Preprint - López-Paredes, A., Saurí, D. & Galán, J. M. (2005). Urban water management with artificial societies of agents: The FIRMABAR simulator. Simulation 81(3), 189-199.
http://sim.sagepub.com/content/81/3/189.abstract doi: 10.1177/0037549705053167

Urban Water Management with Artificial Societies of Agents. The FIRMABAR[1] Simulator

Adolfo López-Paredes[1], David Saurí[2], Jose M. Galán[3]

[1] ETS Ingenieros Industriales de Valladolid. Grupo INSISOC. Universidad de Valladolid
47011 Valladolid Spain
adolfo@insisoc.org
http://www.insisoc.org
[2] Universitat Autonoma de Barcelona, Departament de Geografia,
08193 Barcelona Spain
david.sauri@uab.es
[3] Escuela Politécnica Superior, Departamento de Ingeniería Civil, Universidad de Burgos
09006 Burgos Spain
jmgalan@ubu.es

Abstract. In this paper we present an agent based simulator for the integrated fresh-water assessment in a geographical area. It has been developed and successfully applied to the Metropolitan Region of Barcelona, and it is currently applied to the Metropolitan Area of Valladolid. Such simulator provides the policy makers with an additional tool to evaluate alternative water policies in different scenarios. The design and the validation of the model are based on participatory processes with a platform of the representative stakeholders.

1 Agent-Based Social Simulation and Urban Water Management

Agent-based social simulation (ABSS) is a simulation technique that provides a way for a direct representation of social phenomena. Object Oriented Programming (OOP) is in the foundations of this methodological approach. We can model and implement "the actors" in a (complex) system in terms of "the agents". According to Gilbert and Troitzsch [1] agents would be "self-contained programs which can control their own actions based on their perceptions of their operating environment". So, usually agents in simulation represent human individuals, although they can also be as organizations or social institutions.

ABSS shares with other micro-simulation techniques the explicit and the specific expressions of the behaviour of each one of the individuals that take part in the simulated system. Experimentation in ABSS begins with the creation of the agents and the environment where they interact, and finish with the analysis of the observed collective behaviour. It is important to highlight that although the design phase comes up from micro-definition, at the 'agents' (actors') level, the real aim is to understand the

---

[1] Available at http://firma.cfpm.org/

aggregated emerging[2] behaviour and the appearance of macroscopic properties from micro interactions.

Such methodological approach to study complex systems is growing up fast in a wide range of scientific fields, from socio-economics [4] to political science [5], organizational theory [6], land use [7] or ecology [8]. The growing interest in this technique is due to the possibility to incorporate almost directly and intuitively the behaviour observed in the real world by means of a computational model. This fact allows us to obtain very refined and detailed representations of the individuals, with the hope that this level of detail will give a greater realism to the model.

In this article we show an agent based software for water management integrated assessment. This software is based on the water cycle and the role that agents and institutions play in it. The main actors in the system have been explicitly programmed and users can play simulations either as external observers or as policy makers.

Our model benefits from previous works to evaluate the domestic water consumption: studies based on statistical simulation techniques [9], on the price of water [10], on technological advances, public education campaigns and rationing [11,12], and territorial models [12,13].

Nevertheless, as Arbués et al [14] state, in the urban context, the management of domestic water consumption and the exploration of new policies for its evaluation requires techniques that allow an integrated study of complex systems. In fact, social processes cannot be separated precisely in the sub processes by which they are made of, e.g. economic, demographic, cultural, spatial. In agreement with Epstein [15] agent based modelling fills that methodological gap: when we create an artificial society we are linking all the subprocesses into a single integrated one. In this way we don't need to set artificial boundaries in the construction of the models: "Because the individual is multi-dimensional, so is the society".

Most of the studies in water management were carried out with traditional forecasting methodologies based on a few variables. Recently, some authors have suggested an analysis of the water resources in an integrated way [11,16,17,18]

The simulator that we present is currently in use by ACA[3] and allows the policy makers to simulate and evaluate alternative supply and demand policies under different climatic and technological scenarios. It has been applied to the Metropolitan Region of Barcelona (Spain). Such geographical area is suffering an important change in the urban territorial model: the population is growing mainly due to the immigration phenomena, and the citizens are changing their housing preferences.

In the following sections we will describe the agent based model we programmed in the simulator, the way to setup the simulator for playing it in a specific sociophysic domain, and the main conclusions from its use it in the Metropolitan Region of Barcelona (MRB).

---

[2] For a deeper insight of the concept of emergence see Holland [2] or Johnson [3].

[3] ACA, Agencia Catalana del Aigua (ACA), is the water regulatory institution in Catalonia.

2 Urban water management: problem statement

In figure 1 we sketch the most relevant components of the water cycle. Climate and land use determine the amount of water theoretically available for the system. Supply, on the other hand, represents water actually available in rivers, reservoirs and aquifers. Demand includes all possible uses and Wastewater is the amount of water that enters the Environment once used and eventually treated. For integrated assessment, individuals and social institutions must be explicitly represented. Moreover, individuals modify their water consumption patterns according to their housing and the climatic conditions.

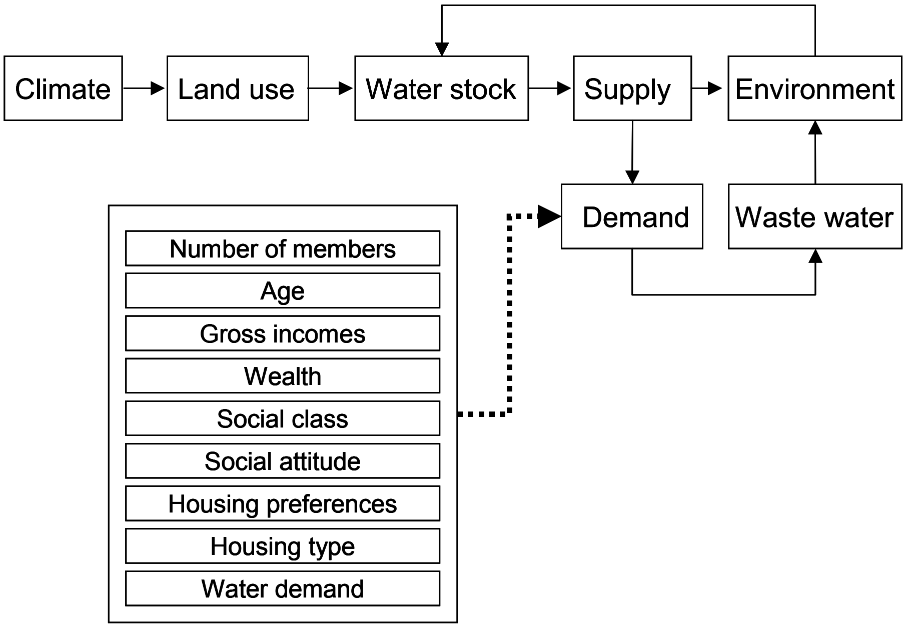

Fig. 1. Sketch of the water cycle for integrated assessment (the arrows mean influence relationships).

