



Jul 1st, 12:00 AM

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System Dynamic Modelling for conflicts analysis in groundwater management

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Abstract: In most Mediterranean countries groundwater is the primary sources for irrigation. Nowadays, water scarcity is a limiting factor for sustainable growth. Designing and implementing effective groundwater protection policies is of outmost importance. Many times the best efforts to solve water management problem actually make it worse due to unanticipated side effects. Avoiding policy resistance requires to expand the boundaries of the system model, so that to incorporate the different actors and their problem definitions. Ambiguity is considered in this work as a distinct type of uncertainty that results from the simultaneous presence of multiple valid and sometimes conflicting ways of framing a problem. In this work, a method based on System Dynamic Modeling (SDM) to simulate conflicts in groundwater management through the analysis of ambiguity in problem framing is described. The aim is to investigate in which conditions ambiguity could lead to conflict.

Keywords: Groundwater management, conflict analysis, system dynamic modelling.

1 INTRODUCTION

Groundwater is a crucial resource for the socio-economic development in many regions of the Mediterranean basin. The overexploitation of groundwater resources causes water quantity and quality impoverishment.

Achieving a sustainable use of groundwater will require changes that go beyond improving efficiency of water use and implies a radical change in the water policy and the implementation of innovative governance. An appropriate resource management which must definitely assume groundwater as a common pool resource (Llamas and Martinez-Santos, 2005). Groundwater resource management could be considered as a complex problem, characterized by the existence of various interests associated with a shared resource (Ostrom, 2005), and as such often introduces a conflict.

Many times, the best efforts to solve groundwater management problem actually make it worse, since the selected policies may create unanticipated side effects. These unexpected dynamics often lead to policy resistance, that is, the tendency for the intervention to be delayed, diluted, or defeated by the response of the system to the intervention itself (Sterman, 2000). The increasing awareness of uncertainty and complexity of water resources management is challenging the traditional management regimes based on a top-down approach and it is increasing the skepticism of decision-makers toward the use of information from models to support decision making (Knüppe and Pahl-Wostl, 2011; Borowoski and Hare, 2007).

Avoiding policy resistance requires to expand the boundaries of the model used as basis for the decisions, so that decision makers become aware of and understand the implications of the feedbacks created by the selected decisions (Sterman,

2000). Therefore, integrated models able to take the complexity of the real world into account are required as a response to the challenges of integration in water management itself (Borowoski and Hare, 2007; Sterman, 2000).

The structure of an expanded system model is composed by both the assumptions about the physical and institutional environment and the assumptions about the decision makers' mental models used by them to select and analyze the available information and to take decisions (Sterman, 2000). Mental models influence an actor's perception of a problematic situation by influencing both his/her observation of the world and his/her conclusions based on observations (Pahl-Wostl 2007). They can be considered as the window through which people view the world (Timmerman and Langaas 2004). Mental models determine what information the actors perceive in the real world and what knowledge the actors derive from it (Kolkman et al. 2005). In other terms, differences in mental models lead to different problem understandings. Problem solving should adopt a "subjectivist" stance that recognizes the importance of participants' perceptions (Rosenhead and Mingers, 2001), rather than an "objectivist" stance that sees problems as independent of individual's views and beliefs.

The way a problem is defined and perceived influences a stakeholder's expectation of future occurrence, and leads stakeholders to adopt different behaviors and to act or react in different ways. This actually describes a potential conflicting situation.

There are many different definitions of conflict in the literature. Conflict is driven by perceived incompatibility with regard to a certain significant aspect – at least for one party – such as different goals, interests or beliefs. The more significant this aspect is perceived to be, the more complex and ingrained the conflict becomes, and the harder it is to resolve (Obeidi et al., 2005; Obeidi et al., 2009). A conflict could also arise also due to interference between different decision makers, which happens when at least one party is unable to attain its goal independently (Obeidi et al., 2005).

