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

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Abstract. Water is an essential and scarce resource. This motivates the development of technologies to make water use more efficient. One such proposal has been to deploy institutional frameworks —referred to as water banks— where water rights may be exchanged more freely and thus foster better water use. Needless to say that good water management is a complex endeavor and the decision to enable a water bank is but one of many actions that policy-makers may take. However, having a water bank is a specially useful device. Once a water bank is enabled, policy-makers may regulate how trading is made and by so doing, have a direct influence on demand and with that foster a "good" use of water. In this paper, we present a decision-support environment constructed around a water-rights market. It is designed so that policy-makers may explore the interplay between i) market regulations, ii) trader profiles and market composition, and iii) the aggregated outcomes of trading under those set conditions. Our environment is designed as a multi-agent system that implements market regulations and is enabled with tools to specify performance indicators, to spawn agent populations and allow humans as well as software agents to participate in simulations of virtual trading.

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

1 Introduction

Water scarcity is a significant 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.

Good water management involves a complex balance between economic, environmental and social factors. These balance is partially determined by physical

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conditions like rainfall, water supply and distribution infrastructure, population distribution, land use and main economic activities. However, actual water demand is the determining balancing condition, and actual water use is the outcome to measure the success of a water management policy. A policy maker has little control over the hydrographical features of a basin but (s)he has legal power to regulate water user behaviour to a larger extent by means of: i) government laws, ii) basin or local norms, and iii) social norms. Therefore, one aim of a policy maker is to design appropriate water laws that regulate users' actions and, in particular, give users the possibility of exchanging water resources.

It has been sufficiently argued that more efficient uses of water may be achieved within an institutional framework, akin to a traditional goods market, where water rights may be exchanged, not only under exceptional conditions but on a day-to-day basis. 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 with other users, complying with some pre-established norms and in exchange of some compensation [6,23]. Water-rights markets allow rapid changes in allocation in response to changes in water supply and demand, and ideally allow to stimulate investment and employment when users are assured access to secure supplies of water. Because of water's unique characteristics, however, such markets do not work everywhere, they cannot be homogenous since they operate under different organizational and institutional schemata, nor do they solve all water-related issues [12,23]. Nevertheless, international experience in the USA (particularly California), Chile, Australia and Mexico has demonstrated that (formal) water markets can improve the economic efficiency of water use and stimulate investment [6,11,18,23].

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, and similarly for other stakeholders like utility companies or municipalities. However, it is not always a matter of price expectations alone what motivates users to trade water rights. Policy makers may wish to promote trading that favours outcomes that may not necessarily be directly associated with price expectations; for instance, to foster trading that guarantees the public good entailed by a healthy environment, or trading that fosters equilibria among different stakeholders (farmers, municipalities, leisure users and power utilities). But formulating market regulations that have the intended effects is a difficult and delicate task. There are many aspects that may be regulated and many parameters involved, and therefore the consequences of the many combinations difficult to foresee, not to mention the oftconflicting interests of the many stakeholders. Because of this inevitable complexity, policy-makers have traditionally tended to follow the cautious strategy of making conventions rigid, so that their enforcement is straightforward and outcomes are easy to foresee.

Some experiences have shown that more flexible regulations may be desirable but policy-makers need means and methodologies that allow them to visualize the potential consequences of new regulations and fine-tune them before enacting them, in order to avoid undesirable outcomes. In many countries, water regulation tends to be too strict. In the case of water-right trading, Spanish regulation, for instance, does not allow final stakeholders to intervene in the basin resource management plans, nor in a 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.[1] This means that the number of (legal) water-right transfers is practically non-existent. It should also be mentioned that from a performance standpoint, it is unclear which is the best quality indicator of water management, because it cannot be measured in terms of just one factor; performance is a multi-objective function that comprises multiple criteria based on differing objectives, responsibilities and interests among the stakeholders and institutions involved in the market. Furthermore, many outcome functions have singularities that are hard to identify and testing and visualizing limit conditions require analytical tools beyond the ones provided by the type of models mentioned above [8].

