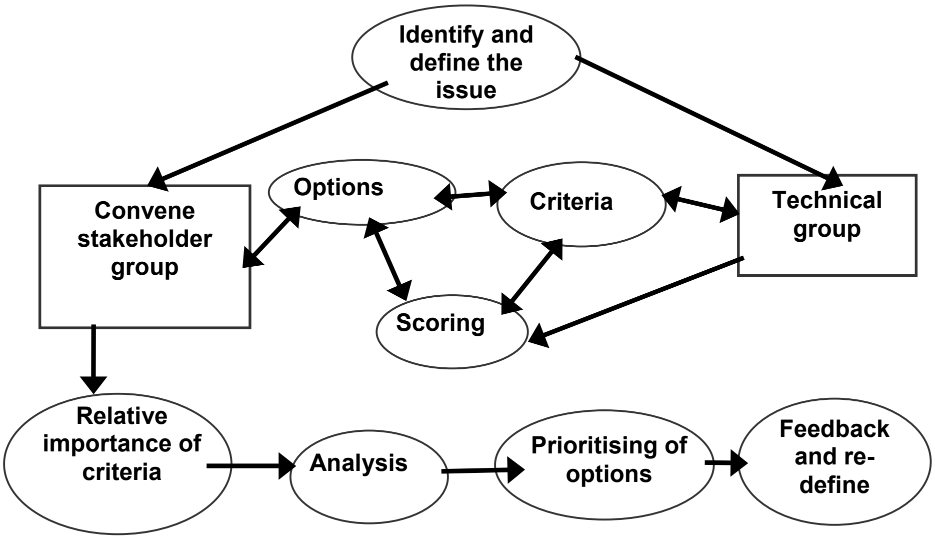
13. Principles and Methods for Developing a MODSS Process for Farm Forestry

Ian Jeffreys and Paul Lawrence

This chapter examines the application of a multi-objective decision-support system (MODSS) to farm forestry. A framework to aid and support decision-making in farm forestry and evaluate farm forestry options is proposed. This framework is developed from previous experiences of the authors and review of the relevant literature on MODSS, multi-criteria analysis (MCA) and community engagement and community participation. An example of a previous MODSS application and process is first described, before drawing on these and other sources to formulate a proposed process.

13.1 MODSS and MCA Applications in Natural Resource and Land-Use Management

The processes of framing and analysing an issue using MODSS as described in Eisner *et al*. (2000) are as follows:



1. *Identify an issue or planning opportunity*. This should be an issue of direct relevance to stakeholders, one that does or will affect their lifestyle.
2. *Convene meetings of a Stakeholder Group and a Technical Reference Group*. The members of the stakeholder group would be persons who feel they are affected by the issue at hand. Care should be taken to be as inclusive as possible; extensive measures may be required to identify and include all interested stakeholders.
3. *Place the issue within a wider context*. Identify the factors that are relevant to address the issue.
4. *Stakeholders define options to be considered*. The definitions should include a detailed description of the properties of each option and possible interactions within the given context. Some technical input may be required in this process.
5. *Stakeholders define criteria against which the options will be evaluated*. Baselines are defined and possible data sources identified. Care should be taken to ensure the criteria are independent, using a series of 'what if' questions to gauge any interdependencies.
6. *Establish a technical reference*. This group considers and provides feedback on options and criteria.

7. *The options and criteria are placed in to a table*. The way of formatting options and criteria is known as an *effects table*, and will be referred to in more detail later in this report. The technical reference group evaluates options against criteria. This process is also described as *scoring*, and the evaluations of options against criteria in the effects table are referred to as the scores. The effects table should be scored using all available data and information, e.g. data from models, statistical data, measured data (including spatial data) and expert opinion.
8. *Analysis the effects table*. The scores are analysed with the results presented to the stakeholder and technical reference group for feedback and further considerations and discussions.

This process has been applied by the Queensland Department of Natural Resources and Mines (QNRM) in several resource planning projects. Two in particular have relevance to regional and whole-farm decision-making in farm forestry. The first is the application of MODSS to evaluate water infrastructure development options (dams and weirs) in the Burnett catchment in southern Queensland (Eisner *et al*. 2000). The Burnett catchment application followed the processes detailed above. In this study, stakeholder groups across industry, indigenous, environmental and agency interests, were convened and met extensively throughout the life of the project. The meetings engaged the stakeholders in the formulation of the decision criteria and provided feedback on the scoring of the options by the technical reference group. The technical reference group comprised mostly of state agency staff with expertise in water resource engineering, planning, environmental, regional development and social science. The process of evaluating the options against the decision criteria, although arduous and at times technically complex, provided a high degree of transparency and opportunity for stakeholders to have input to the process.