In this work we assume that three different level of conflict can exist. The lowest level is characterized by ambiguity in problem understanding. Ambiguity reflects the discrepancies in meaning and interpretation that exists among actors. Ambiguity is an unavoidable characteristic of a participatory process (Brugnach and Ingram, 2010). Nevertheless, ambiguity does not necessarily lead to a conflict. The different perceptions can coexist.

The second level of conflict can be registered when actors perceive incompatibilities with other actors. The perception does not mean that there is an actual incompatibility. Perceptions could also be wrong.

The third and highest level of conflict is due to the interferences between different decision makers. Interferences could be either positive or negative. In this work, an interference is assumed as positive if the achievement of a certain decision maker's goals depends on the actions implemented by the others. The conflict will emerge if the needed actions will not be implemented. An interference is negative if the attainment of a goal is impeded by the implementation of the actions by the others.

The definition of the nature of the conflict (i.e. ambiguity, incompatibility and interference) is crucial to identify the most suitable strategy to reduce the level of conflict and to define the role of negotiation support methods.

This work aims to investigate in which conditions differences in mental models could result in a conflict between different decision makers. To this aim, two sequential analysis were carried out, ambiguity and interference analyses.

This work is organized as follows. Section 2 is devoted to the description of the applied methodology based on cognitive mapping and system dynamic modeling. The results of the experiences carried out in the Apulia Region (Southern Italy) are discussed in section 3.

2 CONFLICT ANALYSIS IN GROUNDWATER MANAGEMENT

2.1 The case study

The Apulia region is a peninsular territory covering about 20,000 km², and it could be considered as a typical example of groundwater overexploitation. Over many centuries, mild orographic features and high population density have led to intensification of agricultural farming, accompanied by replacement of existing natural vegetation with agricultural crops (more than 76% of the total area is devoted to agricultural activity).

During the last three decades, a continuous increase in groundwater withdrawals took place by farmers (as single and irrigation consortia) without an appropriate and effective legislation, resulting in several interconnected environmental pressures involving water resources (seawater intrusion in groundwater, water table depletion), landscape heritage (extensive land-use change, mono-cultures) and biodiversity (soil fertility loss, replacement of natural species).

Considering the serious effects of seawater intrusion (already observed) and the consequent reduction of the irrigated surfaces along the coast, the regional water authority proposed the enforcement of restrictive measures in the use of groundwater. In agreement with the Water Framework Directive (CEE 2000/60) a Water Protection Plan was approved in 2009 in which a 20-40% reduction of groundwater pumping was set with respect to the current amount of used water. However, the new legislation caused strong conflicts between farmers and the regional authority due to the expected economic damages to the agricultural sector which is highly dependent on the irrigation practice.

The aim of this work is to analyze this conflict, to identify the actors involved and to investigate the role of ambiguity in conflict arising. To this aim, the main actors involved in the conflict were interviewed and a literature review was carried out.

2.2 Ambiguity analysis: the role of Cognitive Mapping

The ambiguity analysis requires to compare decision makers' mental models in order to identify differences and similarities. To this aim, we mainly refer to Sterman's (1994, p.294) definition of a mental model, which stresses the implicit "beliefs about the network of causes and effects that describe how a system operates, the boundary of the model (the exogenous variables) and the time horizon we consider relevant - our framing or articulation of a problem". In order to elicit mental models, making them explicit and "external" (Doyle and Ford, 1998; Schaffernicht, 2006) a cognitive mapping approach was adopted (Axelrod, 1976).

A round of semi-structured interviews was carried out involving the three main decision makers, i.e. farmers, Consortium management (management of the public irrigation network) and Regional Authority. Moreover, documents collected during the presentation of the groundwater management plan to the stakeholders were analyzed. A cognitive map (CM) could be defined as a "map of cognition" (Axelrod, 1976), composed by variables and causal link connections, which is an external representation of decision makers' understanding of a certain problem.

