MULTI-CRITERIA DECISION SUPPORT FOR DROUGHT SECURITY

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ABSTRACT

The recently completed *Lower Hunter Water Plan* identified a portfolio of drought response measures to ensure that the region does not run out of water under severe drought conditions. A multi-criteria decision analysis (MCDA) process was developed to guide the assessment of the drought response options against multiple criteria (both quantitative and qualitative), and for the assembly and analysis of drought response portfolios.

The process guided stakeholders in considering a wide range of alternative supply and demand side options, and allowed for the transparent trade-off between options or portfolios of options.

The MCDA process integrated the assessment of social, environmental and risk/resilience criteria with cost effectiveness analysis. The process also included the analysis of contextual uncertainties and risk to determine the flexibility of the options under different future situations. The outcome of this process revealed a portfolio of drought response options that best met the weighted critieria and satisfied the drought response objectives.

INTRODUCTION

Preparation of the Lower Hunter Water Plan (LHWP) to secure the Lower Hunter's water supplies was managed by the NSW Metropolitan Water Directorate (MWD) in the Department of Finance and Services. The primary aim of the LHWP was to provide water security during droughts while also meeting projections of future growth in demand.

A multi-criteria decision analysis (MCDA) process was developed to guide the assessment of the drought response options against multiple criteria (both quantitative and qualitative), and for the assembly and analysis of drought response portfolios (Mukheibir & Abeysuriya, 2013).

Long-term supply and demand modelling for the LHWP indicates that current water sources are sufficient to supply water to meet growth under typical climate conditions for around 20 years, so this was not a key objective for the multi-criteria decision analysis (MCDA) framework.

METHODOLOGY FOR THE ASSESSMENT FRAMEWORK

This MCDA framework was designed for the development of the *Lower Hunter Water Plan* (see Figure 1). The MCDA process guided participants in considering a wide range of alternative supply- and demand-side options, and allowed for transparent trade-offs between options or portfolios of options. The process integrated the assessment of social, environmental and risk/resilience criteria with cost effectiveness analysis, and also included the analysis of contextual uncertainties and risk.

The MCDA process set out to bring together divergent views in a thorough and transparent process. Inputs from the community engagement process fed directly into the MCDA for incorporation into the deliberations of the Lower Hunter Water Senior Officers Group (SOG).

There are two fundamental inputs: good data and good process (Mukheibir & Mitchell, 2011). Data inputs are the available data that inform the assessment of the performance of each option against the agreed criteria. Process inputs ensure engaged participation from an appropriate range of stakeholders, who are well-supported in an effective process to identify meaningful criteria and appropriately diverse options.

The framework for developing the LHWP was based on tried and tested MCDA processes (Belton, S. & Stewart, 2002; White et al., 2006; Hajkowicz & Collins, 2007; Lundie et al., 2008; Dodgson et al., 2009) and has served as an aid for decision-making. The framework sought to balance the multiple perspectives of the stakeholders and community on multiple objectives. The key objectives in this case were to (MWD, 2013):

- provide water security during drought[1]
- ensure reliable water supplies to meet growing water demand
- help protect local aquatic ecosystems and the environment
- maximise net benefits to the community

[1] For the purpose of the drought modelling for the LHWP, water security was defined as storages falling to 10% with a probability of between 1 in 40,000 and 1 in 100,000.

The criteria used for the MCDA to support a decision for the LHWP were assessed against each of the following seven principles to ensure a successful options analysis process (Mukheibir & Mitchell, 2011):

Contextual: A criterion needs to have relevance to the context of the problem and the analysis at hand, i.e. in this case only criteria that matter in the context of drought should be considered.

Discerning: A criterion should distinguish between options i.e. if all options score the same, then the criterion is not meaningful in the analysis.

Assessable: A criterion should be operationally meaningful i.e. it is important that the performance of options can be assessed, either quantitatively through physical measures or qualitatively through judgement.

Consequential: The criteria must focus on the consequences of each option, and of each suite of options.

Independent: Double counting is to be avoided e.g. by not counting both reductions in GHGE and renewable energy generation

Life cycle oriented: Each criterion should consider the whole life cycle of options and/or whole timeframe of decision-making. Consistent boundaries are to be applied for each of the criteria across all the options and suites of options.

Distinguishable: The analysis used pairwise comparisons to apply weightings to the criteria. The criteria should be sufficiently different to allow for a useful comparison between pairs of criteria.