The second QNRM application of this technique involved demonstrations with small groups involved in natural resource and land-use management. These were often local catchment management groups or Landcare groups. About 15 such demonstrations were given throughout southern and central Queensland. The process described in this section for is drawn from experiences from many, although not all, of these workshops. The process of defining options and criteria was unchanged from the Burnett catchment application. Those attending the workshops completed the evaluation process. To complete an analysis in a half-day workshop, the number of criteria was limited normally to two or three for each perspective (economic considerations, environmental considerations, and social and cultural considerations). In the absence of technical input those present scored the effects table. Only crude scoring was undertaken, using categories of 'good, average or bad', or 'high, medium or low'. This was represented on a three or five point scale. The highest score (three or five, respectively) was given to the best option, and the lowest score (one) to the worst, and the other options were assigned intermediate scores. Once the first set of scores was assigned, an initial analysis was performed. Those present evaluated the outcomes compared to their expected outcomes. Criteria were then added or removed, and importance orders and scores changed to reflect more closely the group's expectations. This process is similar to action learning or experiential learning techniques (Dick 1997) or 'learning by doing' (Janssen 1991). The group defined scenarios, tested these scenarios and critically analysed their relative performance using the decision-support system. This process, especially when completed in a short workshop, did not produce definitive answers to given problems, but it increased and deepened the group's understanding of the issues. When demonstrating decision support system (DSS) tools to catchment management groups and Landcare groups, it was observed that 'learning by doing' was achievable within the time constraints and effective in communicating the benefits of decision support tools for decision making.

Scenario development was omitted from the approach taken by Eisner *et al*. (2000), although this was largely due to the nature of the study. The focus placed on scenario development is one of the strengths about the analytical hierarchy process (AHP) as outlined by Saaty (1980). Saaty proposed the construction of hierarchies and networks, which break the components of the issues into clusters and sub-clusters and recognises the interactions between these clusters. This approach was also taken by Keeney (1988).

Janssen (1991) asserted the need for feedback in the development of MODSS analysis, at all stages of the development, recognizing that these processes aid robustness to the analysis and aid structuring of the MODSS. Janssen also asserted that MODSS should support the decision-making process by providing a single and integrated framework combining data management, simulation models, evaluation methods and sensitivity analysis. The process should also facilitate 'learning by doing' allowing the stakeholders to gain experience of how changing data and priorities affects the outcome, thus increasing their understanding of the problem and related issues.

13.2 An Expanded Process for MODSS in Farm Forestry

This section expands on the individual components as developed by Eisner *et al*. (2000) and discusses the application of a MODSS to farm forestry or other natural resource or land-use issues.

1. Identify the issues

When defining issues, the stakeholders should note that issues must arrive from somewhere and that they are a product of the socio-politic environment in which they exist. Eyestone (1978, p. 3) noted that '[an] issue arises when a public with a problem seeks or demands government action, and there is public disagreement over the best solution to the problem.' Issues arise due to a number of external factors including:

- economic forces (e.g. share market fluctuations, interest rates changes, employment and unemployment, business fortunes);
- media attention;
- opinion polls;
- legal shifts (court judgements);
- international relations (refugee arrivals, diplomatic representations over human rights issues, wars between other nations);
- technological development (e.g. the internet); and
- demographic shifts (Bridgman and Davis 1998, pp. 32-33).

Specifically in the context of this study, issues arrive from environmental externalities and declining farmer incomes. Issues are not isolated events. 'They are mental constructs, abstractions from reality shaped by our values, perceptions and interests' (Bridgman and Davis 1998, p. 40). Issues should be identified from areas of pressing need, not just vocal advocacy. Issues should be relevant and of concern to the stakeholders. The process is unlikely to achieve a satisfactory outcome if it is seen as representing a government's agenda.

2. Identify stakeholders and convene stakeholder group

It is necessary to decide who are the stakeholders for a given issue. Prior to this, it is necessary to define a stakeholder. The definitions of stakeholders vary considerably from very constricted definitions to broad definitions. In a constricted view, stakeholders are defined as persons and groups that have a financial interest or have a contract with a given organization. Those who directly influence an issue or organization, or those who are influenced by a decision. Other definitions include those with a 'legitimate interest' in a decision (Mitchell *et al.* 1997). This opinion is reflected in a group's legal standing to challenge planning decisions in court. In a recent case in the Supreme Court of Queensland (NQCC versus QPWS, 2000), the judgement afforded North Queensland Conservation Council leave to challenge a planning decision because they had shown special interest in the planning proposal, mentioning their opposition to this proposal, receiving state funding and had standing as a conservation organisation in the area. The World Bank defines stakeholders as those who are 'affected by the outcome – negatively or positively – or those who can affect the outcome of a proposed intervention' (World Bank 1996). Although not articulating the nature of these affects, they specify that the poor and marginalised are often stakeholders directly affected by an activity. A broader definition of stakeholders includes all who self-define as having interest in the outcome of a planning process. Bridgman and Davis (1998, p. 74) asserted whilst identifying stakeholders 'there must be avenues for others to self-identify as parties to the consultation process.' A desire to seek and include the disadvantaged is also expressed by the Queensland Office of the Cabinet (1993 p. 11), which seeks 'to identify disadvantaged groups with an interest in the topic of the consultation and to ensure that such groups have the resources necessary to participate fully'. Given these statements, there is a risk that the disadvantaged and marginalised community members included in the stakeholder group will be marginalised within this group and the participatory process. It is important to avoid tokenism and ensure these members have meaningful input into the process. 'If participation of the poor and disadvantaged is to be effective, then it has to be on a basis which is independent of the control of not only government agencies but also the pre-existing power structure of local communities' (Adnan *et al.* 1992, p. 179). The stakeholder group may again be biased by time and resource limitations. Government and industry representatives will be paid by their respective organisations to participate in stakeholder meetings, while independent members of the community, including landholders, may not. Sitting fees may be a useful solution to this disparity. When there is no definitive process for identifying stakeholders, the World Bank (1996) suggests the following questions may provide a guide.

