ENGAGING STAKEHOLDERS IN CONSTRUCTION AND VALIDATION OF BAYESIAN BELIEF NETWORK FOR GROUNDWATER PROTECTION

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Abstract: A Bayesian belief network (BBN) for farming contracts has been constructed and validated with direct co-operation and in dialogue with stakeholders. On the one hand, Bbn's can create space for an open dialogue with stakeholders due to the flexibility of the decision support tool. This allows factors (nodes), associations (directed links) and probabilities to be adjusted and validated throughout the process and based on inputs from all involved stakeholders and experts. On the other hand getting stakeholders to understand and accept the idea behind BBNs is demanding. Especially the required probability assessments are not easy to understand by stakeholders.

Keywords: Pesticides, precautionary groundwater protection, bayesian belief networks, stakeholder involvement, voluntary farming contracts

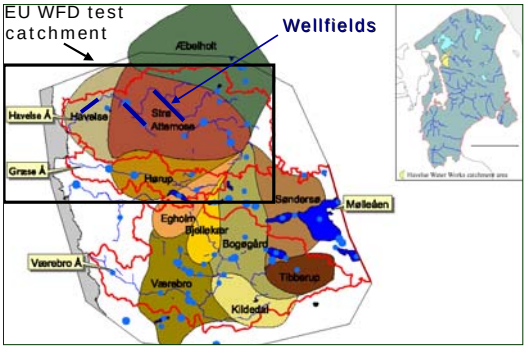
1. INTRODUCTION

CE is the largest water supply company in Denmark. It supplies roughly one million inhabitants in the greater Copenhagen area with drinking water each day. CE operates Havelse wellfield together with 55 other large wellfields located in northern and eastern Zealand (the island on which Copenhagen is located), see Figure 1(Henriksen et al., 2004).

Information, consultation and active involvement of professional stakeholders and general public was carried out using announcements, facilitated public meeting, working group meetings, newsletters, a Web site, individual meetings and a joint working group. The facilitator of the public meeting and workshops was the Agenda 21 Centre in Frederikssund. Various subcontractors have participated in the project, e.g. farm economics (Rasmussen, 2003) and value of biodiversity, land use, etc. (Schou, 2003).

Fig. 1. Danish case study area – Havelse river catchment (approximately 100 km^2). Havelse wellfield capture zone (35 km^2) is located in the downstream end of the river basin near Roskilde fiord. Copenhagen Energy operates two other large wellfields upstream at Strø and Attemose

1.1 Objectives of Danish MERIT case study



The specific objectives of the Danish case study was formulated as follows (Henriksen et al., 2004):

1. To construct a Bayesian belief network (BBN) study site in Denmark with a focus on innovative actions for precautionary groundwater protection against pesticide threats.
2. To investigate the extent to which BBNs can be used as a decision support tool for water resource management at a wellfield abstracting groundwater from the downstream part of a river basin.
3. To develop techniques to encourage and enable full stakeholder involvement in the construction of BBNs. This final but critically important component will provide an evaluation of the most effective means to involve stakeholder groups in the decision-making process.

1.2 Construction of BBN study site

Agriculture currently accounts for two-thirds of land use in Denmark, and the farmed area covers some 2,7 million ha. More than half of the agricultural area is used to grow cereals, mainly winter cereals. These crops have a high leaching potential, because they need additional fertilisers and pesticides. Pork accounts for about a third of agricultural production value, and diary products have a share of 20 % of total production value. Denmark is one of the leading countries in the world exporting pork. Agriculture is a rather marginal activity, if measured in terms of the share of agriculture of the Gross Domestic Product (GDP, only 2%). However, agriculture remains important economically, having a share of approximately 14 % of national exports (Danmarks Statistik, 2000; Brouwer, 2003).

The question in relation to CE now is, how useful are agri-environmental agreements for large-scale groundwater protection in northern Zealand. CE operates 55 large wellfields with thousands of farmers, and the Havelse case study could provide important input for CE's strategy and policy in this area (Brandt and Henriksen, 2003).

A Bayesian belief network (BBN), also called a belief network, is a type of decision support system based on probability theory which implements Bayes' rule of probability. This rule shows mathematically how existing beliefs can be modified with the input of new evidence. Devised by Thomas Bayes, an eighteenth-century English clergyman, BBNs organise the body of knowledge in any given area by mapping out cause-and-effect relationships among key variables and encoding them with numbers that represent the extent to which one variable is likely to affect another (Addin and Jensen, 2004; Jensen, 2002).

BBNs have become a highly successful technique in medical diagnostic systems, analysis, artificial intelligence, and decision-making in real-world domains. They have been applied for many years in practice in a variety of fields, including engineering, science, and medicine (Charniak, 1991; Addin and Jensen, 2004; Jensen, 2002; Cowell et al., 1999). BBNs have gained a reputation of being powerful techniques for modelling complex problems involving uncertain knowledge and uncertain impacts of causes (Aitken et al., 2003; Jensen, 2002). They can be used in a way that promotes an improved understanding of the environmental system, leaving decision-makers to reach their own conclusions on the basis of that understanding. Ideally, BBNs are a technique to assist decision-making that is especially helpful when there is a scarcity and uncertainty in the data used in taking the decision and the factors are highly interlinked, all of which makes the problem highly complex (Addin and Jensen, 2004).

