The Role of MAS as a Decision Support Tool in a Water-Rights Market

Vicente Botti[1], Antonio Garrido[1], Juan A. Gimeno[1], Adriana Giret[1], Pablo Noriega[2]

[1] DSIC, Departamento de Sistemas Informaticos y Computacion, Universitat Politècnica de València,
[2] IIIA, Artificial Intelligence Research Institute, CSIC, Spanish Scientific Research Council,
{vbotti,agarridot,jgimeno,agiret}@dsic.upv.es
pablo@iiia.csic.es

Abstract. Water is getting a more and more scarce resource, which motivates the idea of designing a framework where water rights may be exchanged more freely, thus leading to a more efficient use of water. In this paper, we present a water-right market embedded within a decision support tool designed as a multi-agent system. To our knowledge, there are many sophisticated decision support systems for water management from a hydrological perspective, but they lack of a social perspective. Using a multi-agent system allows us to design intelligent agents that mimic humans, thus implementing different factors such as (mis)conducts, trust criteria and users willingness to water-right trading. Within a decision support tool, we can dynamically change norms and regulation at no cost, and explore the impact on the evolution of the market. Mixing all these elements together, we have implemented our *mWater* system as an electronic institution that demonstrates very appealing for decision taking and policy makers to test: i) how regulations and norms may modify the users' behaviour, and ii) how the quality indicators of the market are affected.

Keywords: Applications of multi-agent systems, decision support, simulation tools, electronic institutions

1 Introduction

Water scarcity is becoming a major concern in most countries, not only because it threatens the economic viability of current agricultural practices, but because it is likely to alter an already precarious balance among its different types of use: human consumption, industrial use, energy production, navigation, etc. Underneath this emergent situation, the crude reality of conflicts over water rights and the need of accurate assessment of water needs become more salient than ever.

It has been sufficiently argued that more efficient uses of water may be achieved within an institutional framework where water rights may be exchanged more freely, not only under exceptional conditions but on a day-to-day basis [18], similarly to a traditional goods market. In hydrological terms, a water market can be defined as an institutional, decentralized framework where users with water rights (right holders) are allowed to voluntarily trade them, always fulfilling some pre-established norms, to other users in exchange of some compensation, economic or not [18]. Additionally, when there exist incentives for an efficient use of water allotment, it is time for a straightforward extension to other types of stakeholders that promote trading for non-irrigation uses, such as industrial uses, aquiculture or leisure, thus improving market conditions and efficiency in water use.

This paper concerns the application of a regulated open Multi-Agent System (MAS), *mWater*, that uses intelligent agents to simulate a flexible water-right market. Our simulator focuses on demands and, in particular, on the type of regulatory (in terms of norms selection and agents behaviour), and market mechanisms that foster an efficient use of water while also trying to reduce conflicts among parties. In this scenario, a MAS plays a vital role as it allows us to define different norms, agents behaviour and roles, and assess their impact in the market, which helps enhance the quality and applicability of its results as a decision support tool.

2 Problem Overview

Water-right markets allow rapid changes in allocation in response to changing demands for water and stimulate investment and employment, as users are assured of access to secure supplies of water. Because of water's unique characteristics, such markets do not work everywhere, they are not homogenous as present different organisation schemata, nor do they solve all water-related issues [18]. Therefore, it is essential to design appropriate water laws and regulate, either privately or publicly, the users' actions, interactions and their eventual trade. By doing this, water markets effectively address rising demands for groundwater and for surface water found in rivers, lakes and canals. In that line, international experience in USA (particularly California), Chile, Australia or Mexico has demonstrated that (formal) water markets can improve the economic efficiency of water use and stimulate investment [18].

The willingness of irrigators to buy or sell water highly depends on the difference between the price of water and net revenue each farmer expects to earn by irrigating. Thus, for a given price of irrigation water, a farmer would be willing to purchase water if (s)he expects a unit of water to generate more incomes than it costs. If another farmer expects a unit of water to earn less that (s)he could sell it for, (s)he might want to sell it thus originating the trading process. But it is not always a matter of price expectations, but also of regulation. The emphasis on regulatory aspects is motivated by the fact that the main objective policy makers have in mind is to achieve an adequate behaviour of users to ensure the success of the market. And regulation is the main tool that policy makers have to modify behaviour by means of: i) government laws, ii) basin or local norms, and iii) social norms. However, in practice, users are prone to achieve "order without law" or, at least, to preserve their practices within the established regulation, whereas policy makers adapt regulation to guide users in a constantly changing environmental and political media. But adapting this regulation and taking the best decisions on the design of the norms for the market are difficult and delicate tasks, and cannot be freely applied in the real world. Also, as the result of enforcing norms in a water market is unknown a priori, a MAS-based simulation tool shows very appealing to analyse the impact in the users, the market itself and its success.

