The Sharing of Water Between Different Users: A Multi-Agent System to Improve the Negotiation

M. Le Bars[a] **and J.M. Attonaty**[b]

[a] *LAMSADE laboratory Université Paris-Dauphine 75775 Paris Cedex 16. France. (lebarsm@aol.com)*
[b] *INRA Station d'économie rurale, BP 01 78850 Grignon France.(attonaty@grigon.inra.fr)*

Abstract: Water sharing has become an important problem for French farming. A lot of negotiations are taking place between farmers, water suppliers, public services and environmentalists to allocate water resources between users. We suggest that an Agent-Based Modelling (ABM) could help these negotiations by showing the consequences of water allocation rules toward respect of different criteria like economic (global output) ethical (disparities between actors) environmental (water savings). The model developed includes different types of agents: reactive and cognitive in the meaning of Multi-Agent Systems, agents with bounded and adaptive rationality in the sense of decision-making theory.

Keywords: Distributed Artificial Intelligence; Multi-Agent Systems; Simulation; Negotiation; Irrigation

1. INTRODUCTION

Sustainable development takes into account the rational use of renewable resources. In France, farmers increasingly irrigate in order to improve and secure their income. In some areas water has become a scarce resource and many conflicts occur between different users and environmentalists. At a global level, the public authorities need to define some general rules for sharing water. At the local level, water allocation depends on negotiation between different players and local bodies enforcing the law. Results often reflect power struggles between bargaining players and few attentions are paid to the consequences of a given decision. For example, in the case of Loiret District, the rule to allocate water is the following:

Water allocated = α [20,000 + β(300*Usable Agricultural Area + Σ water negotiated per hectare * area)] (1)

α is the water annual ratio, β is the crop ratio depending on the type of soil.

What the future revenue and water consumption of the farmers will be with this formulation is difficult to say and has not been considered in the negotiation. In some cases tools from economic theory have been used.

This paper presents the Agent-Based Modelling (ABM) under construction and its initial results.

2. EXISTING MODELS

2.1 Linear programming approaches

Concerning irrigation, several applications were developed in France concerning the Beauce groundwater use [Morardet and al., 2000] or the Charente River water use [Rieu and al., 1994], for example. In both models, the authors maximised a global utility function and used shadow prices to determine quotas or water prices. But taking irrigation issues into account raises specific limitations:

- Most coefficients of the economic function represent a crop margin, which depends on yields and prices. These coefficients are random and often the authors maximise the expected margin. Some applications try to maximise an expected income with a limited level of risk.
- Water availability and crop water needs are random variables.

---

[1] According to Appendix II of the report published by Regional Development and Environmental Ministry [Martin and al, 2000]

- Not all decisions are taken at the same time; some are related to complementary information. For example a farmer decides to sow without knowing what the climate will be and he will irrigate according to the rainfall.

2.2 Game Theory approaches

The aim of Game [Querou and al., 2000] is to formalise the agent decision-making process in a context where each agent tries to optimise its own utility function with respect to the other agents. One of its main outcomes is the emergence of equilibrium states, i.e. situations where no agent has an interest to diverge. Game Theory models provide some valid models at economic level and in different social situations with few players [Morardet and al., 2000].

An application was implemented in the Adour Basin where, in order to estimate farmers' income, the authors [Thoyer and al., 2000] used a linear program to determine income according to water price and allocated amounts of water. In the case of the Farmer agent, this linear function was transformed into a concave decreasing function (increasing the allocated water amount function and decreasing the water price function). On the contrary, the utility function of the Environmentalist agent is related to the river's flow. For the Taxpayer agent the utility function is a decreasing function of hydraulic investment.
This type of model is built with a very strong hypothesis:
- Quantification of political weight for each player.
- Determination of (concave and continuous) utility function for each player.
- Instability of the solutions, which require numerous repetitions to get stable results.

2.3 Comments based on these two approaches

- These models are somewhat limited because they only take into account a few decision-makers [Moss, 2001] and are often monoperiodic.
- They assume perfect knowledge of possible solutions and their consequences.
- These different approaches don't take time into account and take only one collective criterion as a basis.
- These models do not take the evolution of production systems sufficiently into account, nor do they consider the different player learning processes.
- Both assume that the decision-maker is acting completely rationally.
- In the last approach, often the representation of agents as constrained maximising algorithms restricts the density of the network of agent interactions as underline Moss [Moss 2001] in a recently publication where he describes current practice in the game theory literature.