BBNs can help to formulate environmental management strategies by (Addin and Jensen, 2004):

- Allowing users to build their own environmental decision support system (EDSS). By building it themselves, users can ensure that the decision support system meets their needs.
- Helping users to understand the nature of their decisions better. An EDSS should help users make a better decision, not an easier one. It should not make the decision for the user. Instead, it should encourage the user to identify all the relevant information and analyse it more in depth.
- Encouraging users to deal with uncertainty. It is impossible to be certain about the consequences of any environmental management decision. This fact must be recognised together with the effect of that uncertainty of the decision.
- Encouraging consultation with stakeholders. Without stakeholder consultation, it is unlikely that an environmental management decision can be implemented.

The general idea with the BBN for farming contracts was to analyse the effects of compensation payments to farmers for not using pesticides on agricultural fields. The higher the compensation level, the more farmers will join such a voluntary contract. However, farmers signing a contract will also try to optimise land use by growing crops more suitable for farming without pesticides, and this means that contracts will also affect crop rotation. Farming contract restrictions and crop rotation affect the farmers' bottom line, so to speak, and this, together with the compensation payment, has an impact on farm economics as a whole. All the relationships in this part of the farming contract BBN were initially provided by subcontractor Svend Rasmussen from the Royal Veterinarian and Agricultural University (KVL), which also collected the data for pesticide application for different crop rotations (Rasmussen, 2003). The other part of the BBN in Figure 2 shows variables concerning environmental impacts of pesticide application. These variables were based on information from monitoring programmes at GEUS and CE (GEUS, 2003; Brüsch et al., 2004). Furthermore, research from the USA had shown that high concentrations of herbicides in surface water impacts the reproductive capability of leopard frogs (expressed by the variable "biological abnormality"), Nature (2002a,b).

The types of variables in the BBN in Figure 2 can be grouped into five categories (Addin and Jensen, 2004):

1. *Objectives.* Things that are affected: C8 Shallow groundwater quality, C10 Biological abnormality, C12 biodiversity, C15 Surface water quality, C18 Recreational value and C19 Deep groundwater quality. Overall objective: C20 Safe supply.
2. *Interventions.* Things which must be implemented or included in CE policy: C5 compensation, C1 non-point application and C21 remove point sources.
3. *Intermediate factors.* Variables which link objective variables with intervention variables: C2 Farming contracts, C3 Land use, C4 Farm economics, C6 Pesticide load, C7 Diffuse, C9

Surface water quality, C14 Point sources and C17 Hunting/fishing.

4. *Controlling factors.* Factors that control the environmental system: C16 Sand/clay, C13 Animal/vegetation, C11 SFL area. Uncertain controlling factors: C22 Perception of vulnerability – stakeholders do not agree.
5. *Decision and utility variables.* Variables that are included in order to calculate and visualise a certain utility: D1 All-farm economy and U1 Utility node.

