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Validation of multicriteria analysis models

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Abstract

Validation procedures play an important role in establishing the credibility of models, improving their relevance and acceptability. This article reviews the testing of models relevant to environmental and natural resource management with particular emphasis on models used in multicriteria analysis (MCA). Validation efforts for a model used in a MCA catchment management study in North Queensland, Australia, are presented. Determination of face validity is found to be a useful approach in evaluating this model, and sensitivity analysis is useful in checking the stability of the model. © 2000 Elsevier Science Ltd. All rights reserved.

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1. Introduction

A systems model may be viewed as a scientific theory and, like any other scientific theory should be tested for validity. It is necessary for researchers (modellers) to perform a certain amount of testing to gain confidence in any model they develop, as well as demonstrate to others that the model is a reliable representation of a real system. For various and understandable reasons, modellers appear to have paid insufficient attention to establishing the acceptability of their creations (Harrison, 1987).

A model is a representation of an object, system or idea in some form other than that of the entity itself. Its purpose is usually to aid in explaining, understanding or improving performance of a system. A model of an object may be an exact replica of the object (although executed in a different material and to a different scale), or it may be an abstraction of the object's salient properties (Shannon, 1975). A model is, by definition, a simplified version of a part of reality, not a one-to-one copy. Braat and van Lierop (1987) argued that this simplification makes models useful because it offers a comprehensible description of a problem situation. However, the simplification is, at the same time, the greatest drawback of the process. It is a difficult task to produce a comprehensible, operational representation of a part of reality, which grasps the essential elements and mechanisms of that real world system and, even more demanding, when the complex systems encountered in environmental management are involved.

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Issues relevant to management of the environment and natural resources are complex, and often involve various stakeholder groups with conflicting objectives. For sustainable use of environmental and natural resources, there is a need for a systematic approach to evaluate policy options. Multicriteria analysis (MCA) is a useful approach that can incorporate a mixture of quantitative and qualitative information and take account of the preferences of various stakeholder groups. Validation of models used in MCA procedures is a difficult task because it involves many different parameters which affect the model's ability to simulate the outcome of policy options. MCA has been used to compare riparian revegetation options for Scheu Creek catchment, a small catchment in cane-farming land in North Queensland (Qureshi, 1999). Various approaches were applied to test the acceptability of the MCA procedures.

This paper briefly reviews methods of model validation and their application to models of natural systems. The major part of the paper discusses efforts to establish the validity of an MCA model or process developed to compare riparian revegetation options for the Scheu Creek catchment of North Queensland.

2. Model validation

A useful framework for viewing model evaluation is to divide the process into three components, namely verification, validation and sensitivity analysis.[1] Verification refers to building the model correctly, i.e. substantiating that a model properly implements its specifications (O'Keefe et al., 1991). Verification ensures that the model has been developed in a formally correct manner in accordance with a specified methodology (Geissman and Schultz, 1991). In the case of an algebraic model implemented by computer program, verification establishes that the program has been written correctly for the computer and that it behaves as intended.

Validation refers to building the 'correct model', i.e. establishing that a model achieves an acceptable level of accuracy in its predictions (O'Keefe et al., 1991). Tests of data validity, conceptual validity and operational validity may be conducted to determine whether the structure of the model is appropriate for its intended purpose (Harrison, 1987). In practice, most attempts at model validation appear to check for close agreement between outputs of the model and those of the real system, i.e. the validation process has largely been confined to checking operational validity, or the ability of a model to mimic the real system. For these comparisons to be valid, model and real system outputs need to have been generated for the same management policies and under the same sets of uncertain environmental values.

Sensitivity analysis examines the extent of variation in predicted performance when parameters are systematically varied over some range of interest, either individually or in combination. This form of testing may be viewed as checking the stability of a model which has been validated as far as is practicable. Sensitivity analysis provides further confidence in a model, and indicates priority areas for refinement if further versions of a model are to be developed.

Model validation methods include testing for predictive ability, assessment for face validity (including Turing tests), comparison against performance standards, and examination of scope validity (Harrison, 1991; O'Keefe et al., 1991). Statistical methods—both inferential and descriptive—are sometimes used to compare model and real system outputs. Statistical inference approaches include hypothesis tests and confidence intervals. Descriptive statistics (means, variances, autocorrelation coefficients and graphs) are commonly used to compare model outputs with real system values. O'Keefe et al. (1991) reviewed four quantitative approaches to model validation, namely paired sample *t*-tests, Hotelling's one-sample *t*-test, simultaneous confidence intervals and consistency measures.