The CM were developed trying to identify the chain value-belief-action (Brugnach and Ingram, 2010). The CM analysis allowed us to analyze similarities and differences in mental models. The ambiguity analysis was carried out assessing the similarity among the sets of concepts and the similarity among the causal networks.

For what concerns the similarity among the sets of concepts, the analysis should consider the number of similar concepts, the numbers of opposite concepts and the similarity among the importance degree.

The formula was:

$$S_c = \frac{N_c^{(1-\alpha)} - N_o^{(1-\beta)}}{N_t} \quad [1]$$

Where: S_c represented the similarity degree among the sets of concepts; N_c was the number of common concepts; N_o was the number of opposite concepts, and N_t was the total number of concepts. α was the similarity among the importance degree for the common concepts, and β was the similarity among the importance degree for the opposite concepts. S_c belonged to the interval $[-1, 1]$. $S_c = 1$ when $N_c = N_t$ and $N_o = 0$. Contrarily, $S_c = -1$ when $N_c = 0$ and $N_o = N_t$.
 $\alpha = \text{MIN}(S_d^c)$ and $\beta = \text{MIN}(S_d^o)$

$$S_d(I,2,x_i) = |\mu_1(x_i) - \mu_2(x_i)| \quad [2]$$

where $S_d(1,2,x_i)$ defines the distance between stakeholders 1 and 2 regarding the concept x_i , $\mu_1(x_i)$ expresses the importance of concept x_i according to stakeholders 1 and $\mu_2(x_i)$ expresses the importance of the same concept according to stakeholder 2. Thus S_d^c is the semantic distance between common concepts and S_d^o is the distance between opposite concepts.

Given that CM represent the decision makers mental models, differences in CM indicate ambiguity in problem understanding. The differences were analyzed considering the CM structure, that is, variables and degree of importance, and the network of causal links.

The similarity among the causal networks was based on the number of common links and the structure of the causal networks. Two CM can be said to have a common link if there is at least one link between two common concepts. The similarity degree among two common links in two CM was assessed by considering the three main elements: the direction of the link (from A to B or from B to A); the polarity (positive or negative); the strength of the link. The following formula was used for the common direct links:

$$N_{Ld}^c = \frac{\sum C^{(1-D_s)}}{N_t^l} \quad [3]$$

Where N_{Ld}^c represents the degree of similarity according to the number of common direct links; C is equal to 1 if it is a common direct link; -1 if the common links have opposite polarity or opposite direction; D_s represents the difference between links' strength (considering that the strength of a link is expressed as linguistic variables, the difference is assessed as semantic distance); N_t^l is the total number of links.

The indirect links should be taken into account. An indirect link means that two variables are connected through a third one. The following formula was used:

$$N_{Li}^c = \frac{\sum C_i^{(1-D_s)}}{N_t^l} \quad [4]$$

C_i is equal to 0 if there is no indirect link; it is equal to $1/n_c$ if it is a common indirect link, n_c is the number of concepts forming the indirect link. D_s represents the difference between links' strength. This difference is assessed considering the aggregation of all links.

The analysis of the similarity is a pair-wise comparison. The aggregation of the two indicators allowed us to assess the similarity degree among the three main decision makers.

Table 1: Results of the ambiguity analysis

	Farmers	Water man.	Regional Aut.
Farmers	-	Weakly dissimilar	Strongly dissimilar
Water man.	Weakly dissimilar	-	Weakly similar
Regional Aut.	Strongly dissimilar	Weakly similar	-

According to the results of the ambiguity analysis, the main conflict should involve farmers and Regional Authority. Nevertheless, in the real case, strong conflict were also registered between water management and Regional Authority. This allowed us to infer that ambiguity in problem understanding does not always lead to a conflicting situation, and, vice-versa, a conflict does not always require dissimilar problem understandings as a pre-requisite.

The simulation of the interference among the decision makers system dynamic allowed us to identify the main reasons of conflict and to define the policy resistance concerning groundwater protection..