This paper describes a water policy-making decision-support framework, build on top of a regulated open Multi-Agent System (MAS), *mWater* [4,10], that models a flexible water-rights market. Our simulator focuses on the effect of regulations on demand and thus provides means to explore the interplay of norms and conventions that regulate trading (like trader eligibility conditions, tradeable features of rights, trading periods and price-fixing conventions), the assumptions about agent behaviour (individual preferences and risk attitude, or population profile mixtures) and market scenarios (water availability and use restrictions). A policy-maker would then assess the effects of those interactions by observing the evolution of the performance indicators (efficiency of use, price dynamics, welfare functions) (s)he designs.

2 Our Approach

Agent technology and multi-agent systems have been successfully applied to problems such as manufacturing, medicine, aero-space, e-commerce, etc. One promising applications domain of MAS is the simulation of complex real life systems that emulate social behaviour and organizations, where a MAS is used to mimic the behaviour of autonomous rational individuals and groups of individuals [22]. 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

[1] See the 2001 Water Law of the National Hidrological Plan (NHP) —'Real Decreto Legislativo 1/2001, BOE 176' (www.boe.es/boe/dias/2001/07/24/pdfs/A26791-26817.pdf, in Spanish)— and its 2005 amendment.

notions such as organization, norms, negotiation, agreement, trust, etc. to implement computational systems that benefit from these human-like concepts and processes among others [21].

Literature abounds in examples of sophisticated basin simulation models, particularly decision support systems for water resources planning [1,16], sustainable planning of water supply [5,19], and use of shared visions for negotiation and conflict resolution [15,22]. 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. However, the gap is still wide from a social perspective. The need is not only to model hydraulic factors, such as river basins, soil permeability, water requirements, distribution flows, etc., but also norm 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.

Most water management models are based on equational descriptions of aggregate supply and demand in a water basin [19], 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 regulations. Our work takes inspiration from the 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 an overview, see [3]). Other approaches rely the development process on the regulation that defines the MAS behaviour, which is usually encoded as an Electronic Institution (EI) [9,13,17]. 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 visualize and measure the suitability 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 in an actual basin. All in all, *mWater* is not only an aid for a better understanding of the demand dynamics of the water-resource system in question, but it is also a tool for data organization and for communication and negotiation among the different stakeholders of a basin.

mWater uses a multi-tier architecture, as depicted in Fig. 1 [10]. 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*

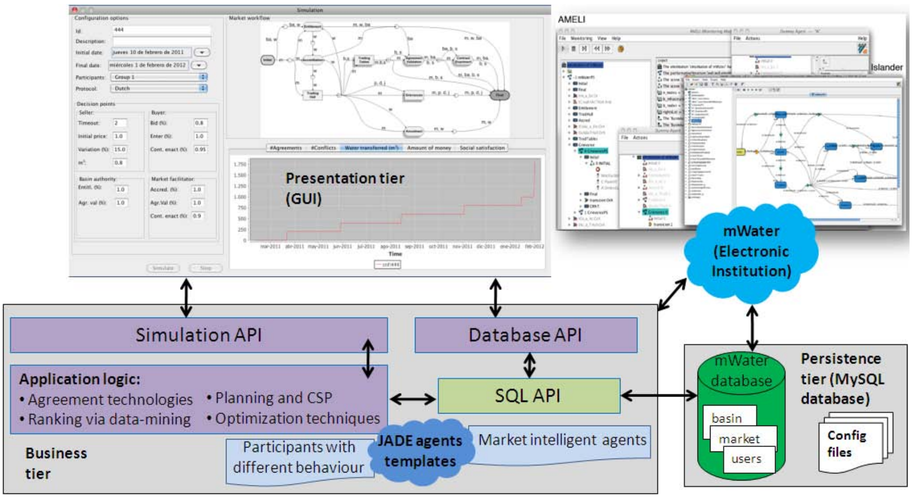

Fig. 1. Multi-tier architecture of the *mWater* decision support tool

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.

2.1 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 [9,14]. 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 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[2].

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.
- 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.

[2] 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.

- 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.

