

GAMING WITH EUTROPHICATION : CONTRIBUTION TO INTEGRATING WATER QUANTITY AND QUALITY MANAGEMENT AT CATCHMENT LEVEL

Lucie Clavel^{1,4}, Raphaèle Ducrot^{1,3}, Suzana Sendacz²

¹UMR G-EAU (*Gestion de l'eau, acteurs usages*) /CIRAD – Visiting scientist FUNCEME, Fundação Cearense de Meteorologia e Recursos Hídricos, Av Rui Barbosa, 1246, Aldeota, CEP 60 115-221 Fortaleza-CE(raphaele.ducrot@cirad.fr)

²Instituto de Pesca, Secretaria de Agricultura do Estado de São Paulo, Av. Francisco Matarazzo, 455, 05001-900 São Paulo/SP/Brazil (sendacz@pesca.sp.gov.br)

³IEA-USP - Av Prof Luciano Gualberto Travessa J 374 Terreo Cidade Universitária - 05508-900 São Paulo/SP Brasil

⁴INRA UMR 1248 - AGIR (*Agrosystèmes et développement territorial*) - B.P. 52627 Auzeville F 31326 Castanet Tolosan Cedex (lucie.clavel@toulouse.inra.fr)

Abstract: Integrated Water Resource management (IWRM) promotes a participative management of water at catchment level and the integration of its different dimensions such as quantity/quality, land and water. Modelling has long been acknowledged as efficient support for technical decisions relative to management at catchment level. Modelling tools offer the possibility to integrate different biophysical dimensions of water flows, but rarely the social aspects of water management. This paper presents an approach based on a catchment model combined with a role playing game (RPG) as a support for analysing social and biophysical interactions that need to be taken into account in IWRM.

It has been developed in the Alto Tietê Cabeceiras sub-catchment, which provides 25% of water destined to the Metropolitan Region of São Paulo (MRSP). This sub-catchment with a downstream part typically peri-urban and an upstream part more rural hosts a complex system of interrelated dams that are facing a decrease water quality .

The RPG and its underlying supports and biophysical model were developed by following a companion modelling approach. It permits to represent the impact of players actions at local and catchment level on water quantity and quality in virtual and simplified catchment similar to the catchment studied.

Monitoring of the game sessions underlined the contribution of such an approach to help participants to better understand the underlying interdependencies between quantity and quality or technical, social and environmental aspects of land and water management. It raised their attention to some biophysical issues to be investigated for improving management of water quality.

Key words: Companion modelling; role playing games; water management; peri-urban catchment

INTRODUCTION

Water management is one of the key issues in sustainable development in mega-cities, i.e. cities with more than 10 millions inhabitants. Expanding urbanization in developing countries dramatically affects water resources in terms of quality (problems of physical, chemical, biological pollution, etc.) and quantity (availability of water resources). Some cities are already facing critical water problems such as restrictions in water use that have led to open conflicts, as in Bolivia for example. Such problems also have a direct impact on health and well-being in many different cities (Niemczynowicz, 1996). Increasing water competition is often associated with land use competition which tends to be

harder in peri-urban areas. As urban expansion is generally associated with the growth of shanty towns without access to water or sanitation, often it is also a vector of water pollution.

New water policies based on the paradigm of IWRM (Gorredale, 1992) are being implemented all over the world. They promote the catchment as a territorial unit for optimizing the allocation of water resources to all users.

Following the 2nd principle of the Dublin Conference (Gorredale, 1992), international institutions also encourage joint participation of users, planners, and policy makers in order to integrate water management at catchment level, as opposed to sectorial, infrastructure-development oriented, administrative management of the resource. The implementation of this new governance scheme is particularly challenging in peri-urban situations with multiple stakeholders and dynamic land-use patterns. The proximity of a city generally increases access to potable water thanks to improved water distribution, but competition for resources is acute due to competition between rural, industrial, and recreational uses in a relatively concentrated area.

Policy makers and scientists have long acknowledged the complexity of water management and the need to integrate its different dimensions; they advocate modelling and simulation as ways to tackle this complexity, facilitate the understanding of the catchment functioning, and support decision making. But the social dimension of water management also needs to be better accounted for in such representations. This paper presents an approach based on a catchment model combined with a RPG as a support for analysing social and biophysical interactions that need to be taken into account in IWRM.

Section 1 describes the conceptual basis of integrated water management in peri-urban catchments and in the context of the Alto Tietê Cabeceiras (ATC) sub-catchment in the MRSP, where the study was conducted. Section 2 describes the participatory approach that was used to develop a role-playing game called *AguAloca*, and its underlying biophysical model. Section 3 presents and discusses the result obtained in the first game sessions with representatives of stakeholders.

1. WATER MANAGEMENT IN A PERI-URBAN AREA: INTEGRATING WATERSHED AND URBAN WATER SERVICES MANAGEMENT.

In peri-urban areas, water management supposes the development and management of drinking water and sanitation services as well as of multiple water uses and protection against flooding and pollution at catchment level. Thus, water service and water resources governance, which are traditionally tackled separately, are on fact intertwined. Both have management frameworks that need to take into account the dynamic pattern of peri-urban areas which are characterized by the amplitude and speed of changes.

