LAND & WATER CONSERVATION

MULTICRITERIA ANALYSIS - A TOOL FOR WETLAND MANAGEMENT DECISION MAKING

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Abstract

Many economic evaluations include the need to value non-market goods which can be time consuming, expensive and consequently often omitted. Therefore they can fall short of accommodating options with non-monetary values which are particularly prevalent in natural resource management. Multicriteria analysis can consider a wide range of alternatives and enables a choice of preferred alternatives based on weighting or tradeoffs between objectives. The technique is versatile in that it can be applied in varying degrees of complexity to qualitative and quantitative issues.

Multicriteria analysis has three main components:

- *A finite number of alternatives*
- *A set of criteria by which the alternatives or options are to be judged*
- *A method for ranking the alternatives according to how well they satisfy the criteria.*

This study undertook a literature review of multicriteria analysis with a particular reference to the complex issues of wetland management.

Keywords: Multicriteria analysis, wetlands, economics

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Multicriteria Analysis -
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1. Introduction

Decision making where natural resources are concerned can be a time consuming and complex task, often resulting in decisions which do not accurately portray the true value of the resource. Monetary based decision support methods such as cost/benefit analysis (CBA) often fail to deliver information which accommodates both economic and environmental aspects of the resource. Wetland management decision making is one such instance where the selection of policies for implementation will depend on qualitative, quantitative and imperfect information. The consideration of these variables as well as different points of view from interest groups can increase the complexity of the management problem. The ability to include both qualitative and quantitative information in the analysis makes multicriteria analysis suitable for establishing priorities where objectives are many and complex, as is often the case with natural resource problems.

Multicriteria analysis (MCA) as a management decision making tool can be used to evaluate alternative strategies in water resource management. Main issues and attributes related to the resources are stated as criteria. The impact of different management strategies on these criteria is then evaluated using both qualitative and quantitative indicators. Unlike the purely monetary based techniques MCA allows non-monetary values to be incorporated into the analysis making it a more comprehensive management decision tool.

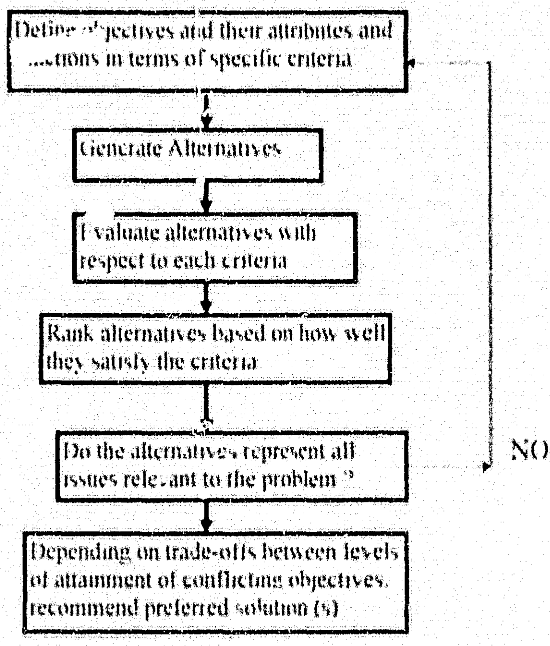
This paper will;
(1) introduce MCA as a decision support tool for wetland management,
(2) show how MCA can be used as an extension of other evaluation methods such as CBA,
(3) outline an MCA framework relevant to wetland management and
(4) show how this can be applied to the Macquarie Marshes in the selection of water management alternatives. The Macquarie Marshes will be used as a case study to illustrate how MCA can accommodate both environmental and economic criteria in management decision making. The development of alternative measures for non-monetary resources and the use of weights to incorporate different points of view were an important part of this analysis.

2. MCA -a wetland management decision making tool

MCA is a decision making tool that can be used in natural resource problems to evaluate a set of alternative scenarios for implementation using a finite set of criteria. MCA is concerned with resolving problems where there is a set of proposed options and several conflicting objectives (Nijkamp and Vos 1977). As a decision support system MCA allows the decision maker to rank objectives, resolve conflicts and identify areas of importance. In wetland management problems a large number of environmental and economic variables are often involved. The interrelationships between these variables add to the complexity of the problem. A MCA allows complexities to be resolved and project objectives formulated by providing a framework for management decision making (RAC 1992b).

The following tree diagram shows the MCA decision making process.

