

Chapter 3.9

Evolutionary Bayesian Belief Networks for Participatory Water Resources Management under Uncertainty

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ABSTRACT

A participatory integrated (social, economic, environmental) approach based on causal loop diagram, Bayesian belief networks and evolutionary multiobjective optimisation is proposed for efficient water resources management. The proposed methodology incorporates all the conflicting objectives in the decision making process. Causal

loop diagram allows a range of different factors to be considered simultaneously and provides a framework within which the contributions of stakeholders can be taken into account. Bayesian belief networks takes into account uncertainty by assigning probability to those variables whose states are not certain. The integration of Bayesian belief network with evolutionary multiobjective optimisation algorithm allows analysis of trade-off between different objectives and incorporation and acknowledgement of a broader set of decision

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goals into the search and decision making process. The proposed methodology is used to model decision making process for complex environmental problems, considering uncertainties, addressing temporal dynamics, uncovering discrepancies in decision analysis process (e.g. completeness or redundancy of the model based on utility function) and generating policy options that trade-off between conflicting objectives. The effectiveness of the proposed methodology is examined in several water resources management problems. The case studies include optimum water demand management, UK; management of groundwater contamination of Copenhagen source capture zone areas, Denmark and simultaneous optimum management of four overexploited aquifers in Spain. It is shown that the proposed methodology generates large number of management options that trade-off between different objectives. The remaining task is to choose, depending on the preference of decision makers, a group of solutions for more detailed analysis.

INTRODUCTION

Water resources management are rarely well structured (Simonovic, 1996) as there is no definitive formulation, no true or false solution, and no easy test, screening procedure or single optimal solution for these problems (Chattopadhyay & Chattopadhyay, 2008; Sivakumar, 2005). Therefore, successful environmental decision making in complex settings will depend on the extent to which stakeholders, processes and tools are integrated. Environmental decision analysis process involves several steps. In the first step the problem and objectives are identified. The boundaries should also be identified, however as decision making process is iterative some boundaries might be modified or new ones introduced as learning takes place over time. This will result in redefinition of the problem. In the second step a qualitative decision tree is developed based on

contribution from experts (stakeholders, decision makers or scientists) that can help in identification of alternative options and their uncertainties. This will be followed by assigning probability to those variables in the decision tree whose states are not certain. These assignments are based on experts' knowledge, existing data, modelling and monitoring. The next step is assignment of value (benefits, costs, risk etc.) to consequence of different alternative options that needs to be optimised. The final step is to find optimum strategy or strategies. Although in simple cases, the main steps of the process will easily be constructed, in complex cases, such as environmental decision analysis, this is not a straight forward task. Traditionally, in order to reduce level of complexity in systems, two very important elements of the systems were overlooked. Firstly, not all the elements influencing the decision making process are considered (over-simplifying the system), especially feedback loops. Secondly, the temporal nature of the problem is usually ignored despite the fact that the consequences of a decision often do not all occur simultaneously. Consistency check can help to develop some confidence in representation of the decision maker's preferences. In checking for consistency it is important to detect errors in the decision making utility function. This is the most common source of error, meaning that it does not represent the decision maker's true preferences. Methodologies to check the properties of completeness and redundancy of developed models based on their utility function are not well developed. Traditionally the decision maker will be asked to suggest a number of possible scenarios to check the expected utility of the preferred situation in order to be consistent. Often in practice, the decision maker may seem not to be interested in the entire possible range of the attributes except for a small variable space. For utility functions implying a complex preference structure, there is a greater need and opportunity for meaningful consistency checks. Another shortcoming of the existing techniques is the way circular relation-

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