In practice, most validation efforts appear to have involved a graphical comparison of model and real system outputs. This may be viewed as a comprehensive but subjective form of testing predictive ability. Output variables which have been plotted include performance levels over time,

[1] The following review draws on Harrison (1987, 1991).

means and variances, as well as extreme values over replicates (Harrison, 1987). When no observations on the real system are available, an assessment of face validity by people familiar with the system may be all that is possible.

Subjective or statistical testing can never prove that a model is valid in an absolute sense, even under the management policies and environments for which the real system has been observed. Because the model is a simplification and abstraction from the real system, the performance levels predicted by the model will differ from those of the real system. The question is whether the difference is so great as to be of practical importance. Validation is a matter of degree rather than a process with a clearly identifiable finishing point. The process continues until sufficient confidence is built up in the model to use it for practical purposes. Confidence is usually gained as a model proceeds through a number of prototypes. The 'acceptable performance range' should be specified during model development (O'Keefe et al., 1991). Harrison (1987) observed that validation tests appear to be problem dependent and that few general rules can be laid down.

3. Evaluating models for environmental and natural resource management

Environmental issues are complex and the time and spatial scales involved as well as the diversity of environmental effects are such that the implications of decisions affecting the environment are not always readily apparent. This complexity, and the number of stakeholder groups involved, makes it difficult to arrive at decisions which accommodate stakeholders' wants and needs. Environmental management involves consideration of social, political and physical indicators as well as economic factors. In designing and selecting environmental policies, decision-makers have to deal with monetary and non-monetary, as well as quantitative and qualitative, information.

Environmental management is essentially an exercise in conflict analysis, evaluation, and action characterised by socio-economic, environmental and political value judgements. Often there is a high degree of diverging public interest in the management of a particular bundle of natural resources and conflict among groups in society about how these resources should be used. Hence local, regional and national government agencies play a key role and it is difficult to arrive at straightforward, undisputed and unambiguous solutions in any environmental planning process (Munda et al., 1994).

MCA has been considered an appropriate approach to examine the impact of various policy options relevant to natural resources and environmental management (Janssen and Nijkamp, 1984; Nijkamp, 1989; Lutz and Munasinghe, 1994; Fleming and Daniell, 1995). MCA is both a conceptual framework and a set of techniques, of varying complexity, designed to guide choice in a way that is consistent with stakeholder preferences. MCA provides insights into the nature of conflicts between stakeholders regarding the use of resources (Munda et al., 1994), and allows the advantages and disadvantages of each option to be compared in a structured framework (RAC, 1992). The analytic hierarchy process (AHP) is frequently used as part of an MCA assessment. AHP helps in structuring a problem in an hierarchical way and obtaining preferences among different stakeholder groups for various outcomes with respect to particular natural resources.

MCA is potentially a complementary appraisal tool to cost–benefit analysis (CBA) (van Pelt, 1993; Lutz and Munasinghe, 1994). Lutz and Munasinghe (1994) suggested using CBA where possible to evaluate environmental management options, and recommended use of MCA to analyse consequences that cannot be measured in monetary terms. MCA can incorporate cost–benefit estimates such as net present value (NPV) as one element of the multi-dimensional consideration of using natural resources.

As with validation of models in other areas, MCA modellers have paid less attention to the credibility of models than to model development. Validation is not generally regarded as a critical component in the development of well-structured models such as mathematical programming models since the model structure is well recognised, and reasonably well accepted. However, MCA models go beyond mathematical programming, and hence have a greater testing requirement.

Table 1 summarises testing procedures employed in recent MCA studies in natural resource and environmental management. Except for Braat (1992), none of these studies carried out the three components of model testing (verification, validation and sensitivity analysis). Jones et al. (1990) tested their multi-attribute model by obtaining the views of model users through workshops. Sensitivity analysis was reported by Bodini and Giavelli (1992), Hokkanen and Salminen (1994), Abu-Taleb and Mareschal (1995), Janssen (1996) and van den Bergh et al. (1996). Others did not report any steps to establish the credibility of their models.

4. Case study: evaluation of Scheu Creek catchment multicriteria analysis

Scheu Creek in the Johnstone River catchment in coastal North Queensland, Australia, runs for 13 km through a high-rainfall volcanic area used predominately for sugarcane production. Farmers along the creek have cleared trees off banks and in some sections straightened the creek, increasing the velocity of water flow and ultimately the risk of downstream flooding. Soil erosion is a common problem in the catchment and the creek is heavily degraded due to growth of Para Grass (*Brachiaria mutica*) which has reduced water depth and flow velocity. The grass mass provides a habitat for rodents which can cause

Table 1
Evaluation procedures reported in studies of natural resource and environmental management

