was validated by the participants. Fields cover an area of 675 ha (of which 85 ha of grassland and 15 ha of forest), divided into 133 individual fields. The size of cropped fields varies from 3 to 20 ha, while that of grassland varies from 3 to 7 ha. The village is located at the outlet of the watershed. Its location means the control of runoff erosion is of utmost importance because people are directly involved. The road crosses the watershed at the centre. Different viewpoints were implemented at the request of the participants during the joint construction workshops in order to display environmental changes based on agents’ choices. For example, the land-use viewpoint includes 23 land-use types (9 types of crops, 2 types of set-aside, 6 types of management of the intercrop period, grassland, forest, road, urban areas, grass strip and storage pond).

3.2. Modelling erosive runoff

During the workshop, participants also discussed the choice of a biophysical model to be implemented in the agent-based model to calculate runoff volume. In the Pays de Caux – as in other regions – the main consequences of erosive runoff occur both on-site and off-site. In such a situation, models that integrate a Geographical Information System (GIS) have become important tools for process analysis and for the development and assessment of management scenarios within a watershed (Baigorria and Romero, 2007; He, 2003; Yeh et al., 2006). Concerning runoff models in the context of silty soils, they have evolved considerably over the last few years, taking into account the temporal evolution and spatial organization of soil surfaces. This is the case of the model called STREAM (Sealing and Transfer by Runoff and Erosion related to Agricultural Management), which was developed in ArcGIS by several teams of the French National Institute for Agronomic Research (INRA). STREAM is a non-dynamic model using a raster-based distributed approach that calculates runoff volume and soil loss within a watershed for a given rainfall event (Cerdan et al., 2002a,b; Le Bissonnais et al., 2005; Souchère et al., 1998). As some participants from extension services knew the STREAM model, they considered it to be particularly suitable for their context. The model explicitly takes
into account soil surface characteristics (i.e. crusting and roughness) to derive infiltration rates and soil surface erodibility, and agrarian features to create the runoff circulation network. So they proposed to use it as biophysical model to calculate runoff volume in the agent-based model. However, as the farmers do not question their choice of cropping pattern after every rainfall event, the participants proposed that the agent-based model estimate runoff volume only twice a year, in December and June. During these two periods, the soil surface conditions are stable with no major changes due to farming activities, but the climatic risks are important. The state of degradation of the surface in December depends on farmers' choices during the first part of the crop year (proportion and location of winter crops, management of the intercrop period, crop management sequence) whereas in June, the state of degradation depends on farmers' choices during the second part of the crop year (proportion and location of spring crops, crop management sequence).

In the STREAM model, the runoff volume is estimated in two steps. During the first step, the potentially infiltrated water depth for all the pixels and for a given rainfall event is calculated by Eq. (1) which is implemented in the agent-based model by means of a cellular automaton:

\[
\text{Infiltration/runoff balance} = R - IR - (IC \times t)
\]

where \(R\) is the rainfall amount in mm, \(IR\) is the amount of rainfall needed to reach soil saturation in mm, \(IC\) is the infiltration capacity class in mm \(-1\) and \(t\) is the duration of the rainfall in min.

To apply this equation, first an infiltration capacity class has to be allocated to each field. In STREAM, the values of infiltration capacity range from 2 to 50 mm h \(-1\) depending on the combination of parameters: surface state degradation, roughness and crop cover. In our case, participants chose to keep the same range of values but to directly set an infiltration capacity average to each potential land use in the two periods (Table 1). This simplification was possible because Joannon (2004) matched crops with soil surface characteristics by analyzing several data sources: plot level survey, results from tests carried out with a rainfall simulator, and knowledge from local specialists. Then, a rainfall event representing the climatic conditions of the two periods (June and December) had to be defined in order to obtain \(R\), \(IR\) and \(t\) parameters. Participants decided to force climate parameters. They attempted to cause a rapid increase in the awareness of players by increasing the probability of the occurrence of catastrophic rainfall events in order to quickly act out the results of implementing solutions. As a result, four rainfall events were selected from expert knowledge: one average event and one disastrous rainfall event for each period (Table 2). When all the parameters are known, the equation can be applied and the infiltration/runoff balance value indicates whether
the pixel will generate runoff (positive balance value) or on the contrary will infiltrate, in addition to the rainfall, a potential upstream runoff (negative balance value).