The local and regional governments manage the urban plans and decide on investment on new infrastructures, affecting the land use and climate. The dynamics of these influences are circular and present different delays. We have selected a set of the social factors with influence in land use and water demand that are explicitly considered in the simulator. They appear in Fig. 1 linked to the water demand box.

In the system we study it is possible to identify three sources of complexity that suggest ABSS as the more suitable approach:

– Heterogeneity. In the system we identify different kind of agents: the citizens (families), the neighbourhoods, the city halls, and the regional government. Each actor has goals and motivations, and some of them can occasionally evolve in time.

- Territorial change (spatial influence). The geographical space plays an important role in the process. Territorial dynamics, land use and migratory movements can be extremely influential in the process. In fact, the problem of land use is considered itself a complex problem [19,20].
- Autonomous processes. There are processes which managers do not control directly, although they affect the system (climatic profiles, and individuals housing preferences or social attitudes).

3 The ABSS approach to the system

We have designed the simulator as two coupled models. They are subsumed in a ‘container’ where the simulator computes the water supply and demand, while the policy maker plays its water decisions.

On one hand there is the territorial model, that represents the physical and urban space where the artificial society plays its activities. Urban dynamics play a central role in the resulting collective behaviour. It is based on cellular automata over a reticulated surface where the agents ‘live’. This methodology has been previously applied to simulate the dynamics of urban systems [21,22,23].

The second one is the social model. The elemental agent in the simulator is the family. Each family is initially endowed with social attributes that can evolve during the simulation (e.g. its social class). Families play their own life cycle: they are born, grow up and finally, die. This model is played for each agent during a simulation time step.

The actors that we have programmed in the simulator are:

- The families. They behave according to the initial endowed social attributes. Each family exhibits its own life style and social attitudes. Families compute at each simulation step the maximum expected water demand and the real consumption.
- The real estate companies. An important requirement of the model was the inclusion of a submodel of the urban dynamics of the region. A fundamental mechanism affecting water consumption in the region is the change in the territorial model (from the compact city to diffused patterns of urbanism). Therefore the model of the artificial society needs an actor that builds new housing around municipalities while he behaves as the intermediary for the second hand market.
- The municipalities: We must locate and set up the different counties which constitute the studied territory in the grid that represents the geographical area. We will call them “municipalities”. Each one of these municipalities is composed of neighbourhoods or districts. Some of them are initially endowed with an urban development plan. It allows the future expansion of the municipality with new houses, which will be occupied by families.
- Regional Government. It is the agent that must play supply and demand policies in the territory. Alternative to the programmed behaviour, the user can play its own decisions during the simulation in an interactive way.

4 The artificial society

The simulator plays the life of a set of families on a grid that represents the territory. The initial number of families is introduced by the user. Each family is randomly located in a neighbourhood within a municipality. Families behave and interact with the rest of agents in the system. The central decisions that each family takes are two: house movement and water consumption. In the model we represent and identify each family:

$${}^{i}F = \{n, age, inc, wea, SC, SA, Hp\}$$

where *n* is the number of members of the family; *age* is that of the family; *inc* are the gross incomes; *wea* is the accumulated wealth of the family; *SC*, the social class; *SA*, the social attitude; and *Hp*, the preference of the family for a type of household.

The decision of house movement for each family depends on their own preferences, mainly: size of the house vs size of the family, social class in the neighbourhood[4], and the evolution of prices for new houses vs second hand market.

The water consumption decision of each family depends essentially on the water price and the gross incomes, the maximum demanded water and the evolution of the reservoirs in the region. Besides, it is affected by the housing type and the appliances technology, the social attitude when the region is in drought or scarcity periods, the social class and the size of the family. Finally, the water consumption is adapted to the local habits by a mechanism of imitation within the closest neighbourhood (see Fig. 2).

Each family computes a maximum of water spending. The difference between such quantity and the real consumption of water determines the level of satisfaction of the family with the water policies[5]. Citizen's disappointment will be a result of water restrictions or water prices.

The water consumption is monthly determined through the maximum water demand of each family, which depends on the number of members of the family, the social class, the previous consumption, and the housing type (appliances). That value is modified by the price of water, the consumption of the families in the same neighbourhood and the existence of emergency situations. The regional government decides about water prices and infrastructures investments, what determines the water stock.

5 The territorial model. Spatial organization

The case study area is the MRB. There are almost 177 municipalities in this geographical area. Notwithstanding, we can define three kinds of territorial units repre-

---

[4] A key issue in the territorial model is the conception of the neighbourhood. There are several definitions (see [24]) that can be applied. We have used the Moore´s neighbourhood U(Hij) defined like each households in the square 3*3 with central cell Hij.

[5] In the simulator this variable is called "unhappiness".

Preprint - López-Paredes, A., Saurí, D. & Galán, J. M. (2005). Urban water management with artificial societies of agents: The FIRMABAR simulator. Simulation 81(3), 189-199.
http://sim.sagepub.com/content/81/3/189.abstract doi: 10.1177/0037549705053167

senting the real urban units of the region: the city of Barcelona, the municipalities with more than 50000 inhabitants and those in the region with less than 50000.

The territorial model must be defined by the final user. The territory is represented by a grid, in this case, of 100x100 cells. Each cell represents a neighbourhood of families living in a housing type.