Topic, author and country	Model testing procedures adopted
Sustainable environmental management, Netherlands (Nijkamp, 1989)	No evaluation steps reported
Multi-attribute value model for the study of energy policy, UK (Jones et al., 1990)	Validation by obtaining comments from users of the model
Compatibility of conservation and development, Salina Island, Aeolian Archipelago, Italy (Bodini and Giavelli, 1992	Sensitivity analysis to test the results but no validation
Sustainable multiple use of forest ecosystems, Netherlands (Braat, 1992)	Verification, validation and sensitivity analysis used to evaluate the model
Solid waste management system, Finland (Hokkanen and Salminen, 1994)	Sensitivity of alternatives evaluated by changing weights and threshold values; technical reliability evaluated using expert questionnaire
Environmental assessment of electric transmission project, Quebec, Canada (Rousseau and Martel, 1994)	No evaluation process reported
Energy planning, Greece (Mavrotas et al., 1994)	No evaluation procedures reported
Water resource planning, South Africa (Stewart and Scott, 1995)	Questionnaire administered to all interest group representatives to establish credibility of model
Water resource planning, Middle East (Abu-Taleb and Mareschal, 1995)	Sensitivity analysis to compare alternative options under different weighting schemes and changes in constraint levels
Coastal management, Greece (Moriki et al., 1995)	No evaluation steps reported
Sustainable use of forests, Australia (Janssen, 1996)	Sensitivity analysis carried out by changing criteria scores ($\pm 25\%$)
Multicriteria evaluation for a Greek Island Region (ven den Bergh et al., 1996)	Sensitivity of results regarding uncertainty of weights and scores investigated
Land and water management plan, NSW, Australia (Assim et al., 1998)	No evaluation steps reported

severe crop damage in sugarcane and impose major control costs (Harrison et al., 1998). Water quality has deteriorated and fish numbers are low. Sedimentation has reduced the depth and attractiveness of local swimming holes. Sugarcane farming involves heavy fertiliser use, and there is concern that sedimentation and nutrient transport may have adverse effects on adjacent areas of the Great Barrier Reef Marine Park, a World Heritage Area.

The appropriate design and width of riparian vegetation buffer zones in sugarcane production areas is a matter of considerable debate. In part, this is due to the multi-purpose nature of these strips, e.g. dense grass can control runoff but only large trees will bind banks and reduce water temperatures in summer. Conservation agencies would like the buffers to be wide and largely wooded but farmers are loath to re-allocate valuable cropping land for these purposes, and trees on headlands present problems for turning of cane harvesters.

The Scheu Creek catchment study involved a number of components, including: identification of major environmental, social and economic issues in the catchment; identification of appropriate riparian revegetation options and stakeholder groups; estimation of environmental, economic and social impacts of riparian revegetation options; elicitation of preference weights of environmental, economic and social objectives and sub-objectives from stakeholder groups; combination of environmental, social and economic impacts of revegetation options and incorporation of preference weights of stakeholder groups; and determination of optimal riparian revegetation options.

A 'long list' of potential objectives of catchment management for catchment stakeholders was drawn up from a review of the literature. A survey of resource management specialists, landholders and other community representatives allowed a shortlist to be obtained. Remaining issues were grouped under the headings of three objectives (environmental, social, and economic), with six environmental, three social and three economic sub-objectives (Harrison and Qureshi, 1999).

A survey by Harrison and Qureshi (1999) revealed that planting vegetation (particularly trees) is a repair practice for riparian areas favoured by both landholders and non-landholders. Depending on the location on the bank profile, various species have been suggested as appropriate in North Queensland, e.g. Goosam and Tucker (1995) and Bell (1996). Views were found to differ as to the appropriate width of vegetation buffers. The outside of meanders tends to have most rapid water movement and be most prone to erosion from highflows. After discussions with staff of the Department of Natural Resources (DNR), the Department of Primary Industries (DPI) and the Johnstone River Catchment Management Association Inc. (JRCMA), four riparian revegetation options were identified for Scheu Creek, differing mainly in terms of tree buffer width.

1. Option A: inside meanders 3 m, outside meanders 6 m, straight reaches 3 m;
2. Option B: inside meanders 5 m, outside meanders 10 m, straight reaches 5 m;
3. Option C: inside meanders 5 m, outside meanders 5 m, straight reaches 5 m; and
4. Option D: inside meanders 10 m, outside meanders 10 m, straight reaches 10 m.

Five major stakeholder groups were identified in discussions with DNR, DPI and the JRCMA, namely farmers of the Scheu Creek catchment, sugar mill staff, recreational fishermen, the local community and environmentalists.