- Who are the 'voiceless' for whom special efforts may have to be made?
- Who are the representatives of those likely to be affected?
- Who is responsible for what is intended?
- Who is likely to mobilize for or against what is intended?
- Who can make what is intended more effective through their participation or less effective by their non-participation or outright opposition?
- Who can contribute financial and technical resources?
- Whose behaviour has to change for the effort to succeed?

In the context of farm forestry in Queensland, Harrison and Qureshi (2000) identified a large number of potential stakeholders, noting that these could be divided into those affected financially or in terms of lifestyle, and those with an administrative involvement. Once identified, stakeholders need to be invited to join the stakeholder group.

3. Identify and convene technical experts and convene technical reference group

The technical reference group will advise on the science and knowledge required to quantify the impacts of the options against the decision criteria within the MODSS process. Depending on the scale, depth and perhaps most critically the budget of a study, this group's function could be supplemented by members of the stakeholder group. In larger studies, the technical reference group will need to possess the expertise to evaluate all of the options against the criteria. Given the diverse nature of natural resource and land-use management issues, the technical reference group will require expertise from a diverse range of disciplines. A typical study will include economic, environmental, social and cultural considerations. Expertise in all these areas will be required. It may be useful for the stakeholders to commence the problem definition before the technical reference group is assembled, to ensure the necessary coverage of broad expertise is achieved.

4. Identify goals and values

With regards to a given issue or planning opportunity, the goals and values of the stakeholders need to be identified. Because these aspirational goals are critical in defining what is to be achieved, the stakeholder analysis should attempt to address these issues at the commencement of decision-support modelling. Saaty (1980, p. 33) described all factors that influence decision-making as actors and states, referring to 'the environment actors, actor objectives, actor policies, and outcomes'. Problem definition can be aided by constructing hierarchies and networks. These reduce the issues into clusters and sub-clusters and recognise the interactions (Saaty 1980, pp. 11-16; Keeney 1988). Hierarchies can link the issue and the history of the issue and the objectives, goals and values of the stakeholders with criteria and possible solutions or options, alternatives or scenarios. Hierarchies will also aid in identifying and defining the options and criteria. This process can be carried out in a number of ways, such as developing questionnaires and conducting interviews, or convening workshops and focus groups where these issues are openly discussed and 'brainstormed'. Participants in such workshops should include both stakeholders and persons with technical knowledge.

All the MODSS techniques discussed in Chapter 4 require discrete options and criteria to be developed. Once the initial work of defining the problem and issue in broad terms has been completed, the stakeholders and experts need to define the problem or issue in a format that can be analysed using MCA tools. The following steps provide a framework for developing options and criteria. The options and criteria then form the *effects table*, which serves as the foundation for all MCA and MODSS techniques.

This stage of the MODSS technique may be divided into a number of steps.

a. Define options

Stakeholders define the options to be considered. These must be feasible, and intended to fulfil the goals and objectives of the stakeholders. The options need to be clearly and extensively defined. Such definitions should include a detailed description of the properties of each option and their possible interactions within the given context. Technical input may be required in this process; however, this should be limited to advice rather than influence. It is crucial for the implementation of the preferred option that the stakeholders and community have ownership of the options.

b. Define criteria

The decision criteria are an abstraction of the values and goals of the stakeholders. They are the measures against which an option will be evaluated to ascertain whether it fulfils these goals and objectives. Like the options, the criteria need to be clearly defined, and baselines need to be established and defined. All parties to the process need to be clear about what the criteria represent (across time, space and function) and about the goals and objectives from which they are derived. This step is vital if new options or composites of existing options are to be included later in the MODSS process.

c. Obtain feedback on options and criteria

The technical reference group should consider the options and criteria defined by the stakeholder group, and provide feedback on these. This feedback should be general in its nature, principally as a feasibility assessment on the ability of the options to satisfy the issue under consideration rather than an extensive evaluation. The technical reference group should consider the relevance of criteria and the ability of the criteria to discern differences in the options. For example, a criterion that receives the same score for each option provides no additional information to the analysis and therefore can be removed. In addition, care should be taken to ensure the criteria are independent. Keeney and Raffia (1976, pp. 299-301) proposed a simple test which takes the form of a set of 'what if' questions asked of the decision-maker or technical reference group: If the score for Criterion 1 is X what would the score for Criterion n be? If the score for Criterion 2 is Y what would the score for Criterion n be? If the decision-maker indicates a change in score for a given criterion relative to another, then the criteria are not independent. Keeney and Raffia assert that the decision-maker is likely to express any possible interactions before every possible question has been asked. Related criteria can be removed or combined. If possible, the technical reference group should seek feedback from the stakeholders before removing or changing criteria.