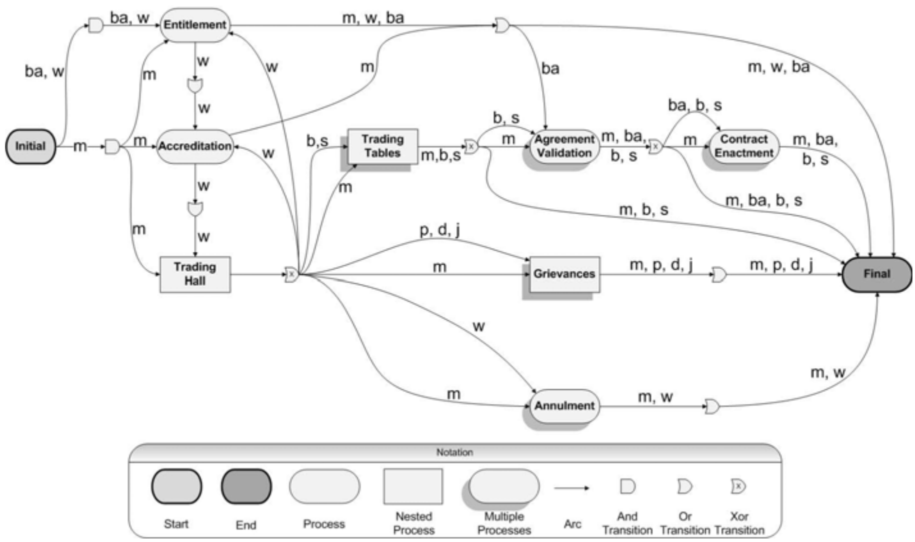

Fig. 2. *mWater* performative structure. Participating roles: g - guest, w - water user, b - buyer, s - seller, p - third party, m - market facilitator, ba - basin authority. See [4] for further details.

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 [20]. In this framework, any grievance process primarily involves negotiation like in any Trading Table (with or without mediation) and an 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.

2.2 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.

2.3 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 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.

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 2.4) to make the simulation more realistic.

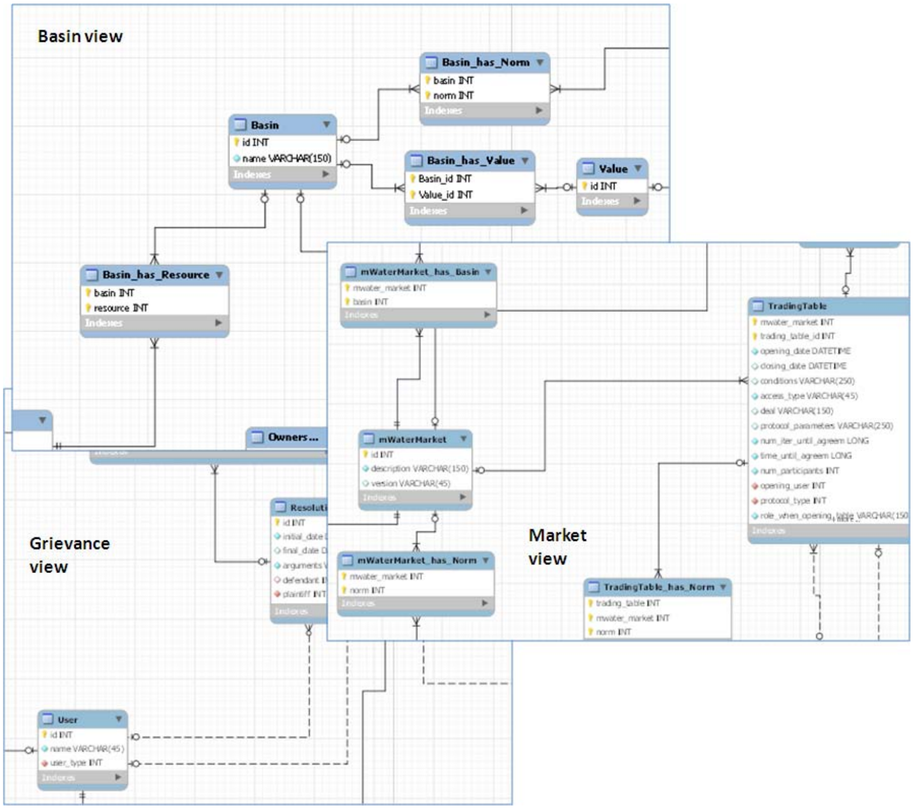

Fig. 3. Fragment of the database: basin, market and grievance views

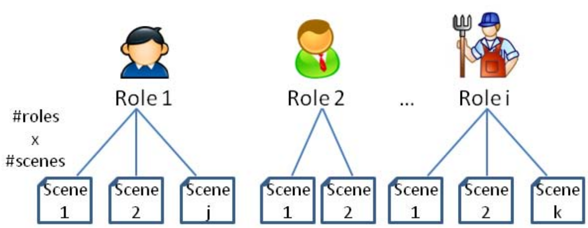

Fig. 4. Schema of the agents implementation. The mapping proceeds by generating one Java class (template) per role in each scene it can be involved.

