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Reflections on the use of Bayesian belief networks for adaptive management

Hans Jørgen Henriksen*, Heidi Christiansen Barlebo

Geological Survey of Denmark and Greenland (GEUS), Øster Voldgade 10, DK-1350 Copenhagen K, Denmark

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Abstract

A broad range of tools are available for integrated water resource management (IWRM). In the EU research project NeWater, a hypothesis exists that IWRM cannot be realised unless current management regimes undergo a transition toward adaptive management (AM). This includes a structured process of learning, dealing with complexity, uncertainty etc. We assume that it is no longer enough for managers and tool researchers to understand the complexity and uncertainty of the outer natural system—the environment. It is just as important, to understand what goes on in the complex and uncertain participatory processes between the water managers, different stakeholders, authorities and researchers when a specific tool and process is used for environmental management.

The paper revisits a case study carried out 2001–2004 where the tool Bayesian networks (BNs) was tested for groundwater management with full stakeholder involvement. With the participation of two researchers (the authors) and two water managers previously involved in the case study, a qualitative interview was prepared and carried out in June 2006. The aim of this ex-post evaluation was to capture and explore the water managers' experience with Bayesian belief networks when used for integrated and adaptive water management and provide a narrative approach for tool enhancement.

Keywords: Groundwater management; Bayesian belief networks; Qualitative interview; Adaptive management; IWRM; Tool enhancement; Participatory integrated assessment; Social learning; Newater; Organizational complexity

1. Introduction

Human dependence on water leaves us vulnerable to climate change, flood and drought hazards, and poverty (Downing et al., 2005). Vulnerability is the differential exposure to stress experienced by different exposure units, and is also a dynamic process, changing over a variety of inter-linked time scales. Social vulnerability is rooted in the actions and multiple attributes of human actors. Social networks drive and bound vulnerability in the social, economic, political and environmental context. Therefore, social and economic vulnerability should be incorporated into decision support systems and tools to capture the dynamic element of vulnerable groups and their relationship to water resources, and to represent the decisions of actors in the construction of adaptive systems. Indicators and indexes are available e.g. poverty index, water stress index etc. (Rijsberman, 2006). Indicators which acknowledge different values, not only in monetary or market units, but thoroughly represent ethical, social and political values and the complexity of water management as it is seen from different mental frames and interest group positions should be used in adaptive water management.

The broad range of tools available for integrated water resource management (IWRM) includes e.g. GWP Toolbox, HarmoniCA/Catchmod tools, decision support systems, simple and comprehensive models, participatory tools etc. (Barlebo et al., 2006). In a new EU research project NeWater (www.newater.info), a tool is defined as: 'A tool supports operational actions to perform IWRM. A tool can be a guideline, a procedure or protocol, a method or technique, a device, an apparatus and a software program' (Barlebo et al., 2006). NeWater is based on the hypothesis that IWRM cannot be realised unless current management regimes undergo a transition towards more

*Corresponding author. Tel.: +45 38 14 27 71; fax: +45 38 14 20 50.
E-mail address: hjh@geus.dk (H.J. Henriksen).

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adaptive water management (Pahl-Wostl and Sendzimir, 2005).

Adaptive management (AM) involves learning from management actions and using that learning to improve the next stage of management (Holling, 1978). AM treats policies and management interventions as experimental probes designed to learn more about the system; they are not confident prescriptions (Lee, 1993). Monitoring before and during the intervention, enables the system response to be determined and thereby allows managers to learn from past experience and to translate the best of current IWRM research into practice.

It is anticipated that AM will (Allan and Curtis, 2003):

- Allow management to proceed in the face of complexity and uncertainty.
- Make learning about water resource systems more efficient.
- Help build flexible management capacity.
- Be a large scale, holistic alternative to reductionism science; and
- Involve social and political values in water resource management.

Walters and Holling (1990) describe adaptive management as a structured process of *learning by doing* with the aim being to

(1) Work with stakeholders to develop a shared understanding of the system to be managed and the desirable outcomes, by developing a system model that can be used for policy screening;
(2) Use this model to identify policies that are likely to succeed or that probe key uncertainties;
(3) Implement policies;
(4) Monitor and evaluate outcomes; apply learning to develop a better understanding of the system.

Uncertainty is a central theme in integrated and adaptive water management, where different disciplines need to be brought together to find a solution that is adequate from multiple perspectives. This, not only requires coping with various sources and types of uncertainty, but also with the ambiguity produced by the various ways in which uncertainty is interpreted and handled. Tools for AM therefore also have focus on transition processes and analysing ambiguities and mental frames that may hinder agreement on a common goal or state.

Bayesian networks (BNs) used with full stakeholder involvement is an example of a tool enabling integration of vulnerability of humans related to their use of water (Henriksen et al., 2007a, b). BNs were tested in a recent EU research project MERIT (Bromley, 2005; www.merit-eu.net) 2001–2004, and this tool is currently considered in NeWater as a possible valuable tool for AM, for interactive and flexible system and action plan modelling that allows integration of environmental and socio-economic complexity and uncertainty in a practical way.

The term *tool* (*for AM*) is broadly framed, which implies that *tool enhancement* (for AM) can have different meanings. Tool enhancement can guide when and how to use a certain tool in the planning cycle in relation to IWRM or the water framework directive (WFD). It can consist of structuring the tool according to a transition framework to AM e.g. from the NeWater knowledge base. It can be by linking the tool to the different themes of importance for AM e.g. for learning, evaluation and for exploring complexity and uncertainty (Barlebo et al., 2006).

In this paper we propose an approach for tool enhancement based on a qualitative interview (Kvale, 1996) of a pair of water managers allowing reflections and interpretations of good and bad about the tool and the participatory process in which it was used when viewed (ex-post) from the perspective of the adaptive water manager. Thereby a narrative is produced which condenses and captures the experiences of the water managers when using a tool for dealing with uncertainty and complexity of the outer system and which attempt to describe the water managers thinking and reflections about the management regime and the organising of the participatory process.

2. BNs with stakeholder involvement and the NeWater context

2.1. Bayesian networks

A Bayesian belief network, also called a BN, 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.

BNs 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 (Jensen, 2002). Factors, associations and probabilities can be adjusted and validated and BNs are powerful for integrating data and knowledge from different sources and domains, e.g. domain models and are also capable of handling uncertain information in a practical and understandable way (Jensen, 2002; Henriksen et al., 2004, 2007a, b; Bromley, 2005).

BNs have gained a reputation of being powerful techniques for modelling complex problems involving uncertain knowledge and impacts of causes. BNs are a technique which is especially helpful when there is a scarcity and uncertainty in the data used in making the decision and the factors are interlinked, all of which makes the problem highly complex. The part of the net defined by variables and links is relatively easily communicated to stakeholders (Henriksen et al., 2007b). However the quantitative part, with the conditional probability tables (CPTs), the numbers, is the step where negotiation between