Figure 1: Multicriteria Decision Tree



Source: Adapted from Atkins and O'Brien (1978)

MCA increases the decision makers' control over the outcome of events by stating the objectives explicitly so that the relative value of different projects can be considered. The objectives used to evaluate the alternative options are often stated as economic criteria or assigned scores to reflect qualitative judgements on perceived importance. The decision maker in a MCA can then choose a set of preferred alternatives based on how well they satisfy the specified selection criteria.

MCA can be applied to a wide variety of economic and environmental problems such as water resource problems, biodiversity preservation and sustainable development (Gum, Roefs and Kimball 1976, Deason and White 1984, Giaoutzi and Nijkamp 1993, RAC 1992a and the Department of Natural Resources 1996). MCA provides various 'points of view' in the analysis which might otherwise have not been included (Gum et al. 1976). As a result the options assessed are not biased towards aspects which can only be measured in economic terms ie. income and employment, but take into account environmental, social and recreational factors related to the problem.

Applications of MCA usually include an integrated analysis of the effects of a proposed project in terms of:

- economic efficiency,
- regional development,
- environmental impacts, and
- social impacts.

Traditional economic valuation methods may not always include the true value of the non-market good and have a tendency to gloss over environmental issues in reaching the final decision (Qureshi, Greenfield, Kingham and Krol, 1995). In wetland management evaluations there are often several issues and attributes of the wetland environment that may not be placed in the analysis due to a lack of information on their monetary value. In such instances a need for a more comprehensive analysis that considers both monetary and non-monetary values in the decision is needed.

MCA provides a framework for incorporating economic and environmental values into the analysis. An MCA does not necessarily negate the need to carry out a CBA or contingent valuation study but can be adopted as an extension of these methods (Qureshi et al. 1995) with values generated from monetary valuation techniques incorporated into the criteria of an MCA. Specific ranges in CBA values can be used as part of the criteria for attributes that can be measured in monetary terms. A CBA ratio can be specified such that it must be satisfied by certain criteria under each alternative examined before that alternative option can be chosen for implementation.

3. Framework for multicriteria analysis

The framework for MCA needs to be flexible so that factors can be incorporated into the analysis as they arise. According to Roy (1990) the objective of MCA is to help the decision maker by structuring the problem so that any development limitations and ambiguity are stated clearly.

3.1 Major Components

The following is a framework for a MCA (Cohon 1978, p 16).

- Identify objectives and clearly state alternatives.
- Define decision variables and constraints, develop criteria.
- Collect data - develop a measurement scale to score criteria and set up an effects table.
- Generate and evaluate alternatives based on how well they satisfy the criteria.
- Conduct a sensitivity analysis by weighting the criteria based on different priorities.
- Select a set of preferred alternatives.
- Implement the selected alternative.

A MCA does not select a final project but rather provides a set of best possibilities based on the different objectives cited. According to Cohon (1978) it is this quality which makes it ideal for natural resource problems where different development paths can be chosen based on different priorities.

Four components which need to be evaluated in a MCA are (RAC 1992c):

- a finite number of alternative plans,
- a set of criteria by which the alternatives are judged,
- a method of ranking the alternatives based on how well they satisfy the criteria, and
- a sensitivity analysis to determine which alternatives are implemented.

3.2 Outline

The following method has been developed to rank criteria and analyse the alternative options put forward in a wetlands management problem and is applied in planning a multicriteria analysis for management options in the Macquarie Marshes.

1 Define the wetland area and specify the system boundary between this area and the surrounding region (Barbier, Acreman and Knowler 1996).

2 Specify the alternative options. These are the specific plans that are being put forward for evaluation in a MCA. Alternative plans that prioritise different aspects of the problem ie: economic, environmental and recreational, need to be included in the analysis to ensure that it is comprehensive. These initial alternatives do not need to be specific but do need to provide the analysis with some direction. Alternative options for implementation will be evaluated using the criteria developed in the next stage of the MCA.