3 Limitations in Current Approaches

Literature abounds in examples of sophisticated basin simulation models, particularly decision support systems for water management [1, 12], sustainable planning of water volumes and hydraulic resources [5, 14], and use of shared visions for negotiation and conflict resolution [11, 17]. From a hydrological perspective, these works have successfully bridged the gap between the state of the art in water-resource systems analysis and the usage by practitioners at the real-world level. Clearly, operational management has benefited from the advances in computing and its applications, particularly in modelling, software engineering and simulation techniques, thus improving the operating rules for efficient water allocation. However, the gap can still be considerably narrowed from a social perspective, which is an important limitation nowadays. The underlying idea is not only to consider hydraulic factors, such as river basins, water demands, pumping flows, etc., but also different norms typology, human (mis)conducts, trust criteria and users willingness to agree on water-right trading, which may lead to a win-win situation in a more efficient use of water. This requires the use of intelligent agent technology, including trust, cooperation, argumentation, negotiation and, in general, agreement technologies [16]. Agreement is a crucial concept that helps human agents to cope with their social environment and deal with any type of human interactions. And how to support and promote agreements in water markets is missing in current approaches, which is also an indication of ineffectiveness.

An additional limitation is imposed by current legislation. In many countries, the norms and their regulation are very strict, which do not allow a full and flexible market. For instance, Spanish regulation is too restrictive and does not let final stakeholders participate freely in the modelling and water-right trading process. In particular, the Water Law of the National Hydrological Plan regulates the power of right holders to engage in voluntary water transfers, and of basin authorities to setup water markets, banks and trading centers for the exchange of water rights, but *only* in cases of drought or other severe scarcity problems. This means that the number of water-right transfers is practically non-existent in reality, reduced to few eligible participants and limited to very short periods. Also, in some tentative scenarios aimed at forming water markets the results were unsatisfactory because: i) water-right holders were reluctant to participate in the market, and ii) regulation and legally binding conditions were too tight.

Finally, from a performance standpoint it is unclear which is the best quality indicator of the market because it cannot be measured in terms of just one factor; we need a multiobjective analysis that comprises multiple criteria based on differing objectives, responsibilities and interests among the stakeholders and institutions involved in the market. Factors such as economic development, social welfare, environment preservation, agricultural self-sufficiency and financial feasibility must be considered. All in all, these issues can be achieved at a high global cost which is based on industry structure, population, quality standards, investment for new treatment plants, and policy for water allocation among agriculture, industry and domestic sectors.

4 Why Use a MAS as a Simulation Tool for Decision Support?

Agent technology and multi-agent systems have been successfully applied to problems such as manufacturing, medicine, aero-space, e-commerce, etc. when developing high-quality and industrial-strength products. One of the most promising domain applications of MASs is the simulation of complex real life systems that emulate social behaviour and organizations, where a MAS is used as a powerful tool that mimics real world behaviours of autonomous agents, i.e. individuals and societies [17]. In this way, complex behavioural patterns are observed from simulation tests in which autonomous entities interact, cooperate, and/or compete to achieve a set of goals. This offers several advantages: i) the ability to model and implement complex systems formed by autonomous agents, capable of pro-active and social behaviour; ii) the flexibility of MAS applications to add and/or delete computational entities, in order to achieve new functionalities or behaviours in the system, without altering its overall structure; and iii) the ability to use notions such as organization, norms, negotiation, agreement, trust, etc. to implement computational systems that benefit from these human-like concepts and processes among others [16].

In the specific domain of water-right management there is a need to foster a more rational use of the resource. And it is agreed that this may be addressed by creating an efficient market of water rights that coexist in a complex, social and legal framework [18]. Although most water management models are based on equational descriptions of aggregate supply and demand in a water basin [14], only a few include an agent-based perspective. Under this perspective, we explore an approach in which individual and collective agents are essential components because their behaviour, and effects, may be influenced by regulation and policy-making. The idea is to follow the thread of MAELIA (`http://www.iaai-maelia.eu`) and NEGOWAT projects (`http://www.negowat.org`) that simulate the socio-environmental impact of norms for water and how to support negotiations among stakeholders in areas where water conflicts arise.

From a technical perspective, there are several approaches to implement MAS applications. Some approaches are centered and guided by the agents that will populate the systems, while others are guided by the organizations that the constituent agents may form (for a literature review please refer to [3]). Other approaches rely the development process on the regulation that defines the MAS behavior, which is usually encoded as an Electronic Institution (EI) [7, 9, 13]. We are interested in this latter approach due to the requirements imposed by the environment. In particular, *mWater* —from the perspective of a MAS simulation tool— implements a regulated market environment as an EI, in which different water users (intelligent agents) trade with water rights under different basin regulations. With such a tool, water-policy makers can easily predict and measure the suitability and accuracy of new or modified regulations for the overall water market, i.e. more transfers, fewer conflicts, increased social satisfaction of the water users, etc., before applying them into the real floor. At the same time, it is a tool to manage the water resource in an effective way, both in the short and medium term. All in all, not only is it an aid for a better understanding of the physical and management aspects of the water-resource system in question, but it is also a good tool for data organization and communication among the different teams of the basin administration.