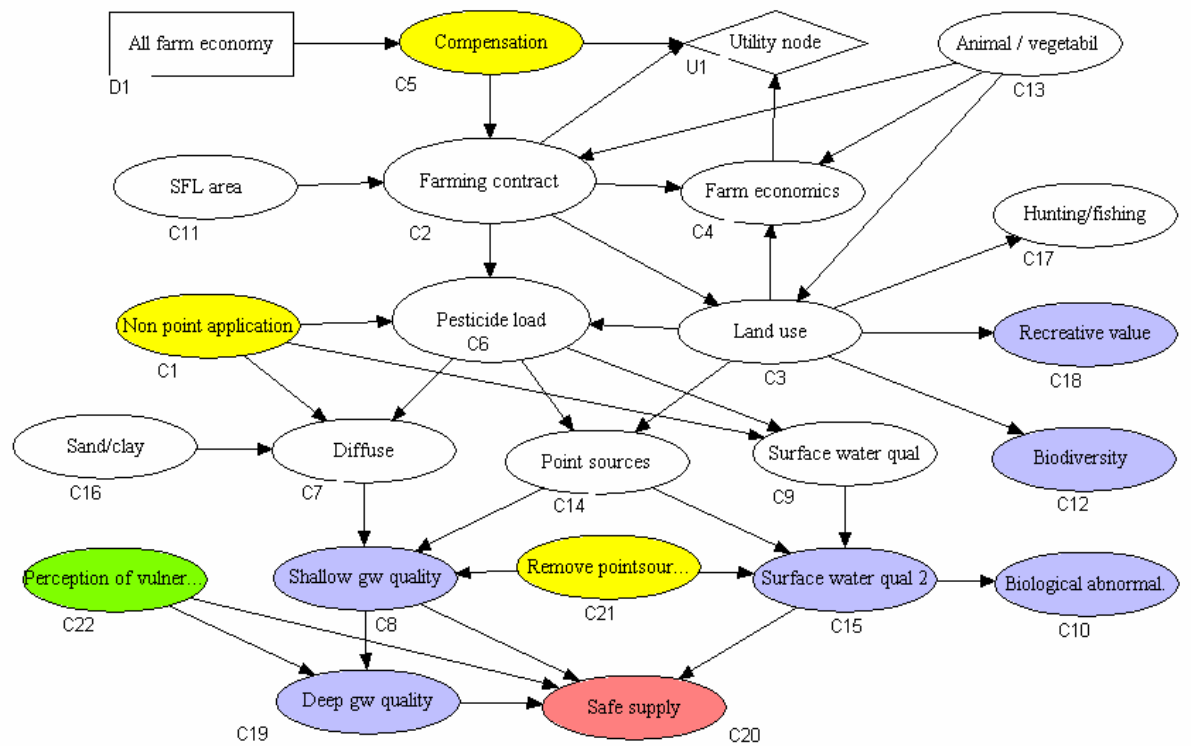


Fig. 2. Final BBN for voluntary farming contracts

Two variables are aimed at balancing the overall BBN and function as focal points to allow a better understanding of the outcome of the BBN. These variables are the indicator "safe supply of drinking water" and the utility variable "total farm economy" (*dækningsbidrag 2* in Danish) of farmers:

1. Safe supply of drinking water to 20 thousand inhabitants in the capital city area (Boolean variable which can be true or false: true means that future clean groundwater with a content of pesticides below the maximum allowed concentration can be abstracted from the wellfield, also after 50 years
2. The utility variable "total farm economy", which is the sum of agricultural production yield (economic benefit exclusive machinery and other fixed costs) and compensational payment

The pesticide found in existing monitoring data is BAM – 2.6 dichlorbenzamide, which is a metabolite of the herbicides dichlobenil or chlorthiamide. BAM is the greatest threat to groundwater quality at the moment (GEUS, 2003; Brüsch et al., 2004). The use of these herbicides is now prohibited. The pesticide findings were made in a village, and it is probably more point-source pollution than diffuse pollution. Similar vulnerable or very vulnerable areas are also found inside the catchment area and in the present wellfield zone. The vulnerability is here an expression of the thickness of the clay layer above the primary reservoir and whether the aquifers are unconfined or confined. NEW pesticide analyses from five drilled wells, four dug wells and Havelse Creek show pesticides in two dug wells and one drilled well, but also in Havelse creek, with all findings above the MAC value CE (2004).

1.3 Use of BBNs as decision support tool

The graphical nature of the approach facilitates formal discussion of the structure of proposed model and the ability of a BBN to describe the uncertain relationships amongst variables is ideal to describe the relationship between events which may not be well understood (Aitken et al., 2993). During the process context, factors, actions, indicators, states and conditional probabilities were identified and pilot BBN's further developed and presented to stakeholders in order to test to stakeholder opinion. Integration of local knowledge, expert knowledge and data was questioned and feedback from different stakeholders and members of general public collected with respect to credibility and identifying points of dispute and disagreement.

Two scenarios were analysed (Henriksen et al., 2004):

1. Farming contracts: voluntary farming contracts (different compensation level)
2. Both actions: voluntary farming contracts (different compensation level plus removal of point sources; it is assumed that all point sources are simply removed)

Figure 3 illustrates that the compensation payment must be MVJ agreements (with a compensation of DKK 4400 per ha/year, of this up to 60% financed by the EU) if the "preventive goal" is to be achieved (minimum a 95% probability for the state "true" of the safe supply). Even if both actions are taken, with an additional cost for removing all the point sources, the result is the same. We have not included the move of the wellfield away from the creek in the present analysis. This could both increase the probability of the "safe supply" being in the state of "true", but other effects could also adversely decrease this probability (intrusion of salt water closer to the Roskilde Fjord bay or unknown point sources close to the new wellfield location).

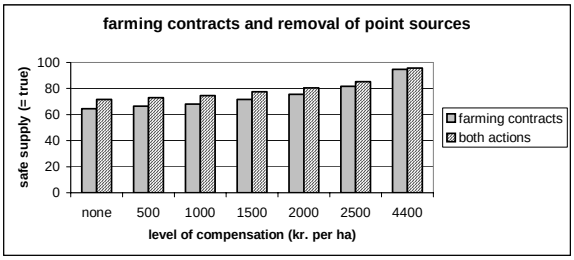


Fig. 3. Comparison of overall indicator (safe supply) for the two alternative scenarios: "Scenario 1: farming contracts" and "Scenario 2: both actions" for different levels of compensation.

For a compensation of DKK 500 per ha/year, few farmers (4 %) would join voluntary farming agreements prescribing no pesticide application. For DKK 1000 per ha/year, a slightly larger fraction would join (11%). At DKK 2500 per ha, nearly 50% would join, but their willingness to sign voluntary preventive farming contracts (no pesticides) is much less than the input from the expert indicated (Rasmussen, 2003), which indicated a break-even point of below DKK 1500 per ha/year.

Thus the main problem is related to a lack of commitment to realistic levels of compensation. Farmers in the area have suggested compensation payment levels of about DKK 5000 per year. Farmers' organisations (NOLA and *Sjællands Familielandbrug*) have indicated that such agreements should either offer a very high compensation (up to DKK 7000 per ha/year) or not be part of groundwater protection at all (expropriation may be necessary and a more feasible method).

