Application of Bayesian Networks to the Upper Guadiana Basin

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Pedro Zorrilla[1], Gema Carmona[2], Africa de la Hera[3], John Bromley[4], Hans Joergen Henriksen[5] and Per Rasmussen[5].

(1) Department of Geological Sciences (5th Floor). Faculty of Geological Sciences. Jose Antonio Nováis s/n. Ciudad Universitaria. 28040 Madrid. Spain. Email: pedro.zorrilla@geo.ucm.es;

(2) ETSI Agrónomos. Departamento de Economía y Ciencias Sociales Agrarias. Avda. Complutense s/n. Ciudad Universitaria. 28040 Madrid. Spain. Email: gema.carmona@upm.es;

(3) Area of Research in Active Processes and Environmental Quality. Department of Research and Geo-scientific Prospective. Geological Survey of Spain (Instituto Geológico y Minero de España, IGME). Ríos Rosas 23. 28003 Madrid. Spain. Email: a.delahera@igme.es;

(4) Oxford University Centre for Water Management, South Parks Road, Oxford, OX1 3QY, United Kingdom. Email: john.bromley@ouce.ox.ac.uk;

(5) Geological Survey of Denmark and Greenland, GEUS. Oster Voldgade 10. DK 1350 Copenhagen NV. Denmark. Emails: hjh@geus.dk; pr@geus.dk;

1. Introduction

1.1 Bayesian Network description

This paper describes the application of Bayesian Networks (hereafter Bns) to the development of long term water management strategies in the Upper

Guadiana basin. Bns are decision support systems that have long been used in other disciplines, such as medicine and artificial intelligence, and more recently in natural resources management (MERIT project: Bromley 2005). They are based on probability theory which implements Bayes' rule of probability. Bns organise the body of knowledge in a given area by mapping out cause–effect relationships among key variables and encoding them with numbers that represent the extent to which one variable is likely to affect another. Bns are based on the concept of conditional probability and have proved to be a powerful technique to model complex problems where there is uncertainty about the state of the system being modelled, and the data relating to that system.

The Water Framework Directive (WFD), which every Member State of the EU is obliged to put into place in the next few years, is based on an Integrated Water Resource Management (IWRM) approach. The main characteristics of IWRM are, to cope with uncertainty, to defuse conflicts, to integrate a wide range of multi-disciplinary factors and to engage stakeholders. Bns offer a number of advantages for IWRM and Adaptive Management strategies, and can play a role in the implementation of the WFD as a decision support tool. The technique offers a number of advantageous features:

(a) They are particularly relevant to problems where there is uncertainty due to paucity of data or a lack of understanding of the system, a situation that is quite common when dealing with environmental issues.
(b) They can also be used to help resolve or defuse potential conflicts between very different points of view.
(c) A particular strength is that they are able to integrate a wide range of data to represent a system in a holistic way.
(d) Equally important, is the ability for both expert and non-expert stakeholders to actively contribute to the construction and design of networks using their local knowledge; in many instances stakeholders can also provide some of the data used. In this way networks provide an excellent means to promote the engagement of stakeholders in the decision making process.

Because of all these features, Bns have been selected as the most appropriate tool to assist water management decision making in the Upper Guadiana basin.

In a parallel work in the Upper Guadiana Basin, Bns is tested as tool for buffering capacity analyses as criteria for provision and management of storage capacity with reference to risks, uncertainties and vulnerabilities for the water users and for the environment. Buffering capacity is related to the number of options the water manager has under different varying conditions to supply the different water users in the area, to manage wetlands, to cope with critical drought periods, etc.

1.2 Area of study

The Upper Guadiana basin, in the central plateau of Spain, represents a good example of social conflict caused by divisive water management strategies. Since the 1970s the region has enjoyed an agricultural boom based on irrigation, which consumes up to 90% of total water resources, mainly groundwater. This has had two major consequences: (1) significant socio-economic development of the area and (2) over-exploitation of the aquifers and a high degree of degradation of natural water-related sites (e.g. Tablas de Daimiel National Park). As a result, conflicts have arisen between the different stakeholder groups: between farmers, environmentalists and the regional water authority, and between legal and illegal water users.

Although our NeWater Case Study involves the Upper Guadiana Basin (UGB), it was decided to focus on the Western Mancha Aquifer, one of five aquifers that underlie the UGB, for various reasons: (a) it is the most important aquifer in the area, supplying 80% of irrigation water in the basin (b) it is representative of conditions in the UGB and there is more information and better data available for this aquifer than the rest of the basin, (c) it is the area with most conflict, and finally (d) it can be used as example and reference for other aquifers in the basin.