To aid the stakeholders define the options for the analysis, it has proved useful to incrementally build the analysis, and construct the problem in the MODSS framework of options and criteria. The basis of the MODSS/MCA process is evaluating options against criteria in the effects table. Most people would be familiar with an effects table or matrix as a structured approach to selecting a preferred item from a range of choices. An application of an effects table for selecting videotapes is presented in Appendix 13.1.

The first iteration may consist of a simple example using a limited number of criteria. Initially, three criteria could be selected to reflect the economic, social and environmental perspectives in natural resource and land-use management. Being an iterative process, the numbers of decision criteria tends to grow rapidly to accommodate the complexity of the issue. However, this exercise serves three purposes. First, it allows the stakeholders to explore and gain a better understanding of the issue in question. Second, it aids familiarity with the MODSS and MCA process, and the opportunities to explore what-if scenarios. Third, and perhaps most importantly, the effects table places a boundary of reference for the decision-support process.

5. Technical reference group evaluates options against criteria

Using all available data sources, the technical reference group evaluates the effects table. When using technical expert panels and expert opinion, analyst should restate scores using logical statements about the relativities of the scores. The analyst may choose statements regarding the relative performance of options for a given criterion, for example, Option 2 outperforms Option 3, Alternatively, the rank order of performance, for example, Option 2 performs highest, the next highest is Option 3, then Option 1, and so on. This questions the experts' assumptions and can aid the development of a robust and defensible set of scores. The analyst should present initial results to the technical reference panel as soon as they are available. With the currently available tools this can be done during the workshop session in which effects table is developed. The technical reference group can then consider the analysis of the effects table and changes can be made. This process of responding and providing quick feedback is similar to that in the selection phase suggested by Janssen (1991).

6. Proposed process for analysis of the options

In the next step of the process, the analyst using a number of the MODSS and MCA tools evaluates the options considering the criteria defined by the stakeholders and scored by the technical reference panel, given the relative importance of the criteria assigned by the stakeholders. There are many methods available for such an analysis, a number of which were outlined in Chapter 4. The analysis can be split into two separate processes. First, relative weights are placed on the criteria. This recognises that some of the decision criteria are more important to the stakeholders than others, and should attract greater weights in the analysis. Second, the scores that the options receive against each criterion judging their performance against that criterion (the effects table) need to be aggregated. That is, the scores need to be combined to create an overall score for each option. The rank order centroid (ROC) technique (Edwards and Barron 1994) can be used to assign weights to the criteria given a statement of rank order importance elicited from the stakeholders. The ROC technique was chosen for this study because it is easy to elicit the rank orders from the stakeholders and the ROC technique has a strong theoretical basis (Edwards and Barron 1994). Two aggregation methods will be used, namely the weighted summation technique (Janseen 1991; Yakowitz *et al.* 1997) and the Electre II technique (Roy 1991). These aggregation techniques are highly complementary and together provide a rounded analysis. The weighted summation technique provides a sound measure of the overall performance, is logically simple and easily gains the acceptance of stakeholders. It is a compensatory aggregation method; that is, poor performance in any one criterion can be compensated by overall good performance in the other criteria. Electre II is a non-compensatory aggregation method; that is, poor performance in any one criterion will be reflected in the overall performance of the option. Electre II is a complicated method and is not easily communicated or understood by non-specialist. Consequently, the method has not received wide application in practical natural resource management issues outside of theoretical studies. Appendix 13.2 provides details of these techniques.

7. Presentation of the analysis results and obtaining feedback from stakeholders and the technical reference group

The analyst presents the results to the stakeholders and technical reference panel. Further iterations (as suggested by Janssen, 1991) can be conducted in response to the suggestions and feedback from the stakeholders. As this discussion is ideally a joint meeting of stakeholder and the technical reference panel, changes can be made immediately, and a number of further iterations can be made. Notwithstanding the earlier investment of time, it may be necessary to revisit the assumptions on which the problem is based in order to clarify the outcomes from the analysis, particularly if some results are contentious. Depending on the outcomes, it may be necessary to commence a further iteration of the process and apply the principles of adaptive management.

13.3 Summary

This chapter has drawn on previous MODSS experiences and applications to formulate a practical, yet structured approach when implementing a MODSS process to farm forestry decision support. This process accommodates an integrated, multi-factor approach for assessing farm forestry options including economic, environmental and social considerations. The process merges the inputs and requirements from stakeholders, including landholders, the forestry industry, local and state government, with the best available scientific knowledge on forestry practices in Queensland.