2.3 Interference analysis: The System Dynamic Model

In order to complete the conflict analysis, a System Dynamic Model (SDM) was developed. The SDM aimed to simulate the perceived and actual interference among the different decision makers' strategies. To this aim, the decision makers behaviors for what concerns irrigation management and groundwater protection was modeled.

The structure of the SDM consisted of two main parts: (1) assumption about the physical and institutional environment, and (2) assumption about the decision processes of the agent. In this work, the physical environment concerned the groundwater and the recharge process. The institutional environment concerned the framework of rules and laws influencing groundwater management. The decision process of the agents referred to the decision rules that determine the behavior of the actors in the system (Sterman, 2000).

The general scheme was composed by six main modules, three physical modules (i.e. groundwater, reservoir and climatic model), and three decision making models. In order to emulate the real world, the SDM was represented as an ecology of interacting agents, each with their own goals and decision rules. Each agent was represented as sub-model. These models were locally rationale given their mental models and knowledge of the system. The decision models were developed using the results of the expert knowledge collection process. The physical models were developed using monitoring data.

Considering that no extensive datasets were available, the capabilities of the system to simulate the actors' behavior were validated interacting with participants. Different scenarios were simulated and discussed.

The sub-models test (Sterman, 2000) was used to simulate the impact of interference among decision makers on the effectiveness of groundwater protection strategy and to assess the level of conflict. Thus, a dysfunctional dynamic of the system would result in a worsening of groundwater quality problems.

The groundwater physical model was at the center of the scheme and had a strong influence on the decision making model of both farmers and regional authority. The groundwater model aimed to simulate the process of groundwater recharge and the impacts of groundwater exploitation for irrigation purposes. It contains the main variable of the model, that is, the groundwater level

The module concerning the decision models of the agents contained their decision rules, that is, protocols and policies specifying how the decision makers processes available information (Sterman, 2000).

Figure 1 shows the farmers' mental model used to take decisions concerning the increase or abandoning of irrigated areas. A stock-and-flow diagram was used to this aim. "Irrigated areas" was considered as a stock variable, whereas the increasing rate was modeled as a flow variable. The rate could be either positive (increase of the irrigated areas) or negative (abandoning).

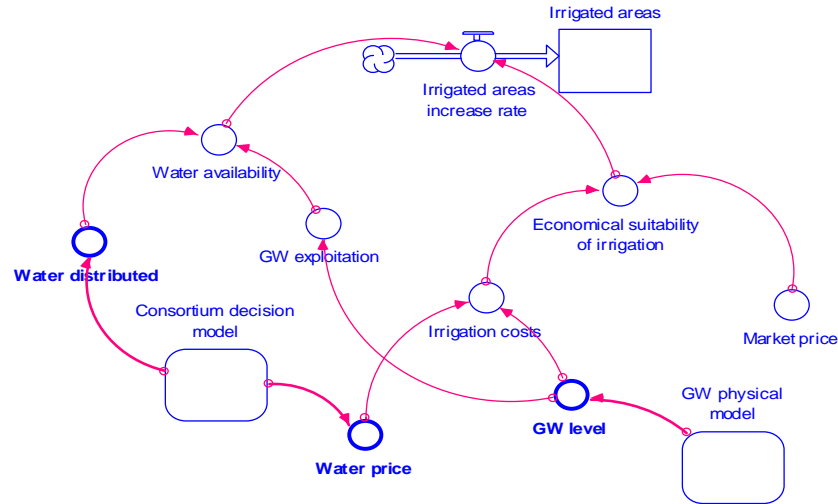


Figure 1. Farmers decision model concerning the irrigated areas.

Inputs from two other sub-models, i.e. "consortium decision model" and "GW physical model", were considered as exogenous input in this model. The decisions concerning the irrigated areas were mainly influenced by both the economical suitability of irrigation and the water availability. Another model was developed to simulate the farmers' decision process concerning the selection of the main source of water for irrigation.

