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# A MCDM-based expert system for climate-change impact assessment and adaptation planning – A case study for the Georgia Basin, Canada

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**Abstract**

An MCDM-based expert system was developed to tackle the interrelationships between the climate change and the adaptation policies in terms of water resources management in the Georgia Basin, Canada. User interfaces of the developed expert system, named MAEAC (MCDM-based expert system for adaptation analysis under changing climate), was developed based on system configuration, knowledge acquisition, survey analysis, and MCDM-based policy analysis. A number of processes that were vulnerable to climate change were examined and pre-screened through extensive literature review, expert consultation and statistical analysis. Adaptation policies to impacts of temperature increase, precipitation-pattern variation and sea-level rise were comprehensively explicated and incorporated within the developed system. The MAEAC could be used for both acquiring knowledge of climate-change impacts on water resources in the Georgia Basin and supporting formulation of the relevant adaptation policies. It can also be applied to other watersheds to facilitate assessment of climate-change impacts on socio-economic and environmental sectors, as well as formulation of relevant adaptation policies.


*Keywords:* Climate change; MCDM; Water resources; Georgia Basin; Adaptation; Policy analysis

## 1. Introduction

Canada has a relative abundance of water, possessing 9% of the world's renewable freshwater (Environment Canada, 2001). However, the water is not evenly distributed across the country, with its availability varying significantly seasons and years. Many regions in Canada have experienced various water-related problems, such as drought, flood and contamination issues (Environment Canada, 1992). In recently years, concerns are growing that changes in climate caused by human activities could pose dramatic and unpredictable impacts on Canada's water resources (Houghton et al., 1996). This is especially true for the Georgia Basin where rapid population growth and continued economic expansion are putting enormous pressure on its water resources. Many issues will be at stake under changing climatic conditions. For example, water-related infrastructure will be threatened by extreme hydrological events; coastal ecosystems are sensitive to sea level rise resulting from global warming. The socio-economic and environmental implications of climate-change impacts on water resources in the Georgia Basin are substantial, especially for the Greater Vancouver Regional District (GVRD). Therefore, it is essential for policymakers to consider such impacts in the regional planning process in order to effectively combat the related threats (Yin, 2001).

Previously, there were many studies of climate-change impacts and the relevant policy responses. For example, Yin and Cohen (1994) developed a goal programming

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approach for assessing climate-change impacts and identifying regional policy responses. Weyant et al. (1996) explored a number of methods, named integrated assessments (IAs), to analyze climate-change impacts and perform policy analysis. Huang, Cohen, Yin, and Bass (1998) proposed a multi-objective programming method for land-resources adaptation planning under changing climate. Smith (1997) proposed an approach for identifying policy areas where adaptations to climate change should be considered. Yin (2001) developed an integrated approach based on analytic hierarchy process (AHP) for evaluating adaptation options to reduce climate-change effects on water resources. More studies in this area can be found in Huang, Cohen, Yin, and Bass (1996, 1994), Morgan and Dowlatabadi (1996), Schneider (1997), Yin, Huang, Cohen, and Gong (1995) and Yin (2003).

Expert Systems are becoming important tools in the planning and management of environmental systems (Durkin, 1994; Huang & Chang, 2003). Over the past decades, extensive studies of expert-system applications were reported in many environmental fields such as groundwater remediation (He, Chan, Huang, & Zeng, 2006; Qin, Huang, Zeng, Chakma, & Li, 2006), air pollution control (Zhou, Huang, & Chan, 2004), solid waste management (Marianne, 1996), and water resources management (Jamieson & Fedra, 1996). However, few applications to climate-change impact assessment and adaptation planning were reported. For example, Li, Li, Huang, Wang, and Chen (2003) developed a decision support system for managing pesticide losses in agricultural watersheds under changing climate; Huang, Huang, Hu, Maqsood, and Chakma (2005) developed an expert system for assessing climate-change impacts within the petroleum sector and supporting formulation of the relevant adaptation policies. These studies demonstrated that the expert systems could effectively link a combination of decision-support tools (e.g., optimization modeling, and cost-benefit analysis) and various information components into a general decision making process (Korhonen & Wallenius, 1990). With such systems, the knowledge of climate-change impacts and the relevant adaptation policies could be obtained interactively and dynamically (Huang, Chen, Liu, Huang, & Li, 2002). However, in the Georgia Basin, very few scientific studies of the stakeholders' inputs were performed, and the impacts of climate change in this particular region were not well known (Yin, 2001).

Furthermore, research on exploring desired adaptation strategies will provide information for determining effective adaptation options and management plans for water resources in the Georgia Basin. Such an effort is linked to a variety of sensitive issues since it affects many stakeholders with tremendous interactions and conflicts. The conventional mathematical models are not applicable to such planning exercises (Yin, 2001; Loukas, Vasiliades, & Dalezios, 2002). Nevertheless, the stakeholders related to the hydrological, environmental and meteorological sectors have accumulated vast amounts of knowledge on the vulnerability of water resources to climate change, the intricate relationships among various criteria for impact assessment, and the multiple indicators of the related performances under the changing climate (Yin & Cohen, 1994). However, few efforts were made in acquiring and using such knowledge to support decisions of adaptation planning of water resources in the Georgia Basin. Moreover, a concrete approach to compare and evaluate adaptation options is important because it will provide policy akers with insight into the trade-offs which the stakeholders are willing to make in their efforts to pursue adaptations for reducing climate change vulnerability (Macharis, Springael, Brucker, & Verbeke, 2003). The multi-criteria decision making (MCDM) techniques can help identify desired measures among a variety of alternatives through analyzing multiple criteria by which the strengths and weaknesses of various adaptation options could be evaluated (Hokkanen & Salminen, 1993). Thus, they could be adopted as evaluation tools to help identify the priorities of sustainable goals and to rank the desirability of adaptation options. Since the early 1970s, MCDM techniques have been developed into many forms and been employed for a wide range of different case studies, such as river basin planning and groundwater remediation (Moeffaert, 2003). However, applications of such techniques to water resources management were still scarce (Yin, 2001).

As an extension of the previous efforts, this study aims to develop an integrated expert system for accessing climate-change impacts on water resources and facilitating adaptation planning in the Georgia Basin. Such a system contains a collection of modules to perform public survey, data management, statistical investigation, and MCDM-based policy analysis. The interactive relationships among climate change, natural-condition variations, adaptation activities, environmental concerns, and the related policy implications will be comprehensively examined and incorporated within an expert system. A series of questionnaire surveys will be conducted for facilitating knowledge acquisition. Processes that are vulnerable to climate change will be analyzed, followed with an integrated impact assessment. A number of MCDM techniques will be advanced for analyzing various adaptation options based on the criteria derived from public survey. Consequently, decision support for the water resources system to adapt to the climate change can be provided.

## 2. Multi-criteria decision making for policy analysis

Impacts of climate change could have far-reaching and unpredictable consequences on water resources in Canadian watersheds. Investigation of relevant adaptive alternatives and advancement of decision support tools can help government and policymakers at local, state and federal levels to design cost-effective adaptive policies. The decision making processes are often complicated with multiple conflicting criteria and discrete sets of feasible alternatives. Multi-criteria decision making (MCDM) methods are helpful for observing the influences under various adaptive