References

Adnan, S., Alam A., Nural, S.M. and. Brustnow, A. (1992), *People's Participation, NGOs and the Flood Action Plan,* Research and Advisory Services, Dhaka.

Australian Consumers' Association, (2001), *Video Tapes – Performance Results*, CHOICE Online, Marrickville, http://www.choice.com.au/articles/a102716p5.htm, accessed 24 Feb. 02

Barron, F. and Barrett, B. (1996), 'Decision quality using ranked attribute weights*, Management Science,* 42(11): 1515-1523.

Bridgman, P. and Davis, G. (1998), *Australian Policy Handbook,* Allen and Unwin, St Leonards.

Dick, B. (1997), *Action Learning and Action Research* [On line] http://www.scu.edu.au/schools/gcm/ar/arp/actlearn.html accessed 26 Feb. 02.

Edwards, W. and Barron, F.H. (1994), 'SMARTS and SMARTER: improved simple methods for multiattribute utility measurement', *Organizational Behavior and Human Decision Processes*, 60: 306-325.

Eisner, R., Lawrence, P. and. Jeffreys, I. (2000), *Use of MODSS (Multi-Objective Decision Support System) in the Burnett River Catchment Study*, Project report, Department of Natural Resources, Indooroopilly.

Eyestone, R. (1978), *From Social Issues to Public Policy,* Wiley, New York.

Goicoechea, A., Hansen, R. and Duckstein, L. (1982), *Multiobjective Decision Analysis with Engineering and Business Applications,* Wiley, New York.

Harrison, S.R. and Qureshi, M.E. (2000), 'Choice of Stakeholder Groups and Members in Multicriteria Decision Models', *Natural Resources Forum*, 24(1): 11-19.

Janssen, R. (1991), *Multiobjective Decision Support for Environmental Management,* Kluwer Academic Publishers, Dordrecht.

Janssen, R., van Herwijnen, M. and Beinat, E. (2001), *DEFINITE (Version 2) Decision Support System for a FINITE Set of Alternatives*, Institute for Environmental Studies, Vrije Universiteit, Amsterdam.

Keeney, R. and Raffia, H. (1976), *Decisions with Multiple Objectives,* Cambridge University Press, Cambridge.

Keeney, R. (1988), 'Structuring objectives for problems of public interest', *Operations Research*, 36(3): 396-405.

Mitchell, R., Agle, B. and Wood, D. (1997), 'Towards a theory of stakeholder identification and salience: defining the principle of who and what really counts', *Academy of Management Review*, 22(4): 853-887.

Nijkamp, P., Reitveld, P. and Voogd, H. (1990), *Multicriteria Evaluation in Physical Planning***,** North Holland Publishing, Amsterdam.

North Queensland Conservation Council Inc v Executive Director, Queensland Parks and Wildlife Service, (2000), *QSC 172,* Supreme Court of Queensland, Brisbane.

Office of the Cabinet, (1993), *Consultation: A Resource Document for the Queensland Public Sector,* GoPrint, Brisbane.

Roy B. (1991), 'The outranking approach and the foundations of ELECTRÉ methods', *Theory and Decision*, 31(1): 49-73.

Saaty, T. (1980), *The Analytic Hierarchy Process: Planning, Priority Setting, Resource Allocation,* McGraw-Hill, New York.

Simpson, L. (1996), 'Do decision makers know what they prefer?: MAVT and ELECTRE II', *The Journal of the Operational Research Society*, 47(7): 919-929.

Winterfeldt, D., von and Edwards W. (1986), *Decision Analysis and Behaviour Research,* Cambridge University Press, Cambridge.

The World Bank, (1996), *The World Bank Participation Sourcebook,* http://www.worldbank.org/wbi/sourcebook/sbpdf.htm.

Yakowitz, D., Wedwick, S. and Weltz, M. (1997), 'Computing multiple attribute value function ranges under a hierarchy of attributes with application to environmental decision making', *Proc. IEEE International Conference on Systems*, Management and Cybernetics, Orlando, pp. 323-328.

Appendix 13.1
A Simple Example of a Multi-Criteria Analysis and Effects Table

A simple example of a multi-criteria analysis is presented in Table 13.1. This example is adapted for an article on the website of the Australian Consumer Magazine, *Choice* (Australian Consumers' Association, 2001), in which various brands and models of videotapes available in Australia are evaluated against two criteria namely, performance and price. Price is expressed as the cost per videotape (as at September 2001). The performance criterion is an aggregation of two sub-criteria, namely, initial picture quality and long-term picture quality. These criteria where not considered to be equally important and a different weight was applied to each. For this example, picture quality received 70% of the weight and long-term quality 30%. The overall score has been calculated accordingly, i.e.

$$\text{Overall score} = (\text{Initial picture quality} \times 0.7) + (\text{Long-term picture quality} \times 0.3)$$

Following this calculation, the videotapes were sorted in order of their overall performance, where high scores indicate high performance. The effects table of videotape brand (listed as rows) and the performance scores (as columns) is shown in Table 13A.1.