The second step of the modelling consists in incorporating the infiltration/runoff balance at the catchment scale. First, the runoff circulation network has to be built to take into account the specific processes at this scale. In cultivated fields on gentle slopes, several studies showed the flow direction of runoff is not always controlled by the direction of the slope. Accounting for tillage direction and preferential flow paths like dead furrows, dirt tracks or ditches allow a flow network to be computed that better represents the real water flow network (Cerdan et al., 2002b). In STREAM, the flow direction can be modified following some rules described in Soucchère et al. (1998). The method used is based on the modification of the flow direction network model computed from a Digital Elevation Model only. But the introduction of constrained flow direction due to human-induced features in a topographic flow direction model generates some artefacts (converging flows, flow loops, crossing flows, etc) which renders the flow network inappropriate for hydrological processing. Furthermore, when the tillage direction is translated into a flow direction, a drift in the modeled flow direction is induced. Indeed, the flow directions on the square grids are set in 45° increments only and intermediate directions cannot be modeled at the scale of a single grid cell. The drift leads to misrepresentation of the flow network and miscalculation of the cumulated flow. Before computing the new flow direction from each cell into one of its eight neighbouring cells, all these problems must be corrected. As processing makes intensive use of the ArcGis software, it was too difficult to implement these modifications in the agent-based model under Cormas. As taking into account human-induced features were essential for participants, we decided to run STREAM with the previously presented game board in order to build a flow network that accounts for agricultural activities. The raster “Flow direction” from STREAM is then combined with the balance runoff/infiltration value inside the cellular automaton in order to calculate the flow accumulation i.e. runoff volume for each pixel of 400 m² belonging to the watershed (Fig. 5). The choice of the pixel size is the result of a compromise between the ability to rapidly calculate runoff risks at the watershed scale and to accurately visualize each pixel in order to change land use according to the decisions made by the players.

3.3. Agent components

Agents are model representations of stakeholders who play a key role i.e. those whose practices have a direct impact on runoff dynamics. Three types of agents were identified during the working meetings: watershed advisors, the mayor, and farmers. Participants

Table 1

<table>
<thead>
<tr>
<th>Land uses</th>
<th>Winter (December)</th>
<th>Summer (June)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Standard practices (mm/h)</td>
<td>Best practices (mm/h)</td>
</tr>
<tr>
<td>Cereals (winter wheat or winter barley)</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>Rape</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>Fields left untilled after harvesting (cereals or rape)</td>
<td>2</td>
<td>Superficial tillage with ploughshare tool</td>
</tr>
<tr>
<td>fields left untilled after harvesting (other crops)</td>
<td>5</td>
<td>NC</td>
</tr>
<tr>
<td>Superficial tillage with plough disc</td>
<td>10</td>
<td>Cover crop</td>
</tr>
<tr>
<td>Superficial tillage with plough tine</td>
<td>NC</td>
<td>20</td>
</tr>
<tr>
<td>Cover crop (mustard)</td>
<td>NC</td>
<td>20</td>
</tr>
<tr>
<td>Flax</td>
<td>NC</td>
<td>NC</td>
</tr>
<tr>
<td>Silage maize</td>
<td>NC</td>
<td>NC</td>
</tr>
<tr>
<td>Sugar Beet</td>
<td>NC</td>
<td>NC</td>
</tr>
<tr>
<td>Pea</td>
<td>NC</td>
<td>NC</td>
</tr>
<tr>
<td>Potato</td>
<td>NC</td>
<td>NC</td>
</tr>
<tr>
<td>Permanent Grassland</td>
<td>50</td>
<td>NC</td>
</tr>
<tr>
<td>Set-aside for environmental use (grass)</td>
<td>50</td>
<td>NC</td>
</tr>
<tr>
<td>Set-aside for energy use (Rape)</td>
<td>5</td>
<td>NC</td>
</tr>
</tbody>
</table>

* NC: Not concerned.

