AN EVALUATION OF OPTIONS FOR MANAGING THE LOWER MURRAY RECLAIMED IRRIGATION AREAS USING MULTIPLE CRITERIA ANALYSIS

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Abstract: This paper presents an application of multiple criteria analysis (MCA) to evaluate alternative strategies for managing the Lower Murray Reclaimed Irrigation Areas (LMRIA). The LMRIA region is located along the Murray River in South Australia, between Mannum and Wellington. It is estimated to contain around 170 dairy farms and provides around 200 jobs. Irrigation practices in LMRIA have created significant problems of River Murray water quality. A primary problem is the high levels of faecal contaminants entering the river through dairy effluent. Evaluation of management options using MCA allowed explicit incorporation of non-monetary criteria into the decision making process in a transparent manner. A panel of 10 persons with community and government backgrounds guided the MCA process by choosing and weighting the criteria. The MCA produced a different ranking of alternatives to a benefit cost analysis, highlighting the impact of incorporating non-monetary decision criteria.

Introduction

This paper presents an evaluation of options for managing the Lower Murray Reclaimed Irrigation Areas (LMRIA) using multiple criteria analysis (MCA). The MCA approach has been used to facilitate integrated assessment of LMRIA management options against social, economic and ecological criteria. In this study, the MCA has been applied to supplement a benefit cost analysis (BCA) of LMRIA management options.

The Lower Murray Reclaimed Irrigation Areas (LMRIA)

The LMRIA are located along the Murray River in South Australia, between Mannum and Wellington. Formerly wetlands, this land was developed for irrigated agriculture, primarily dairy grazing, between 1880 and 1940. Today the LMRIA region contains around 120 dairy farms, covering 5,200 hectares of swampland and 1,700 hectares of highland. In around two-thirds of this area the swamps are government owned and managed, being privately owned in the remaining third.

The development of irrigation involved constructing flood levee banks along the River Murray to control seasonal flooding. Sluice gates were built into the levee banks that could be opened to periodically irrigate dairy paddocks. Water would flow from the Murray, through the sluice gate, and freely over the paddock into a back-channel. The excess water is then pumped back into the Murray. There now exists a complex network of drains, back-channels and pumps that permit effective irrigation of the dairy paddocks.

Whilst this system of irrigation has been effective for many years some problems are becoming increasingly apparent. One of the major drawbacks is the discharge of poor quality water back into the River Murray, which is a major river with human-drinking, recreational and ecological values. The water collects significant amounts of faecal contaminant by flowing across dairy paddocks. Consequently, excess water discharged into the Murray contains high levels of bacteria associated with health problems, e.g. gastrointestinal illness. The water being discharged into the Murray can also be highly salty, as the back channels intercept saline groundwater. Another problem is the low water use efficiency, often arising from uneven paddocks that hinder surface water flows.

In response to these problems the South Australian government is searching for improved ways to manage LMRIA. Environmental problems are only part of what the South Australian government will need to consider. It is estimated that dairy farms in the LMRIA region produce around 15 to 20% of South Australia's milk with a farm gate value of $32m/yr and generate significant benefits to the regional economy, providing about 200 jobs (Wheeler *et al.* 2001).

The results presented here formed part of a study aimed at evaluating several options for managing the LMRIA. The options range from minimal irrigation infrastructure upgrades, that would occur under a business as usual scenario, through to rehabilitation of wetlands on dairy farms or changes to alternative land uses. In the evaluation both a benefit cost analysis and multiple criteria analysis were conducted. This paper presents the multiple criteria analysis.

Multiple Criteria Analysis (MCA)

Multiple criteria analysis is a technique for evaluating a set of decision alternatives against a set of multiple, and sometimes conflicting, criteria. It has been widely applied in natural resource management because it can help decision makers better understand a complex decision problem involving social, economic and ecological factors. The MCA process has much in common with the structured planning framework. It involves the stages of:

1. *Identify objectives*. Objectives are statements describing the desired outcomes from the decision making process. In natural resource management objectives are often classified as economic, social or ecological.
2. *Identify alternatives*. Alternatives are the available actions that achieve some or all of the objectives. In an MCA model alternatives are represented as discrete choices.
3. *Identify criteria*. Criteria are either quantitative or qualitative measures that indicate the performance of an alternative against an objective. For example, the area of habitat (in hectares) could be used as a criterion to measure performance against an ecological objective.
4. *Weight criteria*. Very rarely are all criteria of equal importance in any decision problem. Depending on the particular MCA technique applied, criteria importance can be represented with quantitative (eg percentages) or qualitative (eg rank order from most important to least important) scores.
5. *Rank the alternatives*. Many algorithms can be applied to rank the alternatives based on the weights and criteria values.
6. *Apply Sensitivity Analysis and/or Interact with the Model*. The general rule in MCA is that information on weights and criteria values is estimated. Through sensitivity analysis estimated values are systematically varied to determine their importance to the final result. In addition to sensitivity analysis, people can interact with an MCA model to test the impact a particular set of weights has on the final result. This allows "*what if?*" type experimentation.
7. *Make or recommend a decision.* Following the application of MCA, decision makers should be in a better position to make an informed decision. Hopefully, the MCA will have helped clarify complex trade-offs that a decision maker must consider. Often decision makers choose to disagree with the results of MCA models. This is neither a failing of the decision maker or MCA. As a model the MCA will always be subject to inaccuracies and simplifications. The real value of MCA is through learning about a complex decision problem, rather than prescription of a "*best*" or "*optimal*" course of action.

The MCA model is generally represented using an *effects table*, as shown in figure 1. This is a table that lists the alternative management options as rows and the criteria as columns (or vice versa). A performance measure is included in the effects table to represent the performance of each alternative against each criterion. A performance measure can be in any qualitative or quantitative units (eg dollars, kilometres, hectares, litres, scored on a scale of 1-5 etc). The performance measures are standardised into commensurate units prior to application of ranking algorithms.

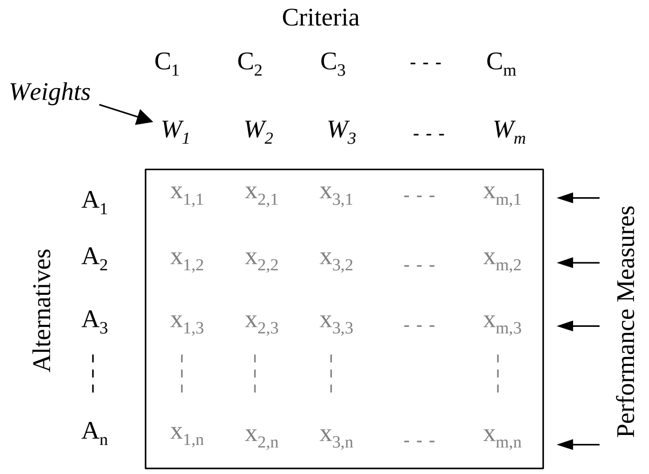

Figure 1. An effects table used to represent a multiple criteria analysis model.

Community MCA Panel

A panel of ten people guided the selection and weighting of criteria in the MCA model. These people were selected to be representative of broader community groups affected by management of the LMRIA. There were three people on the panel associated with State Government departments of Primary Industries and Resources South Australia, SA Water and the Department of Environment and Heritage. The remainder of panel members were from community groups related to:

- Tourism
- Regional development
- Local government
- Wetland management
- Dairy industry

Members of the MCA panel attended two workshops, in December 2000 and February 2001, and completed a survey form to obtain criteria weights.

Identifying the Management Options

Eleven LMRIA management options were evaluated in the MCA model (Wheeler et al. 2001), as shown in Appendix A. They range from minimal changes to irrigation infrastructure, which would occur under a base case scenario, to far-reaching changes to landuse throughout the region. The management options were presented to the MCA panel members prior to identifying and weighting criteria. This was done, because the nature of the alternatives often influences the selection and weighting of criteria. There was little scope for the MCA panel to change the options within the confines of this project.

Selecting Criteria

The first meeting of the MCA panel was used to identify a set of criteria relevant to community concerns. Following an explanation of LMRIA management issues, MCA and the purpose of evaluative criteria panel members were asked to identify all criteria of potential relevance. A total of 33 criteria were identified by the panel. Panel members were then asked to place a mark next to those criteria that they thought should be included in the MCA model. This reduced the number of criteria to 18. Appendix A contains a list of the 18 criteria and the number of votes each received.

Panel members were then informed that the consultants would review the criteria and develop a shortlist of several criteria. This resulted in the identification of six criteria as listed in table 1. The six criteria were selected to:

- *Ensure a manageable weighting task*. Balancing the importance of many criteria simultaneously is a complicated task that easily exceeds people's cognitive abilities.
- *Remove redundant or overlapping criteria.* The set of 18 criteria involved considerable overlap where criteria measured similar or identical impacts.

Table 1. Criteria weighted by panel members in the survey and used in the multiple criteria analysis.

