Department of Mathematics and Systems Analysis

Interactive multi-criteria decision analysis in the collaborative management of watercourses

Mika Marttunen

Aalto University

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Interactive multi-criteria decision analysis in the collaborative management of watercourses

Mika Marttunen

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Abstract

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Abstract

This thesis develops new approaches based on multi-criteria decision analysis (MCDA) to improve the quality of multi-stakeholder processes in large watercourse development projects. The main methodological result is the decision analysis interview (DAI) approach developed and applied in five watercourse management projects. The DAI approach refers to an MCDA process at the core of which are personal interviews with a multi-criteria model. The research questions are: 1) in which ways does MCDA support collaborative planning and joint problem solution, 2) what are the key challenges in multi-stakeholder MCDA processes, and 3) how does the DAI approach meet them? The results of these projects and more than 130 personal DAIs are described in the six appended articles. In the four regulation development projects studied, an agreement on the policy recommendations was achieved. MCDA greatly supported the collaborative planning processes. It provided a structured framework for the whole project and efficient tools to gather, analyse, and present research results as well as stakeholders' knowledge and preferences. MCDA helped to create planning processes that participants find efficient, interesting, and meaningful. There are three features that I found to be crucial in the use of MCDA in collaborative processes. First, MCDA has to be introduced to the planning process in the early phase, because processes that actively engage stakeholders and aim at enhanced learning take time. Second, MCDA tools should be used in intensive interaction between the facilitator and the participants. This improves the quality of the MCDA process and promotes gaining of the potential benefits of the MCDA approach. One major advantage of the interactive weight elicitation is that it reduces the risk of behavioural biases and human mistakes. Third, the decision analyst must understand well the method and its potential problematic elements as well as the decision situation at hand.

Keywords Multi-criteria decision analysis, environmental decision making, public participation, stakeholders, watercourses, management, water course regulation

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Tiivistelmä

Tässä väitöskirjassa kehitetään uusia monitavoitteiseen päätösanalyysiin (MCDA) perustuvia lähestymistapoja ja malleja parantamaan vuorovaikutteista vesistösuunnittelua. Keskeinen tulos on päätösanalyysihaastatteluihin pohjautuva lähestymistapa, jota sovelletaan viidessä laajassa hankkeessa. Olennainen osa tätä lähestymistapaa ovat sidosryhmien edustajien henkilökohtaiset tietokoneavusteiset haastattelut. Tutkimuskysymykset ovat: 1) millä tavoin monitavoitearviointi voi tukea yhteisen ymmärryksen ja ratkaisujen etsimistä tilanteessa, jossa useat sidosryhmät osallistuvat suunnitteluun, 2) mitkä ovat keskeiset haasteet sovellettaessa monitavoitearviointia vuorovaikutteisessa suunnittelussa, ja 3) kuinka päätösanalyysihaastattelu vastaa näihin haasteisiin. Viiden vesistöhankkeen ja yli 130 päätösanalyysihaastattelun tulokset kuvataan kuudessa julkaistussa artikkelissa. Kaikissa kuvatuissa neljässä vesistösäännöstelyn kehittämishankkeessa onnistuttiin laatimaan eri osapuolten hyväksyttävissä olevat toimenpidesuositukset. Työssä kehitetty lähestymistapa tuki monin tavoin vuorovaikutteista suunnittelua ja kompromissiratkaisun etsimistä. Se tarjosi tiekartan ja jäsentelykehikon arvioinnille kokonaisuudessaan sekä työkaluja, joiden avulla oli mahdollista yhdistää, analysoida ja esittää tutkimus- ja asiantuntijatietoa sekä sidosryhmien edustajien näkemyksiä. Monitavoitteinen päätösanalyysi auttoi suunnittelemaan ja toteuttamaan hankkeet niin, että osallistujat kokivat ne tehokkaiksi, kiinnostaviksi ja mielekkäiksi. Tulosten ja kokemusten perusteella on tunnistettu kolme piirrettä, joihin on kiinnitettävä erityistä huomiota sovellettaessa päätösanalyysimenetelmiä vuorovaikutteisessa suunnittelussa. Ensinnäkin, monitavoitearviointi tulisi sisällyttää osaksi suunnittelua heti hankkeen alusta lähtien, koska suunnitteluprosessit, jotka tähtäävät eri osapuolten oppimisen tukemiseen, kestävät usein vuosia. Toiseksi, päätösanalyysimallien soveltamisessa tarvitaan tiivistä vuoropuhelua analyytikon ja haastateltavien välillä laadukkaan lopputuloksen saavuttamiseksi; se edistää monitavoitearvioinnin hyötyjen täysimääräistä saavuttamista sekä vähentää erilaisten harhojen ja inhimillisten virheiden mahdollisuutta. Kolmanneksi, onnistuneen soveltamisen kannalta on tärkeää, että analyytikko tuntee hyvin menetelmän ja sen heikkoudet sekä ymmärtää suunnittelutilanteen.

Avainsanat Monitavoitteinen päätösanalyysi, ympäristöpäätöksenteko, vuorovaikutteinen suunnittelu, osallistuminen, sidosryhmät, vesistöt, vesistöjen käyttö ja hoito, vesistösäännöstely

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Helsinki, 5th of September 2011

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LIST OF PUBLICATIONS

The dissertation consists of the present summary and the following original articles:

[I] Marttunen, M. and Hämäläinen, R.P. 1995. Decision analysis interviews in environmental impact assessment. European Journal of Operational Research 87 (3): 551–563.

[II] Hämäläinen, R.P., Kettunen, E., Marttunen, M., and Ehtamo, H. 2001. Evaluating a framework for multi-stakeholder decision support in water resources management. Group Decision and Negotiation 10 (4): 331–353.

[III] Mustajoki, J., Hämäläinen, R.P. and Marttunen, M. 2004. Participatory multicriteria decision analysis with Web-HIPRE: A case of lake regulation policy. Environmental Modelling & Software 19 (6): 537–547.

[IV] Marttunen, M. and Hämäläinen, R.P. 2008. Decision analysis interviews in supporting collaborative management of a large regulated water course. Environmental Management 42 (6): 1026–1042.

[V] Marttunen, M. and Suomalainen, M. 2005. Participatory and multiobjective development of water course regulation – creation of regulation alternatives from stakeholders' preferences. Journal of Multi-Criteria Decision Analysis 13 (1): 29–49.

[VI] Hämäläinen, R.P., Mustajoki, J. and Marttunen, M. 2010. Web-based decision support: Creating a culture of applying multi-criteria decision analysis and Web supported participation in environmental decision making. In: Rios Insua, D. and French, S. (eds): e-Democracy: A Group Decision and Negotiation Perspective. Advances in Group Decision and Negotiation, Vol. 5. 2010. pp. 201-221.

AUTHOR'S CONTRIBUTION

The author was the principal author of articles I, IV, and V. In addition, he has contributed to the articles as described below:

Article I: "Decision analysis interviews in environmental impact assessment"
The main ideas of the paper were developed collaboratively by the author and the co-author. The author was responsible for planning and undertaking the decision analysis interviews and analysing the results. The article was written in collaboration with the co-author.

Article II: "Evaluating a framework for multi-stakeholder decision support in water resources management"
The author developed the case and participated in testing of the methods.

Article III: "Participatory multicriteria decision analysis with Web-HIPRE: A case of lake regulation policy"
The author developed the case and designed and realised the MCDA process.

Article IV: "Decision analysis interviews in supporting collaborative management of a large regulated water course"
The decision analysis interviews were designed and undertaken by the author. The results were analysed by the author. The article was written jointly with the co-author.

Article V: "Participatory and multiobjective development of water course regulation – creation of regulation alternatives from stakeholders' preferences"
The software was designed by the author, while the coding was done by Ms Liisa Penttinen and Ms Merja Suomalainen. The author was responsible for interviewing the stakeholders collaboratively with the co-author. The article was written with the co-author.

Article VI: "Web-based decision support: Creating a culture of applying multi-criteria decision analysis and Web supported participation in environmental decision making"
The author carried out the MCDA processes. The article was written in collaboration with the co-authors.

1. Introduction

Today's natural resource problems are typically complex, large, multidisciplinary, and ill-structured. Managing the use of natural resources in a sustainable way requires that ecological, social, and economic impacts be identified, assessed, and balanced. In addition to scientific information, public knowledge and values have to be incorporated into decision-making. As a result, there is a general tendency toward participatory processes that collect, analyse, and integrate interdisciplinary information. The extensive growth in the amount and diversity of information has exceeded the capacity of unaided decision-making.

Decision analysis provides formal procedures, methods, and tools for quantitative analysis of decisions with multiple objectives and uncertainties (Keeney and Raiffa 1976, von Winterfeldt and Edwards 1986). This thesis focuses on one specific methodology in decision analysis: multi-criteria decision analysis (MCDA). There is a wide range of MCDA approaches and applications, covering many fields of natural resources management and environmental planning; for references and earlier reviews, see the work of, for example, Keefer et al. (2004), Kiker et al. (2005), Hajkowicz and Collins (2007), Kangas et al. (2008) and Huang et al. (2011).

MCDA is increasingly used to facilitate stakeholder involvement in environmental planning. Experiences from many participatory MCDA applications have been positive – see, for example, the work of Gregory and Keeney (1994), Qureshi and Harrison (2001), McDaniels et al. (1999), Pykäläinen et al. (1999), Hostmann et al. (2005a), Regan et al. (2007), Hajkowicz and Collins (2007), and Munda (2008). Still, many open questions remain in the design and implementation of the MCDA processes such that they would be meaningful and understandable for the participants and the results useful for decision-making.