Similar models were developed for each decision maker in the system. The integration of the different models allowed us to develop the whole SDM, as shown in figure 2.

The relationships influencing the dynamic of the whole system were developed using both qualitative data, i.e. experts knowledge (farmers, water managers and scientists), and quantitative data, i.e. collected data concerning rainfall, groundwater level, market price and water price.

The SDM was used to simulate the dynamic of the whole system due to the implementation of decision makers' strategies. Considering that the achievement of the plan's objectives will be evaluated in 2015, this date was used as limit for the scenarios development. Firstly, the business-as-usual condition in a dry year was simulated. Due to the scarcity of rainfall, the water level in the reservoir was rather low. Thus, according to the consortium management decision model, the water price increased in order to reduce the water consumption and to improve the effectiveness of water allocation among the different users. In the early phase, this allowed the consortium manager to effectively manage the irrigation network. The implementation of this strategy provoked a reaction by farmers. In order to attain their main goal, that is, "increase farmer income", the quantity of water taken from consortium was reduced to keep the irrigation costs as low as possible. Consequently, the groundwater exploitation increased. This had a negative impact on the main goal of the regional authority, i.e. to protect groundwater quality. Moreover, the increase of the groundwater exploitation had a negative impact on the consortium goal, because of the increase of farmers unsatisfaction. Figure 3 shows the trends of the three main goals of the decision makers.