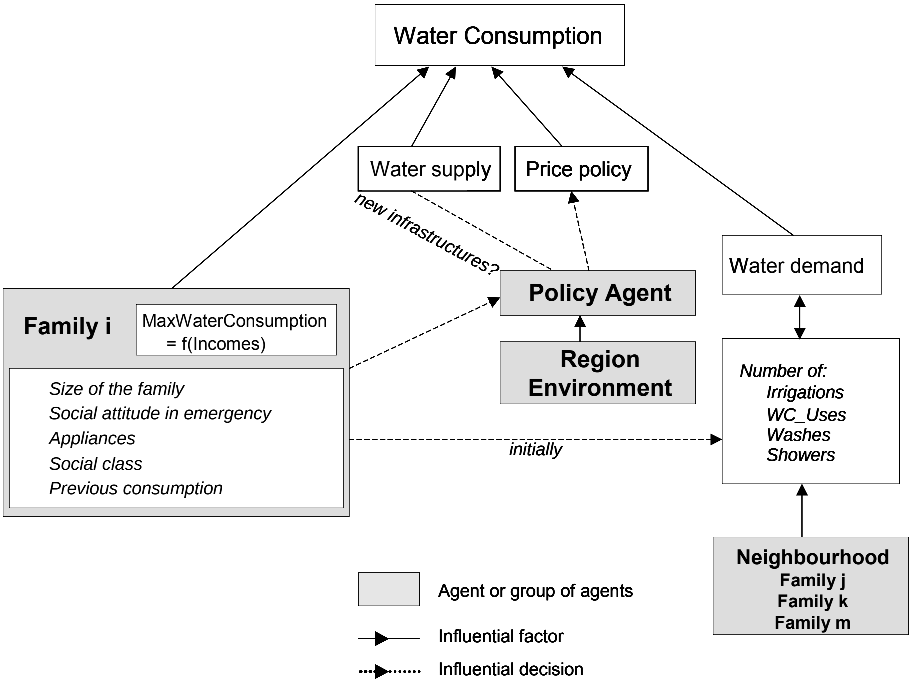

Fig. 2. Sketch of the water consumption decision algorithm for a family in a time step.

In the grid we can define a number of municipalities. In the case study we distinguish three kinds of territorial units (municipalities). Each municipality has a maximum size and occupies a number of cells in the grid.

The different housing types that are associated to a cell are: detached house, semi-detached and flat. There are cells without buildings and ready for future development.

Formally, each cell can be written as:

$$Cell = \left\{ H_{ij}^{Ht}, H_{ij}^{m}, H_{ij}^{p}, H_{ij}^{l} \right\}$$

- H_{ij}^{Ht} is the housing type in the cell.
- H_{ij}^{m} is the municipality that the cell belongs to;
- H_{ij}^{p} is the price of each individual house in the cell and

- H_{ij}^{l} is the list of inhabitants in the cell.

Families are randomly located at the beginning of the simulation. According to their preferences they move and produce the migratory dynamics and a new territorial model. We can observe that new districts emerge [25] in the municipalities as shown in Fig. 3.

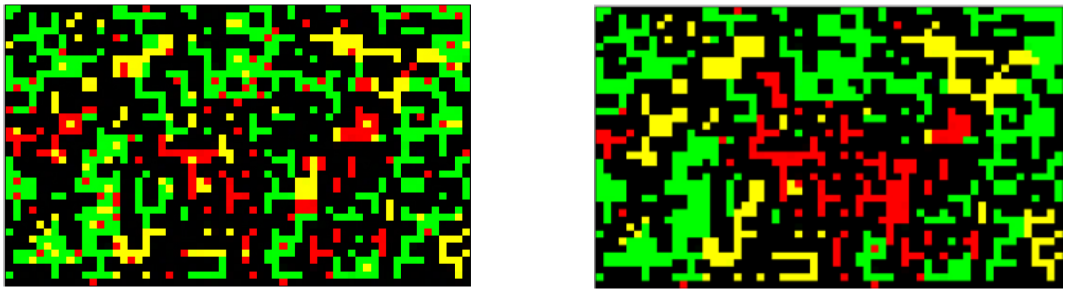

Fig. 3a) 3b). Display of social distribution evolution in a municipality.

In Fig. 3a (left) we show the spatial configuration of a municipality at the beginning of the simulation. The colour of cells is assigned depending on the social class of most of families: yellow for low class, green for medium class and red for high class. In Fig. 3b (right) the same municipality is represented ten years later.

6 Simulation dynamics

We use the month as the step time in simulations. There are four central processes computed each time step, that are represented in Fig. 4. The territorial and the social models make up the core of the simulation. The first one produces the urban growth. The second one contains an artificial society of families, whose life cycle takes place in that territory. Families decide housing movement into the territory and their demand and consumption of water. Users can try price and infrastructure policies in different scenarios.

1. The load of climatic data from the file: the rainfalls and temperatures for the current period of time are introduced in the system.
2. The freshwater supply: the simulator computes the stored water in reservoirs and the production of desalination plants, adding the value of rainfalls and subtracting the water leaks in the supply networks.

${}^{t}P$: Rainfalls in the region, period t

${}^{t}N_{R}$: Number of reservoirs, period t

${}^{t}N_{DP}$: Number of desalination plants, period t
${}^{t}S$: Supply, period t
${}^{t}W_{A}$: Available water, period t

$$ {}^{t}S = \sum_{k=1}^{{}^{t}N_{R}} Min(MaxCapacity, {}^{t-1}W_{A_k} + {}^{t}P \cdot Surface_{k}) + \sum_{\varsigma=1}^{{}^{t}N_{DP}} Water_{\varsigma} - WaterLeak \qquad \textbf{Eq. 1} $$

3. Families decide about house movement and the water consumption:
   3.1. The life cycle of the families evolves randomly in relation with the age of the family. When the families are between 20 and 40 years old, some of their members can become emancipated. The emancipated members can or cannot produce new families. The features of these new families are inherited from the families they come from.