Peri-urban areas are characterized by: (i) a "patchwork structure" in terms of functions, values, strategies of occupation of the territory, or appropriation and transformation of natural resources; (ii) a wide range of transformations and flows (people, goods, income, capital, resources such as water, energy, and building materials); (iii) new economic opportunities they offer to peri-urban dwellers such as land speculation, or informal activities linked to the extraction of raw materials for urbanization, etc. (Allen et al., 1999; Adell, 1999). Peri-urban interface fulfils specific hydrological functions for the city, i.e. a catchment area includes space for drinking water reservoirs and enables groundwater recharge. Peri-urban dynamics thus affect natural hydrological processes through alteration of the natural hydrological network, expansion of impermeable surfaces, and pollution of surface and subterranean aquifers (Dourojeanni and Jouralev, 1999). At this interface, urban water competes with other needs such as irrigation or environmental and recreational uses. Peri-urban processes also directly affect the quality of the water in drinking water reservoirs and aquifers (Baykal *et al.*, 2000).

One of the consequences of urban wastewater discharge in water bodies is eutrophication. It is often linked to illegal occupation of environmentally unsuitable areas (sensitive to hearth slides or floods) (Baroos and Linden, 1990; Douglass, 1992) or shanty growth urbanization without any access to urban water and other services (Brennan, 1994). This phenomenon is characterised by an excessive growth

of algae driven by excessive inputs of phosphorus and nitrogen (Von Sperling, 1996). Added to economical problems (increase of treatment costs), this phenomenon can lead to serious ecological and health problems.

Thus, dealing with water management in peri-urban areas means interconnecting four main dimensions: (i) the availability of water resources, which depends on the geographical, topographical, meteorological, and geological conditions of the basin; (ii) the organisation of the water supply in terms of institutional arrangements and related technologies (networks and treatment plants), and management of the water supply and the infrastructure required to collect, store, possibly treat, and distribute water; (iii) water uses characterised by very diversified demands in terms of the quantity and quality of water depending on the type of sector as well as on the type of user whose needs vary in time and space depending on socio-economic factors and closely linked with land uses in the catchment; (iv) the organisation, management and structure of the drainage network to collect and treat effluents in the basin, which drainage directly affects the quality of the water resources as well as possible flooding, through runoff.

Peri-urban dynamics provide a fertile environment for the development of different sorts of conflicts (Abdalla and Kelsey, 1996), and many metropolitan centres are already facing water uses restrictions or open conflicts, as in São Paulo (Brazil), for example (Braga, 2000). Dealing with peri-urban water management means not only dealing with technical problems (type of infrastructure and maintenance) or economic questions (tariff structure, level, collection), but also organisational and social issues. Very different kinds of stakeholders (in terms of power, organization, and access to information) are involved in urban and peri-urban water management and conflicts among municipal authorities, water companies, health authorities, water agencies, consumer organisations, local residents and environmental associations. The institutions have difficulty dealing with such tensions because of their traditional dual role (rural/urban) and the rapidity of peri-urban changes (Mattingly, 1999). Of course, new institutional arrangements have been implemented to strengthen participatory decision making in water and land management and to involve the whole spectrum of stakeholders, but informed participation is all the more difficult as the mechanisms and processes involved are very complex and are not well understood.

2. COMPANION MODELLING FOR NATURAL RESOURCE MANAGEMENT

The role of models in supporting integration of multi-disciplinary knowledge and understanding such complex processes has long been acknowledged (Bousquet and Le Page, 2004). Simulations allow managers to safely experiment with management choices (and thus policy options) (Mayer, 2004). But decision making in a multi-stakeholders forum supposes the possibility to debate the options and alternative proposed, not only at the level of researchers and managers, but with the whole spectrum of stakeholders. This supposes first that the model assumptions and its functioning are transparent to the actors; and that appropriate methods are developed to collectively elaborate and discuss the scenarios to be tested to ensure effective debate.

Companion modelling (ComMod, www.commod.org) is an approach based on social simulation in various forms to understand and strengthen the collective decision-making process of stakeholders sharing a common resource. In this approach, simulation models integrate the different stakeholders' points of view and are used as platforms for collective learning. For simulations, preference is given to models that allow social and decision making processes to be explicitly represented, especially multi-agent models and RPGs. Traditionally a tool for teaching and training purpose (Hatchuel, 1993), role playing games have been successfully used during negotiations over water and land-use planning and in facilitating communication in a complex system (Piveteau, 1994; Piveteau, 1995; Heathcote, 1998). In the Companion Modelling approach, RPGs are particularly valued for their simulation capacity, their capacity to generate discussion on complex issues between players, even those with little formal education, and their capacity to build trust and empathy (Barreteau et al., 2001). There has recently been increased interest in the use of such tools in the field of water management. The approach has been tested as a support for the creation of water institutions in Asia (Gurung Tayan Raj, 2006), for capacity building in watershed management in South Africa (Farolfi and Rowntree, 2005), and as a

support for negotiation processes related to the development of new potable water infrastructure in the Pacific (Dray et al., in press).

3. STUDY AREA: THE ATC SUB-CATCHMENT

A companion modelling approach has been tested in the headwater catchment of Alto-Tietê Cabeiceras in the MRSP, which hosts 18 million inhabitants, of whom 99% live in the Alto-Tietê (Upper Tietê) catchment. Even though population growth has decreased during the last 15 years (Prette, 2000), the MRSP integrated water supply system is now reaching its limits. The Sabesp (*Compânia de Saneamento Básico do Estado de São Paulo*), public company in charge of the São Paulo water supply, already has to import 50% of the 60 m³ per second of water needed to supply the metropolis from a neighbouring catchment. The supply system is divided into eight sub-systems located in five sub-catchments of the Alto Tietê catchment and the above-mentioned neighbouring catchment.