Table 2

<table>
<thead>
<tr>
<th>Crop year</th>
<th>Round</th>
<th>Type of rainfall event</th>
<th>Period</th>
<th>t* (min)</th>
<th>R* (mm)</th>
<th>IR* (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>A</td>
<td>December</td>
<td>2</td>
<td>15</td>
<td>20</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>B</td>
<td>June</td>
<td>2</td>
<td>15</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>C</td>
<td>December</td>
<td>2</td>
<td>31</td>
<td>20</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>D</td>
<td>June</td>
<td>2</td>
<td>31</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>A</td>
<td>December</td>
<td>2</td>
<td>15</td>
<td>20</td>
</tr>
<tr>
<td>6</td>
<td>6</td>
<td>B</td>
<td>June</td>
<td>2</td>
<td>15</td>
<td>0</td>
</tr>
<tr>
<td>7</td>
<td>7</td>
<td>C</td>
<td>December</td>
<td>2</td>
<td>31</td>
<td>20</td>
</tr>
<tr>
<td>8</td>
<td>8</td>
<td>D</td>
<td>June</td>
<td>2</td>
<td>31</td>
<td>0</td>
</tr>
</tbody>
</table>

* Duration of rainfall event.
* Rainfall amount.
* Rainfall amount needed to reach soil saturation.
spent a lot of time discussing agent-farmers, who were finally divided into three subcategories according to their farming system: cash crop farm, cattle farm or dairy farm. Based on data provided by the Seine Maritime Farmers’ Association, we selected six types of farmers who were the most representative in each previously selected sub-category. The types were distinguished by farm output, usable agricultural area (UAA) from 60 ha to 180 ha (distribution between grassland and cropped fields), cropping pattern (average output per year) and the destination of animal products. We proposed: dairy farm (intensive milk production), cattle breeding and cattle raising and cash crop farms (potato grower, beet and flax grower and cereal grower). Cash crop farms were distinguished by their most profitable crop. Each type was then located on the previously presented game board. The dairy and cattle farms were located near the watershed outlet because of the location of grassland and the cash crop farms were located on less steep areas, which is also characteristic of the region (Fig. 6).

But in the game, agent-farmers do not own a farm with all their fields grouped in a single unit. Each has a few scattered fields upstream and downstream to make them more concerned with the problems at the watershed scale during the game sessions. Participants validated the location and types of farms except for the cereal farm, which was rejected because it was not representative of farms in the Pays de Caux. They asked us to add a second beet and flax grower instead to increase the proportion of these two crops in the watershed.

We also proposed to calculate the income of agent-farmers in two ways: based on a price per crop, which is common to all farmers, or based on gross margins per crop (or livestock) for each type of farm. The latter option was preferred by the stakeholders because it makes it easier to distinguish the different types. We used a group survey conducted by the Centre for Rural Economy of Seine-Maritime in 2005 (about 760 farms) to determine gross margins, overheads, financial expenses, depreciation and annuities for each type of farmer. Subsidies related to the Common Agricultural Policy (CAP) were also integrated. We considered that the financial data should not change during the game. For example, gross margins per crop do not evolve except if farmers changed their agricultural practices. Our aim was not to make a thorough economic analysis of the impact of the introduction of measures to manage the runoff, but simply to depict a sufficiently realistic economic functioning.

Each kind of agent is characterized by specific attributes and sets of actions (Fig. 3 and Table 3) which were discussed during working meetings. In the agent-based model, some attributes are used to

Table 3
Specific attributes and sets of actions for each agent.

<table>
<thead>
<tr>
<th>Agents</th>
<th>Actions</th>
<th>Spatial level of decision</th>
</tr>
</thead>
<tbody>
<tr>
<td>Farmers</td>
<td>Choose crops and practices (standard or better practices)</td>
<td>Farm, Field</td>
</tr>
<tr>
<td></td>
<td>Implement water management without subsidy</td>
<td>Field, Cell</td>
</tr>
<tr>
<td>Watershed</td>
<td>Analyzes runoff risks</td>
<td>Watershed</td>
</tr>
<tr>
<td>Advisor</td>
<td>Finances the implementation of cover crops</td>
<td>Field</td>
</tr>
<tr>
<td></td>
<td>Negotiates the implementation of water managements (location, subsidy)</td>
<td>Field, Cell</td>
</tr>
<tr>
<td>Mayor</td>
<td>Analyzes runoff risks</td>
<td>Watershed</td>
</tr>
<tr>
<td></td>
<td>Invites all other players or a sub-group of players to one or several meetings each agricultural year to discuss runoff risks</td>
<td>Watershed</td>
</tr>
<tr>
<td></td>
<td>Finances the implementation of cover crops</td>
<td>Field</td>
</tr>
<tr>
<td></td>
<td>Co-finances the implementation of water management (grass strips or storage pond)</td>
<td>Field, Cell</td>
</tr>
</tbody>
</table>
define the cost of actions that can be undertaken by players during RPG sessions in order to calculate agents’ incomes. Currently, the agent-based model integrates no behavioural rules. We chose to define the rules by means of several RPG sessions and individual interviews with RPG players. They will be implemented in 2009 in the framework of a future PhD.