The Scenario 1 indicators for water quality show that the probability of polluted deep groundwater drops to below 5% at a compensation level of DKK 2500 per ha/year. This probability varies for the different compensation level from 8.3% (none) to 7.3% (500), 7.5% (1000), 6.6% (1500), 5.8% (2000), 4.3% (2500) to 1.3% (DKK 44 per ha/year). Scenario 2 reaches the 5% level at DKK 1000 per ha/year, signifying that action directed at point sources (removal) may be a necessary element of groundwater protection policy.

In Scenario 1, shallow groundwater has a probability of pesticide content of between 41.7% (none) and 33.2% (DKK 1500 per ha/year). Not until DKK 4400 per ha/year does the probability drop below 10% for clean groundwater (6.6% probability). Scenario 2 results in an achieved goal of a 5% level at DKK 4400 per ha/year including removal of point sources. Similar results were found for surface water.

Active groundwater protection from pesticides requires innovative solutions (Brandt and Henriksen, 2003), coordination of actions by various authorities and commitment to implementation from the different stakeholder groups. Lack of knowledge about different sources of pesticide pollution, vulnerability and spreading of pesticides to drinking water requires precautionary management and sound decisions about preventive groundwater protection. The application of pesticides to agricultural fields according to regulative guidelines, accidents, point sources, past mistakes, and the spread of pesticides (e.g. BAM) all contribute to a high frequency of findings both in shallow and deep groundwater, as well as in surface water (Henriksen et al., 2004).

The aim of the farming contracts BBN was to analyse a complex problem in order to develop a decision support tool that would provide a transparent, flexible and holistic basis for decision-making that included environmental issues, socioeconomics and physical conditions.

Furthermore, the exercise demonstrated that cost/benefit issues and especially the implementation of management action plans are associated with by many more issues than expert knowledge normally takes into consideration. In our case, a barrier for voluntary farming contracts is not data or information on economic conditions in farming, but, to a much greater extent, perception among stakeholders of the soundness of the action. Attitudes, beliefs and group behaviour (Robbins, 2003) among farmers and their organisations, and the uncertainty and lack of data, play a more important role than a possible financial benefit in the short run. Since farming contracts also are rather difficult to manage (Brouwer, 2003), at least as voluntary agreements negotiated within a wellfield catchment area as part of a groundwater protection plan, the entire approach is both costly and difficult to implement.

1.4 Techniques to encourage and enable stakeholder involvement

Havelse wellfield catchment is located in three municipalities: Slangerup, Frederikssund and Frederiksværk, all in Frederiksborg County. There are smaller local waterworks within the wellfield catchment area. Frederiksborg County is responsible for water resources planning, and the municipalities are responsible for the water supply. The land use in the area is predominantly conventional agriculture. The Havelse Creek runs through the area; it is used

for angling, and the county has plans to re-establish wetlands along the creek. Copenhagen Energy's groundwater abstraction license for Havelse wellfield is due for a renewal in a few years' time, and the wellfield will have to undergo renovations in the near future (Brandt and Henriksen, 2003).

The starting point for identifying stakeholders was trying to list categories of water users, potential groundwater pollution sources, and authorities in the area: local waterworks, other water consumers, farmers, industry, anglers, the county and the municipalities.

We started off by sending letters to all professional stakeholder organisations that we found to have a potential or even marginal interest in groundwater protection in the specific area inviting them to a one-day workshop in October 2002. Many "green" NGOs did not show up; the industrial sector preferred to use their political contacts on groundwater issues, they told us. One result of this workshop was the formation of a professional stakeholder working group with ten institutions, including the project end user CE, the local Agenda 21 centre (facilitator in relation to citizens' group), and GEUS (see Figure 6).

The next step was in November 2002: a public meeting in the local community hall. Invitations were distributed to more 1100 local households, and the meeting was announced in the local newspaper. About 100 people and the local TV station showed up for the meeting. At the end of the meeting, a local citizen working group of nine persons had been formed. At both meetings, stakeholders were asked to present issues and problems they found important in relation to groundwater protection.

In the following course of the project the stakeholders were organised into two different groups: the professional stakeholder group, and local citizens stakeholder group. The idea behind the split of stakeholders in two groups was the perception that the professional stakeholders are already deeply involved in groundwater management and protection, whereas local citizens might have another starting point for their involvement in groundwater management and protection (Henriksen et al., 2004).

At meetings and workshops with citizens' group, we used a facilitator from the local joint municipality Agenda 21 centre. Facilitation in relation to the group of professional stakeholders was not systematical throughout the project, but the first meeting was facilitated by Agenda 21 centre.

The citizen group met five times in the first half of 2003. The idea was to give the group the opportunity to develop its own identity without being influenced by professional stakeholders. The meetings were guided by the facilitator. GEUS and CE only participated in two of the five meetings to answer specific questions and to introduce and discuss the development of the BBNs.

The citizen group published two newsletters in the first half-year of 2003. A third newsletter was published in July 2004 after finishing the final MERIT report. They were distributed to 1000 households in the local area. The newsletters included mainly articles related to groundwater protection, water supply and water quality, and introduced the members of the citizen group. The production and distribution of the newsletter was financed by the MERIT project.