The process was designed to encourage discussion and debate around the qualitative issues relating to the implementation of options and combinations of options (portfolios). The process also introduced a step where the investment approach was defined to guide the building of portfolios based on the highest ranked options. The process consisted of the following steps:

1. Undertake an analysis of risk and future uncertainty to inform the development of the options assessment criteria, and for future sensitivity analysis;
2. Develop criteria for assessment of options and portfolios and assign weightings to the criteria
3. Assess the options against the relevant criteria;
4. Prioritise the options by assigning aggregate scores to each option as a weighted sum of ratings against criteria;
5. Define the drought response investment approach to guide the construction of drought portfolios;
6. Assemble portfolios of options;
7. Under the possible hydrological futures, assess the portfolios of options against the objectives to arrive at a preferred portfolio of measures to respond to future drought;
8. Community engagement on values, options and portfolios;
9. Assess the sensitivity of the portfolios to the significant risks identified in Step 1; and
10. Ranking of portfolios based on cost, drought security, environmental impacts, community preferences and risk.

1. Analysis of risks and uncertainties

In order to assess the effectiveness of the drought response options and portfolios, participants identified factors/assumptions that could affect the potential drought response options and portfolios. Of less importance were the assumptions that could have an influence on the whole water supply system.

Once identified, each of the factors/risks was addressed in one of four ways:

- Ignore them if already included in the supply-demand strategy analysis
- Use them to describe future scenarios
- Use the risk as a criterion for option ranking
- Undertake risk sensitivity analysis of the portfolios at the end of the process.

2. Develop criteria for assessment of options and portfolios and assign weightings to the criteria

Drawing from the available literature and on insights of the ISF project team, a long list of potential criteria was developed and synthesised using the principles discussed previously.

In the assessment, the SOG considered how to assess performance against each criterion, and how to make the assessment in a transparent and meaningful way that maintained the distinctions that mattered. The draft set of assessment criteria was also checked for consistency and alignment with the following:

a) The LHWP objectives
b) The problem to be addressed by the LHWP, which is to deal with the vulnerability to droughts
c) The unranked key “community values” associated with water planning, developed through the community engagement processes held in December 2012 and February 2013 (Waters, 2013). The six values were, for a transparent process that leads to:
    - sustainable solutions and water conservation
    - a fair and affordable system
    - safe, healthy water for all uses
    - protecting the natural environment
    - a secure reliable supply for all
    - investing dollars wisely.

An additional value, ‘respecting the value of life water’ was added in September 2013 following engagement with local Aboriginal communities.

It is important that the analysis criteria should be kept to a minimum. That is, the set of criteria should include only those that are needed to solve the problem at hand. The criteria should not require too many assumptions about the future or lead to second-guessing. A key issue at this stage of the process was the consideration of the metric (and its range) assigned to each criterion i.e. how performance against each criterion would be assessed.

The assessment for each criterion needed to distinguish between the options. A small range in the assessment of the various options would indicate potentially low relevance for decision-making, and the criterion would not be useful for the MCDA.

3. Assess the options

In assessing the options against the qualitative criteria, the SOG assessed each option’s relative effectiveness or optimal performance against each criterion. The options were ranked from best to worst using a “deliberative” approach. The ranked options were assigned scores on the basis of the total number of options being considered: the highest-ranked options received the highest score and the worst options received a score of zero.

Whilst the focus in this step was on the assessment of the options against the criteria, the conversations about the ranking of the options were equally important for determining the outcomes.

Modelling approach

Hunter Water’s Drought Portfolio Evaluation Model (DPEM) was used to determine expected present value cost and probability distributions of costs of options by simulating 10,000 different 15-year hydrological sequences, some of which were droughts, using a hydrological model and recording the costs incurred, which were then characterised using statistical analysis.

HWC’s Source Model (SoMo) was used to determine the contribution of the options to drought security, using 250,000 synthetic climate sequences. In all cases SoMo simulations were undertaken for the same time period as the DPEM, which was 15 years, aligning with commencement of the LHWP.

The risk of water storage dropping below 10% was calculated based on the average risk of dropping below 10% over years 6 to 15 of the analysis. Years 1 to 5 were not included in gathering these statistics because there is very little risk of the system running out of water in the first five years with storages starting at close to full, as is currently the case. It was found that the risk of reaching 10% storage is reasonably stable after the first five years, and therefore meaningful statistics could be gathered from year 6 onwards of each analysis.