The overall objective of this thesis is to develop MCDA-based approaches that improve the quality of multi-stakeholder processes in large watercourse development projects. The research questions are the following: 1) in which ways does MCDA support collaborative planning and joint problem-solving, 2) what are the key challenges in multi-stakeholder MCDA processes, and 3) how does the decision analysis interview approach meet them? The main methodological result is the decision analysis interview (DAI) approach, which is developed and applied in five actual planning situations.

The work consists of this summary and six articles, with the following contributions:

- Article I develops the interactive and computer-aided DAI approach and presents results and experiences of its use in two watercourse development projects. The study with personal computer-aided interviews with 59 stakeholders is the first to use an interactive MCDA-based participation procedure.
- Article II presents a general framework for participatory planning. New decision support and negotiation tools for planning are developed and tested with students.
- Article III describes the first Web-based multi-criteria decision support software, called Web-HIPRE, and presents how it can be used in participatory environmental decision-making.
- Article IV describes a process wherein the DAI approach is an integral part of a watercourse regulation development project. The role and advantages of the approach in the collaborative consensus-seeking process are discussed. Key elements in a good MCDA process are identified and described as well.
- Article V introduces and applies the REGAIM model, which is a bespoke MCDA-based multi-model. With the aid of the model, regulation practices reflecting each stakeholder's objectives and preferences were generated and analysed. In addition, some ideas of image theory (Beach 1988) are tested in the watercourse regulation development project with real stakeholders.
- In Article VI, the opportunities for application of Web-based decision analytical tools are described and a framework for their use is developed, based on experiences in four lake regulation development projects. The effectiveness of the DAI approach in the public involvement is evaluated with respect to other public participation methods.

In addition to MCDA, influences and ideas are adopted from behavioural theory, conflict management, public participation, and environmental impact assessment literature. Problems in human judgements are considered very important; hence, ways to diminish the risk of biases and errors in problem structuring and weight elicitation are considered. Although the case studies address water resource management, the methodological results and experiences of the work are expected to be applicable to the other fields of natural resources management as well. This is because participatory planning processes have similar elements and methodological challenges irrespective of the context of the problem.

In this summary, I first briefly describe the principles of MCDA and collaborative planning (in Section 2). The MCDA tools used in this thesis are presented in Section 3. Section 4 introduces where and how they have been put into practice. Section 5 summarises the results and experiences from integrated and interactive use of MCDA, and it analyses reasons for finding compromise solutions in the regulation development projects. In addition, some future perspectives and research needs are discussed.

2. Multi-criteria decision analysis and public participation

2.1 MCDA approaches and principles

There are many definitions of decision analysis. Keeney (1982) defines it as 'a formalization of common sense for decision problems which are too complex for informal use of common sense'. A more technical definition is presented by Howard (1984, p. 476): 'a discipline comprising the philosophy, theory, methodology, and professional practice necessary to formalize the analysis of important decisions'. Decision analytic methods help decision-makers explore problems and possible strategies to solve them.

There is extensive literature devoted to the theory of decision analysis and its practical applications. The foundations of decision analysis are presented in *Decisions with Multiple Objectives* (Keeney and Raiffa 1976) and *Decision Analysis and Behavioral Research* (von Winterfeldt and Edwards 1986). The *Advances in Decision Analysis* (Edwards et al. 2007) and *Decision Behaviour, Analysis and Support* (French et al. 2009) give comprehensive reviews of the state of the art in the field. The book *Multiple Criteria Decision Analysis – an Integrated Approach* (Belton and Stewart 2002) provides an overview of MCDA methods. There are also volumes focusing only on environmental applications of multi-criteria methods (e.g., by Hobbs and Meier (2000), Herath and Prato (2006), and Kangas et al. (2008)).

There is no generally accepted taxonomy of multi-criteria decision analysis methods. 'Multi-criteria decision analysis' or 'multi-attribute decision-making' is used here as a general term that covers methods seeking to explicitly take account of multiple criteria in helping individuals or groups in holistic evaluation of different decision alternatives having conflicting objectives and incommensurable effects and to explore their values in decision-making. Another term that is used frequently to refer to the same type of decision models is 'multi-criteria decision-making'. This often is used to refer to multi-criteria methods used in finding the best alternative in continuous decision spaces.

MCDA aims at helping people to analyse complex decision situations. It is primarily a prescriptive theory. That is, it does not mimic humans' decision-making behaviour and instead includes procedures helping people to identify courses of actions in a manner that is analytically robust and consistent in light of the available information and people's preferences. The key characteristic of this paradigm is that the decision-maker does not optimise a single objective but aims at reaching a balance among several (Belton and Stewart 2002). The main phases in the MCDA methods are identifying the objectives and attributes, assessing the performance of alternatives for them, and determining their relative importance in the decision situation. Although the elicitation of the criteria weights is a demanding task, the modelling of subjectivity can be considered a unique strength of MCDA (Wenstøp 2005).

The number of methods, techniques, tools, and pieces of software within MCDA today is large (Weistroffer et al. 2005, Janssen and Herwijnen 2006). These have different theoretical foundations, such as value functions, optimisation algorithms, goal aspiration, and outranking, or a combination of these. The MCDA models applied in this work are based on multi-attribute value theory (MAVT) (Keeney and Raiffa 1976). In MAVT, a value function describes decision-makers' preferences regarding different levels of an attribute under certainty. Multi-criteria evaluation under uncertainty can be carried out through the multi-attribute utility theory.

The MCDA literature focuses strongly on the different weighting procedures, and the problem structuring phase receives less attention (Belton and Stewart 2002, p. 36). One exception is *value-focused thinking* (VFT), a systematic procedure to identify and structure values and objectives of decision-makers (Keeney 1992). The core idea of VFT can be simply described as 'deciding what is important and then how to achieve it' (McDaniels and Trousdale 1999). Keeney (1992) states that the planning processes often miss out discussion of the participants' objectives and proceed too quickly to evaluation of the alternatives. However, alternatives are relevant only because they are means to reach values; therefore, the focus should first be on the values (Keeney 1992). Structuring decision-makers' objectives is a demanding task that can be aided via their division into fundamental objectives, means objectives, process objectives, and organisational objectives (Keeney 2005).

In some experiments, the VFT procedure has been compared to conventional alternative-focused strategy (Gregory and Keeney 1994, Arvai et al. 2001). The results of these studies suggest that value-focused decision structuring can lead to more thoughtful and better decisions and produce more

innovative alternatives than do traditional approaches. In the MCDA process, VFT can be seen as a useful procedure to support the essential problem structuring phase. Constructing a hierarchy of objectives alongside the stakeholders can guide conversation toward solutions that address the issues important to all participants.

In *multi-attribute value theory*, first the alternatives are evaluated with respect to each attribute and the attributes are then weighted according to their relative importance. As a result, one gets overall values for the alternatives, indicating their overall preference when all of the various attributes are taken into account. The weights have two functions: they rescale the attributes to be comparable while at the same time showing the relative importance of the attributes given the range of impacts (Belton and Stewart 2002, p. 135). The attribute weight reflects the relative importance of the change from the attribute's worst level to its best. MAVT is a compensatory method, which means that an alternative that performs poorly for one attribute can still as a whole be the most desirable if it performs well with the rest of the attributes.

The elicitation of weights for the attributes can be done in different ways. In this thesis, the weighting techniques used evolved from project to project. In the first projects, the analytical hierarchy process (Saaty 1988, Salo and Hämäläinen 1997) was used. However, we soon found it to be too laborious to work for complex problems with many attributes. The number of pairwise comparisons became very high and caused frustration among the participants. Therefore, in the later projects, a technique that featured characteristics of the simple multi-attribute rating technique (SMART) of Edwards (1977) was used. In order to ensure that participants took the decision context into account, the impact ranges of the alternatives were clearly presented, as in the SWING technique (von Winterfeldt and Edwards 1986).

In the weight elicitation, there is always the risk of mistakes due to misunderstandings and biases. These can stem from psychological factors or the elicitation procedures used (Weber and Borcherding 1993, Hobbs and Meier 1994, Pöyhönen and Hämäläinen 2000, Keeney 2002, Hämäläinen and Alaja 2008, Steele et al. 2009). For instance, splitting bias refers to a phenomenon in which an attribute's weight becomes greater if it is divided into sub-attributes and weighting is done in a non-hierarchical mode (Weber et al. 1988). One typical procedural mistake is inadequate consideration of the range of impacts when the attribute weights are elicited. Only a few studies have focused on the different ways of reducing the risk of biases in MCDA processes (Pöyhönen and Hämäläinen 2000,

2001, Pöyhönen et al. 2001, Hämäläinen and Alaja 2008). Hämäläinen and Alaja (2008) study the effects of instruction, training, and different value tree structures on the magnitude of splitting bias with local residents and students, also presenting suggestions for how to diminish its risk. The main conclusion is that practitioners should pay serious attention to the clarity of the procedure and the responsibilities of the analyst.

2.2 Participation in environmental decision-making

The role of public participation is emphasised in the Aarhus Convention (United Nations Economic Commission for Europe 1998) and in the EU Water Framework Directive (WFD), 2000/60/CE). Public participation is considered to be an important element of a democratic society in which a wide spectrum of values exists. In environmental decision-making, it plays an essential role because of the problems' complexity and because different perspectives and subjective judgements need to be incorporated (Creighton 2005, p. 6). Public participation may help to build trust among the parties and thus assist in finding alternatives to the 'not in my backyard' syndrome (Beierle 1999).