Table 13.A1. Videotape performance effects table

Brand and model	Performance			Price ($)
	Overall score (%)	Initial picture quality score (%)	Long-term picture quality score (%)	
TEAC X2 VHS E-180	71	70	73	3.95
ACME E-180 High Grade	68	74	53	2.79
JVC E-180SX	65	70	52	2.87
AKAI HQ E-180	63	70	47	2.99
HANIMEX E-180 High Grade	60	66	45	3.99
TDK SC-180	59	64	48	2.95
YAMANA SG Super Grade E-180	59	60	55	3.20
PALSONIC E180 VHS	58	68	35	2.99
BASF EQ-180 (A)	55	67	26	5.95
BASF SQ E-180	55	68	26	4.95
TEAC ASX E-180	55	60	42	3.95
SONY Super DX-E180	53	60	35	4.95
PANASONIC NV-E180PRA Premium	52	56	42	3.25
FUJI AG E-180 PAL/Secam	51	60	29	4.99
EXCEL Gold E-180 SGX Super Grade	45	52	29	3.20
MAXELL E-180GX Power Tape	42	46	34	3.99

Criteria descriptions

As in all examples, the criteria need to be clearly defined. This aids the evaluation process and allows further options to be added to the analysis and evaluated against the same baselines.

Picture quality

Prior to testing, the tapes were preconditioned for 24 hours at 23°C and 45% humidity. The tapes were rewound to even out stresses that may have occurred during shipping and storage. Tapes were used to record once only and then replayed, so the results do not necessarily reflect typical circumstances, where a tape is over-recorded and played several times. However, if the initial quality is low, it is unlikely to improve with use. Samples from more than one batch number were tested for each brand. The score shown in the table is the averaged result for the brand.

Picture quality takes into account the following measures:

- Dropout is when there is a momentary loss of signal (picture). On new tapes this is due to contamination or missing magnetic material (the coating may not be even or complete). The annoyance caused by dropouts depends on their duration and frequency. More than 100 detectable dropouts per minute would be practically unwatchable.
- Radio frequency – measured frequencies and strength and uniformity of the video signal.
- Signal to noise ratio is an indication of how much the maximum output signal exceeds the background 'noise'. It is a measure of how much graininess, random specks or shifts in colour will appear in the picture.
- Frequency response tests indicate how well tapes record colour and details, such as finely divided black and white patterns.

Long-term score

Tapes were artificially aged to simulate five to 10 years of storage in a tropical climate, and underwent the same picture quality tests as at the initial stage. Signal-to-noise ratio and frequency response are not affected over time to the same extent as dropout and radio frequency, so only the latter two aspects were scored.
The scores for this test were not weighted as heavily as initial picture quality in the overall results because:

- the test was extreme, replicating use in a tropical or sub-tropical climate.
- most people would not use standard-quality tapes for recording something they want to keep long-term.

Tests simulating storage of only two to five years showed little difference from the initial results.

Appendix 13.2
Detailed Descriptions of Weighting and Aggregation Techniques

This section presents a detailed description of the mathematics behind the MCA techniques used in this study. The techniques described are the Rank order centroid (ROC) weighting technique, the weighted summation aggregation technique and the Electre II aggregation technique. These MCA techniques are those proposed in Section 13.2 point 6 in this report.

Rank order centroid weighted technique

This technique is the same as the weighting technique used in the SMARTER (Edwards and Barron 1994) and the expected value method (Nijkamp *et al*. 1990). The technique assigns weights to the individual criteria according to a statement of importance or rank. These are usually in the form ‘Criterion 1 is more important than Criterion 2, which is more important than Criterion 3’ and so on, $Cr1 \geq Cr2 \geq Cr3 \ldots \geq Cr_n$. Given these statements a set of feasible weights can be defined, as well as a feasible area and a probability density function for all the feasible weights. For a simple case $Cr1 \geq Cr2 \geq Cr3$ there will be a triangular feasible area, which can be plotted in three dimensions, with the corner points at (0,0,1), (0,1,1) and (1,1,1). From this the probability distribution function of feasible weights can be defined. Changing the number of criteria will change the shape of the probability density function of the feasible weight set. These sets and distributions are the bases for this method. The rank order centroid (ROC) as used in the SMARTER technique (Edwards and Barron 1994) uses the centroid point of the probability density function as the weight for the criteria. The Expected Value Method (Nijkamp *et al.* 1990) as used in Definite (Janssen 1991 and Janssen *et al.* 2001) also uses the centroid value; the centroid value is also the most probable or expected value.

To convert the rank order into a set of ordinal weights there is a simple algorithm this is described by Edwards and Barron (1994). Given that in our simple example $Cr1 \geq Cr2 \geq Cr3$, the weight assigned to each criteria would follow a similar rule $w1 \geq w2 \geq w3$, were w1 is the possible weight applied to criterion 1 etc.