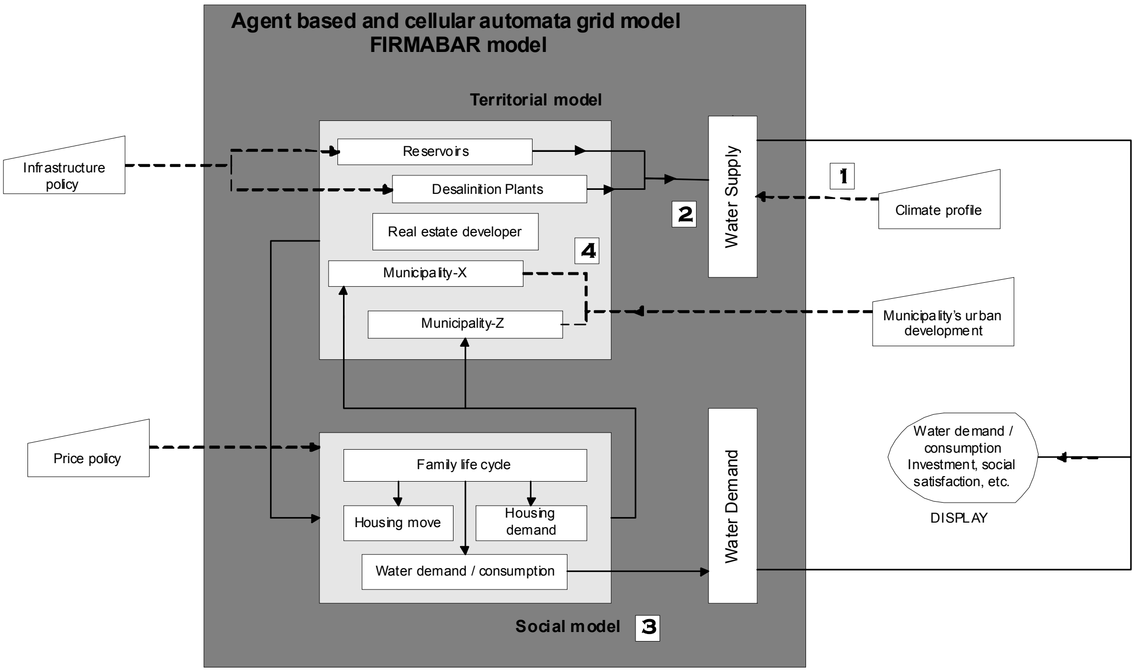

Fig. 4. This figure represents the relationships among the different modules of the simulator. (The numbers in the figure corresponds with the four main steps identified in the *simulation dynamics* section)

Preprint - López-Paredes, A., Saurí, D. & Galán, J. M. (2005). Urban water management with artificial societies of agents: The FIRMABAR simulator. Simulation 81(3), 189-199.
http://sim.sagepub.com/content/81/3/189.abstract doi: 10.1177/0037549705053167

3.2. The migratory model used is based on well known contributions in cellular automata and agent based modelling of urban dynamic in grids by Benenson [22] and Schelling [25]. We adapted the Benenson's model of culture transmission based in the concept of neighbourhood. In our system the families interact in three levels:

1. Individual level. Their beliefs, preferences, performance rules, and memory.
2. Local level. Related to the behaviour of the neighbours (imitative effects).
3. Global level. It is related to problems of emergency situations, drought and scarcity.

Water consumption habits in the neighbourhood can be imitated, as families have free access to each other's water meters. In the model each family selects randomly a group of families in their Moore neighbourhood. If the water consumption in the previous period of the neighbour families was higher than the current demand of the imitator family, the family increases their demand and vice versa.

4. At the end of the time step, the territory is updated. Municipalities are initially endowed with an urban plan for future development.

7 Participatory processes with stakeholders.

In the 90s Integrated Assessment (IA) emerged as an important research method. IA is defined as an interdisciplinary process of gathering, combining, interpreting and communicating knowledge from different scientific disciplines and knowledge domains to allow a better understanding of complex phenomena [26].

One of the basic pillars of IA are the participatory methods. Participatory methods are methods to structure group processes in which non-experts play an active role and articulate their knowledge, values and preferences for different goals [26].

There is a growing trend towards the use of participatory model building processes to capture the behaviour of the representative actors in the system in a realistic fashion [27,28,29] and to include the perspectives of the stakeholders in the design of the models. This approach, participatory simulation, is being used in a growing fashion in the modelling of renewable natural resources. [30,31,32,33].

The advantage of the agent based models against other techniques to be integrated with participatory processes comes from the relative descriptive clarity of this kind of modelling. The straight-forward way in which these models can be interpreted allows active participation of stakeholders and domain experts. When this process is carried out iteratively [25] we can re-design the model with new knowledge and more details. It constitutes a validation method in the design of the hypothesis of the model and in the outcomes.

In order to develop the specific application of the model in the MRB, a platform of social entities was made up of representatives of nine organizations[6].

A series of individual interviews were made with the aim of knowing the attitudes, preferences, roles and objectives of these organizations in relation to domestic water management. Then a questionnaire about the hydrologic cycle in the study area was prepared. It summarized a set of propositions about the possible future trajectories of the different components of water cycle and the different factors with influence in these components. The propositions took into account recent climatic trends, available resources and water supply and demand alternatives. They were estimated in a qualitative way. The platform assessed a total of thirty-six parameters included in different categories: climate, land use, water supply, wastewater, demographic and migratory tendencies, housing tendencies and others.

On the basis of these opinions we design a simulation model to explore different future scenarios and the influence of different aspects in the system. These scenarios were discussed in several meetings with colleagues of the FIRMA project and with the social platform of stakeholders.

8 Implementation and Verification

This simulator was initially developed as part of the FIRMA[7] project. One of the core objectives of the project was to improve water resource planning through the development of new tools applying agent-based modelling. The simulator provides an effective tool to evaluate the results of water policies in different scenarios that have been validated in the region MRB.

The initial version of the model has been implemented in two different multiagent simulation platforms. In order to create the structure and to check the results at low scale we programmed initially a simplified version in Strictly Declarative Modelling Language (SDML) (more details in [34,35]). A second model was developed from the initial one in SDML. In this second model we added a GUI and some suggestions above the final scale made by the stakeholders.

The software allows the user to modify most of the simulation parameters. Notwithstanding, the GUI is intended to evaluate price strategies and modify the water supply infrastructures of the region, adding new desalination plants or increasing the number of reservoirs.

The final version of the model has been implemented in Java using the Swarm libraries of the Santa Fe Institute [36,37]. Swarm is a multi-agent simulation language for modelling collections of concurrently interacting agents in a dynamic environment. Originally it emerged from computational biology [38] and hence it is particu-

---

[6] See a detailed composition of the organization platform in [47] or in the FIRMA project website, http://firma.cfpm.org/ .