2.4 Agent-Based Modelling

In opposition to above mentioned approaches, we think that Agent-Based Modelling (ABM) where simulations are based on Multi-Agent Systems provide new solutions [Doran, 2001]:
- Take into account many agents with different behaviours.
- Enable agents to learn and to change their behaviour in the light of new information.
- Simulate agent evolution over a long period in term of growth and bankruptcy.
- Consider alliances and lobbies linked to exchanges between agents.

We do not intend to provide the optimal solution but only to show to real negotiators the possible consequences of the water allocation rules they have decided, according to different criteria: economic (global output), ethical (disparities between agents), environmental (water savings).

3. OBJECTIVES

The objective is to show on many years the evolution of a set composed of farmers who use a limited water resource. This resource is managed by a water supplier who allocates water to each farmer in accordance to the regulations. The amount of water consumed depends of the climate of the year, the irrigated area and the level of irrigation. The crop yields are related to rainfall and water allocation.
- The farmers: each of them has cash amount, order on crop preference, objectives and an attitude toward risk. He has a crop area divided into plots. He has its own irrigation capacity. Every year, he decides his cropping plan. This choice must respect his crop preferences and agronomic rules. This order is partially related to crop margin. This yield depends on the climate of the year (unknown when he takes his decision) and on the water amount he could provide. Eventually at this time he could negotiate with the water supplier the water he needs. At the end of the year, after his economic results, each farmer can modify his order on crop preferences and decides whether or not to invest in more irrigation capacities.
- The water supplier: each year he gets a water amount and allocates to each farmer right to water access. He has expenses and must keep the account balance.
- The information supplier: each year he receives farmer economic results, establishes their results

and sends to the set of farmers global informations about results of the year.

4. MODEL DESCRIPTION

After the quick description of the actors (2), we will transform them in agents. By agents we mean entities that are autonomous loci of decision making: they decide and act [Doran, 2001]. A Multi-Agent System is composed by a set of computer procedures [Ferber, 1995] where several agents share the same resource, limited or not, and communicate with each other.

The current model is a generic one and does not correspond to a local situation. We have tried to Keep It as Simple as Suitable (KISS) using Axelrod's principle [Axelrod, 1997] as reformulated by Conte [Conte, 2000].

Our modelling approach takes into account two types of agents (Table 1):

- Cognitive agents: Generally speaking they follow a cycle Perception-Decision- Action [Barreteau, 1998] [Wooldridge, 1999].
- Reactive agents: They are represented much more simply than the cognitive agents are but they are also more numerous and active [Erceau and al., 1991]. These agents have inherited artificial life. They have a cycle of the Perception-Action type agent [Wooldridge, 1999].

In the model, the cognitive agents (farmers, water supplier) are composed of knowledge, strategies, information memory and communication modules .

They have to take decisions, so they must be rational [Rao and al., 1999] and the model builder has to choose which type. Roughly speaking we can hesitate between three types of rationality as defined by Decision-Making Theory [Rao and al., 1999]: substantial [Russel, 1999] [Wooldridge and al., 1995], bounded [Simon, 1947] and adaptive [Cyert and al., 1963].

Table 1. Agents in the model developed.

Agents	Number	Type
Farmers	n	Cognitive
Water Supplier	1	Cognitive
Information Supplier	1	Reactive
Crops	n	Reactive
Climate	1	Reactive

Some authors suggest that agents have substantial rationality, so they try to reach an optimum and they are endowed with optimisation skills. with a bounded and adaptive rationality.

We think it would be more realistic, following the criticisms levelled by Simon [Simon 1969] and Cyert and March [Cyert and al., 1963], to endow our agents .

The structure of reactive agents (crops, climate) is only made up of knowledge and communication module.

For example, let us now examine the main components of cognitive agent (farmer agent) and a reactive agent (climate agent):

- **A cognitive agent: Farmers**

1. Knowledge, it can be divided into 3 parts:

- A database containing data: Farm area, crops classified in order of preference based upon profitability and facility, etc.
- A database containing calculation procedures for: Water requirements, crop yields related to rainfall and water allocation, etc.
- A database containing decision-making procedures made up of a set of production rules to determine: Cropping plan irrigated crops and water amount, etc.

2. Strategy, corresponding to a set of rules to enable each farmer agent to reach its own goal: Since these agents have different objectives (increasing or not their revenue and their security level, etc.), strategy contains rules, which can evolve over time with respect to new information and better knowledge of other agent behaviours. The agents decide how to negotiate, what crop yield objective should be reached according to climate conditions, and the minimum cash level to be invested.

3. Different communication modules in accordance with the type of information exchanged.

Private information is processed via mailbox and messages. Each agent can send a message to the mailbox of a receiver, which has the mean to process it. By the same way, he can receive a message in his personal mailbox and process it. This technique is used by farmer agents in their relation to the water supplier agent and information supplier agent.