4. Playing the game

As stakeholder participation is sometimes quite difficult to obtain given their lack of availability, careful attention should be paid to the invitation process (Etienne et al., 2008). Since 1999, 20 watershed management committees corresponding to the main catchments have been set up by the public authorities throughout Seine-Maritime, one of the two departments of Upper Normandy. Supported by existing political structures (prefectures, water agencies, districts, communities of communes, etc.), the watershed management committees benefit from a transfer of competencies on environmental matters through the creation and maintenance of any undertaking aimed at curbing runoff and erosion. As they have the authority to urge the stakeholders to discuss runoff prevention, we decided to ask one or more watershed management committees to organize the RPG sessions and invite the players. As the watershed advisor of the watershed management committees called “Dun-Veules” had participated in the collective constructing of the RPG, she offered to be responsible for organizing the first session in her territory. We asked another watershed management committee to organize the second session. Our choice was the area “Pointe de Caux” where runoff is frequent and where the farmers are, more often than anywhere else, accused of being the cause of this situation. It was also the occasion to mobilize a new watershed advisor who was able to discover the game by using it. Each session was held in the village hall or the town hall in one of the villages belonging to the watershed management committee. Concerning the invitation, we asked the watershed advisor to choose farmers and a mayor located in the same sub-watershed. The idea was that the players, who are neighbours both in the game and in the real world, will be more likely to implement in their territories, the strategies they have tested during a game session. Eight different players were invited to each session: six farmers, one mayor and the agricultural watershed advisor. The game is played by individuals who play their real-life role. It is essential to use the stakeholders’ input and feedback from the RPG sessions to build a more complete agent-based model. Each session is characterized by three steps: a briefing, a game session and a debriefing.

The briefing lasts for 5–10 min. During this time, the facilitator explains the aim of the RPG, takes the players to their place in the room (Fig. 7) and distributes specific information to each player. Farmers receive a map of the watershed on which only their fields are located, and a list of the crops they can produce together with the gross margins per crop. The mayor and the watershed advisor also receive a more detailed map of the watershed where grassland, forests and fields of each farmer are located as well as slopes which are shown by means of contour lines. An imitation of a hydraulic survey is given to the watershed advisor to help him come to a decision. This survey specifies the total length of the grass strips that need to be planted and the total cubic meters of water that need to be stored in one or several new ponds to control erosive runoff at the watershed scale. As he is the technical advisor for the implementation of solutions to reduce runoff, he also receives information about the cost of different actions that may be implemented by players. The mayor and the watershed advisor also receive information about the budget they can devote to reducing runoff. As the budget is insufficient to resolve all the problems, they have to encourage the farmers to modify their practices without grants, especially since runoff carries away sediments that accumulate in storage ponds, which decreases their efficiency and necessitates very expensive cleaning.

The second step, i.e. the game, lasts for 4 h. Our discussions with the group of 15 participants led us to choose a temporal scenario based on four successive agricultural years. The principle, which was validated by the participants, is based on alternating years with average rainfall events and years with disastrous rainfall events (Table 2). This alternation is repeated, which allows the first two years to be compared with the two last years to see the effects of the decisions made by each player. Each agricultural year is divided into two rounds because runoff is calculated in December and in June. There are consequently eight game rounds in each game.