3 State the important issues and potential objectives in the Macquarie Marshes that will need to be addressed in the study. These will form the criteria used in the study to evaluate the alternative options. Since the selection of alternative options will be based on how well they meet the criteria it is important that the different sources of information are considered and conflicting objectives are resolved from the outset. Jelassi, Kerston and Zoints (1990 p.539) suggest that a theoretical framework for group discussion and negotiation support should be a primary factor in developing criteria for use in a MCA. The Nominal Group Technique (NGT) (Deason and White, 1984) was adopted in developing the criteria for the Macquarie Marshes study. The steps involved in a NGT are outlined below:

1. Group members are chosen from the same professional level but from different fields of expertise.
2. The decision maker states the problem and discusses background information with group.
3. Individual group members silently generate ideas on objectives and issues important to the project. There is no discussion between participants as they brainstorm their ideas.
4. A group list of ideas is compiled by recording one idea at a time from each person on a black board by going around the group.
5. All ideas are discussed openly in the group before a set of criteria are chosen. This is for clarification and refinement purposes.

4 Identify components, functions and attributes of the wetland system and show how the components and attributes can be used to measure the different objectives. The criteria generated in the NGT are specified as measurable components, function and attributes of the wetland system. These can be considered to be the sub-criteria. When specifying the criteria four conditions need to be met (Keeney and Raiffa 1976):

- **Minimal and operational;** meaningful to the analysis and comprehensive.
- **Complete;** cover all areas of concern. Bouyssou (1990, p.63) also states that criteria need to be accurate and complete if the procedure is to warrant useful results.
- **Decomposable;** be broken down into sub-criteria which account for one or more specific attributes of the problem.
- **Non-redundant;** avoid double counting.

All potential criteria are identified and listed which allows non-operational ideas and politically sensitive ideas to be culled from the list. Group members may use a tree diagram to show how criteria are related. Criteria can be divided into categories using their attributes, for example main criteria and sub-criteria.

5. *Score the criteria using a pre-defined scale in an effects table.* After determining the required criteria for analysis the information needs to be presented in an effects table, which provides a way of valuing the criteria based on estimated impacts under each alternative specified (RAC 1992c). The rows in the effects table represent the alternative plans or options and the columns represent the criteria by which the alternatives are to be evaluated. Outcome scores for each criterion under alternative scenarios are displayed in tabular form. The actual or approximate values are used for each criterion measured under the different plans or a pre-defined scale may be used to assign scores to the criteria.

For objectives dealing with environmental attributes, as is often found in natural resource projects, unquantifiable criteria can be measured by assigning numbers to them that reflect their importance in the analysis. Any scale developed should have some level of economic or scientific information attached to it for completeness. The type of scale used with an effects table can be based on economic, scientific as well as qualitative information.

An ordinal scale can be used together with an effects table to assess alternatives when not enough quantitative information is available on the impacts. Under this type of scale scores are allocated reflecting the magnitude of the expected change in criteria under each alternative option. The scores assigned to the criteria using the pre-defined ordinal scale show the varying impacts of alternative options on the criteria examined. The use of a pre-defined ordinal scale in an effects table automatically standardises the scores allocated across the criteria for comparison purposes. This allows comparisons to be made between criteria especially where the measurements for these criteria vary or cannot be measured in monetary terms.

6. *Weighting the criteria for a sensitivity analysis.* A sensitivity analysis can be carried out by assigning weights to the main criteria to reflect changes in preferences. Once relationships have been defined and scores allocated, weights can be assigned reflecting the importance of the criteria to the analysis based on value judgements. For example, given two criteria economic and environmental quality, a higher weight may be allocated to the environmental criteria to represent conservation groups' preferences. In this case the selection of alternatives which meet more environmental criteria than economic criteria is more likely.

Group members vote on which criteria are the most important which allows criteria to be ranked. Scores for each criterion are tabulated and the weighted average scores calculated based on group votes. Voting on objectives allows them to be ranked in order of perceived importance using the scores (Deason and White 1984). The votes will be used to represent preferences of different interest groups and develop weights for the sub-criteria in the MCA. If voting is not convenient then a survey questionnaire may be sent out to the general public or interest groups to gather information on preferences (Gum et al. 1976). Preference weights can be incorporated into the analysis using weighted averages for defined interest groups. The sensitivity part of the analysis may be carried out using a computer package.

- *The alternatives that satisfy the most important criteria are selected for implementation.* Different alternatives will be chosen depending on the preference weights assigned to the criteria

4. Case Study - the Macquarie Marshes

The following is a summary of a study applying multicriteria analysis in an economic evaluation of the Macquarie Marshes being undertaken by the Resource Economics Group in the NSW Department of Land and Water Conservation (DLWC). The study is focussing on water management issues in the Macquarie Marshes wetlands.