[7] FIRMA is the acronym of Freshwater Integrated Resource Management with Agents Project supported by European Union's Framework V (contract EVK1-CT1999-00016).

larly suited to explore complex adaptive systems composed of a large number of relatively simple agents that interact.

It consists of a collection of object oriented libraries of reusable components providing a flexible toolkit which the developer uses for building models and analyzing, displaying and controlling experiments using those models.

The fundamental component that organizes the agents of a SWARM model is a 'swarm'. The swarms are the basic components of the simulations; a swarm is not more than a combination of an object collection (the agents), a schedule of activities and events for these objects and inputs and outputs. Each swarm represents an entire model in a simulation with its own representation of time. The agents interact via a time stepped series of discrete events. Their actions are specified by a collection of methods that are unique to each class of agent. The scheduler specifies the order in which these methods are to be executed over time. Nothing in the model specifies the global level behaviour of the system. The global behaviour of the simulation emerges as a result of the interaction of the individual agents through time.

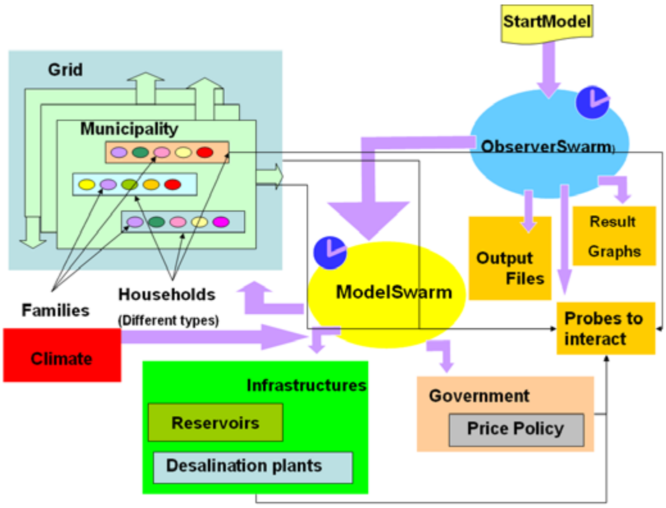

Fig. 5. Observer / Model Swarm structure.

A fundamental and useful feature of the SWARM philosophy is that the structure of the program has two different levels (see Fig. 5). In a first level we implement the model (we can have nested models, swarms inside swarms) and in a second we implement the Observer, an object to "observe" the model. We consider the model as an object to interact with, to get the results and the data that we need, and to send them to the display tools (graphics, charts, histograms...). In SWARM these two levels are totally differentiated, providing an extremely powerful system to control the way of execution of any simulation. In other words, we have the model swarm in the core of the program and the swarm that encapsulates the whole model simulated which is the main input of the observer swarm.

Verification is the process of determining that a computational program that implements a model accurately represents the modeller's conceptual description and specifications. Due to exploratory nature of simulation work, we have not a priori functional requirements of the system to contrast with, so that the results of the simulations are sometimes unexpected. That is the reason why it is difficult to distinguish between an implementation error and an emerging behaviour of the system [39].

In this model, the verification stage has been tackled in two steps, the first one with the step by step debuggers of each one of the development platforms, and afterwards contrasting the results of the initial architecture of the model between both implementations in different platforms.

9 Validation

The validation of a model of a complex system by simulation is one of the most difficult tasks involved in the development process of modelling. Model validation is the process of determining that the behaviour of the model represents the real system to satisfactory levels of confidence and accuracy, which are determined by the intended application of the model and its application domain.

Traditionally the methods used in model validation are based on the comparison of the outputs of the model with the real system, with other models, with results from the model in degenerate situations, etc. However, when modelling complex systems, the use of those methods is not widely accepted [40]. In such case, it is possible to deal with the validation process of the model from two different points of view: from the conceptual model validation and from the validation of the outputs generated by the model [41].

The validation of the conceptual model (structural validation) is the process of checking whether the theoretical foundations and underlying assumptions of a model are correct and reasonable within the context of the objectives of the simulation model and its intended use. The model underlying our simulator has benefited of iterative exchange with stakeholders. The process of knowledge acquisition has been carried out by surveys, interviews and meetings, and verifying information with statistical data of the water consumption in the region.

Adaptive complex systems are inherently unpredictable [42] [43]. When we analyse the evolution of those systems, we should be confident on the hypothesis of the model. In that case, agent based models are more useful than predictive techniques: they provide a wide range of solutions, a priori founded in the characterization and representation of the agents. It is also crucial that agents are conceptually validated. Structural validation can be performed on the basis of a right representation of the agents and the relationship between them.

Participatory methods with experts on the system, more even, with agents of the system, provide the rational frame to analyse the right description of the agents' behaviour, and the credibility of the results provided by the simulations [44] [45].

In the MRB case we applied successfully some participatory techniques [46]. We say successfully because we benefited from many comments and suggestions about

Preprint - López-Paredes, A., Saurí, D. & Galán, J. M. (2005). Urban water management with artificial societies of agents: The FIRMABAR simulator. Simulation 81(3), 189-199.
http://sim.sagepub.com/content/81/3/189.abstract doi: 10.1177/0037549705053167

the system of study. Initially they were sceptic about good results, as they thought that we were preparing new forecasts (in fact, they don't believe in forecasting). Notwithstanding, the first focus group session gave us valuable information to design the territorial model: the resulting aggregation of municipalities in the system is the most relevant. They suggested the set of available strategies for new infrastructures, and removed the wastewater treatment as alternative to the river-transfer, desalination plants and new reservoirs.

Stakeholders also established the three potential future scenarios that were simulated and widely discussed in the last meeting. In this one, interactive process was engaging stakeholders to identify key issues and exploring scenarios in order to integrate the insights into the decision-making of the system. Stakeholders agreed with the global result: in any case, the MRB requires supply and demand policies.

10 Simulation results

The stakeholders proposed to simulate a set of water policies in three alternative scenarios taking the year 2010 as a point of reference. Each one will be named "experiment".