Public involvement processes and methods in environmental planning have been a target of intensive research, particularly in North America, where the first environmental conflict resolution processes began in the mid-1970s (Amy 1987, p. 1). Since then, a number of studies and frameworks have been developed to evaluate public involvement processes (e.g., Wondolleck and Yaffee (2000), Lewicki et al. (2003), Depoe et al. (2004)). Beierle (2002) has presented six goals for public participation: (1) informing and education of the public, (2) incorporation of public values and knowledge into decision-making, (3) higher substantive quality of decisions, (4) building of trust, (5) conflict reduction, and (6) cost-effectiveness. Morgan (1998) and Bayley and French (2008) provide other perspectives, from which criteria such as fairness, openness, transparency, and legitimacy are used to characterise the success of the process.

In the traditional format, citizens and stakeholders have been either a source of information or a target of dissemination of information. In new approaches, relatively small groups of people are involved in intensive, and often consensus-based, collaborative processes (Beierle 2002). Collaboration and a collaborative process actively involve two or more stakeholders working together to identify problems, define objectives, share information, and develop acceptable solutions collectively that none can solve individually; see, for example, the work of Wondolleck and Yaffee

(2001) or Nandalal and Simonovic (2003). At its best, a collaborative process is a mutual learning process in which all parties involved, including also experts, scientists, and project managers, learn from each other. 'Deliberation' and 'deliberative process' are other commonly used terms for participatory processes in which participants exchange information and arguments in a dialogue governed by specific rules (Renn 2006).

The need for better stakeholder involvement raises the question of how to synthesise different participants and their knowledge and values in a defensible decision process. Beierle and Cayford (2002) present a systematic analysis of 239 published case studies of stakeholder involvement in environmental decision-making. One of the key results is that intensive forms of stakeholder involvement produce higher-quality decisions than do less intensive ones. McDaniels et al. (1999), among many others, stress the importance of improved understanding of the problem and better-informed recommendations, and note that 'anything more than this – such as the consensus agreement [....] – is a bonus'. Gregory et al. (2005) state that deliberative processes have both analytical and behavioural components, and that the processes should recognise the associated uncertainty. This is, participants need to be aware of the limitations related to the available information and to the complexity of the trade-offs, and policymakers need an overall understanding of how much they can rely on conclusions from deliberative processes.

In this thesis, I show how MCDA can help to collect, structure, integrate, and analyse information from different sources. I also describe how it can be used to enhance participants' learning in a collaborative process. In Article VI (see Table 2), the DAI approach and other public participation methods used in the case studies are compared with respect to the social goals presented by Beierle (2002).

2.3 MCDA in participatory environmental planning

MCDA's applications in environmental planning are numerous and diverse. There are several reviews of literature in this area. For instance, the following topics are covered: water resource management (Hajkowicz and Collins 2007), fisheries management (Mardale and Pascoe 1999 and Leung 2006), forestry management (Mendoza and Martins 2006), environmental impact assessment (Janssen 2001), ecological risk assessment (Linkov et al. 2011), environmental planning (Kiker et al. 2005), governmental decision-

making (Gamper and Turcanu 2007), and multi-stakeholder applications (Harrison and Qureshi 2000).

There is also a fairly rich body of literature related to MCDA's use in participatory water resource management projects (Brown et al. 2001, Hostmann et al. 2005a, 2005b, Messner et al. 2006, Failing et al. 2007, Ohlson and Serveiss 2007, Calizaya et al. 2010). Hostmann et al. (2005a, 2005b) use MAVT with stakeholder classification and analyse the conflict potential for different river rehabilitation alternatives. A structured multi-stakeholder decision-making approach was developed and extensively used in water use planning in British Columbia (Gregory and Failing 2002, Failing et al. 2007). The approach has many elements in common with the DAI approach developed in this thesis.

Stakeholders' roles in MCDA processes have varied greatly. At one extreme is use of MCDA by experts only with hypothetical weights describing stakeholders' or experts' opinions; see, e.g., the work of Ridgley et al. (1997), Qureshi and Harrison (2001), Prato (2003), and Kiker et al. (2005). However, MCDA can be used as a method to engage stakeholders in different phases of the planning process and to incorporate stakeholders' values into decision-making. Experiences from these real-life applications as well as from other fields of natural resource management suggest that MCDA can support participatory planning in many ways (see Figure 1).

MCDA can be seen as a process that is embedded in a wider process of problem structuring and resolution (Belton and Stewart 2002). However, many environmental MCDA applications lack this perspective and only focus on evaluation of the given alternatives. There is seldom a single decision-making point. This has been noticed recently by Geldermann et al. (2009), who employ multi-criteria decision support tools in the nuclear emergency scenario. Although the process improved transparency and consensus and was perceived as successful, they remark that 'the methods and tools used were not able to reflect the sequential and iterative process of decision making'. Failure to identify the real nature of decision-making may place the quality of the whole analysis at risk and greatly diminish the relevance of the results (Salgado et al. 2006; Munda 2008, p. 181).

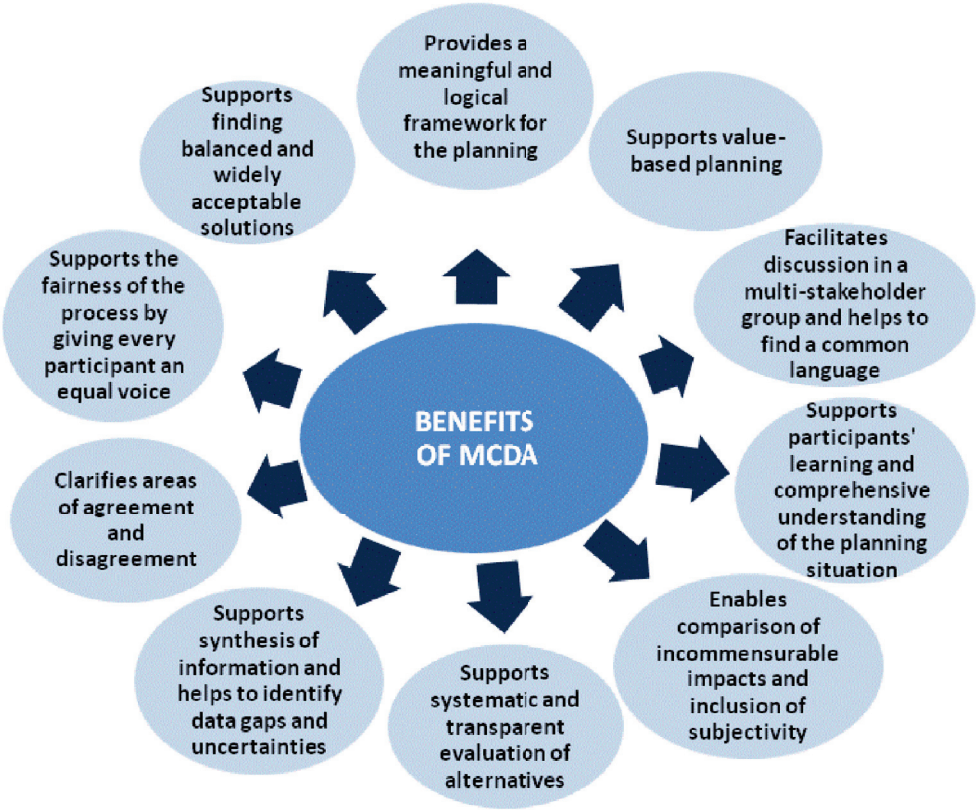

Figure 1. The potential benefits of MCDA in multi-stakeholder planning processes.

Stirling (2006) emphasises that finding a balance between 'opening up' and 'closing down' modes in the assessment processes is important. In the 'opening up' mode, the diversity of opinions, conflicting interests, ignored uncertainties, and new options are highlighted, whereas in the 'closing down' policy process the aim is to assist decision-making by providing information that focuses on priority issues and the most likely outcomes and that identifies the best options. In the case studies, MCDA tools were used largely in 'opening up' mode. In these applications, one of our goals was to explore and describe differences in the stakeholders' values and preferences and the reasons behind them.

Using MCDA as a participatory tool entails several questions, such as the choice of the method and the participants, and the treatment of stakeholders' opinions in the analysis. The choice of method can significantly affect the results and how the participants experience the application (Hobbs and Horn 1997). The complementary use of several MCDA approaches would be an ideal situation (Stewart and Losa 2003). However, this seldom is possible. Choosing from among MCDA methods is a complex task. Each method has its strengths and weaknesses; while some

methods are better grounded in mathematical theory, others may be easier to implement (Kiker et al. 2005).

We used MAVT-based tools in the DAIs because their general principles are fairly simple and understandable. MAVT also provided an illustrative way to systematically compare and to analyse alternatives and to describe the differences in participants' opinions. The number of people who can be actively involved in the participatory MCDA process is often relatively low. Therefore, the choice of the stakeholders is a crucial question. Banville et al. (1998) present an approach how stakeholders and MCDA can be brought together. Harrison and Qureshi (2000) analyse the treatment of stakeholders in some MCDA studies concerning natural resources management.

3. Interactive MCDA approach

3.1 The decision analysis interview approach

MCDA provides generic, flexible methods that can be used in many ways and in many contexts. The decision analysis interview approach developed and applied in this thesis is an MCDA process based on personal interviews with a multi-criteria model. In the case studies, the process consisted of three major phases (see Figure 2). However, it is also possible to apply the DAI approach in a more straightforward way. For instance, structuring, rating, and weight elicitation can be conducted with an individual decision-maker during one decision session. The DAI approach used in the HIPRE applications (see articles II–IV) is described below. Although the REGAIM model approach described in section 3.2 has many elements similar to those of the MAVT applications, there were also some major differences, which were due to the differences in the modelling tools and their purpose of use. The phases of the REGAIM approach are explained in Article V.