![Fig. 7. Spatial organization of the RPG room.](image-url)
Each round of the game is made up of four steps. First, while the players acting as farmers choose their cropping pattern and allocate a land use to each of their fields, the player acting as a mayor and the player acting as a watershed advisor get together to assess runoff risk at the watershed scale in order to design their strategy to manage erosive runoff. Second, a set of negotiations (two by two) between a farmer and the mayor or a farmer and the watershed advisor takes place in order to identify best agricultural practices. Farmers can only be partially financed to sow a cover crop. Then, each farmer goes to the interactive watershed map to communicate their choice of land use for each field. The computer operator enters the information, runs the model and prints the new watershed runoff map. Third, the facilitator gives the new watershed runoff map to the mayor. The mayor is also informed about damage due to erosive runoff in the village and on the roads crossing the watershed through cards that change depending on the degree of damage. He is also informed about the dissatisfaction of the inhabitants in his village that increases with an increase in damage, which may lead them to vote against him in the next municipal elections. To be re-elected, it is thus important to encourage the other actors to reduce the damage. Finally, the mayor and the watershed advisor organize a meeting at the mayor’s table with all the farmers or with a sub-group of farmers to start negotiating to plant grass strips and/or build ponds. At the end of the negotiation, a decision has to be made on what action to take, where, and who will pay for it. Then the watershed advisor goes to the interactive watershed map to change the land use in the cells for which he managed to negotiate the planting of grass strips and/or the building of ponds. These modifications are then taken into account in the next rounds. The budgets and incomes of the different players (farmers, mayor and watershed advisor) are updated every two rounds (at the end of each agricultural year). Then the facilitator presents the new information to the players. After eight rounds, i.e. four years, the RPG ends.

The last step consists in inviting all the players to discuss what happened during the session. Debriefing lasts for 30–45 min. It is mainly focused on five aspects: i. How the players feel? ii. What they think about the RPG? iii. What were their strategies for the management of the intercrop period, best agricultural practices, and the implementation of solutions for water storage? iv. What happened during the periods of negotiation? v. Did the players become aware of the interest of collective management of the watershed?

5. Results and discussion about the use of the RPG

5.1. Knowledge representation

Except for the watershed advisors, all the players were expecting to attend a normal meeting to tackle the recurring runoff problems in their sector. At the beginning of the meeting, they were thus very surprised but quickly joined in the game. All the players agreed that the gaming parameters represented the real situation. They had no difficulty orienting themselves on the map and understanding the changes that were made between rounds in the game. The parameters used for the RPG were not questioned by the players. The gaming environment, farm types, the opposing stakeholders, their roles and their actions as well as the impacts of the solutions that were implemented were entirely accepted by the players. The same was true for the runoff results provided by the biophysical model in the agent-based model. The watershed advisor also commented that the game was very realistic, as in his opinion, it accurately reproduced the urgency which he and his colleagues sometimes have to face in their work and their inability to completely control the situation.

5.2. Negotiation impacts

To more easily measure the impact of the players’ strategies with regard to runoff, we imagined theoretical game sessions with extreme values of comparison (Fig. 8). The first theoretical game corresponded to a simulation without runoff management. The annual cropping pattern was generated based on typical crop rotations in the region (Joannon et al., 2006) by maximizing runoff risk at the time of the choice of the crop location. The second theoretical game corresponded to a simulation with optimal runoff management by all the players. Depending on their budget, the watershed advisor and mayor collaborate to build ponds that allow

![Fig. 8. Changes in runoff volume at the outlet according to the theoretical or real RPG.](image-url)
13,600 m$^3$ of water to be stored and 3 ha of grass strips to be created. They also finance 956 ha of mustard intercrop over a 4-year period. As far as the farmers are concerned, they apply best agricultural practices without an incentive. Comparison with the first theoretical game showed that, during the two RPG sessions, players managed to reduce runoff by 20–50% depending on the round (Fig. 8), by discussing grass strips, storage ponds and management of intercrop period. Table 4 shows how actions and incentives were shared among the players during the real and the theoretical games. In the game on July 2nd, there was no coordination between the mayor and the watershed advisor about financing solutions. The storage ponds and grass strips were financed exclusively by the watershed advisor. In the July 2nd game, the mayor only provided incentives for cover crops, while in the July 3rd game, together with the watershed advisor, the mayor chose to pay to build two storage ponds, the biggest of which was located upstream from his village. In the July 3rd game, the watershed advisor worked in close collaboration with the mayor. Together they drew up all the strategies after long phases of collective discussion. Together, they identified runoff risks, which players were concerned and how much room for manoeuvre they had to implement different solutions. They estimated their expenses and perfected a strategy to negotiate with the other players. For example, all the meetings with the farmers were led by the two players giving them more opportunity to respond to farmers’ arguments and finally to persuade them to implement the solutions they had designed jointly. The relationship between the mayor and the watershed advisor created a real synergy that enabled better management of runoff risks. During the two sessions, the watershed advisors and mayors chose to finance direct actions (grass strips, storage ponds and cover crops).