The Alto Tietê Cabeiceras (ATC) headwater catchment is one of these five sub-catchments. It covers 1,694 km², upstream from the MRSP, and contains the headwater of the Tietê River. It comprises nine municipalities. The five downstream municipalities are typically peri-urban. They host 1.8 million inhabitants (1,101 inhabitants per km²). These cities are supplied through MRSP integrated water supply system. The three municipalities located in the upstream part of the sub-catchment are more rural. They are all supplied by autonomous water supply systems operated or not by the Sabesp.

As the upstream part of the sub-catchment is still quite rural, the sub-catchment is the best preserved of all the Alto Tietê sub-catchments. Medium term projections underlined its strategic role for the integrated water supply system, which will have to produce up to 70m³/s of drinking water until 2015. The ATC sub-catchment already provides 25% of the RMSP water through two hydraulic systems called production systems : the Rio Claro production system, which produces 5 m³/s, and the Alto Tietê Production System, which produces 10 m³/s (to be increased to 15m³/s by 2015).

The study focussed on the 919 km² catchment area of the Alto Tietê production system, which is a good example of the struggle between water quantity and quality for urban supply. Its construction started in 1972 with the Ponte Nova reservoir, whose initial aim was flood protection. In the 1990s, two more reservoirs (Jundiai and Taiaçupeba) were built, filled and connected to the Ponte Nova reservoir by two canals and a pumping station to ensure the supply of water required for the increasing domestic demand. Recently (2000s), two more dams were built, filled and connected to the system to further increase the raw water supply. This progressive extension of the system demonstrated the ability of the sub-catchment to deal with increasing water demand.

The Alto Tietê production system is totally oriented towards MRSP water demand but the system manager (DAEE, Department of Water and Electrical Energy) also has to deal with competitive local demands. Three municipalities have autonomous water services and together consume 0,47 m³/s (Suplicy, 2002). The demand from local industries is high at 4,96 m³/s (Suplicy, 2002). The sub-catchment is also characterized by intensive irrigated agriculture that consumes an average of 2,13 m³/s during the year (81% of MRSP irrigated area is located in the ATC sub-catchment). The Tietê flow is also used to dilute downstream effluents from the metropolis and thus a minimal flow has to be preserved at the catchment exit.

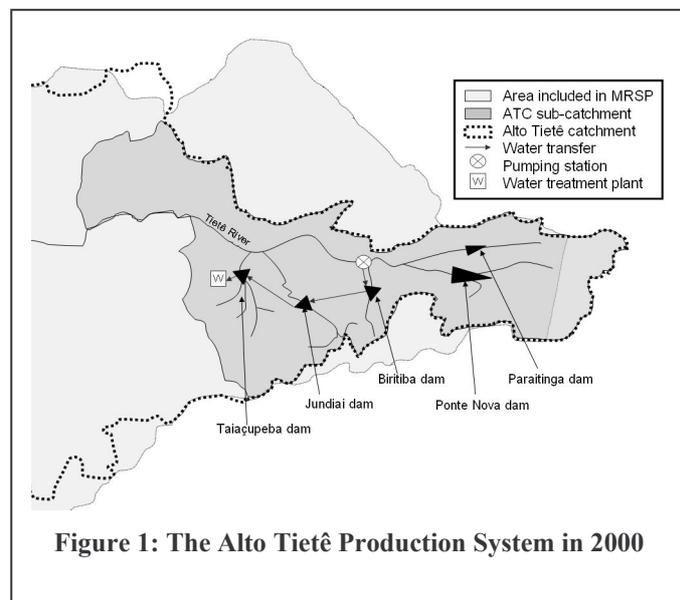


Figure 1: The Alto Tietê Production System in 2000

In addition to the problem of competition between water uses, Sabesp is more and more preoccupied with the observed decrease in water quality in the last reservoir, where the potable water treatment plant linked to the MRSP integrated water supply system is located. Since 1997, the eutrophication rate of the Taiaçupeba dam has been increasing, and causing an increase in treatment costs.

Land use and occupation in the production system catchment was first assumed to be responsible for this degradation, notably urbanization processes and agriculture. The catchment area of the production system is protected by land-use restriction legislation which has not really succeeded in containing the urbanization process. But in this area, the most polluting land uses are mostly located downstream from the dams. Apart from a small irrigated agriculture area, extensive cattle and 26 000 inhabitants (or 85 inhabitants per km²) in a city which only treats about 50% of its effluents (Suplicy 2002), the production system catchment area only contains original or reconstituted forests and eucalyptus plantations. Normally, the depuration capacity of the rivers should eradicate the resulting pollution. Thus, high eutrophication rates observed in water bodies such as the Jundiá reservoir (higher than the rates observed in the Taiaçupeba reservoir) could not be explicated by the land use. In 2005, Sendacz showed that the increasing eutrophication in fact resulted from the management of the hydraulic system itself. Water transfers between dams were responsible for the transfer and accumulation of nutrients. An increase in nutrient concentration is common when dams are filled, even more if the dams are not previously deforested (Bianchini, 2000). To respond rapidly to the increased demand for water, the managers did not wait for the water quality to stabilize in the new reservoirs and nutrients were consequently transferred to the last dam. To solve a quantitative problem (water scarcity), the managers created a qualitative problem.