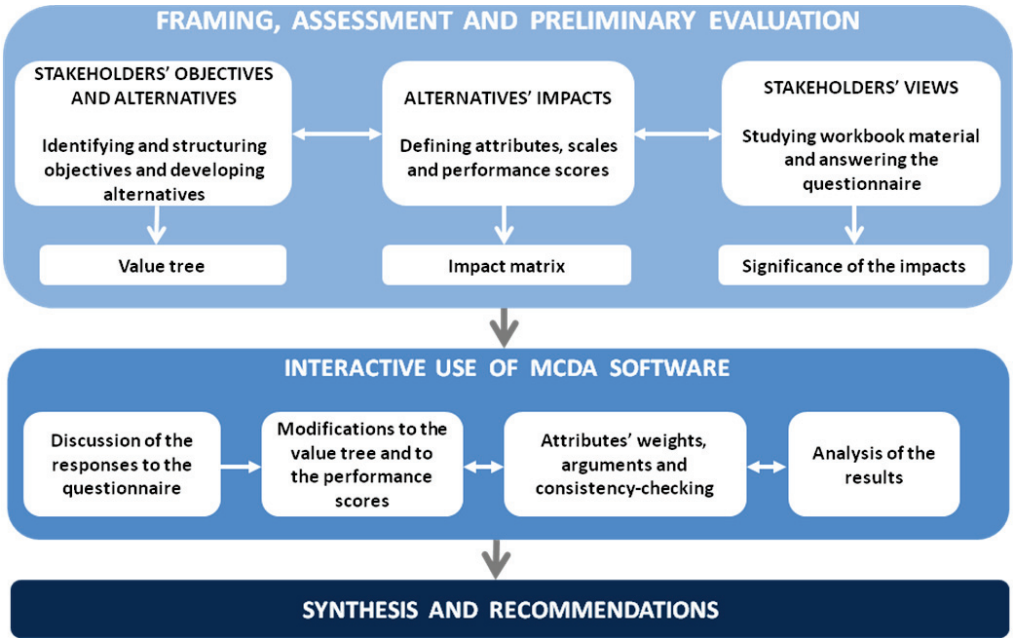

Figure 2. The main phases of the interactive MCDA process used in the projects.

In the projects studied, the framing, impact assessment, and compilation of workbook material took most of the time. The framing and impact assessment was carried out in close co-operation with the projects' steering group. The open discussion of the impacts with the participants was an important phase during which experts had to crystallise their reasoning and argue it clearly. The analysis pinpointed gaps in knowledge and ignored uncertainties. There were many features of the process for which it can be said that the process was carried out in the 'opening up' mode (see Stirling 2006). At the end of this phase, the analyst compiled a workbook including the description of the alternatives and their impacts. The workbook also contained questions regarding the importance of the attributes. It was sent to the participants, who were asked to study it and answer the questions before the interviews. These answers were discussed in the DAIs.

In the interviews, the decision analyst used the MCDA software, asked the elicitation questions, and took care to ensure that the answers reflected the participant's views as well as possible. In the hierarchical weighting technique, which was used in the projects studied, the attributes in the different branches of the hierarchy were not compared directly to each other. Therefore, an essential phase of interactive MCDA was the visual comparison of the bars depicting the overall weights of the attributes. In many cases, the analysis of the priority values of alternatives also revealed a need to revise the performance values of the alternatives, attribute weights, or the form of the value functions. The process continued until an outcome that was acceptable for the respondent was achieved. During the interview, the analyst asked for arguments for the weights and wrote down major points from the participant's responses. The arguments aided in understanding why some attributes were considered important and some less so, and why some alternatives were desirable and some undesirable. The arguments were also useful to the analyst for ensuring that the participant understood the questions correctly and that the numbers were in accordance with the participant's views. Typically, the interviews finished with a sensitivity analysis.

The DAI approach produced a large amount of information about the importance of impacts and the desirability of the alternatives. After the interviews, the analyst analysed and summarised the results. In the analysis of large data sets, one is often tempted to aggregate data by computing averages. However, we preferred to present the results at an individual level and to identify groups that had similar opinions. This helped to illustrate the large variation and subjectivity of the preferences. The arguments listed during the interviews helped us to compile real viewpoints. Drawing recommendations from the DAIs was a delicate task. The DAIs were part of

the iterative process aimed at finding broadly acceptable alternatives. In all of our projects, there was great variety in the stakeholders' preferences and none of the alternatives was preferred to others by all stakeholders. The recommendations were aimed at supporting the joint solution-finding through identification of important objectives that should guide the realisation of the regulation in the various water conditions or through suggestion of alternatives that could be evaluated in the next step of the process.

In the decision analysis literature, there is very little discussion of whether people have really understood the method applied and its assumptions. It is likely that in many cases such problems have remained unnoticed (Hämäläinen 2004). Problems have been identified in cases where there has not been enough time for participants' instruction (e.g., Sinkko et al. 2004, Siebenhüner and Barth 2005). In the DAI approach, we paid special attention to the clarity of the process, the choice of tools, and capacity-building for the participants. Before the interviews, a meeting was arranged wherein the approach was explained and its use was demonstrated. The workbook also included a brief description of the main calculation principles of the MCDA model. Furthermore, early in the interviews there was a short introduction to the method, and the respondent had an opportunity to ask questions. Before the computer-aided phase, the analyst asked whether the participant felt in possession of sufficient understanding of the process and the tool.

3.2 A customised value-tree-based approach

For this thesis, a customised value-tree based approach, the REGAIM model, is developed and applied (see Article V). The name 'REGAIM model' refers to water level regulation and to stakeholder's aim. There were two motives for the development of the model. First, we felt that it would be interesting to test an approach in which each stakeholder has an opportunity to specify his or her favourite regulation practice personally and in a structured manner. In this task, people had to consider several and partly conflicting objectives, they had to combine impact assessment information with water levels and flows, and they also needed some knowledge of hydrology. Second, we hoped that the interactive use of the model would enhance the participants' learning and lead to more informed and realistic 'image regulation' and consequently a better basis for joint problem-solving.

The development of the REGAIM model was also inspired by value-focused thinking and our interest in trying ideas from image theory (Beach 1998) in the watercourse regulation context. The starting point of image theory is that people apply a compatibility test in a screening phase and alternatives that deviate too much from one's ideal reference, image, will be rejected. Images can relate to ones' principles, future hopes and plans. If there is no acceptable alternative, the decision-maker starts from the beginning and either looks for new alternatives or lowers the threshold below which rejection occurs for some attributes. The developers of image theory have presented a mathematical formulation of image theory (Beach and Mitchell 1998, p.15). We did not use that in the REGAIM model, but the theory gave us some ideas related to the development of a conceptual framework regarding construction of participants' image regulation.

The REGAIM model is an Excel spreadsheet model consisting of three sub-models (see details in Article V):

- *The value tree model* is used to compute target water levels for five time points on the basis of the stakeholder's opinion of the importance of the related impacts and the optimal water level for each attribute. For each stakeholder, the target regulation is formed by drawing an adjusted line between the five target water levels (see Article V's Figure 7). In this summary, I use the term 'image regulation' interchangeably with the term 'target regulation'.
- *The hydrological model* is used to calculate the impacts of the target regulation on the water levels and flows in different water years. The results show how well the stakeholder's target regulation can be achieved in different water conditions.
- *The impact assessment model* is used to calculate the scores for the attributes describing the ecological, social, and economic impacts of the target regulation in different water years and summarises them in the impact matrix.

4. Implementing the approach in practice

4.1 Introducing MCDA in the planning process

In this thesis project, the MCDA approach and tools were introduced in watercourse regulation development projects. The development of watercourse regulation is related to the existing watercourse regulation projects and involves a formal process described in the Finnish Water Act. In the process, the effects of alternative options are assessed, stakeholders' opinions and preferences are identified, and opportunities to diminish harmful impacts are studied. Typically in the studied water course regulation projects, the original objectives in the operative use were economic ones: increasing hydropower production and preventing floods. The ecological and social objectives were less important. Before 1994, opportunities to revise old regulation practices were highly limited if the holder of the regulation licence was not in favour of the changes. The amendments made to the Finnish Water Act significantly improved the situation in 1994. This gave strong impetus to the improvement of watercourse regulation projects whose design and realisation had mainly taken place in the 1950s and 1960s.

Typically, early in the development project, distrust and disputes arose between stakeholders. Some people had strong negative emotions directed at the watercourse regulation project and the organisation responsible for it. Discussions were easily dominated by general beliefs and personal experiences of the impact of the watercourse regulation. Each stakeholder had his or her own perception of what constituted good water levels and flows, reflecting his or her interests and values. These images were often very different from the watercourse regulation practice then in place.

Our working style in the projects can be characterised as a search for an acceptable compromise solution (Figure 3). The process aims at finding a regulation practice satisfying multiple objectives at the same time. The projects aimed to create a process during which participants' overall understanding of the watercourse regulation and its effects as well as hydrological and technical constraints and stakeholders' objectives improved. A simultaneous aim of the development projects was to find and present recommendations that alleviate harmful impacts of the watercourse

regulation or increase its overall benefits. The conditions for finding a compromise solution were most favourable when both there were means to improve the existing watercourse regulation and a process providing good opportunities for individual and social learning could be developed.