Questionnaires designed according to the AHP were used to obtain preferences for various objectives, sub-objectives, and revegetation options from the five stakeholder groups. Questionnaires designed to obtain experts' subjective estimates[2] of impacts for each revegetation option were also distributed; an economic (spreadsheet) model was developed to estimate economic impacts of revegetation options; and MCA evaluation procedures were used to rank revegetation options for each stakeholder group. The outputs of the economic model (net present values for the various

[2] These experts were involved in a major riparian vegetation project funded by the Land and Water Resources Research and Development Corporation.

revegetation options[3]), subjective estimates of the impacts of revegetation options, and preference weights for the objectives by the various stakeholder groups, were used as part of the MCA. These impacts have been expressed in the form of an effects table, and rankings of revegetation options according to five stakeholder groups obtained, as presented in Table 2.

Rankings under all three methods are identical for farmers and sugar mill staff, Option A which has the narrowest riparian buffer being most preferred and Option D least preferred. For the recreational fishermen's representative, Option D is most preferred and Option A is least preferred. For the local community representative, Option D is most preferred under two MCA methods, while Option C is most preferred according to the other method. For the environmentalists' representative, Option D is the most preferred by two methods, while Option A is the least preferred. These rankings allow policy implications to be drawn, given the relevant legislation and regulations. For the process to be used with confidence, the rankings need to be a reliable representation of the optimal revegetation policies for the various stakeholder groups.

Table 2
Rankings of options by five stakeholder groups under three evaluation methods

Stakeholder group	Evaluation method	Ranking of options
Farmers	Weighted Summation	A > C > B > D
	Expected Value	A > C > B > D
	Evamix	A > C > B > D
Sugar mill staff	Weighted Summation	A > C > B > D
	Expected Value	A > C > B > D
	Evamix	A > C > B > D
Recreational fishermen	Weighted Summation	D > B > C > A
	Expected Value	D > B > C > A
	Evamix	D > B > C > A
Local community	Weighted Summation	D > C > B > A
	Expected Value	C > D > B > A
	Evamix	D > B > C > A
Environmentalists	Weighted Summation	D > B > C > A
	Expected Value	B > D > C > A
	Evamix	D > B > C > A

Evaluation in this case does not refer to the testing of a single model, but rather to the assessment of performance of a combined set of procedures—including the AHP, the economic model to compare impacts of alternative revegetation options, and ultimately the rankings of the various options under MCA evaluation procedures.

4.1. The verification procedure

Verification was performed by checking the numerical calculations of the computer software packages Expert Choice and DEFINITE used to analyse the impacts of riparian revegetation options and to determine optimal policies. Numerical calculations for the economic model, and survey data to obtain preference weights of objectives and sub-objectives of stakeholder groups, were carried out in a spreadsheet (Microsoft Excel), and steps were taken to ensure that the spreadsheet formulae were correct.

4.2. Testing for face validity

Testing for face validity is the only relevant approach to validation of the present model because no real-system data (such as the impact of alternative revegetation options on water quality, stream habitat or streambank stability) were available. Experts familiar with modelling of natural systems and catchment management decisions were contacted,[4] and they agreed to assist in testing the model's reasonableness. They were sent a summary of the results of MCA with questions

[3] Discounted cash flow analysis has been applied to those costs and benefits which could be quantified, and net present value of each option is used as one criterion in the MCA model.

[4] The experts worked in government and community-based resource management agencies, and universities. Their areas of expertise include systems modelling, natural resource and environmental management, project evaluation and decision support systems. One of the authors had discussions with these people about the model, read their publications and became familiar with their research work.

concerning the reasonableness of model outputs. Results were presented in the form of tables, charts and graphs, and were distributed to experts by post, electronic mail and fax. A total of nine binary (Yes/No) questions were included and further elaboration was invited. Evaluation comments are now summarised.

4.2.1. Suitability of riparian revegetation options for Scheu Creek

The experts were asked whether they considered the four riparian revegetation options appropriate for Scheu Creek. Six out of 11 respondents replied "Yes" and one "No". Supplementary comments included:

1. revegetation options should be approved at a meeting by stakeholders;
2. proposed buffers seem too narrow; and
3. "Is there any biophysical reason why 3 m width will perform differently from 5 m width in high rainfall events?" (Some differences would be expected in bank stability, sediment trapping and habitat value.)

4.2.2. Identification of farmers, sugar mill staff, recreational fishermen, local community, and environmentalists as relevant stakeholder groups

Experts were asked whether they thought the five groups include all relevant stakeholders. Five agreed but six respondents answered "No", questioning the exclusion of organisations, departments and regulatory agencies such as Landcare Groups, Canegrowers, Local Government Authorities (in particular the Johnstone Shire Council), the Integrated Catchment Management Committee, the River Improvement Trust, the Queensland Environment Protection Agency, the Great Barrier Reef Marine Park Authority, and other Commonwealth Government departments. It was also suggested that experts on revegetation management should have been included. In defence of the model, the study sought to find preferences among those stakeholder groups whose objectives in regard to revegetation options might conflict, i.e. those who would benefit and those who would suffer costs from riparian revegetation. While the possibility of conflict among agency goals is recognized, this analysis assumes that the above-mentioned agencies faithfully serve all groups in the catchment.