The Brazilian water law introduced the principle of water licences and water fees based on the uptake and pollution release. Depending on the quantity and quality of the water required from a water body, a water user will be authorised or not to remove water from or release water into the water body concerned. If the user does not comply with the authorisation, he is fined. In the 1990s, São Paulo State also decided to create catchment institutions that were supposed to represent all water users of a catchment and thus enable the State to have a better overview of catchments issues and users stakes. Each sub-catchment of the Alto Tietê also has its own sub-committee, which gathers representatives from government institutions, municipalities and organized civil society. The ATC sub-committee is the only one to represent people from the agricultural sector.

Only recently implemented, this new discussion forum is already facing difficulties in functioning. A companion modelling approach was proposed to strengthen the sub-catchment committee's discussion capacity. The specific objective of our approach was the elaboration of a RPG to allow the member of ATC sub-catchment committee to discuss issues such as relationship between quantity and quality at a catchment level.

4. AGUALOCA: A COLLECTIVELY DEVELOPED REPRESENTATION OF A COMPLEX SITUATION

The elaboration of the AguAloca RPG was part of a process called Agualoca (Figure 2). This process started by a field work by theme (e.g. land use dynamics, reservoir functioning, stakeholders and conflicts). This field work permitted the collective development of a general framework of the game. This framework was used to develop a RPG, its underlying model, and to identify information relevant for the players.

4.1. Collective development of the game

The elaboration phase of the game was seen as a key opportunity to integrate the knowledge of different scientists around a common question. Thus, rather than a simple exercise of developing a didactic tool, the development was explicitly treated as a modelling process to specify the representations of interactions between actors and resources in a given spatial territory. This implied specifying and comparing how different participants perceive and represent different social and biophysical dynamics. It also required selecting a representation that would make sense to all participants and include all potential players.

A workgroup composed of modellers, agronomists, sociologists, hydrologists, and economists was responsible for developing a conceptual framework that would be able to represent interactions between the social and biophysical dynamics, and that stakeholders would be able to use as a virtual negotiation platform. To formalize these dynamics and interactions we followed the “actors-resources-dynamics-interactions” methodology proposed by Companion Modelling group (Etienne, 2006). This methodology permits not only to identify relevant actors, resources, dynamics and interactions of a given question, but also to describe them in terms of tasks, indicators, scales of management (spatial and temporal) relevant for action and decision making of each actor.

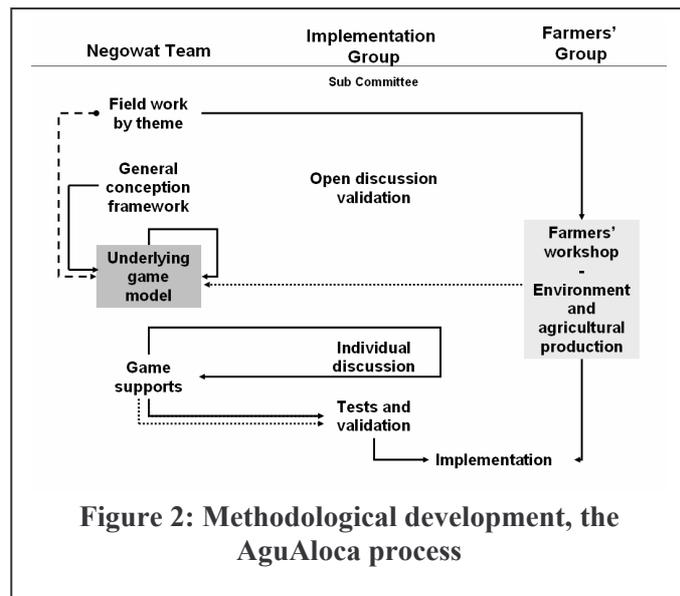


Figure 2: Methodological development, the AguAloca process

This conception framework, elaborated with scientists, was discussed twice with a small group of very active stakeholders who belonged to the committee directly concerned with water management, and a couple of representatives of the municipalities. In parallel, specific activities were carried out in collaboration with farmers concerning the organization and development of less polluting activities which contributed indirect input about their representation in the game. These discussions and activities enabled us to check the relevance of the framework proposed as actors' representation.

This basis was then used for the elaboration of the game material (game-board, description of players, information content, and computer model).

Finally, the game was tested and validated, first with students and then with the focus group from the sub-committee. This session revealed computer problems but validated the basic principles and contents of the game. The timing of the collective discussion was rescheduled and some rules were simplified as players reported they had found it difficult to internalize the quantity of information.

4.2. The AguAloca RPG

The AguAloca game is a computer-based role-playing game developed with the multi-agent software Cormas. It aims to simulate negotiations related to water allocation and its impact on water resource quality at catchment level.

The game environment was based on the ATC sub-catchment, i.e. a peri-urban catchment located upstream from a large urban area, which supplies the water to the urban area.

This virtual peri-urban catchment is characterized by the differences and the competition among water uses. Two municipalities are represented. The first, located close to the city, is typically peri-urban and is connected to an integrated water supply network supplying a metropolitan area located downstream from the virtual territory. The second municipality, located upstream, is typically rural and operates an autonomous water supply and sanitation system. The agricultural sector is extensive and is characterised by different levels of irrigation for horticulture crops. Agriculture is grouped in three different areas of the virtual territory and is assumed to be practised by a large number of small scale farmers. The industrial sector includes two paper factories operating in the catchment. A complex hydraulic system has been build to allocate water to the city downstream and among the different water users. It is composed of three dams interconnected by two channels. This context is depicted on a colourful game-board that represents four different land uses (urban, agriculture, forest and other) on cells (each one representing 5 km²), with the different water bodies (e.g. rivers, canals and dams) depicted as blue lines and triangles.