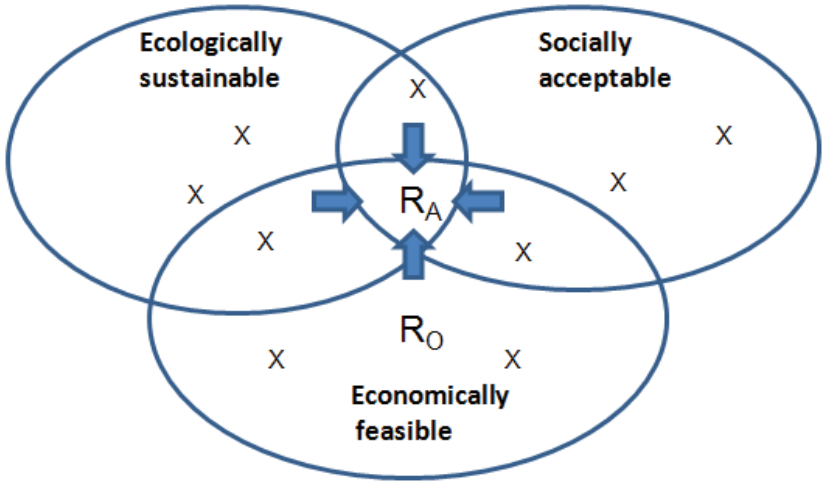

Figure 3. Finding a balanced regulation practice. X refers to stakeholders' views of good regulation practice in the beginning of the lake regulation project. R_O refers to the regulation practice before the project and R_A to an acceptable compromise.

4.2 Participants in the projects

The participants in our watercourse development projects can be divided into six main groups:

- The *problem-owner* was the environment authority, the Regional Environment Centre (now Centre for Economic Development, Transport and the Environment), responsible for execution of the watercourse regulation development process. The holder of the regulation licence, typically either a hydropower company or the state, was also a problem-owner.

- An *MCDA expert or decision analyst or facilitator* designed the approach in collaboration with the problem-owner, research team, and stakeholder steering group. This person was responsible for the realisation of the DAI approach and for its results being used in a responsible manner.

- The *research team* consisted of the project manager, the MCDA expert, and key scientists and experts. The team organised and facilitated the whole process.

- The *stakeholder steering group* consisted of representatives of authorities, hydropower companies, non-governmental organisations, fishermen, and recreational users. The group's task was to assess the opportunities to improve existing practices and to develop recommendations for the new regulation policy. Typically, about 10 meetings of 4–6 hours each were arranged.

- *Citizens* were people who had an interest in the project. They were typically residents, owners of summer houses, recreational users, farmers, and fishermen. They had several opportunities to participate in the process. They could respond to either postal or Internet questionnaires, take part in thematic interviews, or attend public meetings or workshops, for instance. Public meetings were open to all interested people. Postal questionnaires were sent randomly to those property-owners who had a house on the shoreline of the watercourse studied. Citizens' opinions and suggestions were documented, summarised, and discussed in the stakeholder steering group.

- There were also *scientists and experts* conducting studies associated with ecological, social, and economic impact assessments for the existing conditions. They also participated in the stakeholder steering group work whenever their expertise was needed.

4.3 Case studies

The case studies consist of five watercourse planning projects, in which 133 personal decision analysis interviews were undertaken (see Figure 4 and Table 1). Four projects were related to the improvement of watercourse regulation projects and one to the evaluation of flood prevention alternatives. The first project started in 1989, and the last project ended in 2006. The long time span provided good opportunities for developing approaches and tools for participatory multi-objective environmental planning.

Major changes in environmental planning culture and practices have occurred over this nearly 20 years. For instance, the role of public participation in planning processes has increased dramatically. In the early

1990s, the public were mostly only recipients of information on the plans. Today, dialogue between experts, stakeholders, and authorities is considered very important and is also an indicator of a high-quality planning process.

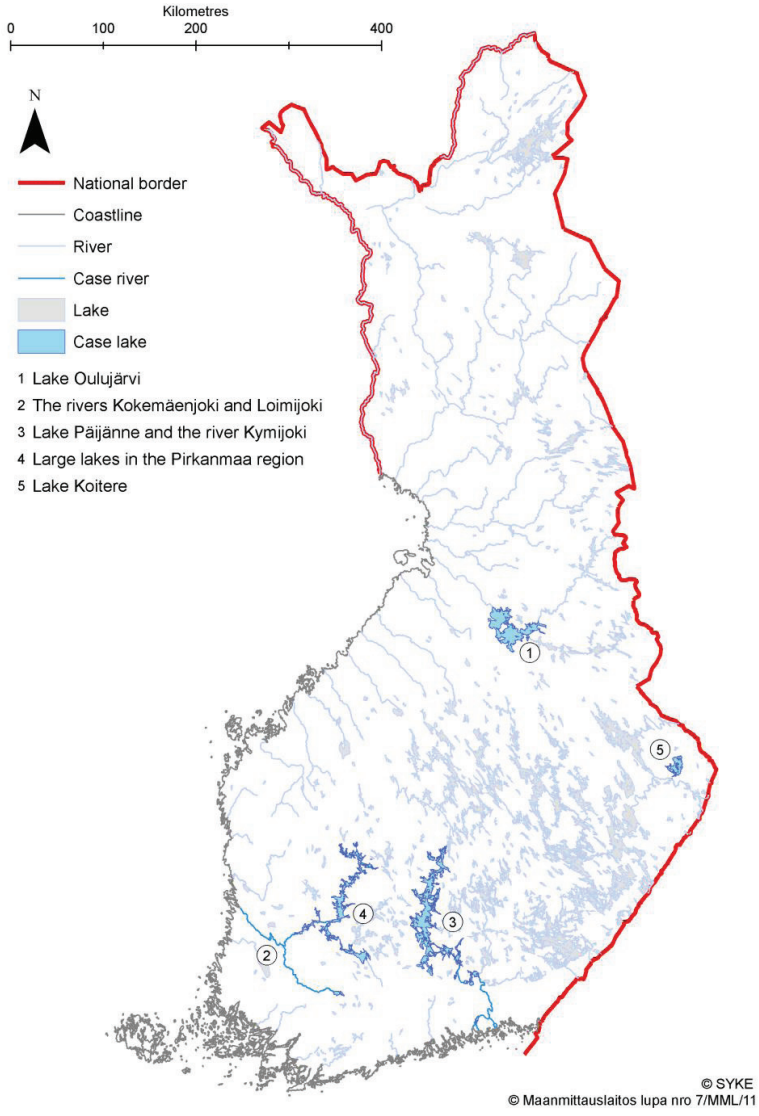

Figure 4. The location of the projects.

The importance of MCDA and stakeholders has increased over the course of time, reflecting the general changes in the planning culture. In the first

projects, MCDA was used largely to compare alternatives having intangible and incommensurable impacts and to find stakeholders' opinions about the alternatives. In the last three projects, MCDA provided a framework for the whole planning process, and it was used in a multi-stakeholder negotiation process in a manner that enhanced joint problem-solving. The differences in MCDA applications also arise from the fact that in each project we tailored the approach to better suit the case.

Table 1. MCDA and public participation approaches used in the projects.

Project	Oulu-järvi[1)]	Koke-mäenjoki[2)]	Päijänne[3)]	Pirkan-maa[4)]	Koitere[5)]
Study years	1989–1993	1990–1993	1995–1999	2000–2003	2004–2006
MCDA tools used	HIPRE	HIPRE3+	HIPRE3+ Web-HIPRE	REGAIM	Value-focused thinking, REGAIM
Number of DAIs	35	24	20	36	18
Mail questionnaire					
Sample size	2,858	24[6)]	2,511	3,216	225
Response %	38%		79%	36%	60%
Web-based questionnaire (Opinions-Online®)	-	-	In closing seminar, 51 participants	333 responses on the Web	-
Thematic interviews	139	24	-	-	22
Number of meetings					
Steering group	6	9	13	7	11
Working group	2	4	24	6	-
Public meetings	1	1	10	6	2

[1)] Lake Oulujärvi (928 km^2)

[2)] The rivers Kokemäenjoki (112 km) and Loimijoki (114 km)

[3)] Lake Päijänne (1,118 km^2) the River Kymijoki (184 km)

[4)] Lake Näsijärvi, Lake Vanajavesi, Lake Pyhäjärvi, Lake Iso-Kulovesi (total area 564 km^2)

[5)] Lake Koitere (164 km^2)

[6)] All participants of the DAIs

I now summarise each case and its specific characteristics:

- In the *Oulujärvi* project, the DAI approach was developed and tested for the first time with real stakeholders. The first version of the HIPRE 3 software (Hämäläinen and Lauri 1992) was used (see Article I). The DAIs concerned evaluation of the regulation alternatives for the lake Oulujärvi. However, the whole project covered all of the largest regulated lakes and rivers in the watershed. Positive results and experiences related to the co-operative approach demonstrated in this pilot project were taken into account in the making of policy-practice-related amendments to the Finnish Water Act in 1994.

- The *Kokemäenjoki* project demonstrated how MCDA can be used in environmental impact assessment (EIA). This was a large river development project. From a methodological perspective, the interesting feature was that the postal questionnaire, DAIs, and thematic interviews were applied complementarily (see Article I).

- There were two separate but interlinked projects which were related to the water level regulation of Lake *Päijänne:* a lake regulation development project led by Finnish Environment Institute and a research project on the practice of MCDA led by the Systems Analysis Laboratory. This enabled us to develop and test new decision support and negotiation tools for planning and then apply them in the real-world project. In the research project, a general decision support framework was outlined. Also, a new bargaining model was tested with students (see Article II). The new Internet-based Web-HIPRE was developed and demonstrated (Mustajoki et al. 2004, Article III). Behavioural biases and how to eliminate them were studied with students and real stakeholders (Hämäläinen and Alaja 2008). The findings of this study were utilized in the decision analysis interviews carried out in the lake regulation development project. Opinions-Online® was used in the closing seminar to analyse the participants' opinions regarding the implementation of the project and the recommendations (see Article VI). Opinions-Online lets you generate a private and customized site for interactive, web based group decision making, voting and surveys.