The objective of UGB water managers is to address and solve the problem of the current unsustainable abstraction of groundwater for irrigation, a process which is causing severe negative impacts on wetlands, rivers and groundwater resources. Until now the water authority has tried to halt aquifer depletion through the introduction of water quotas to farmers, but so far no clear positive results have been obtained. These restrictive policies have met strong social opposition and water authorities will have to cope with a high social cost if they try to strengthen their power of enforcement.

Since 2001 the Water Authority is working on a new management plan with the aim of solving the main problems of the UGB. This plan, called PEAG (Special Plan for the Upper Guadiana Basin) has to manage the objectives of the WFD. After numerous failed drafts, finally the last PEAG proposal was approved by the regional government last August, although it still has to be approved by the Spanish government.

2. Objectives

The objectives of this paper are two-fold;

a) To analyse the effects of different water management options both on the Western Mancha aquifer water level, and on the agricultural economy using Bn techniques. The aim is use Bns to simulate the trade-off between economic and environmental aspects of the system. The approach will be to investigate the impact of the various management actions proposed in the Special Plan for the Upper Guadiana Basin (PEAG) on groundwater levels and the regional and local economy. Among the potential actions proposed by the PEAG are the implementation of water abstraction plans, the purchasing of water rights by water authorities, and measures to improve compliance with the water law.

b) Besides the construction of the networks and comparison of different scenarios, there is a second and very important objective, which is to secure the active engagement of stakeholders in the participatory process. By making actors feel part of the decision making process it is more likely that any final decision will be accepted; this is essential if the over-abstraction problems in the Upper Guadiana Basin are to be successfully resolved.

3. Methodology

3.1. Steps in Bn construction

The work is carried out at two scales: (a) a farm scale network, focused on economic consequences for individual farmers, and (b) an aquifer scale network, focused on the economic consequences for the region. Both networks are intended to evaluate the possibility of recovering water levels in the aquifer. The logic behind the choice of these two scales is based on the following points: (a) The processes taking place at the farm scale are those that are responsible for the problems at the larger scale. (b) The farmers can relate their agricultural practices directly to the farm scale network. (c) The focus of the aquifer scale network is on IWRM and nature conservation. (d) The results obtained by each one of them will be different; and (e) The comparison of both Bns may provide new insights and help to identify new problems that cannot be achieved by working at only one scale.

The construction of the Bayesian network is being held following the stages described in Merit guidelines (Bromley 2005), see Figure 1:

1. Define the problem.
2. Identify variables, actions and indicators.
3. Design pilot network.
4. Collect data from all available sources.
5. Define states for all variables.
6. Construct CPTs.
7. Check, collect feedback and evaluate network.

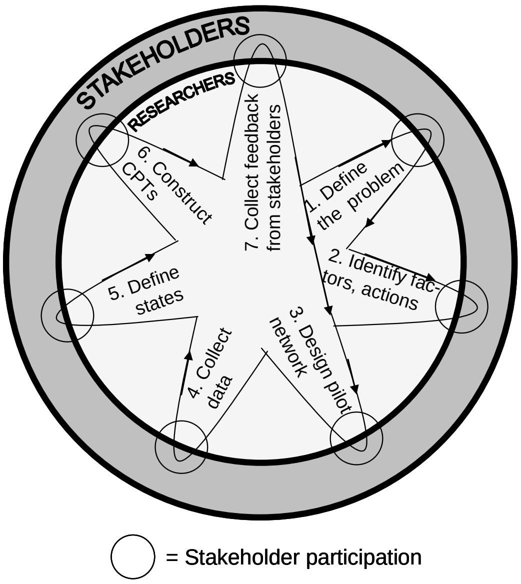

Fig. 1. Seven steps in construction of Bayesian networks with interaction between stakeholders and researchers. Based in Henriksen and Barlebo 2007.

The arrows in Figure 1 reveal that steps 3-7 of Bn construction can be repeated several times before the final configuration of the network is achieved (Henriksen and Barlebo 2007).

As stated in Bromley (2005), a Bn is “far more likely to be successful if stakeholders are encouraged to become involved with its design and construction at an early stage”. Stakeholder involvement is essential as a source of data and information in all the steps of the Bn construction. But stakeholder involvement can also be very useful for the resolution of conflicts, as it creates a “culture of transparency”[1] stemming from the open use of data within the network. Stakeholder engagement generates a sense of ownership towards the network, and therefore towards any decision based on the outputs of the network. For all these reasons, stakeholder involvement constitutes a very important part of our work and it is being carried out in the seven steps of Bn construction.