Five types of actors are represented in the game, which requires six players. The mayors of the two municipalities have to ensure access to water services (e.g. water supply and sanitation) for their

inhabitants. The water company has to operate the integrated water and sanitation system of the downstream city and the neighbouring peri-urban area, to which one of the two local municipalities belongs (the downstream one). The farmer's representative has to defend agricultural interests and give advice regarding crop choice and irrigation practices to the farmers who are not physically present. The industry representative runs the two paper factories. The Catchment Water Department operates the hydraulic system respecting the users' water rights : its aim is to transfer water between dams in order to satisfy all users' demands.

Decisions made by players have an impact on water demand depending on production decisions (e.g. the player who manages the water treatment plant can modify the water treatment capacity, water treatment objective, treatment process and supply network) and/or release of effluent (the player who manages a sewage plant can modify its water treatment capacity, water treatment objective, treatment process, and sewage collection network).

In practice, the six players sit around the game-board and make their personal decisions on players' information sheets which describe their own situation (e.g. the paper manufacturer knows the production capacity of each paper factory and can modify it). The game is divided into 6-month rounds which correspond to the rainy and dry season. This time step is representative of stakeholders' strategies, particularly those of farmers and of the water department. Each round starts by an individual phase when each player has to make personal decisions regarding the system for which he is responsible and its own objectives (e.g. the water department can adjust the flow downstream from each dam). This individual phase is followed by a collective phase simulating a catchment committee meeting, where all players can discuss their past actions and elaborate collective strategies.

During the collective step, the model quickly processes personal decisions in a biophysical model which then simulates the impacts of personal decisions on the environment, and updates the players' information sheets.

4.3. The underlying biophysical model

The game aims to simulate negotiations concerning the quantity and quality of water resources at catchment scale, by focussing on eutrophication processes for the quality part. Relationships between water quantity and quality are the result of (i) management of the local water system at the catchment level or higher (management of dams and transfer of water); (ii) actions of different local users (e.g. uptakes and releases from cities, irrigated agriculture and industry); and (iii) changes in local land use which have an impact on water balance and spread pollution. The use of a computer-based model appeared to be the most efficient way of integrating processes that occur at different spatial, social or temporal scales. The underlying biophysical model was developed by articulating simplified existing hydrological models in the area. It contains three modules.

Inspired by the MQUAL (Prime Engenharia, 1998) model, which is the first existing representation of quality processes in the area, we developed a nutrient export module to estimate phosphorus exports resulting from local land use. For this purpose, the catchment is divided into 299 cells of 5 km² each. Each cell is characterised by a single land use (e.g. forest), which is associated with a phosphorus export coefficient defined by MQUAL for a neighbouring sub-catchment (the Guarapiranga sub-catchment). Cells can be aggregated into micro-catchments, which enables estimation of phosphorus exportation at meso-level.

Following the formalism of an existing model (ACQUANET) used for water allocation in the Alto Tietê production system catchment area, we developed an arc-node model to allow transfers of water and phosphorus between different places in the hydrographical network. Arcs represent superficial and channelled flows (i.e. rivers and channels). When the flow of water transferred by one arc remains constant (not considering infiltration or the contribution of the aquifer), the phosphorus charge transferred by an arc decreases following an exponential decrease equation (Porto, 2003). Nodes represent specific points on the hydrographical network where a change in water flow and phosphorus concentration may occur (i.e. water uptake and release, dam). The different kinds of nodes reflect the way they modify flows and phosphorus concentrations. The catchment node is associated with a virtual micro-catchment. It permits gathering rainfall and nutrient charges data to introduce in the arc-

node system. The junction node represents the tributaries; it is able to add flows and concentrations from different tributaries. The demand node is used to remove water in the arc-node network. And the dam node is used to simulate the specific processes that occur in the reservoir such as nutrient concentration, which is simulated by the use of the Vollenweider equation (Jørgensen, 2000), which is assumed to be adequate for reservoirs with small limited variations in volume such as drinking water reservoirs. As each action of the players concerns a specific node, this architecture allows the representation of the impacts of local actions as well as the water system management.

The model also enables representation of the main trends in land use change, e.g. population pressure. The last module simulates the migration of families within a given area. Mayors can influence where migrants settle by selecting specific areas. The model will then allocate some of the families to these specific cells and other families on other cells for simulating unordered urbanisation.

The model presents several simplifications, e.g. a limited number of land uses, which influence the estimations made by the model. As phosphorus is considered as a limiting factor of eutrophication in tropical areas (Salas & Martino, 1991 in Von Sperling, 1996), it is the only nutrient considered in the eutrophication processes. Its main limitation is the monthly time step, which does not allow satisfactory representation of hydrological processes for focussing on actors' timescale. For example, the flows are averaged monthly, so the model cannot account for the intensity of precipitation, which has been shown to be significant in nutrient discharge processes. However, we observed that this model was sufficient to demonstrate the main trends observed within the ATC sub-catchment (e.g. phosphorus transfer between dams, phosphorus loads from urban areas).