The first scenario (high scenario) is based on: quick migration to the new territorial model, increasing the population in the metropolitan periphery and an urban typology of low density, the non-proliferation of saving and resource conservation measures and the non-use of alternative resources. The second scenario keeps the same trend towards the extended city, but with more weight assigned to the saving measures. Finally, the third scenario introduces the end of the metropolitan expansion and a progressive increase of saving measures and the use of alternative resources. For a complete and detailed description of scenarios see [47].

Each one of these scenarios was evaluated under three different climatic profiles for a period of 10 years. The climatic profile 1 reproduces, with low deviations, the standard climate of the city of Barcelona. The climatic profile 2 introduces five years of consecutive drought followed by five years of recovery. The climatic profile 3 is inverse to the climatic profile 2. The climatic profiles 2 and 3 are justified by the need to evaluate the characteristic climatic cycles of the Mediterranean shore.

A simulation for the scenario A was run under hypothesis of technological improvements, with a fall of 25% in water leaks and a fall of 5% of domestic water consumption, without generating alternative resources of supply in the region. We called it <experiment 1> (see Fig. 6). The results of the simulation show that the territorial change, even though it comes together with efficiency and resource conservation improvements, means a worsening of demand-resources balance, specially under extreme climatic conditions.

Preprint - López-Paredes, A., Saurí, D. & Galán, J. M. (2005). Urban water management with artificial societies of agents: The FIRMABAR simulator. Simulation 81(3), 189-199.
http://sim.sagepub.com/content/81/3/189.abstract doi: 10.1177/0037549705053167

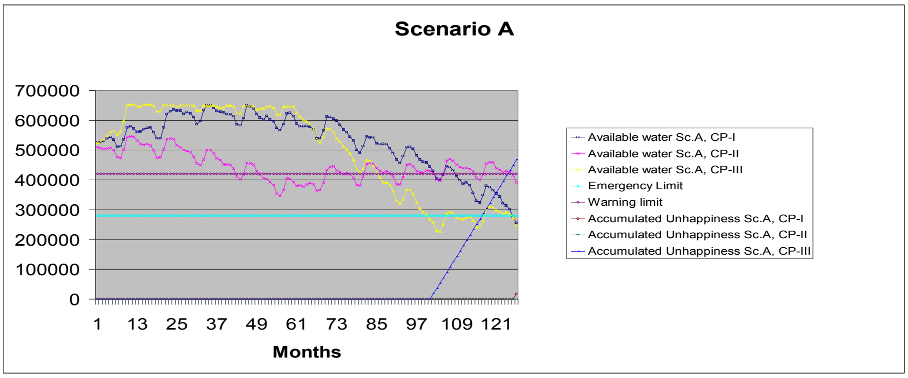

Fig. 6. Typical evolution of water stock for <experiment 1>.

Anther simulation was called <experiment 2> (see Fig. 7). It was considered by the stakeholders platform as not plausible. In this simulation we keep the migratory trends towards the diffuse city due to the high prices of the households in the compact city (among other preference factors) of the experiment 1, but now we do not introduce technological improvement in appliances. Under this assumption the results suggest the relative fast appearance of emergency situations under the three climatic profiles. Just new increments of conventional sources of water supply will make sustainable the region evolution: transfers, new reservoirs and desalination plants.

In the <experiment 3>, also considered as not plausible, although desirable, the city urban expansion towards the low density is slowed down by means of policies to reduce house prices in the compact city and more restrictive urban planning. In this case, even with less technological improvements than in experiment 1, the results of the simulations point out towards a preservation of the demand-resources balance and the absence of emergency situations under any of the climatic simulated profiles (see Fig.8).

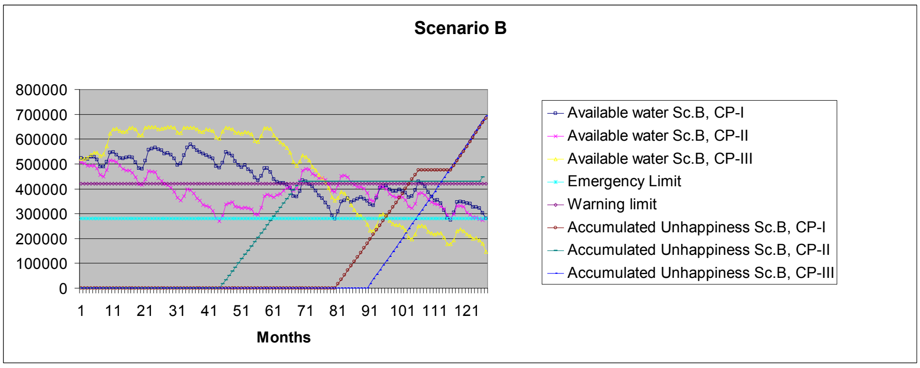

Fig. 7. Typical evolution of water stock for <experiment 2>.

Preprint - López-Paredes, A., Saurí, D. & Galán, J. M. (2005). Urban water management with artificial societies of agents: The FIRMABAR simulator. Simulation 81(3), 189-199.
http://sim.sagepub.com/content/81/3/189.abstract doi: 10.1177/0037549705053167

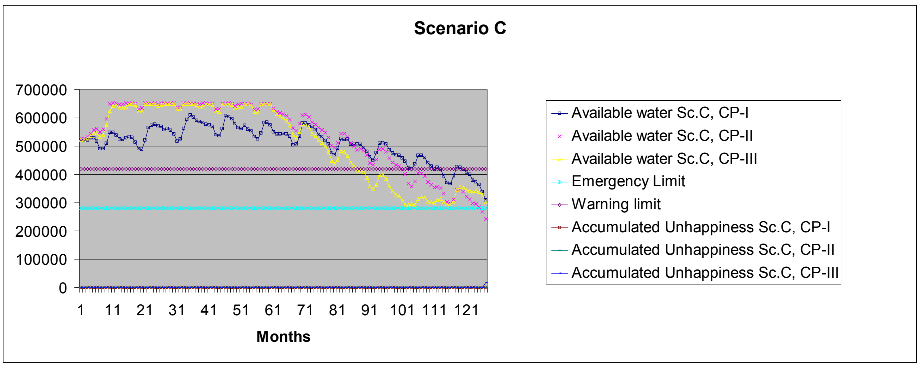

Fig. 8. Typical evolution of water stock for <experiment 3>.