The two watershed advisors did not encourage farmers to use best agricultural practices. The aim of these practices is to delay the formation of a crust that reduces the infiltration capacity of silty soils, for example by creating coarser seedbeds (cereals), by sowing earlier (rape) or by avoiding destroying the surface roughness by rolling immediately after sowing (peas). The aim of other practices is to break up an existing crust by mechanical rather than chemical weeding (sugar beet or maize). Finally, for potatoes, the best is to break up an existing crust by mechanical rather than chemical rolling immediately after sowing (peas). The aim of other practices earlier (rape) or by avoiding destroying the surface roughness by rolling immediately after sowing (peas). The aim of other practices is to break up an existing crust by mechanical rather than chemical weeding (sugar beet or maize). Finally, for potatoes, the best is to break up an existing crust by mechanical rather than chemical rolling immediately after sowing (peas). The aim of other practices is to break up an existing crust by mechanical rather than chemical weeding (sugar beet or maize). Finally, for potatoes, the best is to break up an existing crust by mechanical rather than chemical rolling immediately after sowing (peas).

The two watershed advisors decided to present the RPG as a new mediation and collective thinking tool. For the first experiment, they preferred to invite farmers they had already met, especially concerning problems due to erosive runoff. As a consequence, the farmers were already partially aware of the problem before the game started. They knew the technical solutions proposed in the game even if they were still not aware of their actual efficiency. Above all, the RPG sessions provided an opportunity for the players to see the collective consequences of their individual decisions, to share their knowledge, their ideas and their vision of the problem in order to test different strategies to reduce runoff and associated damage. During the two RPG sessions and associated debriefing sessions, participants improved their capacity to understand their role and to act in a complex situation. They understood that erosive runoff concerns not only the inhabitants of the downstream towns, but also their own upstream farms. They managed to reduce runoff and resulting damage by engaging a dialogue about their own agricultural practices. This approach, based on the use of RPG, offers a way of dynamically linking social and environmental processes at different levels (farm and watershed). According to the watershed advisors, the game contributed considerable self-knowledge and improved the way they work with others. It provides an opportunity to present strategies implemented in a classical way as well as strategies which would only introduced effective measures for the winter season by changing their management of the intercrop period. Better management is still possible, especially since the additional cost of their better agricultural practices is not excessive. Depending on the case, additional cost can vary from €0 to €48 per hectare, which is deducted from the gross margin. The absence of additional cost corresponded to the case in which the farmers only have to advance the rape sowing date which does not require the use of other tools or imply additional work. For superficial tillage or mechanical weeding, the additional cost varies between €6 and €18 per hectare depending on the tool used. €48 corresponds to the cost of introducing a cover crop. For potatoes, it was decided during the collective design stage that the use of a specific tool could only be envisaged by joining a CUMA (Cooperative use of agricultural machinery). To this end, each year a lump sum of €150 would be deducted from the farmer’s income as soon as he decided to change his potato cultivation practices. However in real life, introducing changes like these are not always possible due to the crop management sequence or to work schedule constraints (Joannon et al., 2005). This explains why farmers are not very interested in such solutions. However, even if they did not decide to introduce best agricultural practices, in both game sessions the farmers participated actively in the meetings at the town hall. They tried to find solutions that did not upset their cropping pattern. For example, they often decided to implement set-aside for environmental purposes characterized by a better infiltration capacity in the fields located in the talweg. Some farmers ploughed fields upstream to reintroduce grassland rather than cultivated fields where runoff concentrated because of the topography. They accepted the introduction of grass strips or storage ponds on their farm by negotiating their location as well as the price of the agreements paid by the watershed management committee for the rent of the land required. Negotiations between players were intense because by accepting water management on a plot of land, the amount of money the farmers lose varies with the crop and with the area concerned. For crops with a high gross margin such as sugar beet, flax or potatoes, the compensation does not cover their losses.