4.4. Information management

While the RPG allows players to interact on land and water management issues, the simulation model allows the estimation of indicators that players can mobilize for their actions. The management of information between the model and the players in the form of indicators facilitates the players' individual actions and interactions among players. An indicator can be mobilised during a discussion as an argument, an example or an objective.

The model outputs are displayed to players according to specific rules to mimic a realistic and differential access to information. For example, water quality is checked at different places in the hydrographic network and the data is only available to the water company : the quality indicators simulated by the model only appear on sheets distributed to players who have to deal with the water treatment plant (i.e. the water company and the mayor of the upstream municipality).

The game enables players to share information if they decide to do so. The players can exchange information orally during the simulation of the catchment committee meeting. To facilitate exchange of information, colourful chips are provided and can be used on the game-board. The shape of the chip depends on the nature of the information (e.g. information on water quantity is represented by a cross), and the colour of the chip indicates the type of information (e.g. a blue round chip represents good water quality whereas a red one represents bad water quality). The way the information is shared during the game can thus be analysed during the debriefing session after the game.

5. RESULTS OF THE GAME

5.1. Game session and monitoring

Two game sessions enabled the first results and conclusions to be evaluated. The first game involved Sabesp engineers and representatives of local municipalities. The expectations of this group were rather confused and their concerns were mainly technical. The second game involved members of the Alto-Tietê catchment committee. Not surprisingly, the second group initially appeared to be more collectively aware of the political aspects of water management, its complexity and the importance of negotiation.

Each game session lasted between four and five hours enabling between three to four rounds (2-3 hours) and full debriefing (1-2 hours). The game sessions were monitored by: (i) two persons who

observed the development of the game by focussing on the individual and collective behaviour of the players (using observation guidelines); (ii) two questionnaires that were given to the players before the session started to assess their expectation about the session and at the end of the sessions to assess their satisfaction and possible learning; and (iii) a camera that recorded all the game sessions for further analysis.

Six months before the game sessions, a survey was conducted to identify the representations of the sub-committee members about water management, the main conflicts in the ATC sub-catchment, and the role and place of agriculture. The whole AguAloca process was also assessed through interviews with game designers and game session participants eight months after the last game.

5.2. Development of the game

All the game sessions proved to be enjoyable. However, in both sessions, the players needed time to adapt, to understand, and to appropriate their roles. This often took the whole first round, which was called the “learning round” by the ComMod group, but it could last two or three rounds depending on the players and the roles they had been given. The farther the role from the players’ real-life experience, the longer they needed to adapt. Most players mastered the functioning of the game in the second round, but at this stage did not yet fully grasp that their decisions would have direct consequences for the resources and for other players. The players generally only fully understood the whole set of interrelations between actions and resources in the third or fourth rounds, when the game is stopped for collective analysis due to lack of time. The development of cooperative activity and discussions tended to be very progressive.

One typical interaction resulted from the way the game is designed (which was inspired by the case study). Since the municipality depended on the water management company to create infrastructure for water and sanitation, while the quality of the water in the reservoir depended on municipal urbanisation, bilateral discussions between the water firm and the municipality were among the first relationships to develop during the game sessions. However, players had difficulty recognising this interdependence, which in fact mirrored the limited coordination between water companies and municipalities in real life. Thus, in the game, this relationship has been developed through requests made by one player to another, rather than through a request to share information or for mutual cooperation, for example on collective choices concerning areas for urbanization and the development of infrastructure.

Other partnerships and negotiations were observed. A couple of them were rather unrealistic such as a proposal to reallocate all farmers to one part of the catchment (which would involve some kind of zoning). On the other hand, some partnerships observed during the game probably reflected real or possible practices such as the exchange of water licences.

The game also helped identify real difficulties encountered by most participants in negotiation processes. It clearly highlighted the need for capacity-building in negotiating skills.

The game was intentionally designed to reflect the complexity of real situations and involve different types of conflicts. It did not contain any obvious collective solution. Collective discussion in both game focussed on the management of water quality (Jacobi and Granja, 2006) but their real contents were influenced by the profile of the group. In the first group, collective discussion was dominated by technical arguments. In the second group, a collective discussion developed with stronger arguments and proposals and less concerned with technical problems (Jacobi and Granja, 2006). These discussions never led to a clear collective solution or a clear outcome, except in the case of the game played with the Alto Tietê catchment committee, where the players came up with the idea of creating a monetary fund. However, this was not such an innovative outcome, as for several months the Alto Tietê agency had been debating how to achieve cost recovery. The monetary fund was expected to trigger negotiations in the game. Every stakeholder in the game started with a financial investment. After identifying solutions to problems and agreeing on priorities, players distributed the fund to subsidize specific actions. They expected the monetary fund to help overcome difficulties in the negotiation and competition among the players but discovered it merely transferred the difficulties from selecting options to allocating the fund. However, they suggested formalizing the funding option in the game, which had not been the case, as it had not been implemented in real life.

5.3. Learning process

Many participants emphasised the quality of the game supports (board, model of a virtual catchment) to support meaningful discussions about catchment issues. In particular, it contributed to a new concrete understanding of the notions of “integrated or shared water management” or “collective action related to water management”. It highlighted the underlying interactions between different activities at catchment level and enabled the players to better understand the interests of other stakeholders. It also increased players’ knowledge about how the quantity and quality of water resource are interrelated at catchment level. This was particularly true for players who had strong stakes in water management but expressed these stakes in terms of water quantity only. The game thus appears to be a meaningful frame that helps to organise and structure diverse technical and social knowledge and information and thus to give to a coherent meaning to the complex real life situation.