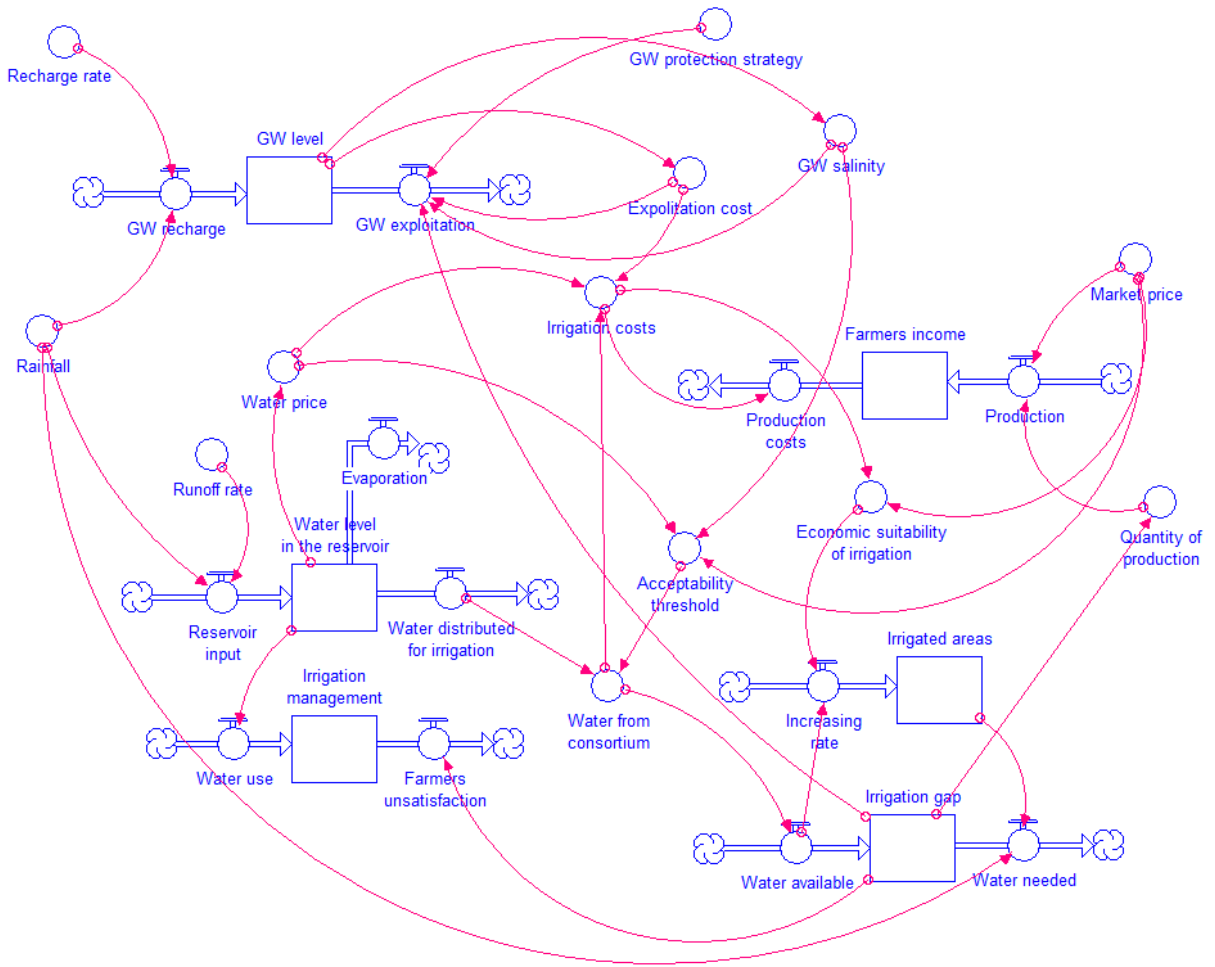


Figure 2. Integrated SDM model

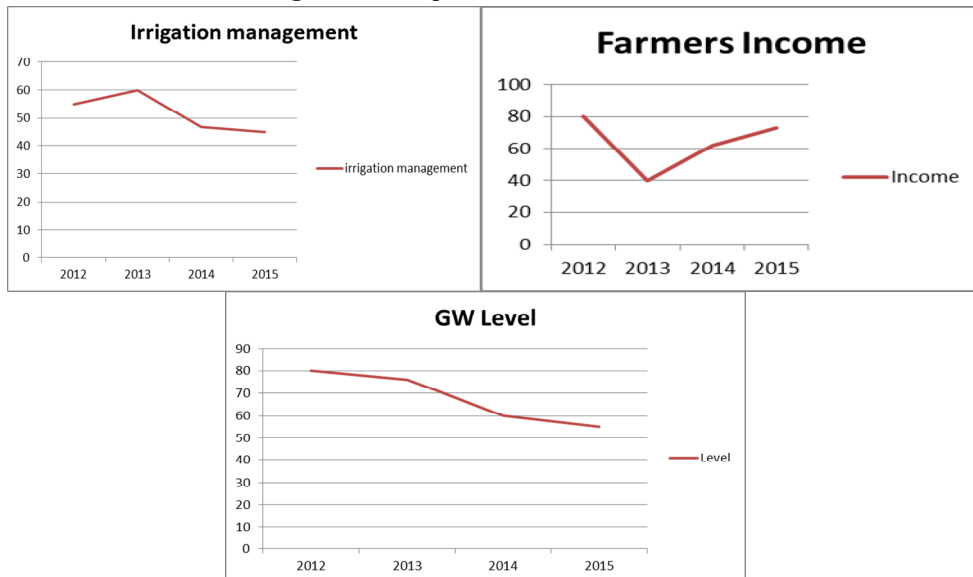


Figure 3. Business-as-usual scenario. The values are expressed as percentage

Therefore, at the end of this round of simulation, the following interferences were identified. The strength of interference was assessed comparing the optimal value

of the goal, as described by the decision makers, with the actual value assessed by the simulation model. The results are described in table 2.

Table 2: interference among decision makers. BaU scenario.