Criteria	**Description**
Economic Efficiency (Benefit Cost Ratio)	Derived from the benefit cost analysis, this indicates the economic performance of each management option. The benefits and costs included here are limited to impacts readily measured in dollar units. They do not include impacts covered by other criteria listed below. Previous benefit cost analyses used to assess rehabilitation options have considered changes to the value of agricultural production associated with changes to water use, salinity effects on land and increases in productivity. These analyses have also included annual operating and maintenance costs, the costs of upgrading the infrastructure and the costs of designing and managing a wetland system.
Employment (Number of people employed in the Murray Mallee region)	This criterion measures the creation or losses of jobs under the different management options. As such, it also provides a measure of the impacts to the regional economy.
Area of Wetland Habitat (ha)	The proposed management options will create different areas of wetland habitat. A larger area of wetland habitat may be beneficial to native species and may be valuable in itself to many people.
Salt Loads to the River Murray (Salt loads of the Murray River from Mannum down)	The management options will affect the quantity of salt discharged into the Murray. The criterion will relate changes in total salt loads discharged to the Murray as a result of the management options.

Tourism (Number of tourists visiting Lower Murray)	Regional tourism is affected by factors such as landscape quality, water quality and river odour. The criterion will relate changes to numbers of tourists to the different management options.
Potential Health Risks (levels of bacteria in Murray River from Mannum down)	It is widely recognised that irrigation drainage from the Lower River Murray Reclaimed Irrigation Areas has led to water quality problems. These include elevated levels of nitrogen, phosphorus and micro-organisms.

Weighting the Criteria

The criteria were weighted by the panel members in a survey mailed shortly after the first workshop. The nature of the weighting task and how it would impact on MCA results was explained in the workshop. Panel members were asked to complete two weighting tasks: an ordinal ranking of criteria importance and expression of importance with percentage weights. This was done to check the consistency of survey responses and enable application of alternative MCA techniques (capable of using ordinal or cardinal weights information) if required. The relevance of weighting tasks in the survey was explained to panel members in the first workshop. Panel members were not asked to assume a "stakeholder" position when weighting the criteria.

Obtaining Performance Measures

A copy of the completed effects table for this study is shown in appendix A. Where possible, the criteria have been measured in quantitative units (employment, salt loads to the Murray, increased area of wetland habitat and reduction in health risks). The other criteria (economic efficiency and tourism) were measured on an ordinal scale. The means by which the performance measures were estimated is described in Wheeler et al. (2001). In brief, performance measures were obtained as follows:

1. *Economic efficiency*. This was obtained from a benefit cost analysis of the options undertaken by Wheeler et al. (2001). The benefits included agricultural production and the sale of water. The costs included annual operating costs, capital costs, additional cow purchases, developing new agriculture and salinity costs.

2. *Employment*. This is equal to the number of people employed in the Murray Mallee region. It was derived from input-output analysis in Wheeler et al. (2001).

3. *Area of wetland habitat*. The area of wetlands was estimated from Stet Government (Planning SA) vegetation data and then adjusted according to land use area changes.

4. *Salt loads to Murray River*. This excluded any costs associated with salt loads in the benefit cost analysis. Experts were consulted on the likely losses or gains of salt associated with evaporation basins or changes to agriculture.

5. *Tourism*. Tourism was assumed to be impacted by changes to water quality, which affects the aesthetic and odour values of the river, and changes to eco-tourism opportunities. A qualitative scale was derived based on these indicators.

6. *Potential health risks*. Estimated from consultant's reports (Tonkin Consulting 2000) detailing how changes to drainage impacted levels of *E coli* entering the river. The amount of *E coli* entering the river was used as the measure of health impact.

Ranking the Alternatives

The alternatives were ranked in order of performance using two methods. The first method applied was weighted summation. This requires standardisation of all performance measures into commensurate units, adjusting the standardised scores by the criteria weights and adding the weight adjusted scores for each alternative. Weighted summation is one of the most commonly applied MCA techniques. The performance measures were standardised using the following formulae:

$$sij = \frac{x_{ij} - \min j}{\max j - \min j}$$ (for criteria where more is better)

$$sij = \frac{\max j - x_{ij}}{\max j - \min j}$$ (for criteria where more is worse)

Where:

s_{ij} = the standardised performance measure of the i^{th} alternative against the j^{th} criterion;

x_{ij} = the performance measure for the i^{th} alternative against the j^{th} criterion;

min j = the minimum performance measure for all alternatives against the j_{th} criterion; and

max j = the maximum performance measure for all alternatives against the j_{th} criterion