4.2.3. Acceptability of objectives

The respondents were asked whether the three major objectives—environmental, social, and economic—are a fair representation of what is required to achieve sustainable catchment management. Eight out of 11 agreed and only two dissented. Supplementary comments included:

1. "development of approaches for sub-catchment use" should have been included as another objective, with the Environment Protection Agency included as a stakeholder group, which presumably would weight this objective highly;
2. the analysis integrates the three objectives well; and
3. the objectives are legitimate but their interpretation by different stakeholder groups may differ. (Briefing and question design for the AHP survey was designed to limit this potential source of error.)

4.2.4. Rankings of objectives

Experts were asked whether rankings by the five stakeholder groups of the three major objectives (reported in Appendix A, Table A1) are in accord with expectations. Six respondents answered "Yes" and five said "No". Comments included:

1. social issues would be expected to be rated more highly by the local community and environmentalists;
2. sugar mill representatives might be expected to provide different ranking of social and environmental objectives;
3. the low emphasis on social objectives is not surprising; and
4. stakeholders may be confused about the relationship between these three objectives.

Every effort was made during data collection (when preferences for objectives were obtained) to clarify the theme, concept and structure of each question and the respondents had ample opportunity to ask questions. When they felt it necessary, respondents discussed various parts of the questionnaire with family members before providing answers. The low ranking of social objectives agrees with the results of a survey by Harrison and Qureshi (1999). Possibly, the social objective is not ranked highly because there was no controversial social issue in the catchment at the time of interviews.

4.2.5. Representation of three major objectives by 12 sub-objectives

The experts were asked whether the 12 sub-objectives chosen to define sustainable catchment management (presented in Appendix A, Table A2) and are a reasonable representation of the situation. Eight of the 11 agreed. Comments included:

1. this may not be a complete list of sub-objectives, and the way they were derived may be questioned. Impacts on property values, tourists, employment and reduction in downstream flooding should be included;
2. the social dimension of the objectives is weak, and social variables should include farm business stability and equity between the stakeholder groups;
3. the sub-objectives are too narrow;
4. the three major objectives are broad and it is appropriate that an attempt had been made to break them into sub-objectives;
5. aesthetic and heritage values should be included in social sub-objectives, but recreational fishing should be excluded;
6. viable communities and infrastructure are important social sub-objectives, and ecosystem function values of the catchment should be included among economic objectives; and
7. all sub-objectives have economic implications.

It would be possible to define a long list of objectives, if these were taken to a fine level of detail, but a compromise is needed to keep the analysis manageable.

4.2.6. Rankings of sub-objectives

Respondents were asked whether rankings of the 12 sub-objectives by various stakeholder groups (indicated in Appendix A, Table A2) are in accord with expectations. Nine out of 11 respondents said "Yes" while two disagreed. The comment was made that 'groundwater quality' should be a higher priority for all stakeholder groups. It is notable that groundwater is not used for drinking and little irrigation is practised in this high rainfall area.

4.2.7. Appropriateness of overall rankings for Scheu Creek catchment

The last question inquired whether the overall rankings of the riparian revegetation options (reported in Table 2) are in accord with expectations and appropriate for the Scheu Creek catchment. Five replied "Yes" and one "No". Comments included:

1. not sufficiently familiar with the particular catchment to make a judgement;
2. not aware of anything that would make the results invalid;
3. the results seem appropriate, but it is not possible to give an unequivocable OK to the model; and
4. validation by other approaches (or comparison with the results of a similar analysis in another catchment) may provide a more rigorous validation (if time and resources permit).

Overall, the experts were reasonably satisfied with the MCA and where criticisms have been raised the approach adopted appears defensible. It is concluded that face validity testing does, in general, enhance the credibility of the Scheu Creek Catchment Model.

4.3. Sensitivity analysis

The DEFINITE software package (Janssen and Herwijnen, 1994) used to rank riparian revegetation options has the facility for performing testing procedures for methods uncertainty, effects uncertainty and weights uncertainty. These procedures have been applied to examine the stability of rankings for revegetation options across stakeholder groups.