At the final joint meeting in March 2004, the stakeholder groups were asked to comment on the involvement process on the basis of four questions (Henriksen et al., 2004):

1. Is there a need for further initiatives for the protection of groundwater and the stream/bay?
2. How have you experienced the MERIT project progress (BBNs, citizens' meeting, workshops, citizen groups, newsletter, individual meetings, etc.)?
3. How should stakeholders be involved in the future in, for example, active groundwater protection and the establishment of wetlands?
4. Other comments to the process?

Two groups presented their comments: the citizens' group and the farmers' organisations.

Comments from the citizens' group

- We were a little confused about the reason for all this! The creek theme dominated our meetings too much. Not until now have we defined the objectives of the group. We will continue with a group of six or seven people under the title "clean water".
- Confusion about the expectations to the citizens' group.
- We were not aware of how important BBNs were for the project.
- The citizens of Copenhagen and Copenhagen Energy must save water. More recycling. Groundwater has to be protected against all man-made and natural threats. Better maintenance of the stream; poor waste discharge is unacceptable.
- We felt MERIT to be a politically decided project in which political groups and "experts" determined the desired result and the establishment of citizen groups, etc. was only for show. The structure of the public meetings was manipulated.
- Do not have complete information; more scenarios/solutions to the problems should have been presented. A little difficult to follow presentations of the BBNs.
- The citizens' group lost momentum because meetings were interrupted due to some financial business, and it was difficult to get the group started again.
- Better description of objections and exceptions to input/output from the citizens' group, and maybe some roles for the group. More openness

from the start of the project from the County and CE.
- Too little focus on local knowledge.
- What is least expensive to purify or to protect the groundwater?

Comments from farmers' organisations
- If the MERIT project is a test related to the EU water framework directive, then substances other than pesticides should have been included.
- Not all relevant stakeholders were involved in the project.
- All participants in the project were stakeholders; all had their goals and agendas.
- We were hostages.
- We did not get minutes from the other group.
- Look at the facts, what happens with the actual wells, focus on local and actual test results. Disagree on groundwater age of 50 years.
- Today it is only the pesticide bentazone that is actually used.
- Is the presented BBN at all useful? It was quite technical, probabilities not useful when dealing with groundwater protection.
- Maybe BBN is applicable when dealing with the water framework directive as a whole.
- It is the opinion of GEUS that only 10% of stream discharge must be abstracted.
- Who is going to pay for the stakeholder's participation in the project?
- It was frustrating that our input was not implemented in the BBN at the following meeting.
- The MERIT project should have been more anchored in the local Havelse area.
- Communication between stakeholders is important.
- Agree that voluntary farming contracts is not the way forward, but instead delineation of vulnerable groundwater areas and the waterworks should buy those vulnerable areas for groundwater protection.

Furthermore, comments and suggestions from the citizens's group to the draft report was collected by consultation (from hearing in May 2004) and consequences for the final reporting addressed. Since the input from this group was rather substantial, it was decided to include these comments as a separate chapter in this final report from the Danish case.

The overall idea was to begin the process as openly as possible, to get an idea of how stakeholders could contribute to an improved protection of the groundwater resources in the area.

There was a frustration due to a lack of information and time to finalise the work in the working groups, which should give input to BBNs, as expressed by the citizens group:
"Next time the project group addresses this subject, they must be more aware of the fact that the citizens' group is often much more interested than expected (and much better qualified – in some areas perhaps even better and more broadly orientated out of interest than the specialists). For this reason, the project group should do better preparatory work with better information; the citizens' group does not wish to be put off with cursory information. And it sounds as though the work has led to somewhat of an understanding of this. It is correct that it is best to include interest groups in the BBN model construction phase, but it should be done openly, objectively and from the beginning. Don't keep the citizens' group outside the door because you don't think they understand the topic. Be aware of the fact that the citizens' group is willing to contribute much more volunteer work than you apparently think; you only have to include and engage them. They know that the result of the work will have an impact on their own situation, and the specialists should not forget that many members of the general public are extremely well qualified when it comes to finding information on the Internet. The old specialist world is changing. The citizens' group can understand a BBN just fine if it is explained properly by the specialists".

Conflicts and frustration should rather be handled as necessary and gaining events than something that should be avoided (Robbins, 2003). Because discussions and maybe frustrations are necessary steps in finding new and innovative solutions to complex problems like possible preventive actions taken against future pesticides in groundwater.

1.5 Evaluation

Even though stakeholders and citizens generally expressed disappointment with participation in the project and in the working groups, including the roles played by GEUS, CE and the Agenda 21 Centre, most stakeholders and citizens also felt that they had had an influence on the development of the BBNs. Some remarks were:
- "The project management was open and positive about discussing the elements."
- "CE and GEUS found out that farming contracts are not an applicable solution."
- "They listened to suggestions."

According to stakeholders and citizens, the greatest advantages of the BBNs were the following:
- "Used properly, a good, flexible tool for integration"
- "Clear overview"
- "Good tool for dialogue"
- "The citizens' group can understand a BBN just fine if it is explained properly by the specialists".