	Farmers	Water man.	Regional Aut.
Farmers	-	Negative	Strongly negative
Water man.	Weakly negative	-	Positive
Regional Aut.	Strongly negative	Negative	-

The SDM was then used to simulate the interferences among the decision-makers due to the implementation of a groundwater protection strategy by the regional authority. To this aim, a limit was imposed to the flow variable “GW exploitation”, which, in turn, reduced the water available for irrigation. According to the farmers decision model, in order to keep the “irrigation gap” low, farmers could increase the amount of water from the consortium. Due to the high water price imposed by the consortium, farmers were forced either to abandon the irrigated areas (with a decrease of farmers’ income) or to illegally exploit water from the ground (reducing the effectiveness of regional authority’s policy). This decision was influenced by the market price. That is, if the products price in the market is reasonably high, according to farmers opinion, then they would rather prefer to illegally exploit groundwater than reducing their income. The dynamic of the system is strongly influenced by this decision and so the effectiveness of groundwater protection strategy. If farmers would decide to reduce the irrigated areas, then the effectiveness of the groundwater protection strategy would be even higher than expected. In case of illegal withdrawal, the policy’s effectiveness would dramatically decrease. Figure 5 shows the trends of the main goals of the actors.

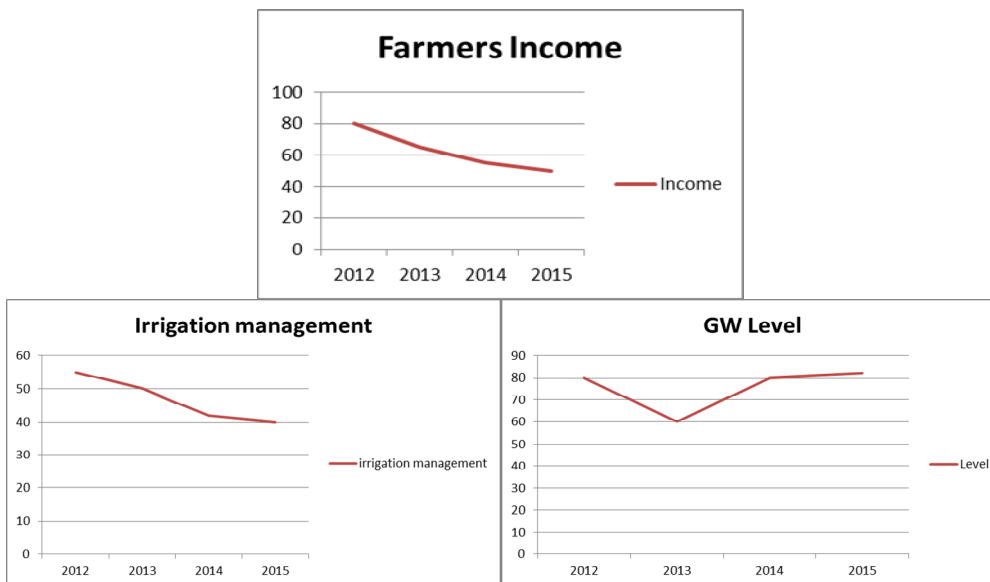


Figure 5. Groundwater protection plan scenario in case of unfavorable market conditions

Table 3: interference among decision makers. GW reduction and unfavorable market conditions scenario

	Farmers	Water man.	Regional Aut.
Farmers	-	Weakly negative	Strongly negative
Water man.	Weakly negative	-	Negative
Regional Aut.	Positive	Positive	-

As shown in table 3, a strong level of conflict was registered between regional authority and farmers. Conflict was also registered between regional authority and water management, because of reduction of irrigated areas due to the groundwater protection plan. This had a negative impact on the effectiveness of irrigation management.

The SDM allowed us to identify the main reasons of the conflict between farmers and regional authority due to the implementation of a groundwater protection strategy.

3 DISCUSSION AND CONCLUSIONS

The approach adopted was discussed with a number of experts in groundwater management policies and irrigation management in order to identify its main strengths and weaknesses.