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 behaviour 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 users 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 [7]. 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.

2.4 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.

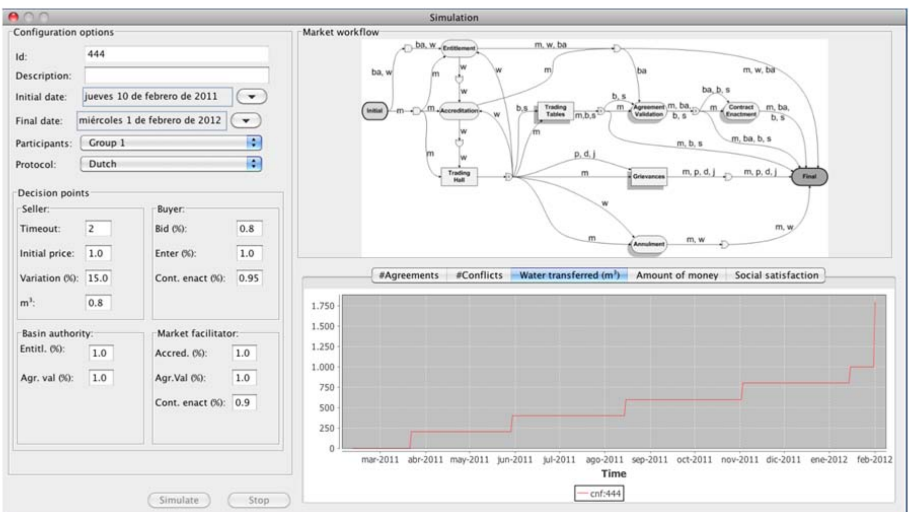

Fig. 5. The *mWater* simulator in action for a given configuration

2.5 Analysis of the Results

One essential part of a simulation tool to assist in decision making 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 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, even if the same values are not that 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.

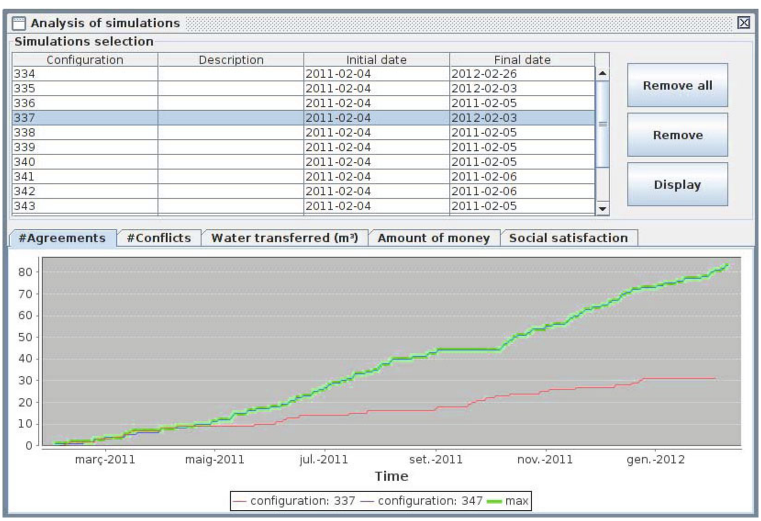

Fig. 6. Analysis of different simulations. Thick line represents the optimal solution, in this case the max number of agreements.

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 behaviour 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.

3 Conclusions and Future Work

This paper has presented *mWater*, a regulated open MAS-based simulator to assist policy makers; we simulate and test how regulations and norms modify the right-holders' behaviour and how that behaviour affects the quality indicators of the basin management. The core component of *mWater* is an agent-based virtual market for water rights, where rights are traded with flexibility under different price-fixing mechanisms and norms that regulate eligibility, tradeable rights parameters, buyer and seller profiles and populations. In addition to trading, as sketched in Fig. 1, the *mWater* electronic institution 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 key objective in policy-making as well as a natural environment for the application of agreement technologies.