The greatest limitations of BBNs:
- "Require insight and understanding"
- "You get the answers you want"
- "Not applicable to groundwater protection"
- "Selection of precise data required"
- "Correctness of information is questioned"
- "A complex tool whose primary strength is as a tool for dialogue"

- "Number of variables must not be too large or overview is lost and relationships less clear"

We experienced both successes and barriers in the Danish case study:

Successes
- Many people showed up at the public meeting.
- The citizen group wants to continue beyond the MERIT project.
- Increased level of knowledge on both sides of the table.
- A deeper understanding of pesticide sources and precautionary actions.
- Implementation of cooperative farming contracts is not only a question of money.
- There are new opportunities to establish waterworks cooperation projects in the area.
- There is now cooperation with selected stakeholders about groundwater protection.

Barriers / Problems encountered
- One of the key players in groundwater management did not go wholeheartedly into the project (Frederiksborg County).
- NGOs/environmentalists were weakly represented and had little voice.
- GEUS and CE defended to some extent the role of NGOs/environmentalists.
- The workshops were not the open forum for dialogue we expected.
- Stakeholders in working groups tended to switch to "political mode" very quickly.
- Stakeholders (also) had their own agenda.
- A vocal minority dominated workshops.
- The importance of facilitation at professional workshops was neglected.
- Facilitator costs were high if facilitators were used extensively.

Table 1 lists an interpretation of the stakeholder engagement process in the case study with respect to strengths, weaknesses, opportunities and threats.

Table 1 SWOT analysis of stakeholder engagement process in Danish MERIT case study

STRENGTHS	WEAKNESSES
Public participation can…	Public participation can be weakened by…
▪ Make use of local and citizen knowledge not known by the authorities ▪ Encourage diverse perspectives (and thus identify issues not thought of) ▪ Enable a better evaluation of the issues	▪ A lack of resources (time, money, staff) ▪ A lack of rules for participation ▪ A lack of in-depth involvement of authorities ▪ A lack of hands-on BBN for the stakeholders ▪ A lack of professional supervision of the stakeholder involvement process
OPPORTUNITIES	**THREATS**
Public participation offers the opportunity to…	Public participation processes can be threatened if…
▪ Build trust and capacity ▪ Empower people by starting a dialogue and improving openness ▪ Expand the limits of understanding (working together to solve problems) ▪ Improve the accountability of stakeholders	▪ The public thinks that the process is a formality (that minds are already made up) ▪ A vocal minority dominates public meetings

If we compare our results with ordinary SWOT analysis for public participation, then we did not experience particular strengths such as "Brings out technical knowledge from the public and others" or "Allows the public to understand the system better". However, we obtained data not known by the authorities or experts, e.g. in relation to the flooding BBN: a citizen had collected daily climate and river level data and various observations of flooding over a ten-year period. We have also identified issues not thought of such as the barriers to voluntary farmer contracts which we would not have expected if we had based the work solely on expert assessments (e.g. the report prepared by Svend Rasmussen of KVL). Certainly, stakeholder engagement has given CE and GEUS a great deal of valuable experience, both about how to run such processes more efficiently and transparently and how to plan the entire stakeholder involvement process more carefully.

Problems encountered in BBN development:
- Stakeholder input to networks and probability tables (numbers) required individual meetings. (Workshops were not enough, even if tables were presented carefully.)
- It was not that easy to understand the networks (a way of thinking that requires a little practice), if not properly explained
- Farmers tend to easily understand decisions in which risk plays a role (everyday case).
- Difficult to motivate stakeholders to become involved in BBN development: "BBN is a toy for researchers." "Water managers without hands-on experience with the BBN won't easily understand it."
- Problems with conditional probability tables in different stakeholder groups.
- We did not receive as much input to the BBNs as expected from stakeholders.

BBNs can help formulate environmental management strategies by allowing users to build their own decision support system that meets their needs, helping users to understand the nature of their decisions better, and encouraging users to deal with uncertainty and to consult stakeholders and members of the general public. Without consultation of stakeholders and general public, it is unlikely that you will be able to implement your decision.

Table 2 contains an interpretation of BBNs with respect to strengths and weaknesses based on experience from the Danish case study dealing with precautionary groundwater protection from pesticide contamination.

In Table 3 the analysis of BBNs is completed with opportunities and threats.

Table 2 Strengths and weaknesses of BBNs as decision making tool for water resource management

Strengths	Weaknesses
Excellent for structural learning, elegant statistical approach and data mining for analysis of complex systems	Difficult to understand for non-experts
Easy to develop a BBN with nodes and directed links and update it with input from stakeholders	Feedback nodes are not allowed; some problems in the real world cause strong feedback
Social and ecological issues can be incorporated and coupled with hydrology	The interdisciplinary approach raises problems with organising knowledge input and data input (academic territories, illusion of techniques)
Excellent for strategic considerations (indicators, actions and additional data requirements)	
Expert knowledge and data can be combined and modified/balanced through stakeholder involvement	Requires panel of expert input for all domains => resources and time (equivalent to numerical models)
Improves conversation/ dialogue with stakeholders	Too much ”hot air”/soft discussion (difficult to govern the process; ”focused stakeholders”)
Very useful for complex systems	There is a danger that use of BBNs causes ignoring of real data and knowledge
Excellent for integration and breakdown of barriers between different domains, e.g. economy, hydrology, ecology, social (different time and spatial aggregation)	Not useful for implementation of specific protection zones (physical-based model required)
Can be used even if data sets are incomplete	The BBN hides the complexity of the system from the users (underlying conditional probability tables are rather complex!)
Ability to predict future state of systems based on simplified assumptions	Data manipulation is possible (it is easy to get carried away)
It is possible to “validate” the importance of value and belief when consulting stakeholders.	BBNs work on “aggregated data” (probabilities). Not possible to utilise all collected data (temporal and spatial variation/information in data)
Inferences allow fast assessment of changes conditions/ evidence etc. => quick tool	