5 Our Approach

mWater uses a multi-tier architecture, as depicted in Fig. 1 [8]. In addition to the three typical tiers of presentation, business and data persistence, we have a module that represents the EI for *mWater*. This way, the construction of *mWater* consists of four stages: i) modelling the system as an EI; ii) designing the information system based on a database of the entire electronic market and basin structure (persistence tier); iii) implementing the agents (business tier); and iv) creating the GUI for simulation tool (presentation tier), which are described next.

5.1 Modelling the system as an EI

Electronic Institutions (EI) are computational counterparts of conventional institutions and represent a set of conventions that articulate agent interactions [7, 10]. In practice, they are identified with the group of agents, standard practices, policies and guidelines, language, documents and other resources —the organization— that make those conventions work. EIs are engineered as regulated open MAS environments in the sense that: i) the EI does not control the agents' decision-making processes, and ii) agents may enter and leave the EI at their own will, which is essential in a market.

An EI is specified through: i) a *dialogical framework* which fixes the context of interaction by defining roles and their relationships, a domain ontology and a communication language; ii) *scenes* that establish interaction protocols of the agents playing a given role in that scene, which illocutions are admissible and under what conditions; iii) *performative structures* that, like the script of a play, express how scenes are interrelated and how agents playing a given role move from one scene to another, and iv) *rules of behaviour* that regulate how

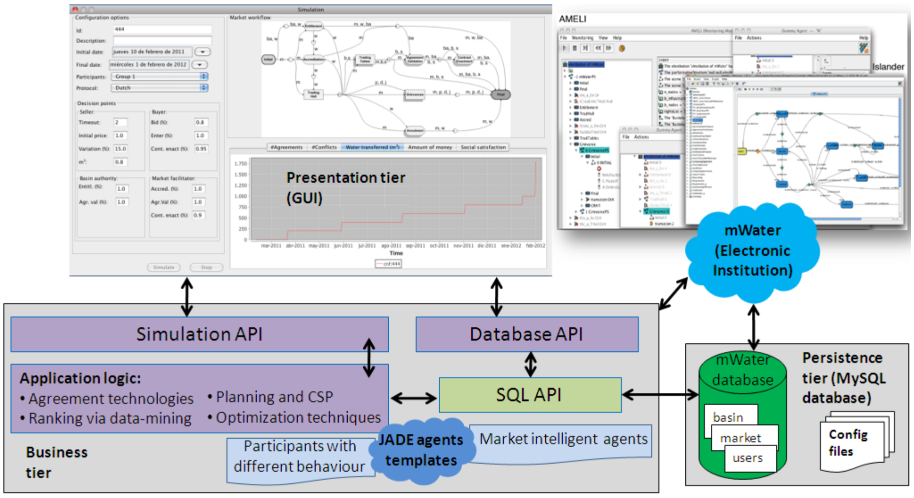

Fig. 1. Multi-tier architecture of the *mWater* decision support tool

commitments are established and satisfied. We have used this specification and modelled *mWater* as an EI. *mWater* uses the notation for the conceptual model introduced in [2], whereas for the actual specification and implementation we use the EIDE platform[1].

The *mWater* institution is specified through a nested performative structure with multiple processes, as depicted in Fig. 2. There are five agents' roles: i) guests, i.e. users before entering the market; ii) water users, i.e. the guests that have valid water rights; iii) buyer/seller, thus representing the particular role the water user currently joins for the market; iv) third parties, i.e. those water users that are direct or indirectly affected by a water transfer —usually conflicting parties; and v) market facilitator and basin authority, thus representing the governing roles of the market. The top structure describes the overall market environment and includes the following elements:

– Entitlement, which represents the bootstrap routine to give access to the market to those water-right holders who prove they are entitled to trade because: i) they have an existing right, or ii) a new right is created by the *mWater* authorities and an eligible holder gets it granted.

[1] EIDE is a development environment for Electronic Institutions, implemented at the IIIA (`http://e-institutor.iiia.csic.es/eide/pub`). It consists of a set of tools that support all the stages of EI engineering, namely: i) ISLANDER, a tool for EI specification; ii) aBUILDER, a tool to support the automatic generation of agent (code) skeletons from ISLANDER specifications; iii) the AMELI middleware that handles the enactment of the institution; and iv) SIMDEI, a testing and monitoring tool.