Our current work is addressing the following issues. First, the development of 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, the design of more expressive performance measures incorporating values such as trust, reputation, and users' satisfaction in order to provide policy-makers additional relevant data for assessing new regulations. Third, we are exploring the use of *mWater* as an open hybrid environment where human users may perform participatory simulations, for policy-assesment but also for negotiation among stakeholders. 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-rights market, the MAS framework is open to other types of (virtual or real) commodity and public-goods markets. An example of this is an electricity market. However, it is important to note some differences that may have an impact on the rights trading. In particular, costs of electricity are higher for the consumers than for water. Also, electricity is more easily traded among the providers, but water seems to be a much more local product that cannot be freely sold at large distances from the source. In consequence, a simulation approach becomes an very valuable tool for decision support in such a complex market.

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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(2), 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. Calatrava, J., Garrido, A.: Water Markets and Customary Allocation Rules: Explaining Some of the Difficulties of Designing Formal Trading Rules. Journal of Economic Issues XL 1, 27–44 (2006)
7. Criado, N., Argente, E., Garrido, A., Gimeno, J.A., Igual, F., Botti, V., Noriega, P., Giret, A.: Norm Enforceability in Electronic Institutions? In: De Vos, M., Fornara, N., Pitt, J.V., Vouros, G. (eds.) COIN 2010. LNCS, vol. 6541, pp. 250–267. Springer, Heidelberg (2011)
8. Easter, K.W., Cortner, H., Seasholes, K., Woodard, G.: Selecting appropriate water policies. Policy Briefs 11908, Environmental and Natural Resources Policy Training Project (1995), http://econpapers.repec.org/RePEc:ags:epatpb:11908
9. Esteva, M.: Electronic Institutions: from specification to development. PhD thesis Universitat Politècnica de Catalunya (UPC), 2003. No. 19 in IIIA Monograph Series, IIIA (2003)

10. Giret, A., Garrido, A., Gimeno, J.A., Botti, V., Noriega, P.: A MAS decision support tool for water-right markets. In: Proceedings of the Tenth International Conference on Autonomous Agents and Multiagent Systems (Demonstrations@AAMAS) (2011)
11. Honey-Roses, J.: Assessing the potential of water trading in Spain. In: ENR 319 Advanced International Environmental Economics. Professor Theo Panayotou at Harvard's John F. Kennedy School of Government (2007)
12. Marinho, M., Kemper, K.: Institutional Frameworks in Successful Water Markets: Brazil, Spain, and Colorado, USA. World Bank Technical Paper No. 427 (1999)
13. Noriega, P.: Agent-Mediated Auctions: The Fishmarket Metaphor. PhD thesis Universitat Autònoma de Barcelona, 1997. No. 8 in IIIA Monograph Series, IIIA (1999)
14. North, D.: Institutions, institutional change, and economic performance. Cambridge Univ. Pr. (1990)
15. 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)
16. Rajasekaram, V., Nandalal, K.: Decision support system for reservoir water management conflict resolution. Journal of Water Resources Planning and Management, 410–419 (2005)
17. Rodriguez-Aguilar, J.A.: On the Design and Construction of Agent-mediated Electronic Institutions, PhD thesis, Universitat Autònoma de Barcelona, 2001. No. 14 in IIIA Monograph Series, IIIA (2003)
18. Rosegrant, M., Gazmuri Schleyer, R.: Reforming Water Allocation Policy Through Markets in Tradable Water Rights: Lessons from Chile, Mexico and California. International Food Policy Research Institute (1994).
19. 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)
20. Schultz, T., Kaufmann-Kohler, G., Langer, D., Bonnet, V.: Online dispute resolution: The state of the art and the issues (2001), http://ssrn.com/abstract=899079 (accessed September 2011)
21. Sierra, C., Botti, V., Ossowski, S.: Agreement computing. KI - Künstliche Intelligenz 25(1), 57–61 (2011)
22. Smajgl, A., Heckbert, S., Straton, A.: Simulating impacts of water trading in an institutional perspective. Environmental Modelling and Software 24, 191–201 (2009)
23. Thobani, M.: Formal water markets: Why, when and how to introduce tradable water rights. The World Bank Research Observer 12(2), 161–179 (1997)