4.1. Issues in wetland management

The following table outlines some issues important to environmental, economic and recreational criteria that need to be resolved in wetlands analysis.

Table 1: Evaluation Issues in Wetland Management

• environmental quality	• economic stability
⇒ ecology	⇒ landholder income
⇒ biodiversity	⇒ stability of local economy
⇒ birds, other fauna	⇒ job opportunities
⇒ fish	⇒ local economy investment
⇒ flora	⇒ cost of conservation
• water quality	• recreational opportunity
⇒ odour	⇒ facilities
⇒ erosion	⇒ aesthetic preservation
⇒ turbidity	⇒ admission costs
⇒ pesticides	⇒ access to wetlands
⇒ clarity	

In this analysis it was assumed that environmental and economic criteria were the two main criteria in the Macquarie Marshes. Water quality attributes were shown to be important to both these criteria and hence were included as sub-criteria. Recreational opportunity factors were not included as criteria in the analysis for the Macquarie Marshes since these only represent a small portion of the issues relevant to water supply management plans and wetlands in the area.

The initial stages of the analysis dealt with generating a list of important issues and potential objectives for evaluation in the Macquarie Marshes. Ideally a Nominal Group Technique, as described in the previous section, should be used as an integral part of criteria production. However due to time constraints an alternative method for generating the necessary information was adopted based on sources within the DLWC.

4.2 Development of Criteria for Evaluation

Using the MCA method developed in the previous section a list of important issues and potential objectives were generated for the Macquarie Marshes. The following is a portion of the original list used in the analysis. This list includes both environmental and economic criteria and deals with issues that are interconnected.

Table 2: Important issues and potential objectives in Macquarie Marshes MCA

- Water quality
- Erosion control in the Marshes
- Socio-economic stability
- The volume of inflows and outflows to the marshes and the extent of flooding
- The distribution and health of wetland vegetation, particularly River Redgum
- Reduction in the flow regime due to irrigation and construction of Burrendong and Windamere Dam
- Land use changes in Marshes resulting in clearing and decline of native vegetation and associated fauna
- The need to maintain and restore water resources in the Marshes
- Prevent further degradation of the Marshes by encouraging land use and agricultural activities which sustain wetland values
- Maintain the ecological character of the wetland and ensure the conservation of it
- Cotton growers required to adopt Best Management Practices (BMP's) to protect the environment - adopt the EPA environmental guidelines for irrigation farming
- Irrigators develop property management plans which are a condition of the water licence
- Maintain stock and domestic supply of water to current users

4.3. Environmental criteria

The paper focuses on the environmental criteria of this study. The following list outlines some of the main environmental criteria that were included in the MCA for the Macquarie Marshes.

Table 3: Environmental Criteria in Macquarie Marshes Wetlands Study

- Water resources used in irrigation, domestic, stock, industrial and town use.
- the frequency, size and success of waterbird events
- the status of native fish populations - for biodiversity
- the status of reptile and amphibian populations
- the status of aquatic invertebrate populations
- fertile land for agriculture
- Nutrient Retention
- Waterbird Breeding Sites
- provision of flood control by the wetland- flood plains reduces flood risk downstream
- groundwater recharge
- sediment pollutant retention - pollutants such as heavy metals may be retained with sediments in the reeds and grasses of the wetlands

It is apparent that many of these components are important to the value of wetlands and are often not accommodated in monetary based evaluation methods. Even though all these issues have been covered in the case study of the Macquarie Marshes only a selection will be discussed in this paper.

4.4. Evaluation of Environmental Criteria

The following steps outline important aspects of this case study and show how a pre-defined scale can be incorporated when evaluating the alternatives for non-monetary environmental criteria.

Step One: Determine the area of application. The area used in the analysis for the Macquarie Marshes was based on the definition given in the "Water Management Plan for the Macquarie Marshes" (DLWC and National Parks and Wildlife Services, 1996).

Step Two: Define the criteria and sub-criteria. In most natural resource problems the criteria defined in the decision process can often be divided into specific groups such as economic criteria, social criteria, recreational criteria or environmental criteria. The sub-criteria defined in these groups are then measured and the overall importance of the criteria determined based on these measurements. MCA examples which use sub-criteria as a function of the main criteria can be found in Deason and White (1984) and Gum, Roefs and Kimball (1976). Although the techniques used to assign weights and assess the criteria do vary the need to break criteria down into components which are measurable is an important part of MCA.