- Accreditation, which allows legally entitled water-right holders to trade by registering their rights and individual data for management and enforcement purposes.
- TradingHall, which represents a nested performative structure. It basically provides information about the market and, at the same time, allows users and trading staff to initiate trading and ancillary operations. Metaphorically speaking, it represents a place where participants stay to be informed and reconvene after leaving a trading table or grievance process.
- TradingTables, which represent a nested performative structure and the core of our market. It allows a market facilitator to open a new trading table whenever a new auction period starts (i.e. automatically) or whenever a right-holder requests to trade a right (i.e. on demand). Our implementation accommodates different trading mechanisms and negotiation protocols, such as Dutch auction, English auction, standard double auction and blind double auction with mediator negotiation, but new negotiation protocols can be easily included.
- Agreement Validation, which validates agreements on water-right transfers according to the market regulation. More particularly, staff have to check whether the agreement satisfies formal conditions and the hydrological plan normative conventions.
- Contract Enactment, which represents the signature among parties involved in a norm-abiding agreement, thus making the agreement active.
- Grievances, which represent a nested performative structure. It allows external stakeholders to initiate a grievance and conflict resolution procedure that may overturn or modify an active agreement. Even if there are no grievances that modify a contract, parties might not fulfill the contract properly and there might be some contract reparation actions.
- Annulment, which deals with anomalies that deserve a temporary or permanent withdrawal of water rights.

The essence of our market relies on the Trading Tables and Grievances structures. The former implements the trading process itself, which entails the participation of the buyer/seller and staff agents. The latter is necessary to allow normative conflicts to be solved within the *mWater* institution, particularly when the agreement execution turns conflicting with third party agents. In our approach, we include a framework for conflict resolution based on grievance protocols in which alternative dispute resolution (ADR) mechanisms are included in order to settle the conflicts internally in the market [15]. In this framework, any grievance process primarily involves negotiation like in any Trading Table (with or without mediation) and a arbitration procedure, or a combination of both. This way, the result of a conflict resolution can be an agreement among the conflicting parties by which they voluntary settle the conflict, or a decision from the arbitrator (a neutral third party) which is final, and binding to both conflicting parties.

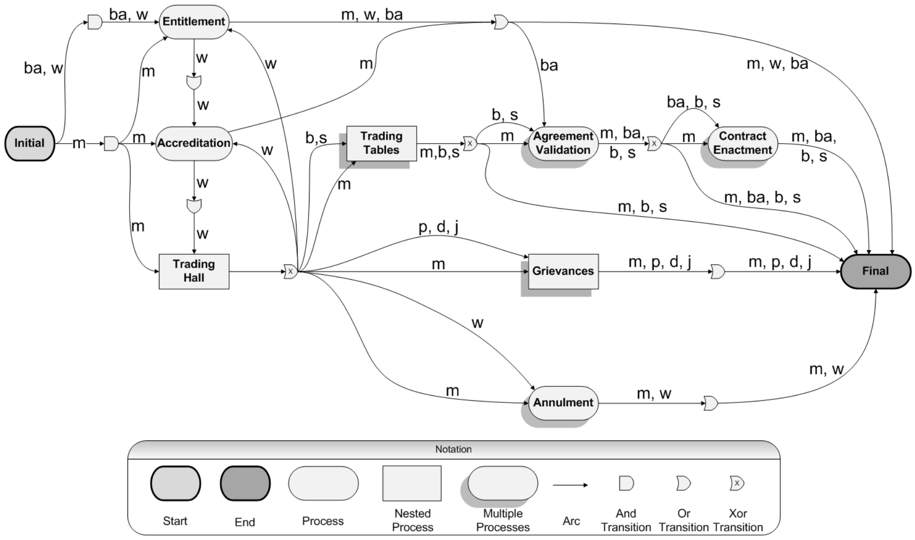

Fig. 2. *mWater* performative structure. Participating roles: *g* - guest, *w* - water user, *b* - buyer, *s* - seller, *p* - third party, *m* - market facilitator, *ba* - basin authority. See [4] for further details

5.2 Persistence Tier: Database Design

mWater implements the persistence tier by means of a MySQL database with over 60 relational tables in which historical data is stored. In essence, we have three views that comprise the basin, market and grievance structure (see Fig. 3). In the first view we model all the information about the nodes, connections, users, norms and water-right definition. In the second view we model information related to the entire market, including the trading tables and their protocols, the water rights to be traded, participants, agreements and contracts that can be signed. Finally, in the third view we model the information about the legislation and conflicts that may appear after an agreement or contract and the mechanisms for solving such a conflict, that is the negotiation stage or arbitration procedure. This way, policy makers can run the whole market with real and simulated data for drought periods, rainfall, norms and users, and analyse how they affect the final results and the number of grievances. Furthermore, all the changes in the market are registered in the database to provide statistical information and/or distributions to the policy makers, which are essential in a decision-support tool.

