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Participatory Building of a Decision Support System for Adaptive Water Management in the Upper Guadiana Basin

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***Abstract*— Water management has evolved in the last years towards more integrated and participatory approaches, aiming at improving the adaptability of water systems. Following this line, we propose a methodology to build a decision support system, based on the participation of stakeholders and the integration of the different disciplines involved in water use, as well as the inclusion of uncertainties in the management planning. The process has been implemented in the Upper Guadiana basin (Spain) with the aim of solving the existing conflicts: the aquifer, which is the main water source in the area, has been over-exploited during the last decades for irrigation. This has lead to serious degradation of natural water-related ecosystems and important social conflicts.**

The river basin authority has tried to implement different policies to attain the aquifer recovery, so far without much success. At present, a new management plan specifically for the Upper Guadiana has been approved, where some policy measures are proposed for attaining the reduction of agricultural water consumption. The methodology proposed in this work is based on the combination of a Bayesian network and an economic mathematical programming model, elaborated with the active participation of stakeholders. The resulting DSS will be used to evaluate different management options, within those included in the Special Plan of the Upper Guadiana, in terms of their impacts on the agricultural income and the environmental sustainability. Results show that new measures would not be successful unless they are accompanied by an increase of compliance of farmers with water regulations.

Keywords— **Decision support system, Bayesian networks, economic model**

I. INTRODUCTION

A. Objectives

The aim of this research is the participatory building of a Decision Support System for water management in the Guadiana basin, in Spain, aiming at the double objective of socio-economic and environmental sustainability.

B. Context of the research

The Common Agricultural Policy has encouraged since the 1970s an important development of irrigation in the Upper Guadiana basin, situated in Spain's inland region of Castilla-La Mancha. This has motivated a considerable socio-economic development in the area, but also the over-exploitation of groundwater resources and the deterioration of valuable associated wetlands [1] [2]. In the last years, the implementation of the Water Framework Directive compels to adopt different modes of water management, where the integration of the different aspects related to water use and the participation of stakeholders become crucial. Trying to achieve the good state of ecosystems, the regional Water Authority has established water quotas to irrigators, a measure that faces strong social opposition and high costs of enforcement [3]. A step forward is needed towards a further involvement of stakeholders in water management and the introduction of social learning in order to achieve a more adaptive regime [4].

II. MATERIALS AND METHODS

The methodology chosen consists on the combination of a Bayesian Network (BN) and an economic model, developed with the direct participation of stakeholders, which results in a Decision Support System (DSS) to be used for testing different water management options in the basin. Some advantages of this methodology are the explicit consideration of uncertainties and the possibility to integrate different disciplines. The participatory process of the DSS construction is shown in figure 1:

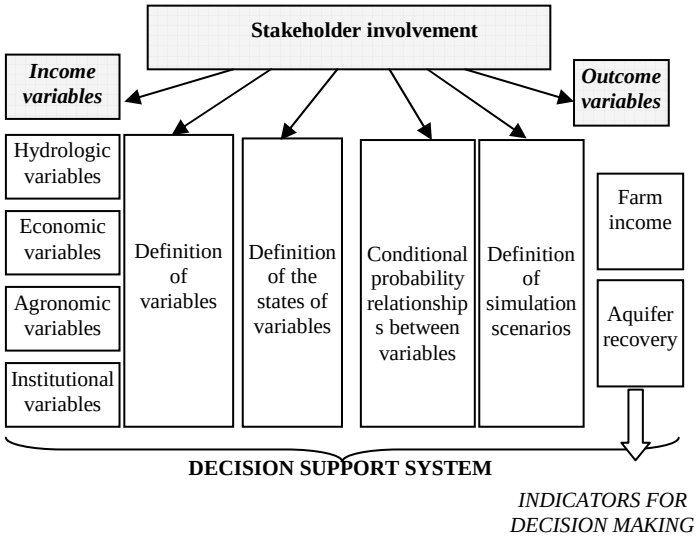

Figure 1. Participatory process in the elaboration of the DSS

The economic mathematical programming model has been developed to evaluate the impact of the joint application of several agricultural policies and water policies in the Upper Guadiana. It provides results concerning farm income, copping patterns and water consumption for the different farm types when alternative policy combinations are implemented. Among the agricultural policies, two CAP options have been tested: Agenda 2000 and the currently in force 2003 Luxemburg reform (with partial decoupling of subsidies). Each of these policies was combined with different water policy options: historical water rights, the current Water Abstraction Plan (WAP), and purchase of irrigation rights (i.e. giving-up water use and turning to rainfed farming). Results from the economic model (income, crop alternative and water consumption for the different farm types and policy options) have been introduced in the BN.

Bayesian networks (BN) are composed by a group of interrelated variables (nodes) which define the system. Each variable is characterized by its states, which are the different values (discrete values, intervals, qualitative or boolean estimations) that it can adopt. Links between variables are expressed through conditional probability tables that express probability for one variable to adopt a certain state, given the possible states of its parent variables. All the data required are obtained from stakeholders' perceptions, statistical data, scientific reports, as well as the economic mathematical programming model.

Once the network is elaborated, different possible actions on water management are selected and simulations are held. These consist on giving fixed values to the input variables, and the model calculates the probabilities linked to them. We will evaluate the values adopted by the output variables, with special interest in farm income and wetlands recovery (directly linked to the aquifer level), as a function of the input variables considered as most significant in this context: (1) policies implemented: purchase of water rights from the irrigators by the water authority, where several price rates have been considered, and (2) the degree of compliance of the farmers to the imposed water quotas (defined qualitatively as high, medium and low).

Figure 2 shows the methodological framework of this research. It illustrates the relationship between the Bayesian network elaborated for water management decision making at a regional level, and the different information sources used for its construction, namely the mathematical programming model for obtaining the economic variables, statistical sources and knowledge/opinions of the stakeholder groups.

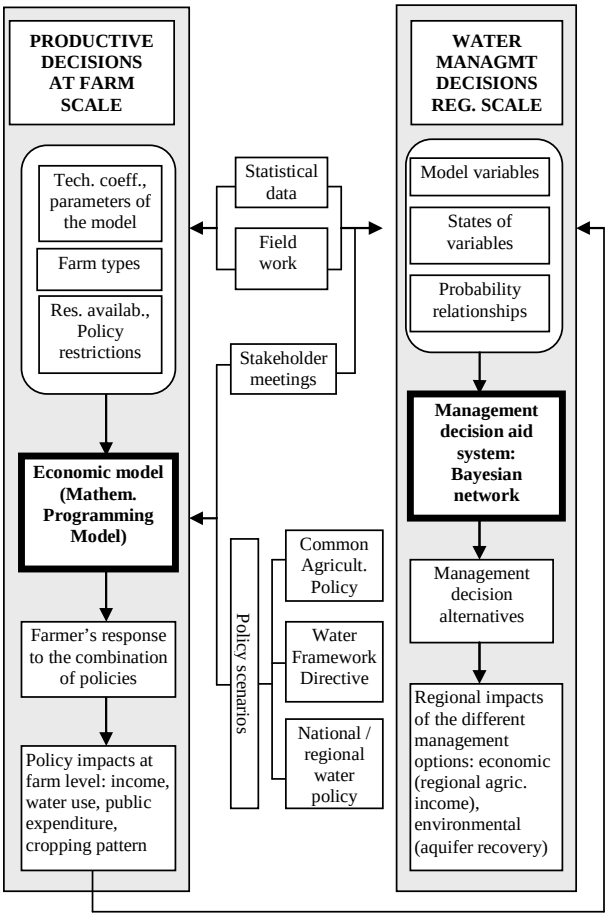

Figure 2. Methodological scheme of the research.