The risks estimated using SoMo were determined by running the model with a constant underlying demand for the 15 years. This annual demand was set at the estimated 2029 demand of 70.9 GL/year (i.e. demand at the end of the 15 years). The actual simulated demand on any given day is a function of time of year, climate and whether or not restrictions are imposed.

4. Prioritise the options by assigning aggregate scores to each option

Based on the inputs from the processes described above, the aggregate score for each option was calculated using a weighted summation of all the criteria ratings. This was done on a simple spreadsheet to allow for transparency in the process and to enable stakeholders to examine the data.

A sensitivity analysis of the criteria was undertaken by sequentially increasing the magnitude of the weights for each criterion by a factor of two and adjusting the others down proportionately so that the sum of the weights was still 100%, and then checking whether the new weights changed the order of the options significantly.

The performance of each option against the criteria was used to inform building the portfolios of options.

5. Define the drought response investment approach

In order to avoid making biased decisions when building the portfolios, drought response investment approaches were defined. One example of such an approach would be to only use options that did not incur a capital investment (e.g. demand side measures). Another example would be a policy that encouraged the implementation of incremental options starting now.

6. Assemble portfolios of options

Based on these approaches, portfolios of options were assembled. The options were selected by giving priority to those that scored highest based on their weighted aggregate scores.

Portfolio 1 consists of options that work on the demand side of the supply–demand balance. This set of six options ranked consistently high across all criteria in the multi-criteria analysis and were considered important to include in **all** portfolios as they would underpin any drought response.

Portfolios 2–4 also include water transfers from the Central Coast, with or without other options such as stormwater use and temporary desalination. These portfolios were developed by adding different combinations of measures to boost the supply of water, selecting from those options which had a medium to high ranking in the multi-criteria analysis.

Portfolios 5 and 6 also include accessing water from Lostock Dam as an alternative supply option. Portfolio 5 uses water available from the existing dam by buying licences on the water market and constructing a new water treatment plant and pipeline. Portfolio 6 involves buying licences and also enlarging the dam so that more water is available when needed in a drought.

7. Assess the portfolios of options against the objectives to respond to future drought

The portfolios were compared with each other, and assessed against cost and the LHWP objectives, which are:

- to provide water security during drought
- to help protect aquatic ecosystems
- to maximise benefits to the community.

SoMo was used to determine the contribution of the portfolios to drought security, using 1,000,000 synthetic climate sequences.

Hunter Water's DPEM was used to determine the expected cost and probability distribution of costs of portfolios using a method similar to the one used for assessing the options.

Consideration of the lead-in times and triggers was important in this step.

When assessing the portfolios, it was also important to account for the interactions between options when they operated together to identify possible issues pertaining to compounding and undermining of impacts or benefits.

The environmental impact of the portfolios was assessed qualitatively by the SOG using the pair-wise comparison process described under Step 2 above.

8. Community engagement

The MWD held three community engagement workshops in April/May 2013 to assess whether the drought response options were consistent with the community values, listed in Step 2. The options were ranked according to the number of times they received a yes vote for consistency.

In September 2013, the community engagement process considered the portfolios. At three community and stakeholder workshops, participants were invited to rank the portfolios based on their values and in doing so, raise relevant issues for discussion, and further consideration by the SOG.

9. Undertake sensitivity analysis

Using the significant <u>quantitative</u> risks and assumptions identified in Step 1, the portfolios underwent a sensitivity analysis, using HWC's options analysis models where appropriate. This step provided an indication of each portfolio's resilience to future changes in the context, through either its flexibility or the diversity of its options.

Each portfolio was rated low, medium or high in its sensitivity to the <u>qualitative</u> uncertainties. Discussion with the SOG on the sensitivity of the portfolios against the qualitative uncertainties revealed where mitigation actions will be required for each portfolio.

10. Ranking of portfolios

Finally, the portfolio of options that best met the LHWP objectives was identified through a ranking process. The ranking was based on the qualitative and quantitative inputs from the technical work by HWC, the community engagement outcomes, and the deliberations of the SOG.