Once the performance measures have been standardised an overall performance for each alternative is calculated by multiplying the standardised scores by the percentage weights and adding across the effects table. The formula for determining the performance of each alternative is:

$$v_i = \sum_{j=1}^{m} w_j \times s_{ij}$$

Where:

v_i = the overall performance of the ith alternative;

m = the number of criteria;

w_j = the percentage weight of the j^{th} criterion; and

s_{ij} = the standardised performance measure of the i^{th} alternative against the j^{th} criterion

In addition to weighted summation, the Rank Order Value (ROV) method developed by Yakowitz and Lane (1993) was applied. This method seeks to rank the alternatives using an ordinal ranking of criteria importance (not percentage weights). This is valuable because decision makers generally feel more comfortable with ordinal ranking of criteria importance as opposed to percentage weights (Hajkowicz *et al.* 2000). The ROV method is based on linear optimisation, in which the best total utility and worst total utility are calculated for each alternative based on an ordering of criteria importance. This is done as follows:

Best total utility:

$$max_{\mathrm{i}} = \text{maximise } \sum_{i=1}^{m} w_i \times v_i$$

$$\text{subject to: } w_1 \geq w_2, \ldots, \geq w_m; \ \sum_{i=1}^{m} w_i = 1; \ w_m \geq 0$$

Worst total utility:

$$min_{\mathrm{i}} = \text{minimise } \sum_{i=1}^{m} w_i \times v_i$$

$$\text{subject to: } w_1 \geq w_2, \ldots, \geq w_m; \ \sum_{i=1}^{m} w_i = 1; \ w_m \geq 0$$

Alternative a^* can be said to dominate (ie perform better than) alternative a if $max_{\mathrm{i}}^* > max_{\mathrm{i}}$ and $min_{\mathrm{i}}^* > max_{\mathrm{i}}$. Dominance may not always result in which case a complete ranking of alternatives could be obtained by taking the midpoint between the minimum and maximum for each alternative. Other more sophisticated procedures are described in Yakowitz and Lane (1993).

The ROV method was applied in this study using a spreadsheet model with Visual Basic code. The results were verified using an independent software package "*Facilitator 1.2.17 beta: Special MODSS' 99 Conference Release*" that is also capable running the ROV method.

Results: Criteria Weights

The average percentage weights assigned to the criteria by the panel members are shown in figure 2. The general ranking of criteria importance from most important to least important is as follows:

1. health risks;
2. economic efficiency;

3. salt loads to Murray River;
4. employment;
5. area of wetland habitat; and
6. tourism

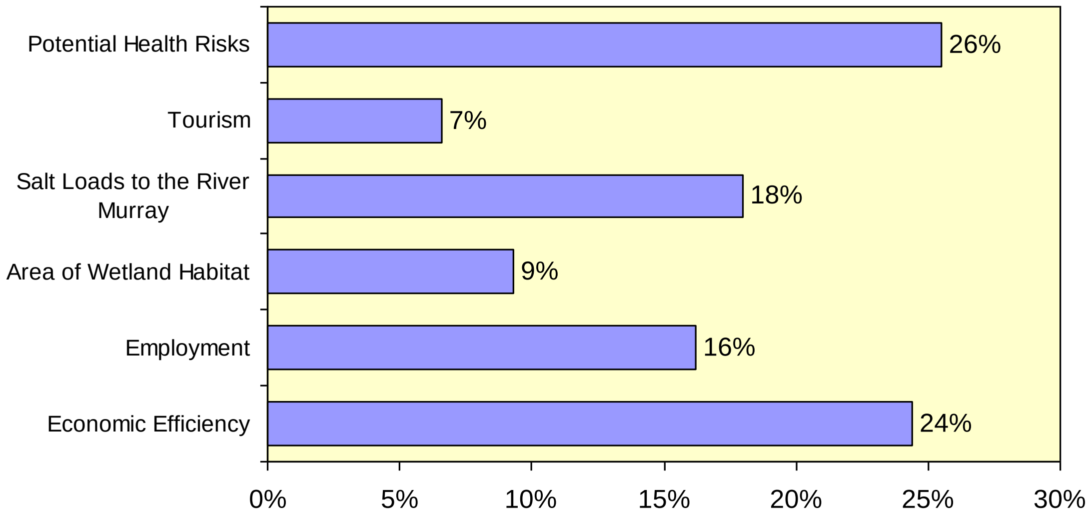

Figure 2. Mean weights assigned to the criteria by panel members.