5.3 Business Tier: Implementation of Agents

mWater implements a schema of agents that include both the internal and external roles. Broadly speaking, there is a JADE (Java Agent DEvelopment Framework, `http://jade.tilab.com`) definition for each class that represents

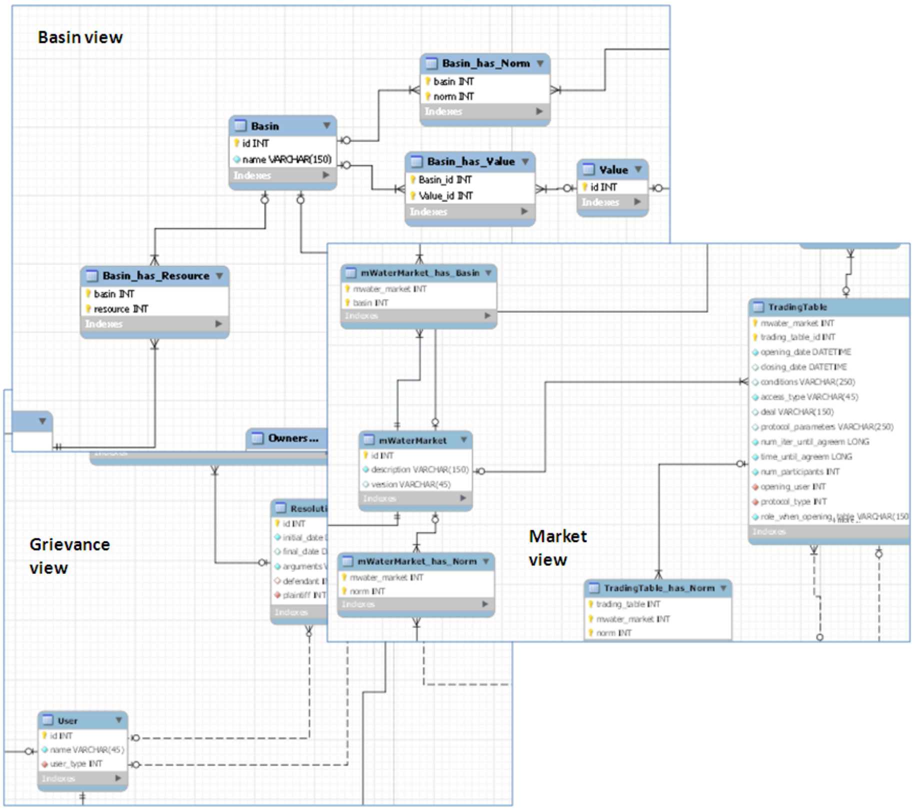

Fig. 3. Fragment of the database: basin, market and grievance views

the roles in the scenes. The generation of the Java classes is done in an automated way, thanks to the tools provided by the EIDE development environment. More particularly, the mapping that is used to generate the agents implementation is shown in Fig. 4. In particular, one Java class is created per valid role (guest, water user, buyer, seller, third party, market facilitator and basin authority) and per scene in which each role can participate. Intuitively, this can be seen as a basic template for an agent participating in a given scene. It is important to note that not all roles participate in all the scenes —recall the definition of the *mWater* EI in Fig. 2—, so there are roles that are translated into more classes than others. The main idea with this is to offer open and flexible templates to implement different agents and norms, which provides more opportunities to the user to evaluate the market indicators under different regulations and types of agents.

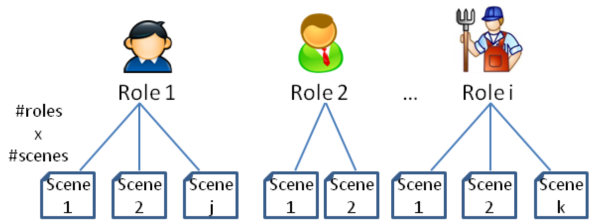

Fig. 4. Schema of the agents implementation. The mapping proceeds by generating one Java class (template) per role in each scene it can be involved

Once the templates have been automatically generated, we can extend them by implementing new classes that represent different behaviours, which is interesting from a simulation perspective. Basically, we override methods to change the original behaviour that allows the agent to move from one state to another, i.e. to execute a transition, or send a message (interact) to other agents. For instance, in the case of the buyer/seller we have implemented a *favourable* and *unfavourable* behaviour. In the former, the agent is always in favour of achieving an agreement to trade and follow the norms of the market, whereas the latter is always against it and does not follow the rules. Additionally, we have placed some decision points that rely on random distributions (inputs of the GUI, see section 5.4) to make the simulation more realistic.