3.2 Define the problem; Identify variables, actions and indicators

The definition of the problem is the first step in the construction of the Bn. It has to be done with the stakeholders from the beginning, so as to assure their active involvement and their acceptance of the final product. They provide us with information about interests, concerns, perceptions, data, etc. At the same time, the stakeholders will be invited to identify the relevant variables in the system, including potential actions and also the indicators that can be used to help evaluate the impacts of different actions.

For our case study collaboration with stakeholders had already started before the idea of Bn development was envisaged. A selection of key stakeholders took place and several thematic meetings were organized as a platform for discussion. Table 1 lists the institutions and individual stakeholders invited to take part in meetings to discuss the problems in the catchment.

Table 1. List of stakeholders included in the NeWater project discussion groups (Martínez-Santos et al. 2007). NWP: NeWater Partner.

	INSTITUTIONS
Central government	1. General Water Directorate (Ministry of the Environment)

1 Bromley 2005.

	2. Guadiana River Basin Authority
	3. Hidroguadiana (Government society)
Regional/ Local government	4. Regional Department for the Environment (REG)
	5. Reg. Department of Agricultural Production (REG)
	6. Regional Water Board (REG)
	7. Daimiel Water Centre (LOC)
Water user associations	8. Groundwater User Association of Spain (AEUAS)
	9. Federation of Groundwater Users
	10. General Association of Water Users (Aquifer 23)
	11. Association of Private Groundwater Users (Aquifer 24)
Environmental conservation groups	12. WWF/ADENA Spain
	13. SEO/Birdlife
	14. Ecologistas en Acción (“Ecologists in Action”)
	15. Ojos del Guadiana Vivos (“Guadiana Springs Alive”)
Farmers’ unions	16. ASAJA (big farmers union)
	17. COAG (small farmers union)
Research institutions	18. Universidad Complutense de Madrid, Spain (NWP)
	19. Universidad Politécnica de Madrid, Spain (NWP)
	20. IGME (Geological Survey of Spain) (NWP)
	21. Instituto de Soldadure e Qualidade, Portugal (NWP)
	22. University of Osnabrück (NWP)
	23. Cemagref (NWP)
	24. SEI Oxford (NWP)
Independent	25. New Water Culture Foundation
	26. International Institute of Environmental Law
	27. Ariño & Associates Lawyers
	38. Individual farmers

The specific objectives of these meetings were (Figure 2): a), to facilitate an informal, unbiased framework for discussion on different aspects of water management; and b) to draft a series of scenarios relating to the development of specific integrated water resources management tools such as hydrological and agronomic models suited to the basin conditions (Martínez-Santos et al. 2007).

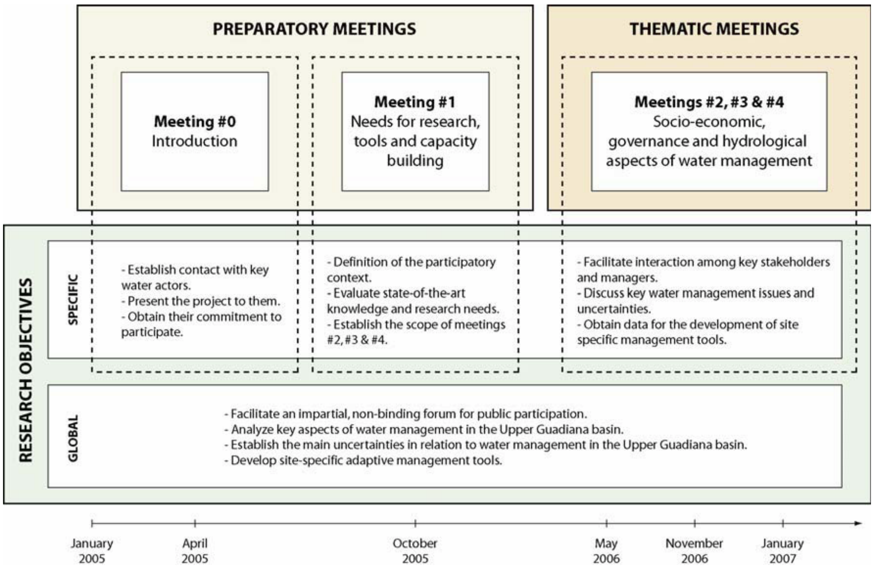

Fig. 2. Methodology applied in the stakeholder meetings according to Martínez Santos et al. 2007.

The approach took the form of five meetings focused on different aspects of water management in the Upper Guadiana basin and designed to cover the concerns of all participating stakeholders.