4.3.1. Methods uncertainty

Three methods—namely Weighted Summation, Expected Value and Evamix—have been used to evaluate impacts of riparian revegetation options.[5] Sensitivity analysis has been carried out to examine the robustness of the rankings under these methods. Rank orders of the four options by five stakeholder groups are presented in Table 2. Rankings do not vary between methods for farmers, sugar mill staff or fishers; minor changes in ranks take place for the other two stakeholder groups. Overall, rankings are highly robust to choice of solution method.

4.3.2. *Values of effects uncertainty*[6]

The 'values of effects uncertainty' procedure estimates the influence of uncertainty about the value of each effect (or sub-objective) on the ranking of revegetation options. Values of effects for the five stakeholder groups are represented as ranges (−30 to +30%) either side of the point estimates. DEFINITE uses Monte Carlo sampling to generate random values from these probability distributions. A set of rankings is obtained for each set of random values. The number of times each of the four options was ranked first, second, third and fourth has been computed, and probabilities are estimated and reported in a probability table. The conclusion is based on the differences between the weighted sums of the probabilities of all rank numbers of the four options (Janssen and Herwijnen, 1994). The original rankings of the revegetation options, and the rankings after deviation in the values of effects, are presented in Table 3.

Placing probability distributions on the values of effects does not change rankings of revegetation options, with the following minor exceptions. For the local community, under two solution methods there is a single change in rankings, Option C being downgraded. For environmentalists, there is a single change in rankings, Option B advancing ahead of Option D under one solution method.

[5] The type of information required varies between these methods. For example, the Weighted Summation method requires quantitative information of the values of effects (called sub-objectives) and their preference weights, while the Expected Value method requires only qualitative information.

[6] 'Effects' refers to the environmental, social and economic sub-objectives.

4.3.3. *Weights of effects uncertainty*

The 'weights of effects uncertainty' procedure assesses the sensitivity of ranking of revegetation options to changes in the weights for each sub-objective varies for the stakeholder groups. Weights of effects for the five stakeholder groups are represented as ranges of −30 to +30% either side of the point estimates. Similar steps are applied to those for values of effects uncertainty. The original rankings and the rankings after deviation in the weights of effects are indicated in Table 4. Minor changes in rankings take place for the last three stakeholder groups, confined to the Weighted Summation and Expected Value methods.

5. Conclusions

Evaluation of a multicriteria analysis includes a broad range of activities designed to assess the model's overall reliability for its intended tasks. For MCA of environmental and natural resource management issues, there is need for appropriate approaches to evaluation. Because MCA methods are different from strictly quantitative models, such as linear programming, where sensitivity analysis is usually considered sufficient testing, or simulation models, where it is often possible to compare inputs and outputs, sensitivity analysis is the only form of testing normally applied to MCA models.

To gain confidence in the Scheu Creek model, three stages of testing—verification, validation and sensitivity analysis—have been performed. The comprehensive but subjective face-validity approach involved eliciting experts' judgements about various aspects of the analysis. While these judgements are not totally supportive of the modelling and its results, they are generally favourable and it is possible to reconcile differences. Some discrepancies have arisen because not all the experts are familiar with the particular sub-catchment being studied. Also, the approaches adopted here (MCA, AHP) are complex and difficult to explain to scientists. However, the results of the analysis are robust because they consider economic and environmental impacts of revegetation options and incorporate preferences expressed by various stakeholder groups. The process of model

Table 3
Rankings of options after 30% deviation in values of effects

Stakeholder group	Evaluation method	Original rankings	Rankings after deviation in values
Farmers	Weighted Summation	A > C > B > D	A > C > B > D
	Expected Value	A > C > B > D	A > C > B > D
	Evamix	A > C > B > D	A > C > B > D
Sugar mill staff	Weighted Summation	A > C > B > D	A > C > B > D
	Expected Value	A > C > B > D	A > C > B > D
	Evamix	A > C > B > D	A > C > B > D
Recreational fishermen	Weighted Summation	D > B > C > A	D > B > C > A
	Expected Value	D > B > C > A	D > B > C > A
	Evamix	D > B > C > A	D > B > C > A
Local community	Weighted Summation	D > C > B > A	D > *B* > *C* > A
	Expected Value	C > D > B > A	*D* > *C* > B > A
	Evamix	D > B > C > A	D > B > C > A
Environmentalists	Weighted Summation	D > B > C > A	*B* > *D* > C > A
	Expected Value	B > D > C > A	B > D > C > A
	Evamix	D > B > C > A	D > B > C > A