Our implementation introduces an explicit intelligent management into the market in the form of market facilitator. This role has demonstrated very helpful to improve and facilitate the internal behavior of the institution. The market facilitator must be aware of the organizational conventions, the rules of the market and the negotiation structure. But more importantly, (s)he offers intelligent capabilities to help the users under three basic scenarios: i) to decide about opening a new trading table, ii) to decide what user is going to be invited to join that table and why (preliminary process of invitation), and iii) to help within the negotiation (trading) process. First, the facilitator must be aware of the current context of application that may forbid or allow the opening of the most adequate trading table based on the current legislation. Similarly, the market facilitator may offer advice during the grievance procedure, thus making it more efficient. Second, the market facilitator sends invitations to join the table by using data mining rankings that assign a priority to each user for being invited to each table —this involves an intelligent deliberative process based on the user's reputation and trust in previous transactions. Third, the facilitator must obey the particular rules of the protocol to be used within the negotiation, which are usually domain-dependent —different protocols require the application of different sequences of steps—, to make the protocol more agile or to converge more rapidly.

Note that we have also two alternatives for norm enforcement [6]. The former is to implement this reasoning process in the institution side, making it impossible for an agent to violate the norms. Although this provides a trustful and safe environment, it is less flexible and forces the implementation of the agents to be more aware of the legislation of the institution. Moreover, in real life problems, it may be difficult or even impossible to check norm compliance, specially when the violation of the norm cannot be directly observable. And perhaps, it might be preferable to allow agents to violate norms, since they may intend to improve the organization functionality, despite violating or ignoring norms. On the contrary, the second alternative moves the norm reasoning process to the agent side, thus making the system more open and dynamic. In this case, the intelligence of the agent can make it more or less law-abiding in order to obtain a higher personal benefit. If a norm is violated and a third party is affected, the grievance mechanism activates and the conflict resolution stage modelled in the EI is launched.

All in all, and as shown in Fig. 1, this tier includes several techniques to deal with agreement technologies, selection procedures based on data mining processes, intelligent agents that can reason on norms, and planning+CSP methods for navigating through the *mWater* EI, while also trying to find optimal solutions in terms of the amount of water transferred and/or the social satisfaction of the participants.

5.4 Presentation Tier: GUI Simulation Tool

The interface of *mWater* as a simulation tool is simple and intuitive, as shown in Fig. 5. The idea is to offer a straightforward and effective way in which the user configures and runs simulation with the following data: i) the initial and final date for the period to be simulated; ii) the participants, i.e. water users, that will participate in the market (different groups/type of water users lead to different results; e.g. a group in which water users do not trust other members of the group results in a low number of agreements and a high number of conflicts); iii) the protocols to be used during trading, which represent the regulation to be applied in the current simulation; and iv) several decision points to include some random behaviour when users (seller, buyer, basin authority and market facilitator) need to take some decisions. The tool outputs graphical statistical information that indicates how the market reacts to the input data in terms of the number of transfer agreements signed in the market (historical data including information about real or simulated users), number of conflicts generated, volume of water transferred, amount of money, etc. Apart from these straightforward parameters, the tool also shows different quality indicators based on "social" functions in order to asses values such as the trust and reputation levels of the market, or degree of water user satisfaction, among others. This is important to evaluate the quality of the market from the stakeholder's point of view, and not only from a mechanistic standpoint based just on the number of agreements or water transferred, among other.

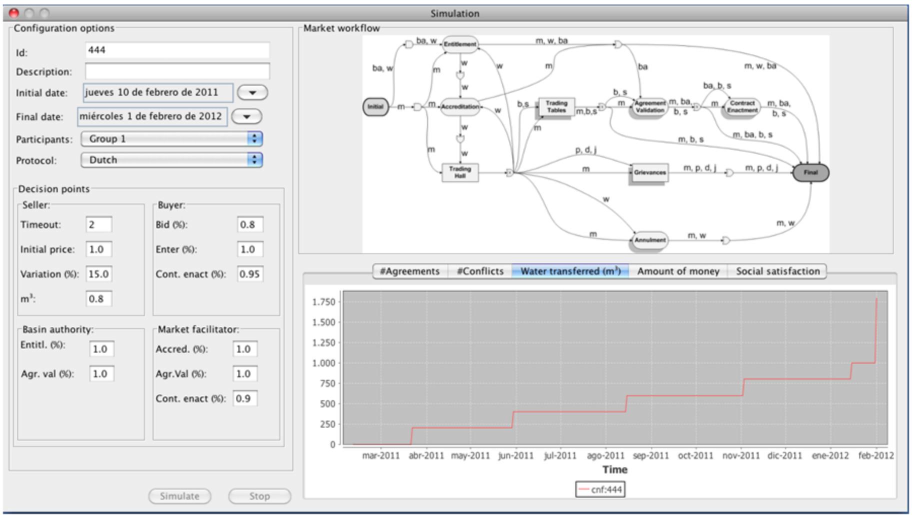

Fig. 5. The *mWater* simulator in action for a given configuration.