- In the *Pirkanmaa* project, the REGAIM model was developed and used in the stakeholders' individual interviews (see Article V). Opportunities for application of image theory in the watercourse regulation development project were assessed with real stakeholders. A Web-based questionnaire was the primary way of

collecting public opinions about the preliminary policy recommendations before the steering group made the final decision (see Article VI).

- The REGAIM model was also applied in the *Koitere* project. Value-focused thinking was used to identify and categorise fundamental, means, process, and organisational objectives of the steering group (see Article VI).

4.4 Levels of integration and interaction in the MCDA applications

The realisation of the five case studies and MCDA applications differed greatly from each other. For instance, the levels of integration and interaction increased in the course of time, reflecting our aim of improving the quality and effectiveness of the MCDA applications (see Figure 5). Here, integration refers to how MCDA is linked to the planning process and how it supports various phases of the process. Designing processes in which the phases of planning and tasks of MCDA are integrated produces synergies and decreases the risk of MCDA remaining a separate exercise with little or no impact on decision-making. A high level of interaction means that key stakeholders are actively involved in the various phases of the process and that weight elicitation and analysis of the results are interactive and computer-aided.

In the Koitere project, the use of MCDA was an integral part of the planning process. The steering group participated actively in every phase of the planning process. This was also the only project in which the identification and structuring of the stakeholders' objectives was realised by means of value-focused thinking. In our first project (for Oulujärvi), the framing and structuring phase was carried out in a small steering group consisting of some key stakeholders and the MCDA expert. We also have recent experiences from a project in which MCDA was introduced only at the end of the project (Mustajoki et al. 2011). As a result, some of the potential benefits of MCDA did not emerge.

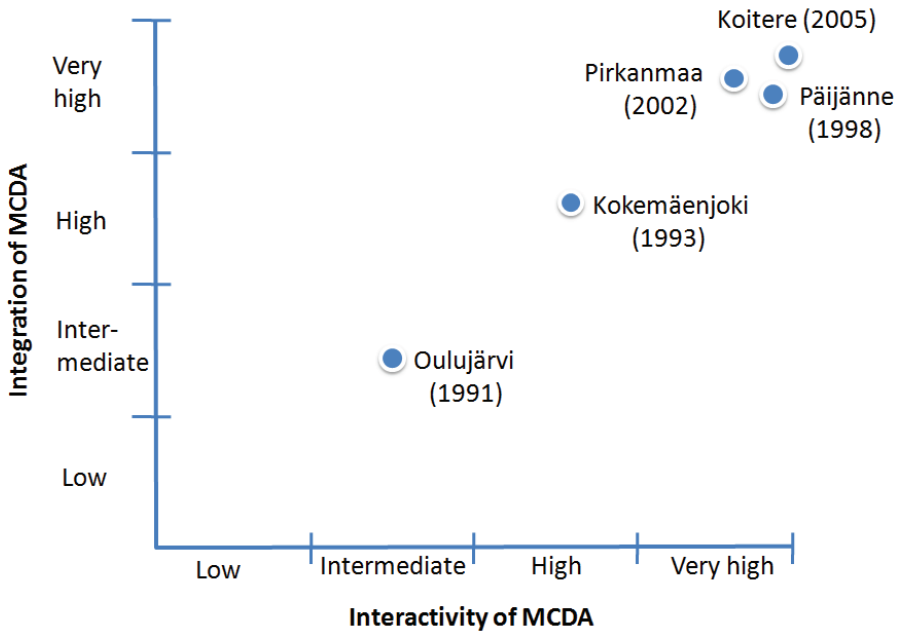

Figure 5. Evaluation of the MCDA applications with respect to the level of interaction and integration.

5. Reflections and conclusions

5.1 Integrated and interactive use of MCDA

MCDA is a generic method with great opportunities for application in environmental decision-making. Although much research has been conducted in this field, there are only a few cases wherein stakeholder involvement and the use of MCDA tools have been tightly bound to the actual decision-making process. This thesis shows how MCDA can be used to support participatory planning processes and also presents arguments as to why the interactive use of MCDA is recommendable. One of the main claims and conclusions of this thesis is that the levels of integration and interaction have a crucial impact on the quality and effectiveness of the MCDA process and its outcomes. The following reasons emerged.

Improved opportunities to identify contradictions between participant's views and the weights of the attributes and the outcome of the analysis: The 133 personal DAIs provided an excellent opportunity to observe participants' behaviour when they elicited weights, and to identify problems found in the process. The findings are in line with earlier studies showing that people have difficulties in assigning consistent and unbiased weights (e.g., Pöyhönen and Hämäläinen 2000, 2001, Hämäläinen and Alaja 2008). An implication of this is that close interaction between the analyst and the participant in the weight elicitation is necessary. In interactive interviews, the analyst can detect possible misunderstandings, inconsistencies, and biases in participants' answers. I also noticed that people answered questions more carefully in the presence of the facilitator than when they were working independently. My findings suggest that interactive and iterative weight elicitation can lead to outcomes that better reflect stakeholders' preferences.

Enhanced learning: In the watercourse management projects, as in environmental planning generally, decision-making is typically an ongoing and iterative process aimed at seeking acceptable compromises. Both the HIPRE and REGAIM models provided a 'learning by analysing' opportunity for the participants. In the Päijänne project, careful deliberation of different value tree options and separate consideration of different water conditions helped the stakeholders to understand that the regulation practices had to be adjusted to water conditions (see Article IV); the shared understanding was a good starting point for the multi-stage iterative process aimed at

finding a feasible and acceptable regulation practice. In the Pirkanmaa and Koitere projects, the REGAIM model was used to develop a target regulation for each participant. From these target regulation scenarios three were chosen for further consideration (see Article V). The MCDA models inspired learning and understanding in a different manner than that of traditional meetings. The interactive use of the models supported the systematic analysis of the stakeholders' preferences and helped to analyse how the preferences affected the ranking of the alternatives.

For me as the analyst, the personal DAIs were a good learning process too. The DAIs showed that differences in preferences resulted in very different target water levels and flows. When applying MCDA, one can aim for agreement among participants on criteria weights; however, my experiences have led to a belief that in the deliberative processes this is not of primary importance. More important was that people became more conscious of the other stakeholders' interests and preferences and accepted that other views could also be well justifiable and legitimate.

Improved trust in the results: By using MCDA methods interactively, people could see how their answers were used as input values for the analysis and also how they affected the outcome. The interactive nature of the DAIs helped to ensure that the participants had sufficient understanding of the theoretical principles of the MCDA models used. As a consequence, stakeholders' trust in the model, the results, and the whole planning process increased. Interactive use also reduced the risk of people feeling manipulated by a 'black-box' methodology (e.g., Hobbs and Horn 1997).

Greater fairness and transparency: The personal decision analysis interview was a good way to give each participant an opportunity to express his or her opinions and get those opinions documented equally to others'. One can even say that in this respect the DAIs had a positive effect on the perceived fairness of the planning processes. The DAIs signalled that each participant's opinion was appreciated and taken into account. The DAIs also indicated that the problem-owner had a genuine desire to identify and balance different interests and objectives. This probably increased the stakeholders' commitment to the process and final decision. The results of the DAIs were useful in explaining differences in preferences and why finding an acceptable solution was difficult to those people who did not actively participate in the planning process.

Sustained participant interest in the process: In projects lasting several years, keeping participants active and committed was a big challenge. In the

latest projects, the MCDA expert was also responsible for managing or co-ordinating the whole regulation development project. This aided in designing processes that accounted for case-specific needs and had MCDA as an integral element. The integrated, interactive use of the MCDA tools helped create conditions for meaningful and effective interaction, which has been found to be one of the key objectives for the design participation processes (Webler and Tuler 2006).

The interactive and integrated MCDA approach is quite laborious. However, it does not mean that the approach automatically would delay decision-making process or increase planning costs. Rather, the participatory, systematic and structured approach supports the identification of the most significant impacts in the early phases of planning. This diminishes the risk of surprises in the later phases of planning as well as the risk for additional studies and extra costs. The developed approach and transparent planning process may also reduce citizens' complaints to different instances and thus speed up the decision-making process.

5.2 MCDA's role in finding compromise solutions

In all four regulation development projects, agreement on the recommendations was achieved. However, this was not an easy task in any of the projects and required considerable work and intensive discussions in the projects' steering groups. In all cases, the outcome was a compromise and not all stakeholders were entirely happy with it. Some stakeholders were disappointed because their hopes regarding the magnitude of changes in water levels were greater than what was finally included in the recommendations.

Evaluation of the role of MCDA in reaching agreement is very difficult: we cannot have two projects that are identical except that MCDA is used in one but not the other. It is also very hard to separate the use of the DAIs from the whole planning process – the DAIs were an integral part of it. Therefore, I cannot claim that finding acceptable compromises was a consequence of the use of MCDA. However, MCDA has several characteristics that directly improved the quality of the planning and decision-making process and thus supported joint problem-solving. I see many of them as resulting from the systematic, interactive, transparent, and value-based approach.