Table 3 Opportunities and threats of BBNs as decision support tool for water resource management

Opportunities	Threats
Possible to understand for representatives of general public if explained properly by the specialists	Not easily understood if not properly explained
The opportunity to work with more disciplines	Over-expectations with respect to modelling capabilities
New problems can be structured and analysed quickly	Political manipulation
Holistic approach	BBNs describe an understanding of the system and processes that are not physically based (more information flow than mass flow). Non-linearity not incorporated.
A possible tool when dealing with water managers sceptical about comprehensive models and questioning the need for catchment modelling	Experts do not want to provide input for the conditional probability tables (numbers): defending academic territories!

An important characteristic of BBNs is that the tool can be used “interactively” for uncertainty assessment and communication with the stakeholders involved. However, it is important to apply a kind of a “protocol” for BBN construction in order to explain to stakeholders, experts, users, etc. what input is required at different stages of the development. This leads us to our second statement and input for guidelines regarding BBN construction with stakeholder involvement:

1.6 Discussion

The results of the Havelse BBN study site experience showed "a paradox". On the one hand, Bbn's can create space for an open and non-deterministic dialogue with stakeholders due to the flexibility of the decision support tool. This allowed factors (nodes), associations (directed links) and probabilities of the graphical model to be adjusted, reconstructed and validated throughout the process and based on inputs from all involved stakeholders and experts. This means that BBN's were powerful for integrating data and knowledge from different domain experts and capable of handling uncertain information in a practical and easy understandable manner. Constructing the qualitative part of a belief network (nodes and links), although elaborate, seemed relatively straightforward and experts seemed comfortable doing so. This part of the net was relatively easily communicated to stakeholders (Ames and Neilsson, 2001).

On the other hand getting stakeholders, general public and even experts to understand and accept the idea behind BBN's used for decision making was a demanding task (Varis and Kuikka, 1999). Especially the required probability assessments for the BBN's were not easy to understand or accept by stakeholders. Even domain experts had problems to express all these probabilities numerically, something they were reluctant to do . So the quantitative part, with the probabilities over the variables, were more problematic.

Probabilities offer an alternative approach to communicating data and model results which takes advantage of the ability of people to understand outcomes presented in probabilistic language. Instead of a pesticide concentration of 0.12 μg/l simulated by a model, which is likely to be received with scepticism by stakeholders because it does not account for natural variability in the system, the information should be presented categorically in the following form: "There is a 37% probability that the concentration will be below 0.01 μg/l, a 51.5% probability that it will be between 0.01 and 0.1 μg/l, and a 11.5% probability that it will be greater than 0.1 μg/l."

One reason why probabilistic information of this form is useful is that it lends itself to evaluating the risk associated with different alternatives. Probabilities can be multiplied by the potential cost or benefit of different outcomes in order to elicit the "expected value" of a decision (Ames and Neilson, 2001). Expected values of different management alternatives can then be compared to aid decision-makers in selecting an option. Additionally, the risk of an outcome can be interpreted as a margin of safety associated with the option. In a BBN, this is done by introducing "utility nodes" that perform risk assessment by multiplying and adding total costs or benefits (in monetary value or other type of utility).

When applying the precautionary approach in groundwater protection, the role of uncertainty is vital: the higher it is, the lower the pressures allowed from various non-point and point pollution sources should be. In addition, recent paradigms for risk-informed decision-making call for a participatory procedure in which the various stakeholders become involved early on in the risk assessment process to "characterise" risks even before a formal assessment of them is made. This does not diminish the role of modelling and quantification, but is aimed at eliciting the "values" and the perspectives of the community involved so that the multiple dimensions of risk can be taken into account early in the assessment (Ha et al., 2004; Amendola, 2001).

Decision-makers need to be informed not only of the available scientific knowledge but also of policy-relevant uncertainties and lacunae in the knowledge base (Levin et al., 2003). For this to be possible, uncertainties must be transparently discussed and communicated.
A key problem with the probabilistic approach is that most people feel more at ease with verbal probability expressions than with numbers. When people communicate probabilities, they frequently do so in words rather than in numbers. So when it comes to reasoning and to communicating the results of BBNs to users, the mode in which people normally represent probability must be taken into account as well (Renooij et al., 1999). This has often been considered a major obstacle, one of the reasons being that experts are reluctant to provide numerical probabilities. However, recent research activities have made some progress in this field by developing a probability scale that contains words as well as numbers (Renooij et al., 1999; Witteman and Renooij, 2003; Gaag et al., 2002).

The objective of our study was to present and discuss the methodology adapted for the construction and validation of a Bayesian belief network for groundwater protection based on the active involvement of stakeholders and general public. The case study showed that it was possible to engage stakeholders and general public in construction and validation of a BBN for preventive groundwater protection against pesticides.