If $Cr_1 \geq Cr_2 \geq \ldots \geq Cr_n$

then $w_1 \geq w_2 \geq \ldots \geq w_n$

If k is the number of criteria

then
$w_1 = (1+1/2+1/3+ \ldots +1/k)/k$
$w_2 = (0+1/2+1/3+ \ldots +1/k)/k$
$w_3 = (0+0+1/3+ \ldots +1/k)/k$
$w_k = (0+ \ldots +0+1/k)/k$

More generally

$$w_k=(1/K) \sum_{i=k}^{K} (1/i) \qquad \textbf{(13.1)}$$

Table 13.2, adapted from Edwards and Barron (1994), contains the weights calculated from Equation13.1, for a given number of criteria (2 to 9).

Table 13.A2 ROC weights for indicated number of criteria

Rank	Number of criteria							
	2	3	4	5	6	7	8	9
1	0.7500	0.6111	0.5208	0.4567	0.4083	0.3704	0.3397	0.3143
2	0.2500	0.2778	0.2708	0.2567	0.2417	0.2276	0.2147	0.2032
3		0.1111	0.1458	0.1567	0.1583	0.01561	0.1522	0.1477
4			0.0625	0.0900	0.1028	0.1085	0.1106	0.1106
5				0.0400	0.0611	0.0728	0.0793	0.0828
6					0.0278	0.0442	0.0543	0.0606
7						0.0204	0.0335	0.0421
8							0.0156	0.0262
9								0.0123

When two or more criteria are considered equally important, that is they have tied ranks, the weight given to each criterion is the average weight for the tied ranks. For example if $Cr_1 \geq Cr_2 = Cr_{3,}$ that is Criterion 1 is more important than Criterion 2, which is equally important to Criterion 3. The weights would be assigned as follows.

$$Cr_1 = w_1 = 0.6111$$
$$Cr_2 = (w_2 + w_3)/2 = (0.2778+0.1111)/2 = 0.1945$$
$$Cr_3 = (w_2 + w_3)/2 = (0.2778+0.1111)/2 = 0.1945$$

Weighted summation aggregation technique

This is the simplest and most commonly used aggregation technique (Janssen 1991,Yakowitz *et al.* 1997); it is also described as the Multiattribute value (MAV) model (Barron and Barrett 1996). The value attributed to an option is the sum of the value the option receives for each criterion multiplied by the weight given to that criterion. The weighting of the criteria is derived from the weighting technique chosen by the decision-maker or embedded in the tool being used. The weighted summation it is one of many Multi-Attribute Utility Models (see Keeney and Raffia 1976), and whilst other models have a stronger theoretical basis they are rarely used being complicated and time consuming to calculate (Winterfeldt and Edwards 1986). However, with current computer technology and integrated MODSS software, time constraints and complicated algorithms are no longer an issue with regards to ease of analysis.

The additive value function (the weighted summation) takes the form:

$$V(w,v) = \Sigma_i\, w_i\, v_i \qquad \textbf{(13.2)}$$

where V = the weighted value or overall score for a given option
w_i = the weight for a given criterion i
v_i = the value or score for criterion i for a given option

This method is described as a compensatory method – i.e. poor performance is a criterion in compensated for be overall good performance in the other criteria – and this is not always desirable. The weighted summation is a sound and mathematically simple measure of the overall performance of the options.

Electre II aggregation technique

The Electre technique (*El*imination *e*t *c*hoix *t*raduisant la *ré*alité or Elimination and choice corresponding to reality) (Roy 1991) is a non-compensatory aggregation method, that is poor performance in any one criterion will be reflected in the overall performance of the option. This makes this technique an ideal check against which to compare the results from the weighted summation technique. If the results are the same it can be assumed that the option has no critically poor performing criteria. If there is difference in the results the analyst should identify the poor performing criteria by looking at the raw data. Poor performance in an important criterion may be a fatal flaw in that option.

There are five versions of Electre being Electre I, II, III, IV and TRI. Electre I is designed for selection problems, Electre TRI for assignment problems and Electre II, III and IV for ranking problems. As this project focuses on assessing the relative performance of forestry options compared to current practice, it is appropriate to use Electre II, III or IV. However, the decision support software application used in this study (*Definite*) uses the Electre II method; the analyses reported in the following chapters have been completed using the Electre II method. Therefore only Electre II will be described in detail, and comments made on the variations between the versions.

The following summary of the Electre II aggregation method is drawn from the detailed description provided by Goicoechea *et al.* (1982, pp. 197-214), Roy (1991) and Simpson (1996).

The first step in the Electre II method is to establish a complete rank order of the options using a number of tests. The first three of these are the indifference test, the preference test and the veto test. These are evaluated between two options for each of the criteria. These tests are now outlined.