5.5 Results: Analysis of the Results

One essential part of a simulation tool to assist in decision taking is to be able to compare the results of different simulations, executed under different configurations. Having this in mind, and aiming at providing as much valuable information as possible, we have also implemented in the GUI a specific decision tier for comparing and analysing simulations. The idea is easy but very effective: the user chooses some simulations from those previously executed and stored in the database, the tool plots them together and extrapolates the best result for each unit of time (day, week, month and so on). For example, if we plot the number of agreements of two simulations, e.g. configurations #337 and #347, and the objective is to maximize this number, a third graphic is added which always shows the highest number of agreements over the timeline (extracted from

#337 and #347), as shown in Fig. 6. This is helpful for the policy makers, as it allows them to find out which *part* of the simulation (and, consequently, which input values for participants, protocols and decision points) leads to the best results in a particular time window, despite the same values are not so good in other windows. In other words, the simulator gives us more precise information on the best result over very particular time units; e.g. the input values for one configuration lead to a higher number of agreements during summer, but the input values for another configuration are better for winter, though none of the configurations in itself is clearly better than the other for a whole year. In particular, in Fig. 6 we can see that configurations #337 and #347 are very similar until May 2011, but afterwards configuration #347 is better —it represents the optimal solution of both configurations. Although the reader may think that this simply puts some sugar on the result simulation form and the user could do this by him/herself, it is important to note that policy makers run dozens (and even hundreds) of simulations for periods that may range from one month to many years. So, doing this analysis by hand and independently for each simulation becomes prohibitive in most scenarios.

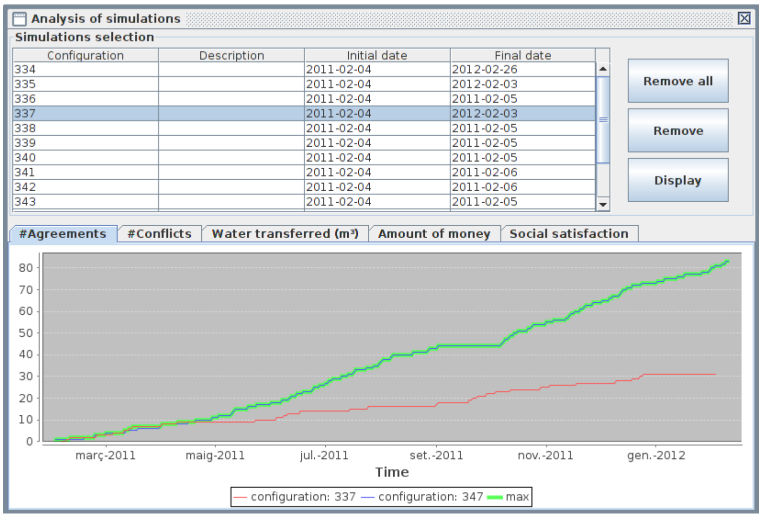

Fig. 6. Analysis of different simulations. Thick line represents the optimal solution, in this case the max number of agreements.

From the experts' point of view and their advice, we can conclude that a model+simulator like this provides nice advantages: i) it successfully incorporates the model for concepts on water regulation, water institutions and individual behavior of water users; ii) it formally represents the multiple interactions between regulations, institutions and individuals; iii) it puts strong emphasis on user participation in decision making; and iv) it finally provides a promising tool to evaluate changes in current legislation, and at no cost, which will surely help to build a more efficient water market with more dynamic norms. Note, however, that the simulation tool is currently mainly policy-maker-oriented rather than stakeholder-oriented. The reason for this is that we have focused on the possibility of changing the norms within the market and evaluate their outcomes —which is the policy makers' labor—, but not in the participation of stakeholders to change the model of the market itself. But clearly, in a social context of water-right management it is important to include tools for letting stakeholders themselves use the system. In other words, the framework should be also able to incorporate the participation of relevant stakeholders, thus helping validate results, which is part of our future work.

6 Conclusions and Future Work

This paper has contributed with *mWater*, a rather sophisticated regulated open MAS-based simulator to assist in decision taking and policy makers; we simulate and test how regulations and norms modify the users' behaviour and how it affects the quality indicators of the market. The core component of *mWater* is an agent-based virtual market for water rights that intends to grasp the components of an electronic market, where rights are traded with flexibility under different price-fixing mechanisms and norms. In addition to trading, *mWater* also simulates those tasks that follow trading, namely, the negotiation process, agreement on a contract, the (mis)use of rights and the grievances and corrective actions taken therein. These ancillary tasks are particularly prone to conflict albeit regulated through legal and social norms and, therefore, they represent a crucial objective in policy-making and a natural environment for the application of agreement technologies. In summary, this type of MAS has a vital importance for decision support as it provides the foundations for the study of that interplay among agents, rule enforcing and performance indicators.