The division of environmental criteria into sub-criteria for the Macquarie Marshes case study is given in Table 4.

Table 4: Environmental Criteria and Sub Criteria

Broad Criteria and Definition	Sub Criteria			
Environment: Impacts based on current preservation levels undertaken in the marshes	Water quality close to natural levels	Water quantity close to natural flow conditions	Maintain Vegetation at its current state	Soil Quality

Step Three: Clearly define what is meant by impact in terms of each of the main criteria to be assessed. Here environmental impact refers to the reduction in actual or beneficial values compared with current preservation levels in the absence of land and water degradation. This definition can be varied depending on the type of criteria being examined but it essentially remains the same in meaning.

Step Four: Define the scale and scoring benchmarks to be used in the analysis. An ordinal scale was utilised in this part with a score between 1 and 5 assigned to the criteria based on the expected impact of each alternative option examined. A score of 1 was allocated when there was a low impact whereas a score of 5 was for a very high impact.

Step Five: The most important part of scoring the criteria using a pre-defined ordinal scale is to make sure that the meaning of the scores allocated for the impacts remain consistent throughout the analysis even for different criteria. That is, a score of 5 under both economic and environmental criteria will be associated with a high impact.

Table 5 gives a selection of the environmental criteria used in the MCA. The meanings behind the definitions in an ordinal scale change depending on the criteria under consideration however, the scores allocated to the criteria are consistent in their definitions. The availability of data and value judgements of the decision makers will be an important part of the assessment procedure. According to the Department of Natural Resource Economics Priorities Team

(1996) 'scoring should be on the basis of quantitative information as far as possible, and beyond that from the judgement and experience of participants in the scoring workshop'.

Some of the sub-criteria included in the environmental criteria are measures of two separate attributes. For example even though water birds are an important part of the Macquarie Marshes biodiversity and wildlife they have not been included in the sub-criteria as separate components. The reason for this is that the sub-criteria of water quantity can be viewed as a measure of the level of breeding in the Marshes. If the combined effect of natural and dam releases is close to natural levels then bird breeding will remain at a sustainable level. A score of 3 or greater under the sub-criteria of WATQUANT will indicate a water supply that allows for a sustainable level of bird breeding in the area as well as indicating water quantities close to natural flows.

Table 5: Environmental Criteria for Health and Distribution in Wetland Ecosystems

Sub Criteria Indicators	Score	Desirable/ Undesirable	Compared to current state	Category Definition
Extent of Broad Vegetation Types (VEG)	5	Desirable	High Impact	A high impact will mean a large % increase in area of BVT's expected under the scenario examined compared to pre-scenario situation
	4			
	3			
	2			
	1		Low Impact	
Preserve River Redgums (REDRIV)	5	Desirable	High Impact	A high impact will indicate a large proportion of trees preserved under the scenario examined.
	4			
	3			
	2			
	1		Low Impact	
Number of endangered or vulnerable species (ENDSPEC)	5	Undesirable	>20	The score reflects the expected number of endangered or vulnerable species.
	4		15-20	
	3		10-15	
	2		5-10	
	1		1-5	
Water Quality (WATQUAL)	5	Desirable	100%	The impact of the scenario on nutrient and pesticide content of the water.
	4		75%	
	3		50%	
	2		25%	
	1		0%	
Pollutants retained in the soil from fertilisers and spraying (SOILPOLL)	5	Undesirable	High Impact	This refers to the amount of sediment, fertiliser residue or heavy metals expected to be found in soils in the wetland under the scenario examined
	4			
	3			
	2			
	1		Low Impact	
Soil erosion by water (SOILERO)	5	Undesirable	High Impact	Soil erosion can be caused by high levels of water being passed through the Marshes
	4			
	3			
	2			
	1		Low Impact	
Species diversity Native mammals and wildlife (SPECDIV)	5	Desirable	High Impact	High means a sustainable and increasing level in the number of species.
	4			
	3			
	2			
	1		Low Impact	
Water releases as close as possible to natural flows (WATQUANT)	5	Desirable	100% Natural	Combined effect of natural and dam releases are considered in this analysis.
	4		75%	
	3		50%	
	2		25%	
	1		0%	
The extent of weeds, clearing and vegetation changes (CLWEEDS)	5	Undesirable	>20%	A score of 5 will reflect an expected detrimental change in vegetation greater than 20% of the current area
	4		15%-20%	
	3		10%-15%	
	2		5%-10%	
	1		<5%	

Step six: Specify the alternative options to be assessed using the criteria developed. The alternative options used in this study were derived directly from river flow objectives developed for the Macquarie Valley (DLWC 1996) as part of the NSW Government 1995 Water Reform Package. The objectives developed and used in the MCA for the Macquarie Marshes are listed below.