The responses and feedback from the participants indicate that the potential benefits of MCDA illustrated in Figure 1 were well achieved, particularly in the Päijänne, Pirkanmaa, and Koitere projects. Thus MCDA contributed to reaching of the social goals of public participation listed by Beierle (2002). For instance, in the Päijänne project, some stakeholders emphasised that in the interviews their rigid opinions were softened, which they felt was a prerequisite for compromise. The DAI approach helped participants to analyse the problem from a broader perspective. The evaluation was based on a versatile setting of criteria. The approach also encouraged participants to get acquainted with attributes related to perspectives of the other stakeholder groups. Because of this improved understanding of other stakeholders' objectives, participants had more willingness and ability to see the problem through others' eyes too. This result is familiar from the literature, where MCDA methods' ability to facilitate more consensus-oriented decisions has been noted (von Winterfeldt and Edwards 1986, Hobbs and Horn 1997, Hostmann et al. 2005b).

In addition to the DAI approach, there were several other characteristics of the planning processes that contributed to reaching agreement on recommendations. A good knowledge base, which helped direct discussions from beliefs toward facts, was gathered. In addition to MCDA, many other participation methods were used (see Table 1). Open and participatory processes consolidated trust in the project and the authorities responsible for it. The length of the processes, up to four years, probably engendered feelings of togetherness in the steering groups. This and the substantial time required of the participants might have increased commitment to trying to achieve a compromise. It was also considered important that there was a recommendation that the effectiveness of the suggested measures be monitored; evaluated; and, if needed, modified.

5.3 Research needs and future perspectives

Use of MCDA in actual environmental planning and decision-making is still relatively limited in comparison to its great potential in the evaluation of alternatives in complex multi-stakeholder settings. This thesis has addressed how to design and realise participatory MCDA processes in real-world projects. However, this still remains among the key challenges for the future. More attention should be paid to study of elicitation procedures that

people find easy and understandable. Improving participant and facilitator interaction during MCDA modelling is another important issue for research. Applied research needs to pay more attention to the communicative and deliberative aspects of a participatory MCDA process. It would also be important to develop procedures that aid in utilising the DAIs' results in the joint problem-solving process. There is also a need for further study of the best ways of using MCDA over the Internet.

MCDA has many characteristics, such as integration of diverse information and handling of conflicting objectives, that make it very useful to support the entire environmental impact assessment process (e.g., Mendoza and Prabhu 2000, Bojórquez-Tapia et al. 2005, Sadok et al. 2008). In the EIA process, determining the impact's significance is recognised as a crucial, most complex, and little-understood activity (Lawrence 2007). Several approaches and calculation principles have been developed for this, but none is in routine use. MCDA provides approaches and techniques that could be useful in this process. In particular, more systematic analysis of facts and values would improve the transparency of determination of the impact's significance.

The need for interdisciplinary and participatory processes combining, interpreting, and communicating scientific and local knowledge is great and still increasing. MCDA methods have many characteristics that make them useful to support decision-making processes in a management and policy levels. One great challenge is how to bridge the gap between the need for MCDA expertise and its supply. This requires extensive education in public and private organisations and at universities. Increasing the number of MCDA professionals may, for one, drive the use of MCDA in environmental decision-making and hopefully result in more satisfied stakeholders and problem-owners.

REFERENCES

Amy, D.J. 1987. The Politics of Environmental Mediation. New York: Columbia University Press. 250 p.

Arvai, J.L., Gregory, R., McDaniels, T.L. 2001. Testing a structured decision approach: Value-focused thinking for deliberative risk communication. Risk Analysis 21 (6): 1065–1076.

Banville, C., Landry, M., Martel, J.-M., Boulaire, C. 1998. A stakeholder approach to MCDA. Systems Research 15 (1): 15–32.

Bayley, C., French, S. 2008. Designing a participatory process for stakeholder involvement in a societal decision. Group Decision and Negotiation 17 (3): 195–210.

Beach, L.R. 1998 (ed.). Image Theory: Theoretical and Empirical Foundations. Mahwah, NJ, USA: Erlbaum. 284 p.

Beach, L.R., Mitchell, T., R. 1998. The basics of image theory. In: Beach, L.R. (ed.), image Theory: Theoretical and Empirical Foundations. 1998. Mahwah, NJ, USA: Erlbaum, 3-18.

Beierle, T.C. 1999. Using social goals to evaluate public participation in environmental decisions. Policy Studies Review 16 (3): 75–103.

Beierle, T.C. 2002. The quality of stakeholder-based decisions. Risk Analysis 22 (4): 739–749.

Beierle, T.C., Cayford, J. 2002. Democracy in practice: Public participation in environmental decisions. Resources for the Future. Washington, DC. 147 p.

Belton, V., Stewart, T.J. 2002. Multiple Criteria Decision Analysis – an Integrated Approach. Boston, Dordrecht, London: Kluwer Academic Publishers. 372 p.

Bojórquez-Tapia, L.A., Sánchez-Colon, S., Martinez, A.F. 2005. Building consensus in environmental impact assessment through multicriteria

modeling and sensitivity analysis. Environmental Management 36 (3): 469–481.

Brown, B., Neil-Adger, W., Tompkins, E., Bacon, P., Shim, D., Young, K. 2001. Trade-off analysis for marine protected area management. Ecological Economics 37 (3): 417–434.

Calizaya, A., Meixner, O., Bengtsson, L., Berndtsson, R. 2010. Multi-criteria decision analysis (MCDA) for integrated water resources management (IWRM) in the Lake Poopo Basin, Bolivia. Water Resources Management 24 (10): 2267–2289.

Creighton, J.L. 2005. The Public Participation Handbook: Making Better Decisions through Citizen Involvement. San Francisco: Jossey-Bass.

Depoe, S.P., Delicath, J.W., Elsenbeer, M.-F.A. (editors). 2004. Communication and Public Participation in Environmental Decision Making. State University of New York Press. 312 p.

Edwards, W. 1977. How to use multiattribute utility measurement for social decisionmaking. IEEE Transactions on Systems, Man and Cybernetics 7 (5): 326–340.

Edwards, W., Miles, R., von Winterfeldt, D. 2007. Advances in Decision Analysis: From Foundations to Applications. 623 p.

Failing, L., Gregory, R., Harstone, M. 2007. Integrating science and local knowledge in environmental risk management: A decision-focused approach. Ecological Economics 64 (1): 47–60.

French, S., Maule, J., Papamichail, N. 2009. Decision Behaviour, Analysis and Support. Cambridge University Press. 472 p.

Gamper, C., Turcanu, D. 2007. On the governmental use of multi-criteria analysis. Ecological Economics 62 (2): 298–307.

Geldermann, J., Bertsch, V., Treitz, M., French, S., Papamichail, K.N., Hämäläinen, R.P. 2009. Multi-criteria decision support and evaluation of strategies for nuclear remediation management. Omega 37 (1): 238–251.

Gregory, R. 2000. Using stakeholder values to make smarter environmental decisions. Environment 42: 35–44.

Gregory, R., Failing, L. 2002. Using decision analysis to encourage sound deliberation: Water use planning in British Columbia, Canada. Journal of Policy Analysis and Management 21, 492–499.

Gregory, R., Keeney, R. 1994. Creating policy alternatives using stakeholder values. Management Science 40 (8): 1035–1048.

Gregory, R., Fischhoff, B., McDaniels, T. 2005. Acceptable input: Using decision analysis to guide public policy deliberations. Decision Analysis 2 (1): 4–16.

Hajkowicz, S., Collins, K. 2007. A review of multiple criteria analysis for water resources planning and management. Water Resources Management 21 (9): 1553–1566.

Huang, I.B., Keisler, J., Linkov, I. 2011. Multi-criteria decision analysis in environmental sciences: Ten years of applications and trends. Science of the Total Environment. In press.

Hämäläinen, R.P. 2004. Reversing the perspective on the applications of decision analysis. Decision Analysis 1 (1): 26–31.

Hämäläinen, R.P., Alaja, S. 2008. The threat of weighting biases in environmental decision analysis. Ecological Economics 68 (1–2): 556–569.

Hämäläinen, R.P., Lauri, H. 1995. Hipre3+ Users Guide. Helsinki University of Technology. Systems Analysis Laboratory.

Harrison, S.R., Qureshi, M.E. 2000. Choice of stakeholder groups and members in multi-criteria decision models. Natural Resources Forum 24 (1): 11–19.

Herath, G., Prato, T. 2006. Using Multi-criteria Decision Analysis in Natural Resource Management. Athenaeum Press Ltd. 243 p.

Hobbs, B.F., Horn, G.T. 1997. Building public confidence in energy planning: A multimethod MCDM approach to demand-side planning at BC Gas. Energy Policy 25 (3): 357–375.

Hobbs, B.F., Meier, P.M. 1994. Multicriteria methods for resource planning: An experimental comparison. Power Systems, IEEE Transactions 9 (4): 1811–1817.

Hobbs, B.F., Meier, P. 2000. Energy Decisions and the Environment: A Guide to the Use of Multicriteria Methods. Kluwer Academic Publishers. 257 p.

Hostmann, M., Borsuk, M., Reichert, P., Truffer, B. 2005a. Stakeholder values in decision support for river rehabilitation. Archiv für Hydrobiologie, Supplement 155 (1–4): 491–505.

Hostmann, M., Bernauer, T., Mosler, H.J., Reichert, P., Truffer, B. 2005b. Multi-attribute value theory as a framework for conflict resolution in river rehabilitation. Journal of Multiple Criteria Decision Analysis 13 (2–3): 91–102.

Howard, R.A. 1984. Readings on the Principles and Applications of Decision Analysis: Professional Collection. Strategic Decisions Group. 955 p.

Janssen, R. 2001. On the use of multi-criteria analysis in environmental impact assessment in the Netherlands. Journal of Multi-Criteria Decision Analysis 10 (2): 101–109.