11 Conclusions

In this paper we have summarized a way to apply agent based social simulation to freshwater management. We have justified the reasons that suggest the adoption of this methodology as an alternative to the traditional methodologies of demand-resources balance: ABSS facilitates a detailed representation of the individual participants in the system, capturing their heterogeneity and representing with realism social processes, the explicit representation of the space and the local interactions between agents.

Agent based modelling is an ideal methodology for the analysis of those domains characterized by a high degree of localization and distribution, dominated by discrete decisions, instead of equations based modelling which are suitable for systems that can be centrally modelled, with dynamics dominated by physical laws rather than information processing (see a complete methodological comparison in [48]).

We have also underlined the possibilities of ABSS to allow an interdisciplinary approach in the model simulation development and to integrate participatory processes with stakeholders. In fact, the presented work is an example of the use of a platform with the most representative entities of a problem domain as methodology for designing and validating social simulation models.

We have described the model that supports a water management simulator currently in use. It is based on an artificial society of families whose behaviour determines the urban dynamics. Simultaneously, the social environment affects families' patterns of water consumption.

The validation process has consisted of two stages. The first one, the conceptual validation of the model, carried out through the inclusion of the hypothesis and assumptions of the stakeholders, and empirically compared with statistical data. The second one, the consumption patterns generated in the simulator has been evaluated by a platform of the stakeholders.

Preprint - López-Paredes, A., Saurí, D. & Galán, J. M. (2005). Urban water management with artificial societies of agents: The FIRMABAR simulator. Simulation 81(3), 189-199.
http://sim.sagepub.com/content/81/3/189.abstract doi: 10.1177/0037549705053167

The analysis of some of the results of the simulator applied to the specific Barcelona Metropolitan Area shows:

- Water demand policies should focus on more efficient new domestic appliances and on cutting off water leaks in distribution networks.
- Climate profiles are very important. The Mediterranean climate alternates cycles of abundant rainfall with periods of climatic stress. Currently these cycles tend to spread over five or six years. If the cycle becomes longer new infrastructures will be needed.
- The change from the compact to the diffuse urban model implies an important increase in water demand, that can only be partially satisfied with water demand decisions.

Currently, the simulator is been used to evaluate supply and demand freshwater policies in the fast growing up metropolitan area of Valladolid, a medium sized city in the middle of Spain.

Acknowledgements

This work has been produced as part of a program research that has received financial support from the FIRMA Project (EVK1-CT1999-00016), the Spanish Ministry of Science and Technology Grant Ref.: BEC-2001-2108, and the Junta de Castilla y León Grant Ref.: VA034/04.
We acknowledge comments from the colleagues in the EU FIRMA Project, anonymous reviewers of a previous version of the paper and by Prof. Hernandez Iglesias. Usual disclaims apply.

References

[1] Gilbert, N. and Troitzsch, K., *Simulation for the social scientist*. Buckingham: Open University Press.1999

[2] Holland, J. H., *Emergence. From chaos to order*. Reading, Mass: Addison-Wesley.1998

[3] Johnson, S., *Emergence: the connected lives of ants, brains, cities, and software*. New York: Scribner.2001

[4] Lopez, A. Hernández, C. and Pajares, J., "Towards a New Experimental Socioeconomics. Complex Behaviour in Bargaining," *Journal of Socioeconomics*, Vol. 31, pp. 423-429, 2002.

[5] Axelrod, R. M., *The complexity of cooperation. Agent-based models of competition and collaboration*. Princeton, N.J: Princeton University Press.1997

[6] Prietula, M. J. et al., *Simulating organizations. Computational models of institutions and groups*. Menlo Park, CA: AAAI Press/MIT Press.1998

[7] Polhill, J. G. et al., "Imitative versus nonimitative strategies in a land use simulation (vol 32, pg 285, 2001)," *Cybernetics and Systems*, Vol. 33, No. 5, pp. 537-538, 2002.

[8] Janssen, M., *Complexity and ecosystem management. The theory and practice of multi-agent systems*. Chelteham, UK: Edward Elgar Pub.2002

[9] Zhou, S. L. el al., "Frequency analysis of water consumption for metropolitan area of Melbourne," *Journal of Hydrology*, Vol. 247, No. 1-2, pp. 72-84, 2001.

[10] Rogers, P. el al., "Water is an economic good: How to use prices to promote equity, efficiency, and sustainability," *Water Policy*, Vol. 4, pp. 1-17, 2002.

[11] Baumann, D. D. et al., *Urban water demand management and planning*. New York: McGraw-Hill.1998

[12] Renwick, M. E. and Archibald, S. O., "Demand side management policies for residential water use: Who bears the conservation burden?," *Land Economics*, Vol. 74, No. 3, pp. 343-359, 1998.

[13] Nauges, C. and Thomas, A., "Privately operated water utilities, municipal price negotiation, and estimation of residential water demand: The case of France," *Land Economics*, Vol. 76, No. 1, pp. 68-85, 2000.

[14] Arbués, F. el al., "Estimation of residential water demand: a state of the art review," *Journal of Socioeconomics*, Vol. 32, pp. 81-102, 2003.

[15] Epstein, J. M., "Agent-based computational models and generative social science," *Complexity*, Vol. 4, No. 5, pp. 41-60, 1999.

[16] Harris, G., "Integrated assessment and modelling: an essential way of doing science," *Environmental Modelling & Software*, Vol. 17, No. 3, pp. 201-207, 2002.

[17] Parker, P. el al., "Progress in integrated assessment and modelling," *Environmental Modelling & Software*, Vol. 17, No. 3, pp. 209-217, 2002.

[18] Rotmans, J. and Dowlatabadi, H., "Integrated Assessment Modeling," in *Human Choice and Climate Change. Vol. 3, The Tools for Policy Analysis*. S. Rayner and E. L. Malone, Eds. Columbus Ohio: Battle Press, 1997, pp. 291-377.

[19] Couclelis, H., "Of mice and men: what rodent populations can teach us about complex social dynamics," *Environment and Planning A*, Vol. 20, pp. 99-109, 1987.

[20] Itami, R. M., "Simulating Spatial Dynamics - Cellular-Automata Theory," *Landscape and Urban Planning*, Vol. 30, No. 1-2, pp. 27-47, 1994.