1. The indifference test is designed for testing that Option A is indifferent to another Option B (notation *A**I**B*) for a given criterion. This allows for options with a small variation in score to be considered equal. An example could be the difference with a cup of tea with 1 gram of sugar and a cup of tea with1.1 grams of sugar. Numerically there is a difference but in opinion of the tea drinker there may be no difference. In Electre II the decision-maker sets the indifference measure q for each criteria. In our example q may equal 0.5 grams of sugar.

   $$A\mathbf{I}B \;\; if \;\; | a_j - b_j | \leq q_j \qquad \textbf{(13.3)}$$

   where a_j is the performance (the score it receives in the effects table) of option A on criterion j, b_j is the performance of Option B on criterion j, and q_j the indifference measure. The indifference measure will be different depending on the score range of the criteria. In this study all the criteria are scored between 1 and 10, therefore the indifference thresholds will be set at the same level.

2. The preference test evaluates whether an Option A is preferred to another Option B (notation *A**P**B*), that is Option A outperforms or outranks Option B. This determines a strong or strict preference for Option A; that is, the score received by option A for criterion *j* is considerably better than that for option B. The preference threshold p_j is the level at which the decision-maker considers Option A to strongly outperform Option B.

   $$A\mathbf{P}B \;\; if \;\; a_j > b_j + p_j \qquad \textbf{(13.4)}$$

   where a_j is the performance of option A on criterion j, b_j is the performance of option B on criterion j, and p_j is the strong preference threshold. This test is applied to all the criteria and the results from all the criteria are considered further in the analysis.

3. The veto test evaluates whether an Option B is not preferred to another Option A; that is, the score received by option B for criterion j is considerably worse than that for option A (notation *B**P**A*). The Veto level v_j is the level at which Option B is not preferred to Option A. for any criterion. If the option B performs at a level that is lower than the performance of option A by greater than the Veto level for any criterion, Option B is always not preferred to Option A, regardless of the scores in the other criteria.

$$BPA \text{ if } a_j + v_j < b_j \quad \textbf{(13.5)}$$

where a_j is the performance of option A on criterion j, b_j is the performance of option B on criterion j, and v_j is the veto measure. This test is applied to all the criteria. Failing this test in one criterion will result in Option B always being considered not preferred to Option A.

The performance of a set of two options for each criterion can be assigned. This can be categorised into four groups. The first is indifferent ***I*** group, the comparisons that fulfil equation 13.3, the second the strongly preferred ***P*** group, the comparisons that fulfil equation 13.4 or equation 13.5. The third group ***Q*** is a group of weak preference all those that fall between the indifferent set and the strong preference set. A fourth group ***R*** is created from the residual – those that failed all of the above tests – and these are deemed to be incomparable.

Using these threshold tests and the subsequent group Electre method builds an outranking relationship ***S***, for each criterion. This group (notation aS_jb) is the set for each criterion where option A is at least as good as Option B. therefore for criterion j:

$$aS_jb: A \text{ is at least as good as } B \text{ on criterion } j \text{ if } a_j \leq b_j - q_j$$

$$\{aS_jb\} = \{aP_jb\} \cup \{aQ_jb\} \cup \{aI_jb\}$$

Using the groups *S, P,* and *Q,* Electre specifies values know as the concordance and discordance coefficients. The concordance coefficient is a measure of the strength of the argument *A is at least as good as B*, ***c(A,B)***. The discordance coefficient is the strength of the argument against; that is *A is not as good as B*, ***d(A,B)***. In many examples the criteria do not carry equal weight. As in this study some criteria are deemed to be of greater importance than others, weights are applied to each criterion using the ROC method (described earlier in this appendix). These weights are included in defining the Concordance and Discordance indices.

$$c(A,B) = \Sigma P(w_j) / \Sigma (w_j)$$

Using ROC weighting method $\Sigma (w_j) = 1$, so, in this example

$$c(A,B) = \Sigma P(w_j)$$

The next stage of the Electre II technique requires the decision-maker to set concordance and discordance thresholds. The level of the concordance threshold c^* and the discordance threshold d^* are set according to the aims of the analysis. High levels are likely to filter out all but the better performing options, while lower levels will identify acceptable and unacceptable groups of options. The levels used in this analysis are the default levels in the decision support tool, Definite, as described by Janssen *et al*. (2001).

The following decision rules are applied to the pairwise comparison of all the options against each other.

A outranks B if	$c(A,B) \geq c^*$	*and*
	$d(A,B) \leq d^*$	
A outranks B if	$c(A,B) > c^*$	*and*
	$c(B,A) \geq c^*$	*and*
	$d(B,A) \leq d^*$	

A and B are incomparable if

$$c(A,B) \geq c^{*} \text{ and } d(A,B) > d^{*} \text{ or}$$
$$c(A,B) > c^{*} \text{ and } c(B,A) < c^{*} \text{ or}$$
$$c(A,B) \leq c^{*} \text{ and } c(B,A) < c^{*} \text{ and } d(B,A) < d^{*}$$

Statements of outranking can be drawn from the outcomes of the decision rules. The statements of outranking can then be interpreted as an ordinal ranking of the options. Options that are incomparable or outrank the same group of options should be given equal ranking. These ranks can be displayed as lists of position or as histograms.