Table 4
Rankings of options after 30% deviation in weights of effects

Stakeholder group	Evaluation method	Original rankings	Rankings after change in values
Farmers	Weighted Summation	A > C > B > D	A > C > B > D
	Expected Value	A > C > B > D	A > C > B > D
	Evamix	A > C > B > D	A > C > B > D
Sugar mill staff	Weighted Summation	A > C > B > D	A > C > B > D
	Expected Value	A > C > B > D	A > C > B > D
	Evamix	A > C > B > D	A > C > B > D
Recreational fishermen	Weighted Summation	D > B > C > A	B > *C* > *B* > A
	Expected Value	D > B > C > A	D > *C* > *B* > A
	Evamix	D > B > C > A	D > B > C > A
Local community	Weighted Summation	D > C > B > A	D > *B* > *C* > A
	Expected Value	C > D > B > A	*D* > *C* > B > A
	Evamix	D > B > C > A	D > B > C > A
Environmentalists	Weighted Summation	D > B > C > A	*B* > *D* > C > A
	Expected Value	B > D > C > A	B > D > C > A
	Evamix	D > B > C > A	D > B > C > A

validation adopted in this analysis has enhanced the credibility of the model and indicates that the validation procedure is a useful approach. It has demonstrated that the model is a sufficiently accurate representation of the real system for the purpose for which it has been designed.

The sensitivity analysis routines of DEFINITE have also been applied to the Scheu Creek model.

These involve a simulation procedure which differs from the typical form of sensitivity analysis of systems models. Results of sensitivity analysis provided further confidence in the MCA.

References

Abu-Taleb, M.F., Mareschal, B., 1995. Theory and methodology, water resources planning in the Middle East: application of the PROMETHEE V multicriteria method. European Journal of Operational Research 81 (1), 500–511.

Assim, F., Bari, M., Hill, C., 1998. Multicriteria analysis—application to the Murrumbidgee Irrigation Area and Districts Land and Water Management Plan. Paper presented at the 42nd Annual Conference of the Australian Agricultural and Resource Economics Society, University of New England, Armidale.

Bell, R., 1996. Johnstone River Catchment Revegetation Strategy. Johnstone River Catchment Management Association Inc, Innisfail.

Bodini, A., Giavelli, G., 1992. Compatibility of conservation and development in Salina Island. Environmental Management 16 (5), 633–656.

Braat, L.C., 1992. Sustainable Multiple use of Forest Ecosystems. An Economic–Ecological Analysis for Forest Management in the Netherlands, PhD thesis, De Vrije Universiteit te Masterda, Central Huisdrukkerij VU.

Braat, L.C., van Lierop, W.F.J., 1987. Economic–Ecological Modelling. North-Holland, Amsterdam.

Fleming, N.S., Daniell, T.M., 1995. Matrix for evaluation of sustainability achievement (MESA): determining the

Appendix A. Assigned ranking for each objective/sub-objective by stakeholder groups

Table A1
Assigned ranking for each objective by the stakeholder groups

Objective	Ranking				
	Farmers	Sugar mill staff	Fishermen	Local community	Environmentalists
Environmental	2	2	1	1	1
Social	3	2	3	3	3
Economic	1	1	2	2	2

Table A2
Assigned ranking for each sub-objective by the five stakeholder groups

Sub-objective	Assigned importance ranking				
	Farmers	Sugar mill representative	Fishermen representative	Local community representative	Environmentalists representative
Environmental sub-objectives					
Groundwater quality	12	12	7	9	9
Surface water quality	10	11	2	8	6
Land stability	5	6	8	3	5
Watercourse stability	6	5	5	1	4
Land habitat	8	7	4	2	1
Stream habitat	7	10	1	4	2
Social sub-objectives					
Protection of human health	4	4	6	7	7
Protection of recreational fishing	11	9	12	10	12
Protection of recreational values	9	8	11	12	10
Economic sub-objectives					
Reduction in loss of land	1	3	10	11	11
Reduction in water treatment cost	3	2	9	6	8
Reduction in off-site damage cost	2	1	3	5	3

sustainability of development. Paper Presented in the 1995 National Environmental Engineering Conference, Melbourne.

Geissman, J.R., Schultz, R.D., 1991. Verification and validation of expert system. In: Gupta, U.G. (Ed.), Validating and Verifying Knowledge-Based Systems, Chapter 2. IEEE Computer Society Press, Washington, pp. 12–19.

Goosam, S., Tucker, N.I.J., 1995. Repairing the Rainforest: Theory and Practice of Rainforest Re-Establishment in North Queensland's Wet Tropics. Wet Tropics Management Authority, Cairns.

Harrison, S.R., 1987. Validation of models: methods, applications and limitations. In: Computer Assisted Management of Agricultural Production Systems. RMIT Press, Melbourne, pp. 26–42.

Harrison, S.R., 1991. Validation of agricultural expert systems. Agricultural Systems 35 (3), 265–285.