Participation of stakeholders is crucial in the BN construction [5]. It has taken place in several stages. In the first stage, five thematic meetings have been held with the aim of discussing the main problems related to water management in the basin. The format of the meetings was based on discussions guided by questionnaires that were previously distributed to stakeholders, who were divided into heterogeneous groups. In the second stage, a set of specific meeting for the construction of the Bayesian networks has taken place, including two general meetings in which the methodology was explained and a preliminary version of the BN was constructed. Following, the network structure and data were completed using individual interviews with stakeholders, and finally a general meeting for the validation of the network was held. Parallel to these meetings, field work was also carried out to obtain the data for the economic model.

III. RESULTS AND DISCUSSION

Table 1 shows the results of the BN simulations. Results are presented as a set of probabilities taken by the output variables in the different states, as a function of the different states that the input variables will take.

				States of input variables			
Input var.	**Level of compliance**			*Low*	*Low*	*High*	*High*
	Price of water rights paid by the Water Authority (€/m3)			*Low (3000 - 6000)*	*High (9000 – 10000)*	*Low (3000 - 6000)*	*High (9000 – 10000)*
Output variables	**Purchase of water rights**	*State*	*Yes*	2.65	8.70	2.65	8.70
			No	97.35	91.3	97.35	91.30
	Total farm income (€/ha)	*States*	*< 300*	0.21	0.20	9.53	8.94
			300 - 500	3.44	3.40	15.33	14.55
			500 - 700	12.04	14.14	32.58	33.41
			700 - 900	40.32	40.63	35.52	36.14
			> 900	44.00	41.63	7.04	6.96
	Wetlands recovery	*States*	*Before 2027*	4.46	5.11	10.51	10.79
			Before 2050	19.33	22.17	45.54	46.75
			Later / never	76.21	72.72	43.95	42.47

Table 1. Main results of simulations with preliminary Bayesian network in the Upper Guadiana Basin

Results show that the highest level of recovery of the aquifer and the wetlands will take place when the price of water rights is high and the level of compliance with water restrictions is also high. If this second condition is missing, the level of recovery of the aquifer is very low. That is, the level of compliance to the imposed water abstraction restrictions by the farmers is much more determinant for attaining the aquifer's recovery than the price paid for the water rights.

Farm income is reduced by 30% when the level of compliance with water restrictions is high, as compared a medium-low level of compliance. The price paid by the Water Authority for buying irrigation rights has a small impact on farm income. Higher prices result in a slight redistribution of income, reducing the probability of attaining either the highest and the lowest income level.

IV. CONCLUSIONS

The participatory construction of the Bayesian network implies the representation of a complex reality that, when analyzed as a whole system by the stakeholders, may be sufficiently simplified to facilitate its use. However, it has to be assured that the network includes all the variables that are considered relevant by the stakeholders. This type of participatory methodology can therefore be used for adaptive water management.

The level of compliance with water policies is a key element for attaining the aquifer's recovery. However, compliance with water restrictions leads to important farm income loss. This is the reason why irrigators show a strong opposition to the strict water quota system imposed by the River Basin Authority that, in turn, has to face high social and enforcement costs related to the water policy implementation. In this context, the synergy between the EU WFD and the national Water Abstraction Plan can help to increase social acceptance and reduce social costs.

It is not possible to attain the aquifer's recovery and the restoration of the associated wetlands without a loss in socio-economic welfare in the area. Water restrictions imply a decrease in farm income for most farmers, and certain less-adapted farmers will have to abandon the agricultural activity.

ACKNOWLEDGMENT

We would like to gratefully acknowledge the support of the European Commission in providing funds for the NEWATER Project ("New Approaches to Adaptive Water Management under Uncertainty", FP6-2003-GLOBAL-2-SUSTDEV-6.3.2-511179-2, DG Research), where this research has been developed, and to the Technical University of Madrid for providing complementary funds for this work.

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