In the view of the experts, one of the main positive results of the methodology developed was the ability to simulate the impact of decision makers' behavior on the system dynamic. The simulation of policy resistance due to the interaction among the different actors was particular interesting. Previous works aiming to evaluate the state of groundwater in the Apulia Region due to overexploitation for irrigation have neglected the role of farmers as decision-making agents, being mainly based on the estimated balance between crop irrigation needs and water availability.

The results of the present work show that the selection of the main sources of water for irrigation does not rely only on water demand and climatic conditions. It is also influenced by irrigation network management policies and by market conditions. This enables the model to assess the pressure on groundwater resources to be made to correspond more closely to reality. The experts were also interested in the ability to simulate the impacts of groundwater protection strategies on farmers' objectives and to identify the main reasons of conflicts. In their view, this information can be used by decision makers to increase the range of potential alternatives and to identify conflict mitigation measures, such as enhancing the management of irrigation network, introducing policies aiming to keep low the water price from consortia even in dry years, timely dissemination of information concerning the availability of water for irrigation in the Consortia.

The policy resistance often results from neglecting the complex interactions and loops between decision maker strategies. The SDM, developed integrating the physical models and the decision makers' mental models, allowed to identify those loops and to investigate the impacts on the conflict degree.

REFERENCES

- Axelrod, R. (ed.) *The Structure of Decision: The Cognitive Maps of Political Elites*. Princeton, NJ, Princeton University Press, 1976.

- Brugnach, M., Ingram, H. Rethinking the role of humans in water management: towards a new model of decision-making. *Water, cultural diversity and environmental change*, B.Rose Johnston, Editor-in-chief, Springer, Netherlands, 2010.
- Doyle, J.K. and Ford, D.N. Mental models concepts for system dynamics research. *System Dynamic review*, 14(1), 3-29, 1998.
- Knüppe K. and Pahl-Wostl C. A Framework for the Analysis of Governance Structures Applying to Groundwater Resources and the Requirements for the Sustainable Management of Associated Ecosystem Services. *Water Resources Management*, 25: 3387-3411, 2011.
- Kolkman, M.J., Kok, M. and van der Veen, A. Mental model mapping as a new tool to analyse the use of information in decision-making in integrated water management. *Physics and Chemistry of the Earth*. 30 (4-5): 317-332, 2005.
- Llamas M.R. and Martínez-Santos P., Intensive groundwater use: a silent revolution that cannot be ignored. *Water science and technology series*, 51, 8, 167-174. IWA. ISBN 1 84339 494 4, 2005.
- Obeidi, A., Hipel, K.W., Kilgour, D.M. The Role of Emotions in Envisioning Outcomes in Conflict Analysis. *Group Decision and negotiation* 14, 481-500, 2005.
- Obeidi, A., Hipel, K.W., Kilgour, D.M. Perceptual Graph Model Systems. *Group Decision and negotiation* 18, 261-277, 2009.
- Ostrom, E. *Understanding Institutional Diversity*. Princeton: Princeton University Press, 2005.
- Pahl-Wostl, C. The implication of complexity for integrated resources management. *Environmental Modelling and Software*, 22 : 561-569, 2007.
- Rosenhead, J., Mingers J. A New Paradigm for Analysis. In Rosenhead, J., Mingers J. (eds). *Rational Analysis for a Problematic World*. John Wiley and Sons, Chichester, UK, 2001.
- Schaffernicht, M. Detecting and monitoring change in models. *System Dynamics Review*, 22(1), 73-88.
- Sterman, J.D. Learning in and about complex systems. *System Dynamics Review* 10(2/3), 291-330, 1994.
- Sterman, J.D. *Business Dynamics*. McGraw-Hill, 2000.
- Timmerman, J.G. and Langaas, S. Conclusions. Pages 240-246 in: Timmerman, J.G. and Langaas, S. (eds.). *Environmental information in European transboundary water management*. IWA Publishing, London, UK. ISBN: 1 84339 038 8, 2004.