[21] Batty, M. and Xie, Y. C., "From cells to cities," *Environment and Planning B-Planning & Design*, Vol. 2, p. S31-S48, 1994.

[22] Benenson, I., "Multi-Agent Simulations of Residential Dynamics in the City," *Computing, Environment and Urban Systems*, Vol. 22, No. 1, pp. 25-42, 1998.

[23] White, R. and Engelen, G., "Cellular automata as the basis of integrated dynamic regional modelling," *Environment and Planning B-Planning & Design*, Vol. 24, No. 2, pp. 235-246, 1997.

[24] Weimar, J., *Simulation with Cellular Automata*. Berlin: Logos-Verlag.1998

[25] Schelling, T. C., *Micromotives and macrobehavior*, 1st ed ed. New York: Norton.1978

[26] van Asselt, M. B. A. et al., "Building blocks for participation in integrated assessment: a review of participatory methods," International Centre for Integrative Studies. Maastricht,01_17, 2001.

[27] Downing, T. E. et al., "Understanding climate policy using participatory agent-based social simulation," *Multi-Agent-Based Simulation*, Vol. 1979, pp. 198-213, 2001.

[28] Moss, S. et al., "Agent-based integrated assessment modelling: the example of climate change," *Integrated Assessment*, Vol. 2, pp. 17-30, 2001.

[29] Pahl-Wostl, C., "Agent Based Simulation in Integrated Assessment and Resources Management,", 2 edi. EMSs 2002 pp. 239-245 2002.

[30] Bousquet, F. el al., "Multiagent simulations of hunting wild meat in a village in eastern Cameroon," *Ecological Modelling*, Vol. 138, pp. 331-346, 2001.

[31] Barreteau, O., "The joint use of role-playing games and models regarding negotiation processes: characterization of associations," *Jasss-the Journal of Artificial Societies and Social Simulation*, Vol. 6, No. 2, <http://jasss.soc.surrey.ac.uk/6-2/3.html>, 2003.

[32] Barreteau, O. and Bousquet, F., "SHADOC: a multi-agent model to tackle viability of irrigated systems," *Annals of Operations Research*, Vol. 94, pp. 139-162, 2000.

[33] Lynam, T. et al., "Adapting science to adaptive managers: Spidergrams, belief models, and multi-agent systems modeling," *Conservation Ecology*, Vol. 5, No. 2, <http://www.ecologyandsociety.org/vol5/iss2/art24>, 2002.

[34] Moss, S. et al., "SDML: A Multi-Agent Language For Organizational Modelling," *Computational & Mathematical Organization Theory*, Vol. 4, No. 1, pp. 43-63, 1998.

[35] Wallis, S. and Moss, S., "Efficient Forward Chaining for Declarative Rules in a Multi-Agent Modelling Language," *CPM Report No. : 004.*, <http://cfpm.org/cpmrep04.html>, 1994.

[36] Hiebeler, D., "The swarm simulation system and individual-based modeling," in *Decision Support 2001. 17th Annual Geographic Information Seminar and the Resource Technology '94 Symposium*. J. M. Power, M. Strome, and T. C. Daniel, Eds. American Society for Photogrammetry and Remote Sensing, pp. 474-494. 1994.

[37] Minar, N. et al., "The Swarm Simulation System: A Toolkit for Building Multi-Agent Simulations," *Santa Fe Institute,SFI Working Paper 96-06-042*, 1996.

[38] Carley, K. M. and Gasser, L., "Computational Organization Theory," in *Multi-agent Systems. A Modern Approach to Distributed Artificial Intelligence*. G. Weiss, Ed. Cambridge, Massachusetts: MIT Press, pp. 299-330. 1999.

[39] Edmonds, B. and Hales, D., "Replication, replication and replication: Some hard lessons from model alignment," *Jasss-the Journal of Artificial Societies and Social Simulation*, Vol. 6, No. 4, <http://jasss.soc.surrey.ac.uk/6-4/11.html>, 2003.

[40] Brown, T. N. and Kulasiri, D., "Validating models of complex, stochastic, biological systems," *Ecological Modelling*, Vol. 86, No. 2-3, pp. 129-134, 1996.

[41] Moss, S. and Edmonds, B., "Sociology and Simulation: - Statistical and Qualitative Cross-Validation," *CPM Report No. : 03-105*., <http://cfpm.org/cpmrep105.html>, 2003.

[42] Bradbury, R. H., "Futures, predictions and other foolishness," in *Complexity and Ecosystem Management: The Theory and Practice of Multi-agent Systems*. M. Janssen, Ed. Cheltenham: Edward Elgar, pp. 48-62. 2002.

[43] Lempert, R., "Agent-based modeling as organizational and public policy simulators," *Proceedings of the National Academy of Sciences of the United States of America*, Vol. 99, pp. 7195-7196, 2002.

[44] Barreteau, O. et al., "Role-playing games for opening the black box of multi-agent systems: method and lessons of its application to Senegal River Valley irrigated systems," *Jasss-the Journal of Artificial Societies and Social Simulation*, Vol. 4, No. 2, <jasss.soc.surrey.ac.uk/4/2/5.html>, 2001.

[45] Moss, S., "Policy analysis from first principles," *Proceedings of the National Academy of Sciences of the United States of America*, Vol. 99, pp. 7267-7274, 2002.

[46] Slocum, N., *Participatory Methods Toolkit. A Practitioner's manual* UNU-CRIS, the King Baudouin Foundation and the Flemish Institute for Science and Technology Assessment..2003

[47] Saurí, D. et al., "Aproximación a la Demanda Domestica de Agua Mediante Modelos Multiagente. El Caso de la Región Metropolitana de Barcelona," *Ingeniería Civil*, Vol. 131, pp. 147-151, 2003.

Preprint - López-Paredes, A., Saurí, D. & Galán, J. M. (2005). Urban water management with artificial societies of agents: The FIRMABAR simulator. Simulation 81(3), 189-199.
http://sim.sagepub.com/content/81/3/189.abstract doi: 10.1177/0037549705053167

[48] Parunak, H. V. et al., "Agent-based modeling vs. equation-based modeling: A case study and users ' guide," *Multi-Agent Systems and Agent-Based Simulation*, Vol. 1534, pp. 10-25, 1998.