Panel members were also asked to provide an ordinal ranking of criteria importance in the surveys. This concurred well with the average percentage weights. The modal rank positions were the same as shown above, except area of wetland habitat and tourism were ranked equally.

The panel members had fairly high levels of agreement on the relative importance of the criteria. Figure 3 shows the weighting of criteria for each panel member. It can be seen that there is relatively strong agreement amongst the panel on the general order of criteria importance. Potential health risks and economic efficiency are generally seen as thew two most important criteria.

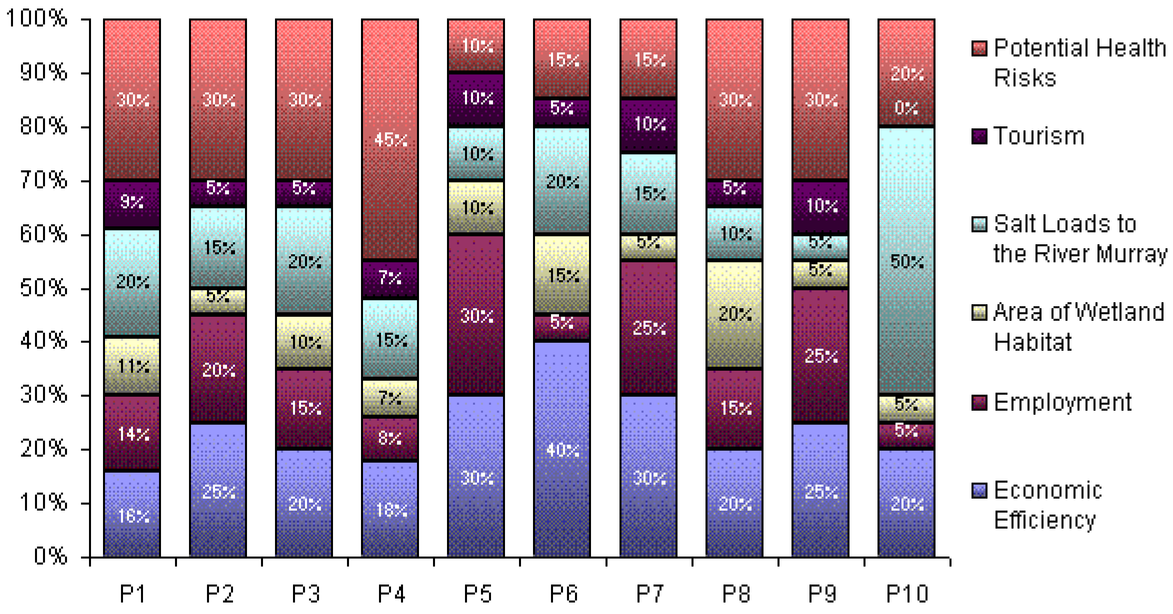

Figure 3. Weights assigned by individual panel members (P1, P2, P3, …, P10)

Results: Ranking of the LMRIA Management Alternatives

The results of weighted summation are shown in table 3. Three sets of ranking are shown. The first set of ranks shows the results obtained when the mean panel weights are applied. The second set of ranks shows the results when the rank position given by each individual panel member is averaged. The third set of ranks shows the best rank position obtained for each LMRIA management alternative over the whole MCA panel. The level of agreement within the panel on the aggregated ranks and best rank position is also shown.

Table 3. Ranking of alternatives obtained using weighted summation.

#	Management Option	Ranking using mean weights[1]	Panel Rank (average of ranks)[2]	Agree-ment[3]	Best Rank[4]	Agree-ment[5]
1	Base case scenario	11	11	100%	11	100%
2	Rehabilitation with sprinklers	7	6	0%	3	30%
3	Rehabilitation with sprinklers and evaporation basins	1	3	0%	1	40%
4	Rehabilitation with flood infrastructure extension of Wall Flat and Monteith designs	2	2	0%	1	40%
5	Rehabilitation with minimal infrastructure upgrade	10	10	90%	8	10%
6	Removal of Dairying from the swamps (not highlands) conversion to other agriculture	6	7	40%	3	10%

7	Removal of Dairying from the swamps (not highlands) conversion to managed wetlands	8	8	10%	1	10%
8	Removal of Dairying from the swamps (not highlands) and abandonment	9	9	40%	4	10%
9	Rehabilitation of most viable areas with conversion of remainder for other agriculture	3	1	0%	2	70%
10	Rehabilitation of most viable areas with conversion of remainder for wetlands	5	5	30%	2	10%
11	Rehabilitation of most viable areas with remainder abandoned	4	4	50%	1	10%