Our current works addresses the following issues. First, to develop a richer normative regulation in order to allow us to simulate more complex types of norms and to observe what are the effects of a given regulation when different types of water users interact in the market. Second, to elaborate more expressive performance measures to evaluate social issues in the market behaviour in order to asses values such as trust, reputation, and users' satisfaction. We believe that this type of measures will provide the policy makers with extra valuable data for decision making about new regulation. Third, although we now consider *mWater* as a simulation tool for decision-support taking, as a long-term research we are also interested in it as an open environment to human users for conducting social and participatory simulations. This would allow us to: i) let stakeholders use directly the system, ii) apply this approach to a specific basin and particular regulation, and iii) see how this is able to reproduce some real data. In such situations, human subjects will take part in the simulation to see the effects of their interaction with virtual agents, applicable norms and their adaptation. Finally, although we focus on a water-right market, the MAS framework is open to other types of (virtual or real) markets, such as energy (electricity) or stock markets. In this line, it would be interesting to compare whether this agent-based water-right market would differ from electricity trading and the systematic effect on the market outcomes.

Acknowledgments. This paper was partially funded by the Consolider AT project CSD2007-0022 INGENIO 2010 of the Spanish Ministry of Science and Innovation; the MICINN project TIN2008-06701-C03-01; and the Valencian Prometeo project 2008/051.

References

1. Andreu, J., Capilla, J., Sanchis, E.: AQUATOOL, a generalized decision-support system for water-resources planning and operational management. Journal of Hydrology 177(3–4), 269–291 (1996)
2. Arcos, J., Esteva, M., Noriega, P., Rodriguez-Aguilar, J., Sierra, C.: Engineering open environments with electronic institutions. Engineering Applications of Artificial Intelligence (18), 191–204 (2005)
3. Argente, E., Giret, A., Valero, S., Julian, V., Botti, V.: Survey of MAS Methods and Platforms focusing on organizational concepts. In: Frontiers in Artificial Intelligence and Applications. vol. 113, pp. 309–316. IOS Press (2004)
4. Botti, V., Garrido, A., Gimeno, J., Giret, A., Igual, F., Noriega, P.: An electronic institution for simulating water-right markets. In: Proceedings of the III Workshop on Agreement Technologies (WAT@IBERAMIA) (2010)
5. Cai, X., Lasdon, L., Michelsen, A.: Group decision making in water resources planning using multiple objective analysis. Journal of Water Resources Planning and Management 130(1), 4–14 (2004)
6. Criado, N., Argente, E., Garrido, A., Gimeno, J.A., Igual, F., Botti, V., Noriega, P., Giret, A.: Norm enforceability in electronic institutions? In: Proceedings of the MALLOW Workshop on Coordination, Organization, Institutions and Norms in Agent Systems in On-Line Communities (COIN@MALLOW). pp. 49–64 (2010)
7. Esteva, M.: Electronic Institutions: from specification to development. IIIA PhD Monography 19 (2003)
8. Giret, A., Garrido, A., Gimeno, J., Botti, V., Noriega, P.: A MAS decision support tool for water-right markets. In: Proceedings of the 10th International Conference on Autonomous Agents and Multiagent Systems (DEMO@AAMAS 2011). p. In press. (2011)
9. Noriega, P.: Agent-mediated auctions: The fishmarket metaphor. IIIA Phd Monography 8 (1997)
10. North, D.: Institutions, institutional change, and economic performance. Cambridge Univ Pr (1990)
11. Palmer, R., Werick, W., MacEwan, A., Woods, A.: Modeling water resources opportunities, challenges and trade-offs: The use of shared vision modeling for negotiation and conflict resolution. In: Proc. of the Water Resources Planning and Management Conference (1999)
12. Rajasekaram, V., Nandalal, K.: Decision support system for reservoir water management conflict resolution. Journal of Water Resources Planning and Management pp. 410–419 (2005)

13. Rodriguez-Aguilar, J.: On the design and construction of agent-mediated electronic institutions. IIIA Phd Monography 14 (2001)
14. Martin de Santa Olalla, F., Dominguez, A., Ortega, F., Artigao, A., Fabeiro, C.: Bayesian networks in planning a large aquifer in Eastern Mancha, Spain. Environmental Modelling and Software 22, 1089–1100 (2007)
15. Schultz, T., Kaufmann-Kohler, G., Langer, D., Bonnet, V.: Online dispute resolution: The state of the art and the issues (2001), available at: http://ssrn.com/abstract=899079 (accessed January 2011)
16. Sierra, C., Botti, V., Ossowski, S.: Agreement computing. KI - Künstliche Intelligenz In press, DOI: 10.1007/s13218-010-0070-y (2011)
17. Smajgl, A., Heckbert, S., Straton, A.: Simulating impacts of water trading in an institutional perspective. Environmental Modelling and Software 24, 191–201 (2009)
18. Thobani, M.: Formal water markets: Why, when and how to introduce tradable water rights. The World Bank Research Observer 12(2), 161–179 (1997)