- Meeting 0: Introduction (April 2005).
- Meeting 1: Needs for research, tools and capacity building (October 2005).
- Meeting 2: Social and economic aspects of water management (May 2006).
- Meeting 3: Governance aspects of water management (October 2006).
- Meeting 4: Hydrological aspects of water management and climate change (November 2006).

These first five meetings were based on the methodology designed by the research team (Varela-Ortega et al. 2006) which involves a series of steps, including stakeholder analysis and participation, questionnaire and meeting design, meeting implementation, and reporting (Figure 3).

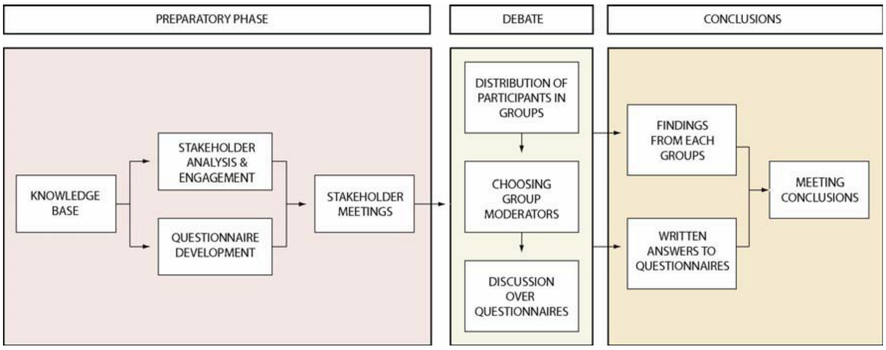

Fig. 3. Phases described in the methodology according to Martínez Santos et al. 2007.

All the data obtained from these five meetings, together with individual interviews held with many of the stakeholders, allowed us to establish the basis for the Bn.

3.3. Design pilot network; collect data from all available sources

To initiate the design of the pilot Bayesian networks, two more recent meetings have been held with stakeholders to elicit their contributions to the network design and to identify new sources of data.

We separated the stakeholders into two different groups according to their main interests: one group consisted of farmers and regional agriculture institutions; the other group of environmentalists and water authorities. The reason for this separation was that the conflicts between the different stakeholder groups made it potentially difficult to talk freely, openly and constructively about every issue. Because these meetings sought to identify as many variables and relationships as possible, it was better to have a format that did not restrict discussion to the most contentious issues, something that could have happened in a joint meeting.

We organised one meeting for each group, maintaining a common structure and development. The meetings, both of which were controlled by a facilitator, opened with a brief introduction to Bns followed by an explanation of the steps to build a network based on the methodology proposed by Bromley (2005). Questionnaires were then handed out and the responses used to help lead discussion, prevent side-tracking, avoid the predominance of one or another view and to guarantee the discussion of as wide a range of issues as possible (De la Hera et al. 2007).

The questionnaire (Table 2) was divided into two blocks, one related to the aquifer scale management, the other to farm management. The aquifer scale management questions involved social factors, incomes from the agricultural sector, regional distribution of crops, prices and irrigation rights, and environmental and hydrological issues of the Upper Guadiana Basin as a whole. Farm management questions were concerned with agricultural income, the choice of crop patterns, and water use at the farm scale.

Table 2. Methodology used for the designs of the questionnaires that guided the stakeholder meetings (De la Hera et al. 2007).

Methodology of the questionnaire design
• We used networks previously drafted by the research team as reference for the design of the questionnaire • The questions aimed to clarify the importance and relations of variables • The questions aimed to find out new possible variables • Most of the questions expected to get possible data and states • The questions touched familiar issues for the stakeholders • We used a "easy to understand" question wording

The facilitator read out each of the questions one by one, which the stakeholders answered; in some cases this generated interventions that led to friendly discussions about the issue involved. During the course of discussions variables and links were identified, which made it possible to construct a Bn based on the input received from the group. This transparent and open approach made it possible for stakeholders to see how the networks were being constructed and enabled them to make changes if they felt this was necessary. Following the meetings each group produced a network which reflected the views and opinions of that group.

Not surprisingly the meetings produced two different Bns. But by closely examining both networks, and the answers to the questionnaires that were set, it was possible to identify variables and relationships in the system that were common to both groups. From this analysis two new networks, one at farm scale and one at the aquifer scale were constructed to reflect the combined input of both groups.

Data collection began during the 1st stage of network construction to help establish the states of variables (Tables 3 and 4) and to complete the conditional probabilities tables (CPTs). With the data obtained from this second set of meetings, some variable states and conditional probability tables have already been completed, but more data from other sources are still being collected to complete the remaining CPTs. Data has been obtained from one-to-one interviews with individual stakeholders, statistical data, legislation material, and from scientific reports and papers.