BBN's was useful for water resource scientists and water managers dealing with complex problems by permitting carefully elicited expert knowledge as a practical alternative to "hard" data, and facilitating extension of models to ecological and socio-economical endpoints (Borsuk, 2003).

This leads us to the following conclusions regarding BBNs as a decision support tool. BBNs demonstrated several advantages compared to traditional approaches. BBNs enabled locally based solutions (more than before). They provided local acceptance of decisions and solutions and improved the dialogue between the water company, local stakeholders and authorities. They encouraged diverse perspectives (and thus identified issues not thought of). They enabled a better evaluation of the issues. They made use of local and citizen knowledge not known by the authorities (Henriksen et al., 2004), see fig. 4.

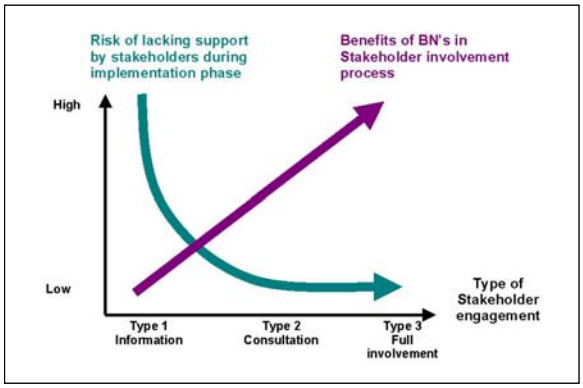


Fig.4 Type of stakeholder engagement compared to risk of lack of support and the benefits of BBNs in the stakeholder involvement process

The weaknesses of BBNs as a decision support tool were the time-consuming and long-lasting process in construction and evaluation of BBNs, which had to be properly organised and conducted. This means that, if there is a lack of resources (time, money, staff), rules for participation, in-depth involvement of authorities, hands-on BBN for the stakeholders and professional supervision of the stakeholder involvement process, then the credibility of the BBNs are likely to be questioned by stakeholders and general public.

Regarding involvement of stakeholders and general public (Mostert 2003a,b) in BBN development we made the following observations in the Danish case study:

- Stakeholders had an impact on the BBN development (on variables, links and CPT's, e.g. 'perception of vulnerability' variable and behaviour of farmers in relation to compensation payment)
- Evaluation of BBNs with input from stakeholders and general public was a necessary step.
- In the early, more qualitative stages, broader groups of stakeholders and the general public provided relevant input to BBN development.
- In the later, more quantitative stages, it was better to consult stakeholders and members of the general public at individual meetings or maybe in stakeholder and citizens' groups that each focused on a "domain of interest" because they were reluctant to give quantitative inputs in larger groups.
- Experts were necessary for quantitative input to BBNs. In the case study, we had two experts in farming economics and socioeconomics in addition to the geological and hydrological experts from CE and GEUS. It would have been an advantage in BBN development if the panel of experts had included an expert on biodiversity and/or pesticide-exposed aquatic environment as well.
- The results of BBNs must be followed by a detailed description of the parameters used and why, plus a description of the results and their consequences in order to make BBNs as transparent as possible. It is much to risky to allow politicians or civil servants to make decisions based on the "naked" data. So one should rather allow stakeholders and citizens to become more involved
- It was important to provide users with more easily understandable explanations of the results, for which numbers not necessarily was the best option and verbal communication are a necessary alternative. Furthermore, an expert's assessments may reflect various biases, where an expert consistently gives probability assessments that are higher or lower than the true probabilities.
- In order to provide a credible BBN it was necessary to engage stakeholder groups in the validation of BBN's. This was a crucial and demanding task.

1.8 Conclusion

In conclusion, the use of BBNs went beyond information and consultation and required the full involvement of stakeholders in their construction and validation. The advantage was a reduced risk of later support by stakeholders during the implementation phase of a given action plan. The benefits of BBNs were greatest when there was a high degree of interaction between researchers, users, water managers, stakeholders and general public.

- BBNs are most powerful when integrating different domains, e.g. physical, social, economic and ecological, in the early stages of preparing a management plan with the involvement of stakeholder groups and general public (Mostert 2003a,b)
- A panel of experts is valuable in covering each domain included, for providing proper input and/or for reviewing the results from the BBNs developed.
- Clear rules of the game are important: it is necessary to prepare a stakeholder involvement plan describing how to involve stakeholders and general public which is balanced with respect to problem framing and the type of decision support system used for the planning and/or implementation.
- It is better to involve stakeholders and general public in "temporary" groups or in individual meetings when direct input is required, especially when collecting data for BBNs; feedback on states, links and CPTs than it is to run the process with broad, permanent working groups of stakeholders and citizens'.
- Don't be afraid of actively involving citizens: but be careful to inform and explain properly about the tasks and goals and do always allow feedback and comments on the BBN development process by presenting the graphical

model and easily understood descriptions and results.

- If representatives of the general public are involved, be sure there is enough time and money to run the process according to the stakeholder involvement plan.

1.9 Acknowledgement

The present work was carried out within the Project 'Management of the Environment and Resources using Integrated Techniques (MERIT)', which is partly funded by the EC Energy, Environment and Sustainable Development programme (Contract EVK1-CT-2000-00085).

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