5.3. Learning and outcomes

The two watershed advisors decided to present the RPG as a new mediation and collective thinking tool. For the first experiment, they preferred to invite farmers they had already met, especially concerning problems due to erosive runoff. As a consequence, the farmers were already partially aware of the problem before the game started. They knew the technical solutions proposed in the game even if they were still not aware of their actual efficiency. Above all, the RPG sessions provided an opportunity for the players to see the collective consequences of their individual decisions, to share their knowledge, their ideas and their vision of the problem in order to test different strategies to reduce runoff and associated damage. During the two RPG sessions and associated debriefing sessions, participants improved their capacity to understand their role and to act in a complex situation. They understood that erosive runoff concerns not only the inhabitants of the downstream towns, but also their own upstream farms. They managed to reduce runoff and resulting damage by engaging a dialogue about their own agricultural practices. This approach, based on the use of RPG, offers a way of dynamically linking social and environmental processes at different levels (farm and watershed). According to the watershed advisors, the game contributed considerable self-knowledge and improved the way they work with others. It provides an opportunity to present strategies implemented in a classical way as well as strategies which would

Table 4

<table>
<thead>
<tr>
<th>Actions implemented during each theoretical or real game and expenditure of the two players most concerned.</th>
<th>Theoretical game</th>
<th>Real game 2 July 2007</th>
<th>Real game 3 July 2007</th>
<th>Theoretical game runoff management</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cover crop</td>
<td>0%</td>
<td>586 ha</td>
<td>399 ha</td>
<td>956 ha</td>
</tr>
<tr>
<td>Paid for by:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Farmer</td>
<td>0%</td>
<td>28%</td>
<td>5%</td>
<td>0%</td>
</tr>
<tr>
<td>Mayor</td>
<td>0%</td>
<td>44%</td>
<td>0%</td>
<td>16%</td>
</tr>
<tr>
<td>Watershed Advisor</td>
<td>0%</td>
<td>28%</td>
<td>95%</td>
<td>84%</td>
</tr>
<tr>
<td>Grass strip</td>
<td>0 ha</td>
<td>1.8 ha</td>
<td>1.7 ha</td>
<td>3 ha</td>
</tr>
<tr>
<td>Water storage</td>
<td>0 m$^3$</td>
<td>8000 m$^3$</td>
<td>12800 m$^3$</td>
<td>13600 m$^3$</td>
</tr>
<tr>
<td>Better agricultural practices</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>100%</td>
</tr>
<tr>
<td>Watershed Advisor's budget spent</td>
<td>0%</td>
<td>52%</td>
<td>90%</td>
<td>100%</td>
</tr>
<tr>
<td>Mayor's budget spent</td>
<td>0%</td>
<td>12%</td>
<td>46%</td>
<td>100%</td>
</tr>
</tbody>
</table>

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normally never be taken into consideration due to prejudice. The game thus provides the opportunity to question the impression
given by the watershed advisors that everything has already been
achieved and nothing else will be required. The game identified
a new lever of action for the watershed advisors other than
communication via the organization of collective meetings.

The representatives of the extension services and the institu-
tions who participated in the collective construction of the RPG
were able to learn several lessons from observing the game
sessions. In real life, since 2001 farmers have been declaring the
surface area of land under cover crops to the watershed advisor and
receive a voucher to obtain cover crop seeds from their cooperative
free of charge. In the framework of the game, if the farmer did not
obtain the agreement of the watershed management committee in
the form of a card on which watershed advisor noted the area of
land under the cover crop he agreed to finance, the farmer had to
finance the cover crop himself. During the first game round,
farmers did not discuss this point with the watershed advisor.
When they went to the watershed interactive map to specify their
choices of land use, the computer operator asked to see the card.
Informed about the consequences of failing to present the card,
major farmers then corrected their sheet by changing the land use of
field concerned to avoid having to pay. From the second round until
the end of the game, no cover crop was sown without outside financing.
This was interesting behaviour as outside financing is
currently being questioned in real life. The extension services and
the institutions previously had the impression that, given the effi-
ciency of this measure to limit runoff, farmers would agree to
continue plant cover crops in winter even without financing.
Observing the farmers’ behaviour during the game sessions made
them realize that they should expect a decrease in the area of land
under cover crops without regulation.