Table 3. Variables defined at aquifer scale (Own elaboration).

VARIABLES OF THE AQUIFER SCALE BAYESIAN NETWORK	
1. Climate change	14. Purchase of water rights
2. Temperature	15. Scenarios
3. Rainfall	16. Regional crop distribution
4. Natural recharge of the aquifer	17. Regional irrigation requirement
5. Irrigation Technology	18. Abstractions
6. Irrigation knowledge	19. Natural Events
7. Irrigation efficiency	20. Other inputs
8. Crop water use	21. Annual yields
9. Capacity of enforcement	22. Regional agricultural income
10. Compliance with water restrictions	23. Groundwater balance
11. Water abstractions plan	24. Wetland recovery
12. Water availability 1	25. Social welfare
13. Offer Price of water rights	

Table 4. Variables defined at farm scale (Own elaboration).

VARIABLES OF THE FARM SCALE BAYESIAN NETWORK	
1. Water abstractions plan	10. Purchase of water rights
2. Capacity of enforcement	11. Price of water rights
3. Compliance with water restrictions	12. Prices of products
4. Water availability	13. Type of year
5. Annual yields	14. Marketing improvement
6. Natural events	15. Agricultural subsidies
7. Climatic conditions	16. Selection of productive plan
8. Climate change	17. Farm size
9. Water level	18. Farm income

Some of the variables whose states were defined by stakeholders were: water abstraction costs, farm income, production costs, and agricultural subsidies. Table 5 shows one example of the inputs (variables and states) provided by stakeholders: farm income identified by type of farm (type 1, 2 and 3 defined according to farm size) and type of year (good, average and bad):

Table 5. Farm income by type of farm and type of year, defined by stakeholders.

FARM TYPE	Total income per farm (€)			Income per ha (€/ha)		
	Good	Average	Bad	Good	Average	Bad
Type 1	23.750	17.375	10.000	791,17	579,17	333,33
Type 2	31.250	26.875	15.000	520,83	447,92	250,00
Type 3	137.750	100.750	58.000	459,17	335,83	193,33

During this step, significant uncertainties about the state of some variables were revealed. For instance, it was difficult to establish the degree to which farmers complied with their water allocation under the Water Abstraction plan. We are aware that non-compliance is a major problem, but the question is: to what extent? Another difficult variable to define is "Marketing improvement". To quantify this we need to know how the prices of crops are likely to change in the future, something which is subject to a whole range of influences and is very difficult, if not impossible, to predict.

3.4 Construct CPTs

The results from the two latest meetings were used to build two preliminary Bns (one for each scale). The improvement of these networks needs the revision of the data and the structure of the links between variables. On this purpose, a recent Bns workshop was held in Copenhagen in June 2007, where researchers involved in the present study had the opportunity to discuss the state of the pilot network so far, as well as to schedule future plans for its improvement.

Some of the questions that arose were related to issues such as:

a. How to modify the networks based on the input from stakeholders?
b. How to deal with time scale, future situations / predictions in Bn?
c. How to represent different farm types in a basin scale network?
d. How to take into account different types of crop?

Bns are based on Bayes' rule, which shows how existing beliefs can be modified with the input of new evidence. This rule means that the probability of a child variable (i.e. a variable receiving at least one link) to be in a particular state depends on the states of the parent variable, or variables, linking to it.
If we consider variable A, which has two states a_1, a_2 and A is a child of a second variable B, with states b_1, b_2, then the joint probability P(a, b) is given as:

$P(a|b) \bullet P(b) = P(a,b)$……………………………………..Fundemental rule

This is known as the 'fundamental rule', from which Bayes' rule is obtained:

$P(b|a) = \frac{P(a|b)\,P(b)}{P(a)}$ ……………………………..…..Bayes' rule

For more information on the statistics of Bayesian networks the reader is referred to Jensen (2001).

In a Bn, where all variables are linked through conditional probability relationships, the probability of the different states for the output variables (the ones that we have selected as indicators) is calculated based on Bayes' rule. The conditional probabilities of each variable are represented in the conditional probability tables (CPTs) lying behind each variable. These tables show the probability of each variable to be in a particular state given the states of the parent variables. Figure 4 shows how the probability of each state for one variable (Node 3) depends on the probabilities taken by the parent variables (Nodes 1 and 2).