The weighted scores of the portfolios in the ranking process were established by members of the SOG assigning the maximum score to the highest ranked portfolio, while a score of 1 was assigned to the lowest ranked portfolio, e.g. if the choice was between three portfolios, then the highest ranked one received a score of 3, the second highest a score of 2, and so on. Based on the number of individual rankings, the final score for a portfolio was the aggregate of all its scores, expressed as a percentage of the sum of all the scores.

While the objective was not to arrive at a consensus position, discussion of the trade-offs between the portfolios was informative.

<u>OUTCOMES</u>

Rather than relying on a black box analytical approach, the process followed by the Metropolitan Water Directorate ensured transparency and allowed conversations relating to the tradeoffs in costs and benefits between options and portfolios to take place.

An agreed set of evaluation criteria were selected as a means of ranking and initially screening the supply and demand options. These included:

- cost per unit of improved drought security[2]
- consistency with community values
- controllability: the degree of certainty with which the implementation can be guaranteed

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[2] Calculated as dollars per unit of reduced risk of storage levels reaching 10% over the planning period. This method captured some of the uncertainty associated with triggering options during droughts.

- impact on the natural environment
- flexibility to change: the ability to be implemented in a modular manner.

Since not all the criteria have equal relevance in the MCDA process, they were assigned relative weightings by the SOG, using a pairwise comparison method (Table 1). The options were ranked based on the scores assigned to the options according to each criterion, and the relative weighting of each criterion.

The list of ranked options (Figure 2) was used to compile the six portfolios for further consideration (see Table 2) against the objectives of the Lower Hunter Water Plan. The process successfully combined expert input from agencies with community engagement outcomes.

A rigorous modelling analysis of the portfolios was used to compare the mean expected costs of the portfolios.The portfolios were also assessed against their impact on the environment and their sensitivity to previously identified risks and uncertainties. Based on this information, and on feedback from the community engagement, the SOG ranked the portfolios from most preferred to least preferred.

The process identified the preferred portfolios based on weighted average scores. The results were consistent with the preferences expressed through the community and stakeholder engagement workshops.

The plan is expected to be finalised in early 2014.

CONCLUSION

The MCDA process ensured a structured means for integrating the multiple objectives of the *Lower Hunter Water Plan*, and provided a process for weighing up the performance of the list of available options against these goals. It was able to synthesise, in a structured and transparent way, qualitative and quantitative values and preferences without resorting to disputable monetary 'equivalents'.

MCDA is especially useful in the public sector because of the need to be responsive to broader goals and to engage with stakeholders and the community. In particular, the method allows for trade-offs between the objectives as the levels of achievement change with different options and portfolios of options.