Public information where an agent sends public or semi-public information. This information can be processed by agents who have the method to retrieve it. For instance, climate agent sends public information about the climate of the year which is used by farmer agent to calculate crop yields.

4. A record (memory) of information exchanged with other agents.

- **A reactive agent: The climate**

The structure of these reactive agents is only made up of knowledge that can be divided into two types:

---

(2) [Bousquet and al., 1996] " It is right to distinguish between a data processing agent and an economic agent although one can build data processing agents representing some economic agents. " Hereafter we will use the term agents for computer entities and actors for the real world.

- A database, which corresponds to individual information on each agent.
- A database containing calculation procedures.

For instance the climate contains the probability of different types of weather (Wet, Dry, Very Dry) and a function to select randomly the type of weather for a given year.
And they have method to send public information.

5. MODEL IMPLEMENTATION

The general structure is composed by classes, attributes and methods as presented in the UML Diagram (Figure 1). This is a discrete event simulator [Misra, 1986], which is, a sequential process of unrelated events [Poix and al., 1998].

The simulation is carried out over a number of years (12). Every year is made up of four sequences:

5.1 Cropping plan determination

Each farmer agent determines its cropping plan and its water needs.

This is an iterative procedure: a farmer agent determines a first cropping plan, fixes its yield objectives for a climatic type of year according to its behaviour and calculates its global water needs. This request is done at a time when neither the climate of the year nor the other water requests are known.
The water supplier agent receives a set of water requests, adds them up and proposes a water amount to each farmer agent in accordance with the water allocation rule tested.

Each farmer agent receives information about its amount allocated.
These exchanges stop when the water supplier agent has no more water to allocate or no new requests.
The water supplier agent has determined his answer in accordance with the regulation tested.

5.2 Climate determination and crop growth

The climate of the year is fired at random. Each crop agent knows which water response curve use to calculate yields.

5.3 Economic results

Each farmer agent calculates its yields and its economic results. It sends its results to the information supplier, which synthesises the information coming in from every farmer agent.
The information supplier agent provides each farmer agent with global information concerning the highest, average and lowest revenues and crops yields.
Each farmer agent decides whether or not to invest in more irrigation capacities and possibly to change its behaviour.

6. INITIALS TESTS AND PRELIMINARY RESULTS

The model has been written in C++ under Builder5. We chose this tool because of the ease with which object classes can be defined, quality of the interfaces and the runtime.

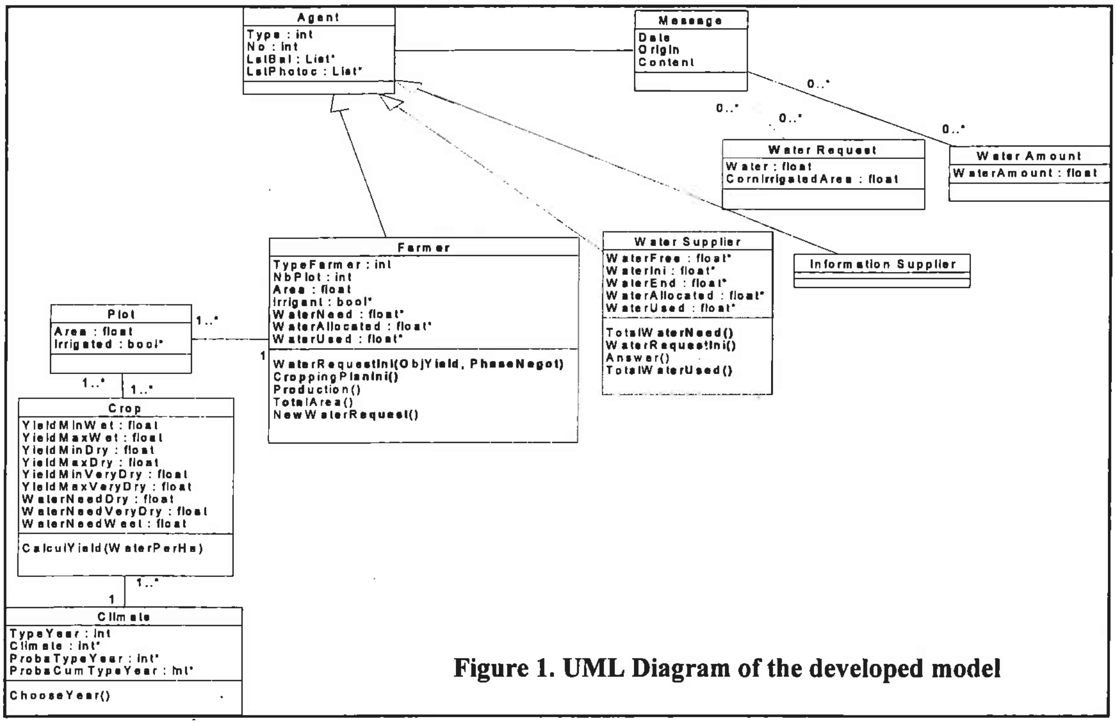

Figure 1. UML Diagram of the developed model

The initials simulation have been done with the following elements:

- Three types of climatic years: Wet, Dry and Very Dry.
- One hundred farmer agents with the same crops rotation but with different areas.
- Water availability is fixed at a level that is slightly above dry year needs.
- Water allocation rule.

The model progressively evolves in function of the result analysis for each water allocation rule tested.

The different rules tested are explain below:

- Rule based on water demands pro rata :

If the amount of water request is less than the water available, then, each farmer agent can use the water amount asked. Else the water allocation is done in function of the request pro rata.

Two farmer agent behaviours have been considered:

- The first one (A) is greedy and selfish: The farmer agent asks for 120% of its water needs in very dry years.
- The other one (B) is reasonable: it only asks for its water needs in dry years.

Results are paradoxical but can be explain as following: In the absence of reasonable farmer agents, global production is higher but heterogeneity of demands leads to great yield disparities. Increase heterogeneity of needs leads not only to a bigger demand disparity but also to a global reduction in yield. This rule does not seem satisfying neither on the collective point of view nor on the ethical point of view.

- Rule based on crop areas irrigated:

With this rule we obtained better results on the short time in the sense of global production and disparities. But it seems to belong to a centralised economy.

- Rule based on demands with better knowledge of the others :

The farmer agent has an adaptive rule, it knows the water allocation of every farmer and asks for the maximum. Results show that we get the same results after three years in this bottom-up evolution, based on better knowledge, as in the top-down way of fixing water allocation. Other simulations have been done for example to test the possibility to decrease disparities between small and big farmers by the way of water allocation.

These first results have been discussed with professionals to make a first model validation: do they understand the model, do they understand results from the model. After these first results, the model is under modification to introduce long term effect on crop area evolution, water use and farmer "death" for economic reasons.

7. VALIDATION

Before improving this model we have to consider its validity or at least the methods needed to validate this type of model. Taking into account the proposals made by Rykiel [Rykiel, 1996] and Donnely and Moore [Donnely and al., 1997] we have been led to consider the following elements:

- Data validation (inputs data, methods).
- The ability of the model to answer questions (verification) that we formulate as follows:

- Users understanding of the model.
- Users understanding of the results of the model (called result confirmation [Rykiel, 1996]).

- Users are able to use the model.

To satisfying the above requirements we have considered the following measures:

- To build a very simple generic model we used general agronomic data that agronomists agreed with (defined by face validity [Rykiel, 1996] production functions.

Some tests made with decision-makers showed us that the principle of the model was understood quickly if we didn't insist on details of Multi-Agent modelling.

- In the same way the preliminary results were accepted immediately. They were even considered to be merely stating the obvious and of no interest: of course, a rule based on water needs pro rata is going to give more water to farmers who ask for more. It is only after showing the different consequences (in terms of yield disparities and global production) of different behaviours that we see an increased interest on the part of the decision-makers; they imagine new water allocation rules and ask to see the consequences. Finally, the conclusion that we can get the same satisfactory results in terms of both collective interest and a reduction in disparities either in an authoritative way or in a decentralised way by providing more information to farmer agents corroborates the results of the economic theory.

8. CONCLUSION

This Agent-Based Modelling is a prototype that is already operational. At this stage the model developed is not a negotiation model. It intends only to present to the actors involved in negotiation process the consequences of water attribution rules. After improvement and extension, notably to other type of water resource, experiments in real condition will tell us if we have to keep it as a model to help negotiation or if we have to evolve it as a negotiation model. The negotiation problem can be addressed by Multi-Agent communities and by Game theory, but few relations exist between the two. This model would be greatly improved by integrating the approaches of these two communities. A question needs to be settled: is it necessary to stay at a generic model level or should we create a model representing a complex reality? In this case many field studies must be carried out and the problem of the typology of the players, their behaviours and their different relation networks and influence must not be forgotten. On the contrary, a generic model, which doesn't aim to draw fine distinction, would allow us to take into account a great diversity of agents' diversities with different attitudes, based on game theory. A recent publication [Buchanan, 2000] shows us that extremely simple models, devised by physicists would shed a new light on the old wealth-sharing problem as posed by Pareto a century ago.