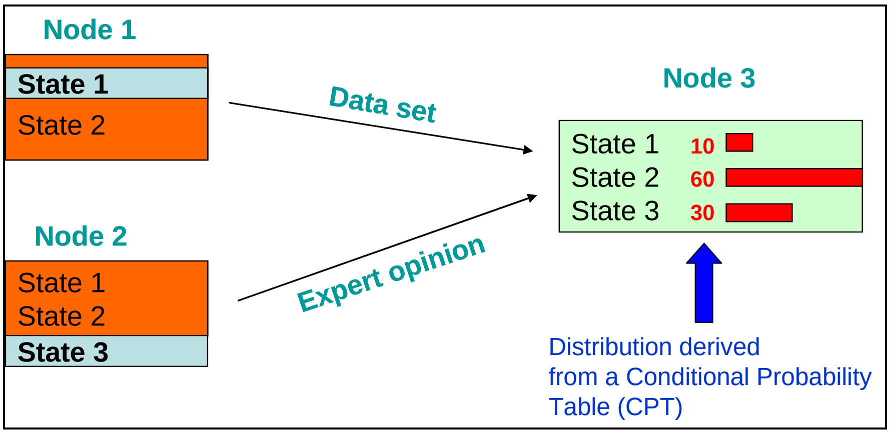

Fig. 4. Construction of the Conditional Probability Tables (Bromley, 2005).

Filling in the CPTs correctly is of fundamental importance in Bn construction because it is the CPTs that control the network functioning. Incorrect CPTs will lead to incorrect results. To ensure that tables are as accurate as possible it is important to have good data and to involve stakeholders to provide a check on the reality of the information being used. If the networks do not respond in a way that seems logical to the stakeholders, based on their experience, then it is unlikely the results will be accepted.

The Copenhagen meeting proved to be a good opportunity to examine the CPT structure of the draft networks. However, the CPTs constructed to date are only preliminary and need to be improved through further interviews with stakeholders that are planned to take place in the coming months. Nevertheless, examining the tables at the meeting forced us to reflect about possible inconsistencies and allowed us to make some initial runs of the network. Analysing the outputs obtained from the network also helped us to pin-point possible mistakes. All this information will be used to prepare the next stakeholder meetings where we expect to solve critical aspects of the current version of the network.

In the Copenhagen meeting we solved the four previous questions:

a. We were concerned about how much we could change the networks that were built during the stakeholder meetings, because we wanted to respect their decisions, but we needed to make changes in order to make them more real. We concluded that we should use the inputs from stakeholders as useful information but not as fix statements. By the same way, we considered very important to inform stakeholders about the changes and to allow new insights from them.

b. We concluded that the best time scale is one year, as it includes hydrological, crop and economic natural cycles.
   We thought that it will be very interesting to evaluate the Bns for several years, so we concluded that we should study the way to do it. The problem is that the states and CPTs can suffer big changes in a small period of time, and that there is no software to do it.
c. We thought that there are two ways to do it: To do small Bns for each farm type or to introduce a variable with the number of the different farm of each type.
d. There are also here two ways to do it: to do a small Bn for each crop or to introduce a small number of possible crop distributions.

4. Results

This full paper presents two Bayesian Networks based on the data that has been collected so far. The form of both networks will continue to be modified as new inputs are obtained from official statistics, models and the forthcoming stakeholder meetings and interviews that will take place during 2008, as well as from the '*Train the Trainers*' initiative under the activities that WP4.3 is carrying out in the Guadiana basin case study.

It is important to note that the construction of the Bns requires continuous revision, responding to feedback obtained from stakeholders and to new data throughout the process. The Bns shown in this paper are not the final, definitive product of our research, but simply reflect our current state of knowledge; they will inevitably be modified in the light of stakeholder feedback at future meetings. Figures 5 and 6 show the version of the Bns that emerged following the modifications made at the Copenhagen meeting. Figure 5 shows the Bn at the aquifer scale, while figure 6 shows the Bn at the farm scale.