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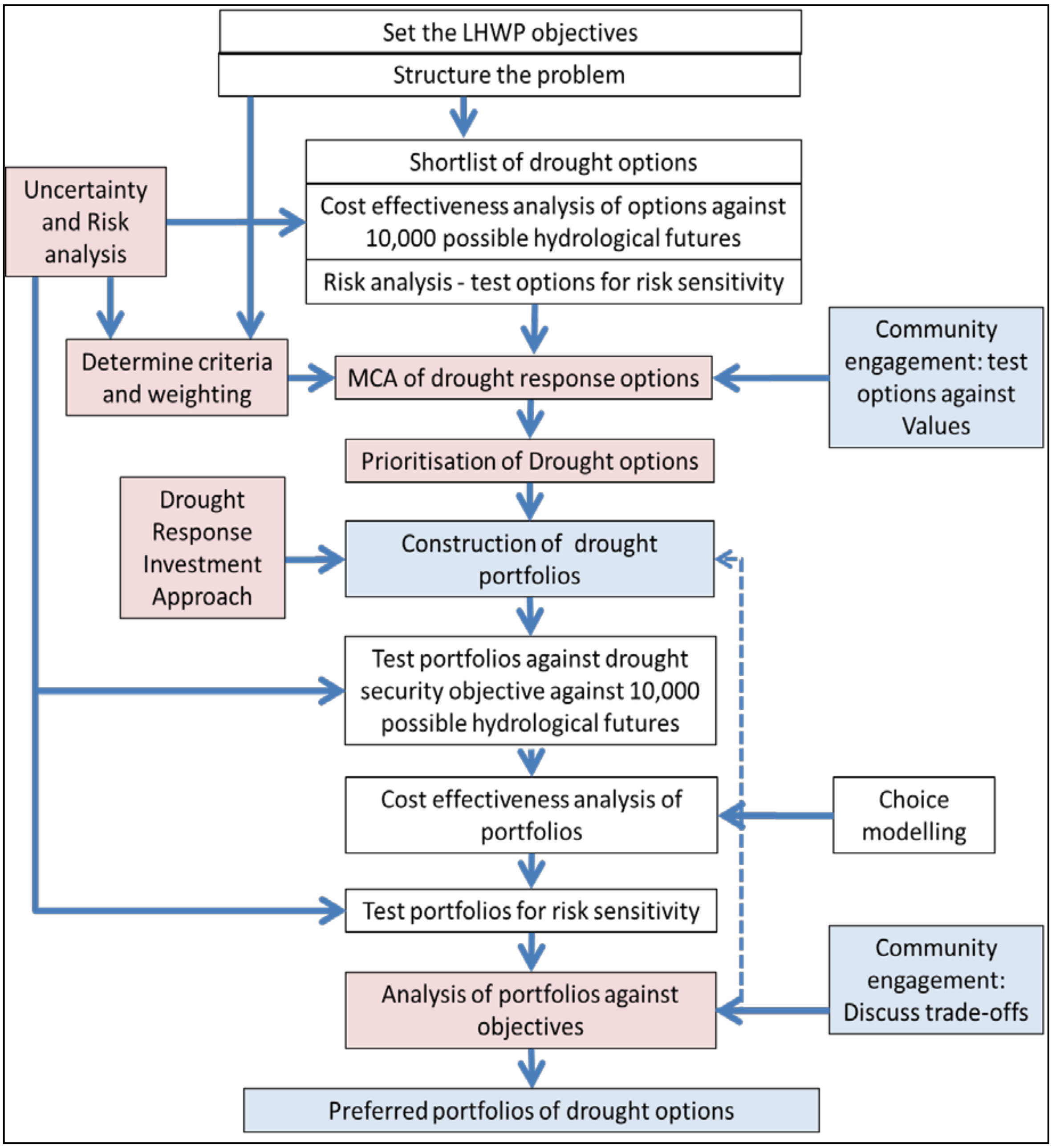