Table 6: Alternative Options for Assessment

Alternatives	Explanation
Current Conditions	93/94 level of irrigation, development and on-farm management
Higher Wildlife Allocation	Current conditions but with a higher wildlife allocation
1996 Water Management Plan	System operated in accordance with the 1996 Macquarie Marshes Water Management Plan
Natural Flow Conditions	Hypothetical conditions with no water pumped from river for on-farm use
No Cotton	Current conditions but with no cotton grown in the area
No Grazing	Current conditions but with no grazing on Marsh land

Step Seven: Assess the impact of each alternative on the criteria using the scale developed in Table 5. Using scales and scores overcomes the problem of inadequate data on the expected impacts of alternative options on natural resource criteria. Environmental criteria dealing with biodiversity, flora and fauna as well as water quality can be allocated a value using the scores developed in the scale in Table 5. The inclusion of such criteria in the analysis, previously considered to be unmeasurable, allows a more complete investigation into the likely impacts of alternative scenarios to occur in the effects table.

Table 7 shows how a set of scores for each environmental sub-criterion is added and averaged to provide a subtotal for the alternative option considered. The subtotal shown reflects how important the alternative option is to water supply management in the Macquarie Marshes. The greater the subtotal, the more likely this option will be chosen for implementation in the Marshes.

Table 7: Effects Table for some Environmental Criteria

	Criteria					
Alternatives	**VEG**	**ENDSPEC**	**WATQUAL**	**SOILPOLL**	**WATQUANT**	**SUB-TOTAL**
Current Conditions	3	-2	3	-3	4	5
Higher Wildlife						
1996 Water Management Plan						
Natural Flow Conditions						
No Cotton						
No Grazing						

Using the ordinal scale developed in Table 5, the decision maker can assign a score or ranking to the criteria based on the expected impact of the alternative option considered. In the above table the impact scores for the alternative option 'current conditions' was only considered for illustrative purposes. Negative scores indicate undesirable criteria and a positive score desirable criteria. A score of 3 under vegetation shows an expected medium percentage increase in the level of Broad Vegetation Types.

Step eight: Once the scores have been allocated to the criteria different weights can be assigned to reflect the criteria which are of priority to the decision maker. Weights are primarily used for a sensitivity analysis. The information collected in the effects table can now be used as input in a computer package such as 'Topdec', designed for assessing environmental management options. 'Topdec' utilises this information together with criteria weights assigned by the decision maker to rank the alternative options.

Preference weights assigned to the sub-criteria can be provided by the decision maker, interest groups or the general public. In the Macquarie Marshes case study weights were allocated based on the expected preferences for different interest groups. The expected weights assigned to represent different interest groups formed part of the sensitivity analysis where changes in the criteria weights resulted in changes in the alternatives chosen for implementation in the Marshes.

5. Conclusions

The main characteristics of a wetland management problem are the conflicting economic and environmental objectives, the different points of view from stakeholders, the lack of quantitative information on the ecosystem and uncertainty associated with the impacts of decisions. A structured framework as provided by MCA has been shown to help decision making for natural resource problems where the examination of several conflicting criteria is required.

The inclusion of value judgements in a MCA allows more environmental impacts to be accounted for in the assessment of natural resource management problems such as determining optimal supply of water to wetlands. A lack of quantitative information on environmental criteria is a major factor affecting valuation of wetland management issues. Criteria specified for wetlands management options are typically stated in different units of measurement and may be qualitative. MCA allows both quantitative and qualitative information to be considered in the analysis. For comparison these can be expressed in the same measurement scale using MCA techniques such as a standardised effects table or a pre-defined ordinal scale.

The use of weights to evaluate alternatives in a MCA allows preferences of different interest groups to be incorporated into the analysis. A computer package such as 'Topdec' allows complex relationships between criteria to be structured and alternatives to be re-assessed based on priority weights. The use of a decision support system such as MCA provides the necessary framework for evaluating wetland management issues and water supply problems where both quantitative and qualitative values are involved.

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