1. This is the ranking of options obtained when the panel's average weights are applied in a weighted summation.
2. This is the rank position obtained for each option by averaging the ranking obtained for each individual panel member.
3. The level of agreement within the panel for the rank position obtained at *#2*. As there were 10 panel members an agreement of 60% indicates that 6 panel members agreed on a given rank position.
4. The best rank position obtained by a LMRI management option over the whole panel. For example, an option getting a rank position of 3 means that the best rank given to that option by any individual panel member was third place.
5. The level of agreement for the best rank position given at #4.

It can be seen that options 3, 4 and 9 perform best under weighted summation. Considerable variation of the weights in the interactive meeting of the MCA panel lead to little change in these results. The weighted summation model was fairly robust in its favouring of these options.

As a check on the weighted summation methodology the results were compared against those obtained using the ROV method. This was done to check the whether the results were dependent on the selection of MCA ranking/weighting technique. A comparison between ROV and weighted summation output is shown in table 4.

Table 4. Comparison of output from weighted summation and the Rank Order Value (ROV) multiple criteria analysis technique. Both involve a different way of ranking the alternatives and weighting the criteria.

LMRIA Management Option	O1	O2	O3	O4	O5	O6	O7	O8	O9	O10	O11
Weighted Summation Rank	11	6	3	2	10	7	8	9	1	5	4
ROV Method Rank	11	8	4	2	10	6	9	7	1	5	3
Difference (absolute value)	0	2	1	0	0	1	1	2	0	0	1

From this comparison it can be seen that the ranking of options 9, 11, 4 and 3 hold the top three rank positions under at least one of the MCA techniques. It can also be seen that there is relatively strong agreement on the ordering of alternatives, with only minor variations. This suggests that the results obtained are not dependent on the particular MCA weighting or ranking technique applied.

Conclusion

Multiple criteria analysis provided a contrasting evaluation of LMRIA management options when compared to benefit cost analysis. It is interesting to observe that the option with the lowest net present value, option three involve upgrading irrigation infrastructure to sprinklers and evaporation basins, score was given the highest weighted performance score by MCA. This suggests that incorporation of criteria beyond an economic efficiency score, e.g. employment and health risks, significantly alters the outcome of a decision. The MCA technique played an important role in flagging the potential value of option three, which would otherwise have been overlooked by the benefit cost analysis.

Presentation of the MCA results to a community-based panel using an interactive customised spreadsheet provided an opportunity to learn about the decision problem. At a basic level the interactive MCA was used to assess the affect of assigning 100% weight to any single criterion. It could also be used to assess the differences between individual panel members and the impacts of a range of weighting scenarios. This helped move the MCA away from the role of prescribing a 'best' or 'optimal' land management option and towards one of an interactive learning tool. It is as learning tools that techniques such as MCA become most useful in the decision making process.

References

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Appendix A

Effects table used in the multiple criteria analysis. This shows the performance of each alternative against each criterion.

			C1 Economic Efficiency ($NPV*1,000)	C2 Employment (jobs created or lost)	C3 Increased Area of Wetland Habitat (ha)	C4 Change in Salt Loads to the River Murray (000' t/yr)	C5 Tourism (scores/50, where 1 is worst, 50 is best)	C6 Reduction (%) in Potential Health Risks
O1	Base case scenario		186,750	0	0	0.0	13	35%
O2	Rehabilitation of all irrigation areas	Sprinklers	154,471	219	0	0.0	33	86%
O3		Sprinklers and evaporation basins	24,534	219	0	-68.0	38	100%
O4		Flood infrastructure extension of Wall Flat and Monteith designs	205,409	268	0	0.0	30	80%
O5		Minimal infrastructure upgrade	192,313	17	0	0.0	14	40%
O6	Removal of Dairying from the Swamps (not highlands)	Conversion to other agriculture	170,980	9	0	-6.8	34	90%
O7		Conversion to managed wetlands	119,220	-332	5,127	0.0	48	95%
O8		Abandonment	200,799	-332	256	0.0	36	95%
O9	Rehabilitation of Most Viable Areas and Conversion of less viable areas to alternative land uses	Remaining area used for other agriculture	195,575	117	0	-5.6	33	88%
O10		Remaining area used for managed wetlands	175,872	-10	1,904	0.0	38	88%
O11		Remaining area abandoned	208,537	-10	95	0.0	33	88%