As their knowledge increased, some players started to investigate the biophysical model. For example, one player in charge of the hydraulic system’s management had skills in water allocation models. He tried to profit from these skills to investigate the possibility of diluting water effluents allowed by the quality module of the model. Other examples were a manufacturer, who decided not to treat effluents from paper factories to assess the impact on water quality downstream, or the participant playing the role of farmers’ representative, who tried to promote rural sanitation in order to assess the potential impact on water quality. These behaviours indicated that such games can be interesting tools to prepare more complex simulation exercises based on calibrated models.

The debate about quality especially interested the technicians from the Sabesp team in charge of the Taiaçupeba water treatment plant. They requested a detailed conversation with the Negowat water quality specialist to help them better understand the dynamics linking water quality and quantity at catchment scale in order to incorporate them in their management practices. This led to the implementation of a specific workshop about quality management in a multi-level reservoir system some months later.

The game also led some players to investigate the relationships between water management and urban planning. However, the highly simplified representation of land use and population dynamics in the AguAloca game led to frustration on the part of planners. We had deliberately chosen to simplify the land use changes processes in order to develop the allocation mechanisms. It would have been possible to develop both processes in detail but this would probably have led to a very complex game with a high risk of losing its explanatory and structuring force. Another source of frustration stemmed from the players’ rather perfunctory vision of land planning and urbanisation control. Once an agreed zoning policy was in place, municipal players expected the (simulated) families to act exactly according to their plan, but the software did not necessarily take into account what the urban planners had selected and neither do real people.

As expected, part of the discussion focussed on agriculture issues, either as an activity affected by water management at catchment level or as a potentially polluting activity. The development of the discussion depended more on the involvement of the player who represented the farmers in the collective discussion than on the actions or choices of this actor. As a mere representative of atomized meaning unclear actors with their own objectives, this player in fact had little direct impact on the simulated resource. These discussions underlined the fact that most participants are not well informed about agricultural activities.

5.4. Long term learning

Some months after the game, most players no longer remember the specific role they had played in the game or the detailed content of the negotiations. However, all the players mentioned the capacity of the game to raise their awareness about other actors, their interests, and the influence of their actions on the resources. Experimenting and being confronted with the management difficulties of other actors was particularly appreciated. Some participants mentioned their increased ability to listen to or to consider other actors’ contributions in real life meetings and debates. It helped participants to better understand how the whole system functions, as well as the interdependence between actors or between decision making, resources and actors. Actually a couple of participants mentioned the game as a

frame of reference or model base for understanding or analysing what was going on in real life catchment meetings and in discussions at specific meetings. This was especially important for people who did not have a detailed, in-depth picture of the whole catchment functioning because, for example, they had only been involved recently or superficially in the issue. The session also drew their attention to the relation between decision making, its possible impact on the system, and the potential irreversibility of processes. It appears to provide a good basis to open discussions about the interest of scenarios and options whose potential contribution is not always as well perceived by stakeholders as assumed by scientists (Becu N. et al., 2008).

Of course long-term learning also depends on each stakeholder's interests. Someone involved in municipal management mentioned he now had more concern for the agricultural sector than before the game because he had played the role of the farmers' representative. An engineer from Sabesp mentioned he gave greater importance to other types of information that those he was used to managing because he had realised during the game that other actors had also to deal with complex information, even if it was related to other aspects

CONCLUSION

Experiencing a virtual interactive management situation helped the participants understand the full meaning of integrated water management. The RPG provided a comprehensive framework of the whole complexity of the peri-urban catchment studied, identified the different dimensions to take into account, and the interaction mechanisms. The biophysical processes and social interactions simulated by the model over a period of a few hours are normally disseminated in time and space. It thus gave a concrete meaning to the concept of integration by helping participants analyse and understand the different interdependencies. It helped participants (i) to connect the social aspects of catchment management and the functioning of the committee with technical environmental aspects (ii) to better integrate other stakeholders' roles and interests; (iii) to question some unexpected biophysical dynamics resulting from proper water management such as transfer of nutrients between dams; and finally (iv) to identify the need for capacity building for negotiation.

But although the participants obviously did learn, it remains unclear how this learning was actually put into practice and whether it actually contributed to more active participation in meetings and discussion forums. Another limit is the small number of participants involved in the game during the timeframe of the process, as we underestimated the time needed for the collaborative development of the models and the validation tests. However, the collaborative development was important to achieve the balance between the representation of the complexity of real life situation and the simplification required by the model. If the situation had been too virtual it would have been difficult for the participants to become involved in the game, while if it had been too representative, its analytical ability would have been limited.

The approach was valuable in preparing participants for more complex work ahead and some participants asked to use calibrated and validated simulation tools in their real-life situations as the next step of the project. It would thus be interesting to assess the contribution of the RPG in a subsequent phase of scenario simulation on a multi-stakeholder platform.