9. REFERENCES

Axelrod R, Simulating Social Phenomena. » In: R. Conte, R. Hegselmann and P. Terna (eds). Berlin: Springler-Verlag, Lecture Notes in Economics and Mathematical Systems, 1997.

Barreteau O., Un système multi-agent pour explorer la viabilité des systèmes irrigués : dynamique des interactions et modes d'organisation. *Thèse de doctorat de l'Ecole Nationale du Génie Rural, des Eaux et des Forêts*. 1998.

Bousquet, F., O. Barreteau, C. Mullon, and J. Weber, Modélisation d'Accompagnement: Systèmes Multi-Agents et Gestion des Ressources Renouvelables. Quel environnement au XXIème siècle? Environnement, maîtrise du long terme et démocratie, Abbaye de Fontevraud. 1996.

Buchanan M., That's the way the money goes, In: *New Scientist*, 167 issue 2252, 2000.

Conte, R, The necessity of intelligent agents in social simulation. In: *Applications of Simulation to Social Sciences,* Hermes, pp19-38, 2000.

Cyert, R.M. and J.G. March, *A Behavioural Theory of the Firm,* Prentice-Hall, New Jersey.1963.

Donnely J.R., and A.D Moore , Decision support: delivering the benefits of grazing systems research, presented at XVIII Int. Grass. Congr., 1997.

Doran J. "Agent-Based Modelling of Ecosystems for Sustainable Resource Management." , In: *ACAI 2001 and*, *EASSS2001*Springler-Verlag, 383-403.2001.

Erceau J. and J Ferber, L'intelligence Artificielle Distribuée, *La Recherche* 233 (22) .1991.

Ferber J. *Les Systèmes Multi-Agents, Vers une intelligence collective,* InterEditions,1995.

Martin S., L. Maurer, and P. Scherrer La gestion volumétrique des irrigations: pratiques actuelles et potentialités." *Rapport auprès du Ministère de l'Aménagement du Territoire et de l'Environnement,* Février 2000.

Misra J, Distributed Discrete-Event Simulation. *Computing Surveys*, **18**(1), 1986.

Moraitis P. COSMINA: A hybrid Agent framework for Distributed decision Making. *LAMSADE Université Paris IX-Dauphine*.1994.

Morardet S., and S. Hanot *La gestion volumétrique de l'eau en Beauce: Impact sur les exploitations agricoles.* In : *Rapport final Agence de l'eau Loire- Bretagne*. 2000.

Moss S. 2001."Game Theory: Limitations and an Alternative." In :*Journal of Artificial Societies an Social Simulation.*4(2).

Poix C., and Y. Michelin Utilisation d'un modèle multi-agents dans un système de simulation d'évolutions paysagères, In: *Modèles et systèmes multi-agents pour la gestion de l'environnement et des territoires.* SMAGET'98 A. d. c., Ed. : Cemagref Editions. Pp. 187-192.1998.

Querou N., M. Tidball, and A. Jean-Marie, Equilibres conjecturaux et fonctions de réaction dans les jeux statiques et dynamiques. In: *Modelling Agents interactions in natural resources and environment management,* International workshop Montpellier 2000.

Rao A. and Wooldridge M., "Foundations of rational agency.," in *Foundations of rational agency.*, vol. 14, *Applied logic series.*, Wooldridge M. and Rao A., Eds.: Kluwer Academics Publishers., 1999, pp. 1-10.

Rieu T., and V. Palacio Equipements hydrauliques collectifs et réforme de la PAC: Des conséquences conflictuelles? Le cas d'un projet de barrage en Charente. *Actes et Communications INRA*. N°12 p187-203.1994.

Russel S., "Rationality and Intelligence.," in *Foundations of rational agency.*, vol. 14, *Applied logic series.*, Wooldridge M. and Rao A., Eds.: Kluwer Academics Publishers., 1999, pp. 11-33.

Rykiel E.J, Testing ecological models: the meaning of validation. *Ecological Modelling,* 90, 229-244, 1996.

Simon, H.A. *Administrative Behavior,* MacMillan, New York.1947.

Simon, H.A. *The Sciences of the Artificial,* Cambridge, MIT Press, 1969.

Wooldridge M. and Jennings N. R., "Intelligent Agents: Theory and Practice," *Knowledge Engineering Review*, vol. 10, pp. 62, 1995.

Wooldridge, M. Intelligent Agents. In: *Multiagent systems.* MIT Press. 1999.