Janssen, R., Van Herwijnen, M. 2006. A toolbox for multicriteria decision-making. International Journal of Environmental Technology and Management 6 (1–2): 20–39.

Kangas, A., Kangas, J., Kurttila, M. 2008. Decision Support for Forest Management. Managing Forest Ecosystems, Volume 16. Springer. 222 p.

Keefer, D.L., Kirkwood, C.W., Corner, J.L. 2004. Perspective on decision analysis applications, 1990–2001 (and comments by Cantor, S.B. and Hämäläinen, R.P.). Decision Analysis 1 (1): 4–34.

Keeney, R.L. 1982. Decision analysis: An overview. Operations Research 30 (5): 803–838.

Keeney, R.L. 1992. Value-Focused Thinking. Cambridge, MA, USA: Harvard University Press. 416 p.

Keeney, R.L. 2002. Common mistakes in making value trade-offs. Operations Research 50 (6): 935–945.

Keeney, R.L. 2005. Framing public policy decisions. International Journal of Technology, Policy and Management 4 (2): 95–115.

Keeney, R., Raiffa, H. 1976. Decisions with Multiple Objectives: Preferences and Value Tradeoffs. Wiley. 569 p.

Kiker, G.A., Bridges, T.S., Varghese, A., Seager, T.P., Linkov, I. 2005. Application of multicriteria decision analysis in environmental decision making. Integrated Environmental Assessment and Management 1 (2): 95–108.

Lawrence, D.P. 2007. Impact significance determination – back to basics. Environmental Impact Assessment Review 27 (8): 755–769.

Leung, P. 2006. Multiple-criteria decision-making (MCDM) applications in fishery management. International Journal of Environmental Technology and Management 6 (1–2): 96–110.

Lewicki, R.J., Gray, B., Elliott, M. 2003. Making Sense of Intractable Environmental Conflicts: Concepts and Cases. Washington, DC: Island Press. 469 p.

Linkov, I., Welle, P., Loney, D., Tkachuk, A., Canis, L., Kim, J.B., Bridges, T. 2011. Use of multicriteria decision analysis to support weight of evidence evaluation. Risk Analysis, DOI: 10.1111/j.1539-6924.2011.01585.x. Published online 3rd of March 2011.

Mardale, S., Pascoe, S. 1999. A review of applications of multiple-criteria decision-making techniques to fisheries. Marine Resource Economics 14 (1): 41–63.

McDaniels, T., Trousdale, W. 1999. Value-focused thinking in a difficult context: Planning tourism for Guimaras, Philippines. Interfaces 29 (4): 58–70.

Mendoza, G.A., Martins, H. 2006. Multi-criteria decision analysis in natural resource management: A critical review of methods and new modelling paradigms. Forest Ecology and Management Vol. 230 (1–3): 1–22.

Mendoza, G.A., Prabhu, R. 2000. Multiple criteria decision making approaches to assessing forest sustainability using criteria and indicators: A case study. Forest Ecology and Management 131 (1–3): 107–26.

Messner, F., Zwirner, O., Karkusche, M. 2006. Participation in multi-criteria decision support for the resolution of a water allocation problem in the Spree River Basin. Land Use Policy 23 (1): 63–75.

Morgan, R.K. 1998. Environmental Impact Assessment: A Methodological Perspective. Kluwer Academic Publishers. 307 p.

Munda, G. 2008. Social Multi-Criteria Evaluation for a Sustainable Economy. Springer-Verlag Berlin Heidelberg. 210 p.

Mustajoki, J., Hämäläinen, R.P. 2000. WEB-HIPRE: Global decision support by value tree and AHP analysis. INFOR 38 (3): 208–220.

Mustajoki, J., Saarikoski, H., Marttunen, M., Ahtikoski, A., Hallikainen, V., Helle, T., Hyppönen, M., Jokinen, M., Naskali, A., Tuulentie, S., Varmola, M., Vatanen, E., Ylisirniö, A.-L. 2011. Use of decision analysis interviews to support the sustainable use of the forests in Finnish Upper Lapland. Journal of Environmental Management 92 (6): 1550-1563.

Nandalal, K.D.W., Simonovic, S.P. (editors). 2003. State-of-the-art report on systems analysis methods for resolution of conflicts in water resources management. A report prepared for the UNESCO Division of Water Sciences. PCCP series, No. 4. 127 p.

Pöyhönen, M., Hämäläinen, R.P. 2000. There is hope in attribute weighting. INFOR 38 (3): 272–282.

Pöyhönen, M., Hämäläinen, R.P. 2001. On the convergence of multiattribute weighting methods. European Journal of Operational Research 129 (3): 569–585.

Pöyhönen, M., Vrolijk, H., Hämäläinen, R.P. 2001. Behavioral and procedural consequences of structural variation in value trees. European Journal of Operational Research 134 (1): 216–227.

Prato, T. 1999. Multiple attribute decision analysis for ecosystem management. Ecological Economics 30 (2): 207–222.

Pykäläinen, J., Kangas, J., Loikkanen, T. 1999. Interactive decision analysis in participatory strategic forest planning: Experiences from state owned boreal forests. Journal of Forest Economics 5 (3): 341–364.

Qureshi, M.E., Harrison, S.R. 2001. A decision support process to compare riparian revegetation options in Scheu Creek catchment in North Queensland. Journal of Environmental Management 62 (1): 101–112.

Regan, H.M., Davis, F.W., Andelman, S.J., Widyanata, A., Freese, M. 2007. Comprehensive criteria for biodiversity evaluation in conservation planning. Biodiversity Conservation 16 (9): 2715–2728.

Renn, O. 2006. Participatory processes for designing environmental policies. Land Use Policy 23 (1): 34–43.

Ridgley, M., Penn, D.C., Tran, L. 1997. Multicriterion decision support for a conflict over stream diversion and land–water reallocation in Hawaii. Applied Mathematics and Computation 83 (2–3): 153–172.

Saaty, T.L. 1988. Decision Making for Leaders: The Analytic Hierarchy Process for Decisions in a Complex World. University of Pittsburgh. RWS Publications. 291 p.

Sadok, W., Angevin, F., Bergez, J.-E., Bockstaller, C., Colomb, B., Guichard, L., Reau, R., Doré, T. 2008. Ex ante assessment of the sustainability of alternative cropping systems: Implications for using multi-criteria decision-aid methods. A review. Agronomy for Sustainable Development 28 (1): 163–174.

Salgado, P., Quintana, C.S., Pereira, A.G., del Moral Ituarte, L., Mateos, B.P. 2009. Participative multi-criteria analysis for the evaluation of water governance alternatives: A case in the Costa del Sol (Málaga). Ecological Economics 68: 990–1005.

Salo, A., Hämäläinen, R.P. 1997. On the measurement of preferences in the Analytic Hierarchy Process. Journal of Multi-criteria Decision Analysis 6 (6): 309–319.

Siebenhüner, B., Barth, V. 2005. The role of computer modelling in participatory integrated assessments. Environmental Impact Assessment Review 25 (4): 367-389.

Sinkko, K., Hämäläinen, R.P., Hänninen, R. 2004. Experiences in methods to involve key players in planning protective actions in the case of a nuclear accident. Radiation Protection Dosimetry 109 (1–2): 127–132.

Steele, K., Carmel, Y., Cross, J., Wilcox, C. 2009. Uses and misuses of multi-criteria decision analysis (MCDA) in environmental decision making. Risk Analysis 29 (1): 26–33.

Stewart, T., Losa, F.B. 2003. Towards reconciling outranking and value measurement practice. European Journal of Operational Research 145 (3): 645–659.

Stirling, A. 2006. Analysis, participation and power: Justification and closure in participatory multi-criteria analysis. Land Use Policy 23 (1): 95–107.

Weber, M., Borcherding, K. 1993. Behavioral influences on weight judgments in multi-attribute decision making. European Journal of Operational Research 67 (1): 1–12.

Weber, M., Eisenfűhr, F., von Winterfeldt, D. 1988. The effects of splitting attributes on weights in multiattribute utility measurement. Management Science 33 (4): 442–450.

Webler, T., Tuler, S. 2006. Four perspectives on public participation process in environmental assessment and decision making: Combined results from 10 case studies. Policy Studies Journal 34 (4): 699–722.

Weistroffer, H.R., Smith, C.H., Narula, S.C. 2005. Multiple criteria decision support software. In: Figueira, J., Greco, S., Ehrgott, M. (eds), Multiple Criteria Decision Analysis: State of the Art Surveys. New York: Springer Science+Business Media, Inc., pp. 989–1018.

Wenstøp, F. 2005. Mindsets, rationality and emotion in multi-criteria decision analysis. Journal of Multi-Criteria Decision Analysis 13 (4): 161–172.

Wondolleck, J.M., Yaffee, S.L. 2000. Making Collaboration Work: Lessons from Innovation in Natural Resource Management. Island Press. 277 p.

von Winterfeldt, D., Edwards, W. 1986. Decision Analysis and Behavioral Research. Cambridge University Press. 604 p.

Managing the use of natural resources in a sustainable way requires that ecological, social, and economic impacts be identified, assessed, and balanced. Decision analysis provides formal procedures, methods, and tools for quantitative analysis of decisions with multiple objectives and uncertainties. This thesis focuses on one specific methodology in decision analysis: multi-criteria decision analysis (MCDA). The overall objective of this thesis is to develop MCDA-based approaches that improve the quality of multi-stakeholder processes in large watercourse development projects. The main methodological result is the decision analysis interview (DAI) approach, which is developed and applied in five actual planning situations.

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