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BIBLIOGRAPHY

- Abdalla, C.; Kelsey, T.W. 1996. Breaking the impasse : Helping communities cope with change at the rural-urban interface. *Journal of soil and water conservation*, Nov-Dec, 462-464.
- Adell, G. 1999. Theories and models of the periurban interface : a changing conceptual landscape. Literature review. DPU.
- Baroos, P.; Linden, J.V.d. 1990. *The transformation of land supply system in third world cities*. Averbury, Aldershot.
- Barreteau, O.; Bousquet, F.; Attonaty, J.-M. 2001. Role playing game for opening the black box of multi-agent systems : method and lessons of its application to Senegal River Valley irrigated systems. *Journal of Artificial Societies and Social Simulation*, 4, 2, 12.
- Baykal, B.; Tanik, A.; Gonenc, I. 2000. Water quality in drinking water reservoirs of a megacity, Istanbul. *Environmental management*, 26, 6, 607-614.
- Becu N.; Neef A.; Schreinemachers P.; C., S. 2008. Participatory computer simulation to support collective decision-making : Potential and limits of stakeholder involvement. *Land Use Policy*.
- Bianchini, J.I. 2000. *A decomposição da vegetação e o consumo de oxigênio nos reservatórios : implicações ecológicas*. Departamento de Hidrobiologia. 1-20. Universidade federal de São Carlos, São Carlos.
- Bousquet, F.; Le Page, C. 2004. Multi-agent simulations and ecosystem management : a review. *Ecological Modelling*, 176 (3-4), 313-332.
- Braga, B.P.F., Jr. 2000. The management of urban water conflicts in the Metropolitan Region of São Paulo. *Water International*, 25, 2, 208-213.(Porto 2003)
- Brennan, E. 1994. Mega-city management and innovation strategies : regional views. In: Roland J. Fuchs; Ellen Brennan; Joseph Chamie; Fu-chen Lo; I., J. (Editors), *Mega-city growth and the future*, 233-255. United Nations University Press, Uitto, Tokyo, Japan, .
- Douglass, M. 1992. The political economy of urban poverty and environmental management in Asia : Access, Empowerment and Community based Alternatives. *Environment and urbanization*, 4, 2, 9-32.
- Dourojeanni, A.; Jouralev, A. 1999. Gestion de cuencas y rios vinculados com centros urbanos. p 176. CEPAL, Santiago.
- Dray, A.; Perez, P.; Page, C.L.; D'Aquino, P.; White, I. 2007. Who wants to terminate the game? The role of vested interests and metaplayers in the ATOLLGAME experience. *Simulation and Gaming*, 38(2), 494-511.
- Etienne, M. 2006. La modélisation d'accompagnement : un outil de dialogue et de concertation dans les réserves de biosphère. Biodiversité et acteurs, des itinéraires de concertation. *UNESCO-MAB*, Réserves de Biosphère, note technique 1-2006, 44-52.
- Farolfi, S.; Rowntree, K. 2005. Accompanying Local Stakeholders in Negotiation Processes Related to Water Allocation through Simulation Models and Role-Playing Games : An Experience from South Africa. *EMPOWERS Regional Symposium: End-users ownership and involvement in IWRM*, 7p, Cairo, Egypt.

- Gorredale, E. 1992. The Dublin Statement on Water and Sustainable Development. *Environmental Conservation*, 19(2), 181-181.
- Gurung Tayan Raj, F.B.; Guy Trébuil. 2006. Companion modelling, conflict resolution, and institution building : sharing irrigation water in the Lingmuteychu Watershed, Bhutan. *Ecology and Society*, 11(2), art. 36, 1-49.
- Hatchuel, A.; Moisdon J.C. 1993. Modèles et apprentissage organisationnel. *Cahiers d'économie et de sociologie rurales*, 28, 18-32.
- Heathcote, I.W. 1998. *Integrated watershed management. Principles and practice*. John Wiley and sons.
- Jacobi, P.R.; Granja, S.I.B. 2006. Monitoramento e Análise dos Jogos - Agualoca e Teráguas. Negowat Project. 185p. PROCAM/USP, São Paulo.
- Mattingly, M. 1999. Institutional structures and progresses for environmental planning and management of the peri-urban interface. 9p. University College London, London.
- Mayer, I.; De Jong M. 2004. Combining GDSS and gaming for decision support. *Group decision and negotiation*, 13, 223-241.
- Niemczynowicz, J. 1996. Megacities from a water perspective. *Water International*, 21, 198-205.
- Piveteau, V. 1994. L'avenir à long terme des zones rurales fragiles, approche par le jeu : prospective d'une question complexe, *Sciences Economiques*. Université de Paris I, Paris.
- Piveteau, V. 1995. *Perspective et territoire : apport d'une réflexion sur le jeu*. Cemagref éditions.
- Porto, R.L.L. 2003. *Sistema de suporte a decisão para análise de sistemas de recursos hídricos*. 0-144. São Paulo, Universidade Politécnica de São Paulo, Labsid.
- Prime Engenharia. 1998. *Avaliação da Poluição por Fontes Difusas Afluentes ao Reservatório Guarapiranga*.
- Sendacz, S.; Monteiro, A.J.; Mercante, C.T.J.; Menezes, L.C.B. 2005. Cargas de nutrientes (nitrogênio e fósforo) na bacia do Alto Tietê (Cabeceiras e Guarapiranga). *Negowat Brazil* Nº5, 1-13, São Paulo - Brazil, Instituto de Pesca - APTA.
- Suplicy, M.T. 2002. Relatório de situação dos recursos hídricos - Sumário executivo. 1-67. São Paulo.
- Von Sperling, M. 1996. Introdução à qualidade das águas e ao tratamento de esgotos DESA-UFGM, Brasil. 13p.