Harrison, S.R., Qureshi, M.E., 1999. Identification of stakeholder objectives for multicriteria analysis. Paper presented at the 2nd International Conference on Multiple Objective Decision Support Systems, Sheraton Hotel, Brisbane, August 1–6.

Harrison, S.R., Qureshi, M.E., Sharma, P.C., Tidey, M.E., 1998. Using GIS in multicriteria analysis of riparian revegetation options. In: Lai, P., Leung, Y., Shi, W. (Eds.), Proceedings of International Conference on Modelling Geographical and Environmental Systems with Geographical Information Systems, Vol. 1. The Chinese University of Hong Kong, Hong Kong, June 22–25.

Hokkanen, J., Salminen, P., 1994. The choice of a solid waste management system by using the ELECTRE III decision-aid method. In: Paruccini, M. (Ed.), Applying Multiple Criteria Aid for Decision to Environmental Management. Kluwer Academic Publishers, Boston, pp. 111–155.

Janssen, R., 1996. Multicriteria evaluation for sustainable use of Australian forests. In: van den Bergh, J.C.J.M. (Ed.), Ecological Economics and Sustainable Development: Theory, Methods and Applications, Chapter 10. Edward Elger, Cheltenham, pp. 231–242.

Janssen, R., Nijkamp, P., 1984. A multiple criteria evaluation topology of environmental management problems. In: Yacove, Y.H., Chankong, V. (Eds.), Proceedings of Decision Making with Multiple Objectives. Cleveland, Ohio, pp. 495–514.

Janssen, R., van Herwijnen, M., 1994. DEFINITE: A System to Support Decisions on a FINITE Set of Alternatives, User Manual, Environment and Management, Vol. 4. Kluwer Academic Publishers, Dordrecht.

Jones, M., Hope, C., Hughes, R., 1990. A multi-attribute value model for the study of UK energy policy. Journal of Operations Research Society 41 (10), 919–929.

Lutz, E., Munasinghe, M., 1994. Integration of environmental concerns into economic analysis of projects and policies in an operational context. Ecological Economics 10 (1), 37–46.

Mavrotas, G., Diakoulaki, D., Assimacopoulos, D., 1994. Energy planning and trade-offs between environmental and economic criteria. In: Paruccini, M. (Ed.), Applying Multiple Criteria Aid for Decision to Environmental Management. Kluwer Academic Publishers, Boston, pp. 187–198.

Moriki, A., Coccossis, H., Karydis, M., 1995. Multicriteria Evaluation in Coastal Management. Journal of Coastal Research 12 (1), 171–178.

Munda, G., Nijkamp, P., Rietveld, P., 1994. Qualitative multicriteria evaluation for environmental management. Ecological Economics 10 (2), 97–112.

Nijkamp, P., 1989. Multicriteria analysis: "a decision support system for sustainable environmental management". In: Archibugi, F., Nijkamp, P. (Eds.), Economy and Ecology Towards Sustainable Development. Kluwer Academic Publishers, London, pp. 203–259.

O'Keefe, R.M., Osman, B., Smith, E.P., 1991. Validating expert systems performance. In: Gupta, U.G. (Ed.), Validating and Verifying Knowledge-Based Systems, Chapter 1. IEEE Computer Society Press, Washington, pp. 2–11.

Qureshi, M.E., 1999. Development and Implementation of a Decision Support Process for Sustainable Catchment Management. PhD thesis, The University of Queensland, Brisbane.

RAC., 1992. Multi-criteria analysis as a resource assessment tool. Resource Assessment Commission, Research Paper No. 6, Canberra.

Rousseau, A., Martel, J.M., 1994. Environmental assessment of an electric transmission line project: a MCDA method. In: Paruccini, M. (Ed.), Applying Multiple Criteria Aid for Decision to Environmental Management. Kluwer Academic Publishers, Boston, pp. 163–186.

Shannon, R.E., 1975. Systems Simulation: the Art and Science. Prentice-Hall, New Jersey.

Stewart, T., Scott, L., 1995. A scenario-based framework for multicriteria decision analysis in water resources planning. Water Resources Research 31 (11), 2835–2843.

van den Bergh, J., Janssen, R., van Herwijnen, M., Nijkamp, P., 1996. Integrated dynamic and spatial modelling and multicriteria evaluation for a Greek Island Region. In: van den Bergh, J.C.J.M. (Ed.), Ecological Economics and Sustainable Development: Theory, Methods and Applications, Chapter 11. Edward Elger, Cheltenham, 243–279.

van Pelt, M.J.F., 1993. Sustainability-Oriented Project Appraisal for Developing Countries. PhD thesis, Department of Development Economics, Wegeningen Agricultural University, Rotterdam.