Figure 1: MCDA process diagram

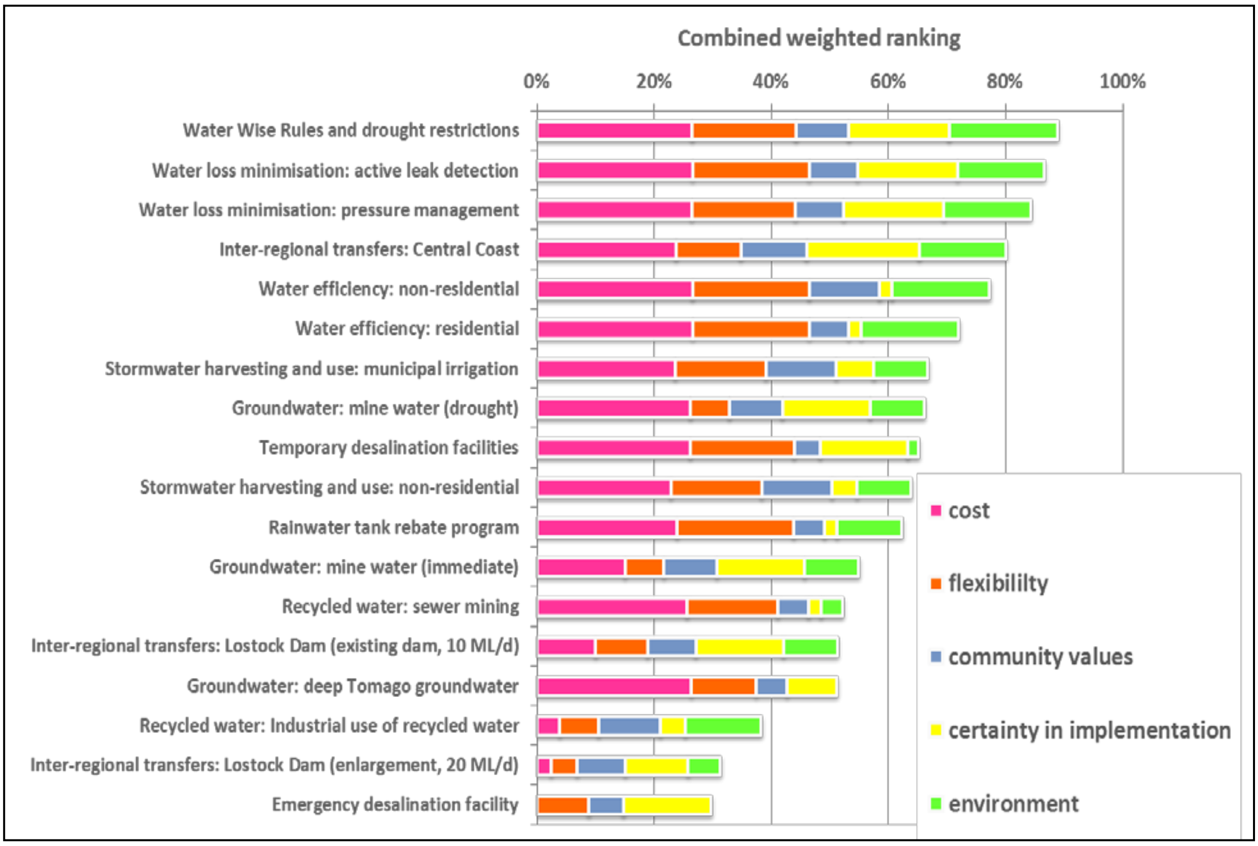

Figure 2: Ranking of options from multi-criteria decision analysis

Table 1: Assessment criteria and relative weighting

Criterion	Criterion definition and description	units and weighting
Cost of water supplied or saved per unit of improved drought security	Risk-adjusted cost per unit of contribution to drought security over the assessment period (15 years). The contribution to drought security is an index based on the risk of the water storages reaching near empty (10%) Maximum, minimum and mean values for were reported. Costs do not include externalities (e.g. community value placed on unsatisfied demand, as derived from choice modelling)	**Units**: $/unit of risk of reaching 10% storage levels **Relative Weighting: 27%**
Consistent with community values	Degree to which the options are consistent with community values based on outcomes of community engagement, where participants selected options that aligned with the six community values. (three workshops and six values = potential score of 18)	**Units**: Cumulative score out of 18 **Relative Weighting: 13%**
Controllability	The degree of certainty with which implementation or uptake can be guaranteed when an option's performance depends on third parties' discretion – e.g. recycled opportunities not taken when needed. This criterion should not to be confused with reliability, which is considered as part of the drought security modelling.	**Units**: relative ranking **Relative Weighting: 19%**
Natural environmental impact	Consideration of the environmental impact during a drought situation, such as loss of land use, damage to fauna, flora and aquatic life (ecosystem disturbance). This assessment should not include the cost of off-sets or GHG emissions – these should be included in the cost analysis Heritage concerns should not be considered here, since they are site-specific.	**Units**: relative ranking **Relative Weighting: 19%**
Flexibility to changes	The assessment of the flexibility of an option is based on its ability to supply/save water in an incremental (modular) manner i.e. the degree that it can be scaled up (staged) if necessary when further supplies/savings are needed. This criterion also reflects whether or not future upscaling of the option can be put on hold, when new technology or other changes in circumstance require that another option be pursued (i.e. whether or not it locks out any other options in future).	**Units**: relative ranking **Relative Weighting: 22%**

Table 2: Portfolios developed from ranked options

Options	Portfolio					
	1	2	3	4	5	6
	DSM	DSM + CC	DSM + CC +SW	DSM + CC +TD	DSM + LD	DSM + LD
Water Wise rules	✓	✓	✓	✓	✓	✓
Drought restrictions (levels 1 to 4)	✓	✓	✓	✓	✓	✓
Water loss minimisation: active leak detection	✓	✓	✓	✓	✓	✓
Water loss minimisation: pressure management	✓	✓	✓	✓	✓	✓
Non-residential water efficiency (enhanced drought programs)	✓	✓	✓	✓	✓	✓
Residential water efficiency (enhanced drought programs)	✓	✓	✓	✓	✓	✓
Inter-regional transfers - Central Coast		✓	✓	✓		
Stormwater capture			✓			
Rainwater tank rebates			✓			
Temporary desalination				✓		
Inter-regional transfers - Lostock Dam (existing size)					✓	
Inter-regional transfers - Lostock Dam (enlarged Dam)						✓

Abbreviations:

DSM – Demand side measures, CC – Central Coast water transfers, SW – Stormwater, TD – Temporary desalination, LD – Lostock Dam