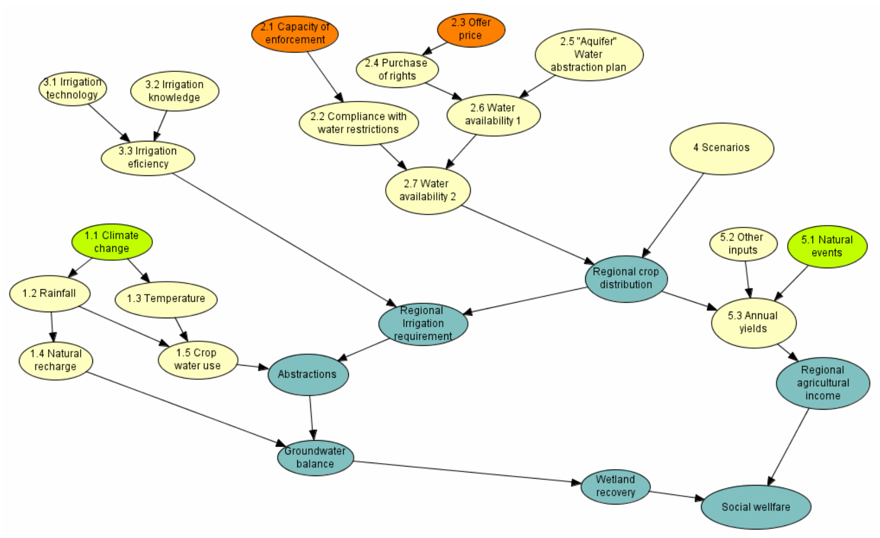

Fig. 5. Bayesian Belief Network aquifer approach (Own elaboration).

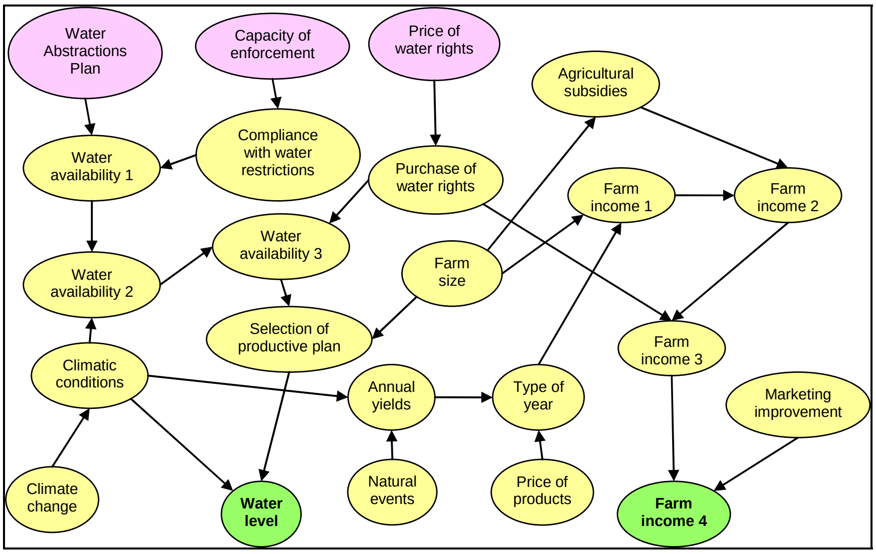

Fig. 6. Bayesian Belief Network Farm approach (Own elaboration).

Once revised and confirmed the variables the states of the network were completed. Tables 6 and 7 show the variables and states selected for both the aquifer and farm scale networks.

Table 6. States defined for the variables included in the Bn at aquifer scale (Own elaboration).

VARIABLES	STATES OF VARIABLES
1. Climate change	Yes / No
2. Temperature	High / Low
3. Rainfall	<370mm/year / 370<460mm/year / >460mm/year
4. Natural recharge of the aquifer	<260Mm^3/year / 260<390,84Mm^3/year / >390,84Mm^3/year
5. Irrigation Technology	Actual / Updating / Degradating
6. Irrigation knowledge	Actual / Increasing
7. Irrigation efficiency	Low / High
8. Crop water use	Increase / Decrease
9. Capacity of enforcement	High / low
10. Compliance with water restrictions	<50% / 50%<85% / >85%
11. Water abstractions plan	<200 Mm^3/year / 200<300 Mm^3/year / >300 Mm^3/year
12. Water availability	<200 Mm^3/year / 200<300 Mm^3/year / >300 Mm^3/year
13. Offer Price of water rights	High / Medium /Low
14. Purchase of water rights	<10% / 10%-15% / 15%-25%
15. Scenarios	Current / High incomes / Water saving
16. Regional crop distribution	Actual / Crop distribution A / Crop distribution B
17. Regional irrigation requirement	<228 Mm^3/year / 228<410,5 Mm^3/year / >410,5 Mm^3/year
18. Abstractions	<310 Mm^3/year / 310 <586,6 Mm^3/year / >586,6 Mm^3/year
19. Natural Events	Yes / No
20. Other inputs	High / Low
21. Annual yields	High / Medium / Low
22. Regional agricultural income	274,7 M€ / 299,9 M€ / 380,7 M€
23. Groundwater balance	Improving / Balanced / Decreasing
24. Wetland recovery	Less than 20 years / More than 20 years / Never
25. Social welfare	Better conditions / Worse conditions

Table 7. States defined for the variables included in the Bn at farm approach (Own elaboration).