5.4. Agent-based model and improvement of the RPG

After the first two game sessions, we modified the agent-based
model to take the players’ behaviour into account. The modifica-
tions resulted from our observation of the players during game
sessions or players’ suggestions voiced during the debriefing
sessions. For example, we had not envisaged that storage ponds
could be jointly financed by the mayor and the watershed advisor.
During the July 3rd game, the mayor financed one fifth of the value
of each storage pond built. We rewrote the method used by the
program to change the land use of cells intended to receive a
storage pond while at the same time debiting the budget of the
player who desired the change. The model allocates 100% of the
cost of the storage pond to the budget of one of the players (mayor
or watershed advisor). The model now also accepts shared costs if
the two players decide to jointly allocate the cost to their two
budgets according to the share they negotiate during the game.

During debriefing sessions, all the players confirmed the interest
of using “CauxOpération” as an awareness-raising tool throughout
the Pays de Caux. The watershed advisors were very interested in
conducting the same experiment in all vulnerable sub-watersheds
managed by their watershed management committee. They also
suggested using it to test different scenarios such as the introduc-
tion of a new agri-environmental measure or stopping subsidies for
cover crops for example. This would enable them to anticipate
farmers’ reactions and may be – through the game – find convincing
arguments to better change their behaviour in real life. For the
moment, “CauxOpération” is simply a learning experience and it is
not possible to foresee whether any regulations will result.
The interest is to see if the RPG would be able to create new behaviours
among the farmers who participated in the game sessions. However
such changes can only be assessed in the long term.

6. Conclusion

The aim of this study was not to build a model to predict the
future state of the environment, but to use a continuously evolving
model to support discussions among stakeholders about the
system to be managed and to explore possible future scenarios.
Because of the complexity of the management problems, the
results of the collective design and of the game sessions showed
that modelling and simulation can be very useful to accompany
a collective learning process. The RPG made the participants aware
of their own responsibilities and encouraged them to engage in
negotiations between themselves to improve runoff management.
For the watershed advisors, the RPG allowed them to test the
interest of organizing meetings with all the farmers concerned to
design a collective management strategy for runoff. Until now, they
usually only had discussions with individual farmers. They also
noticed that they did not sufficiently encourage the farmers to
change their agricultural practices or to adopt best agricultural
practices. They really tend to favour grass strips and storage ponds
because they believe they are most effective actions. This new way
of working was welcomed by all the participants, farmers and
mayors included. The watershed advisors who took part in the July
2nd and 3rd RPGs as well as local stakeholders who manage the
problems (extension services) and/or finance the measures (water
agencies) expressed a wish that other RPG sessions be organized in
the 20 watershed management committees of the Seine-Maritime
Department.

The first results of this work are particularly interesting at the
regional but also European level. Indeed, runoff and soil erosion are
among the major environmental threats related to agricultural land
use in Europe. In recent decades, European research has contrib-
uted to improving our understanding of soil erosion processes and
of runoff and soil erosion modelling at different scales (from the
plot to the regional scale), and of associated off-site impacts.
However, the transformation of scientific achievements into inno-
vation and optimisation of soil conservation and land management
has remained very limited. There are still large gaps between our
knowledge of the processes of runoff and erosion, and their use in
soil protection from the farm to the watershed scale. One reason for
the lack of implementation may be that soil conservation has too
often been understood as being predominantly a technical
problem, while economic, environmental, political and social
aspects have been ignored. The ComMod approach, which
combines scientific expertise, political interest, and practical
experience, appears to be an appropriate way of developing soil
protection strategies that are suitable for practical implementation.
By simultaneously addressing the scientific, political, administra-
tive and management aspects involved in land-use decision making
and soil conservation, this approach should help to identify as well
as solve potential conflicts, and help to promote integrated solu-
tions for soil protection and land management that are acceptable
to all interest groups. Such an approach is consistent with the
principles of the Water Framework Directive and of the planned
Soil Protection Framework Directive which address the issues of
runoff and soil erosion at the scale of European policy. However,
there is a need to demonstrate that such an approach is able to
initiate collective agricultural land management in the real world
which is more efficient than traditional management.

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