VARIABLES	STATES OF VARIABLES
Water abstractions plan	800 / 1200 / 2000 / 2640 m^3/ha
Capacity of enforcement	High / low
Compliance with water restrictions	Yes / no
Water availability	0 / 800 / 1200 / 2000 / 2640 / >2640 m^3/ha
Annual yields	High / average / low
Natural events	Yes / no
Climate change	Yes / no
Climatic conditions	Current / more rainfall / less rainfall
Water level	Stable / up / down
Purchase of water rights	Farmer sells / Farmer doesn't sell
Price of water rights	[3000-6000] / [6000-9000] / [9000-12000] €/ha
Prices of products	Good for vegetables / good for cereals / good for all / bad for all
Type of year	Good / medium / bad
Marketing improvement	High / medium / low
Agricultural subsidies	156 / 95 / 56 €/ha
Selection of productive plan	Plan 1 / plan 2 / plan 3 / plan 4 (*)
Farm size	30 / 60 / 300 ha
Farm income	>150 / [150-300] / [300-600] / [600-1000] / >1000 €/ha

(*) Plans with different intensity in water use

Bringing the stakeholders to negotiation and involving them in management decision-making requires the use of decision aid tools which are simple, transparent and flexible (Henriksen et al., 2007 in press). The Bns have not yet been completed; and the work to be completed in the coming months is focused on new stakeholder meeting in order to analyse whether or not the results are acceptable; but the positive response that we have received so far confirms the suitability of Bns for encouraging public participation. The process of construction of the Bns is providing a platform for discussion in which different groups of stakeholders with opposite interests can exchange their views of the problem. The meetings held so far have been positive: participants have actively worked on the Bn construction, allowing the elicitation of knowledge.

5. Conclusions

The results obtained so far with both Bns provide a sound framework to establish scenarios of long term strategic water management and to discuss with stakeholders the usefulness and practicability of the networks. These analyses are presently being undertaken by Carmona and Zorrilla and are expected to be completed by the end of 2008.

The results obtained by our research can be summarised as follows:

1) Bns provide a participatory process tool that encourages discussion and analysis with stakeholders involved in the problem, and by generating a sense of ownership provides a possible path toward the eventual solution of problems that at present appear to be intractable.
2) The two Bns presented in this paper show the main variables and actors identified in the study area.
3) The Bns obtained are not completed; the work pending on new stakeholder meetings is a key element in order to verify the results obtained up to now.

References

Bromley, J. (2005). MERIT Project Guidelines. Management of the Environment and Resources using Integrated Techniques. Guidelines for the use of Bayesian networks as a participatory tool for Water Resource Management. Centre for Ecology and Hydrology, UK, 2005.

De la Hera, A.; Carmona, G.; Zorrilla, P. (2007). First report on stakeholder meetings for Bn design in the Upper Guadiana Basin. Results obtained with two different stakeholder groups. June 4, 2007. Draft internal NeWater report.

Henriksen, H.J.; Barlebo, H.C. (2007). Reflections on the use of Bayesian belief networks for adaptive management. Journal of Environmental Management, 2007. doi:10.1016/j.jenvman.2007.05.009 (published on-line)

Henriksen, H.J.; Rasmussen, P.; Bromley, J.; De La Hera, A.; Llamas M.R. (2007). Tools in NeWater for participatory integrated assessment and adaptive management. Geological Survey of Denmark and Greenland (GEUS). Bulletin 10. 2007 (accepted). Copenhagen, Denmark.

Jensen, F.V. 2001. Bayesian Networks and Decision Graphs. Springer Verlag, New York. 268pp.

Martinez-Santos P (2007). Hacia la gestión adaptable del acuífero de la Mancha Occidental. PhD Thesis. Universidad Complutense de Madrid. 383p.

Martínez-Santos, P.; Llamas, M.R.; De Stefano, L.; Martínez-Cortina, L.; De la Hera, A. (2007). Stakeholder meeting #4: Hydrological aspects of water management and climate change. April 27, 2007. Internal report of NeWater Project.

Varela-Ortega C, Sumpsi , J.M. and Blanco, M. (2003). Análisis económico de los conflictos entre el regadío y la conservación de humedales en el Alto Guadiana. In: C Coleto, L Martinez-Cortina and MR Llamas (eds). Conflictos entre el desarrollo de las aguas subterráneas y la conservación de los humedales. Fundación Marcelino Botín. Ediciones Mundiprensa. Madrid, 257-276.

Varela-Ortega, C.; Blanco, I.; Esteve, P. (2006). Stakeholder meeting 2: Economic and Agronomic aspects of water management in the Upper Guadiana Basin (Spain). Report for NeWater WP1.7: Methods for Transition to Adaptive Management. NeWater Project (nº 511179-2)-DGResearch, European Commission. Madrid.