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# Putting the economics in its place: decision making in an uncertain environment

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ABSTRACT

This paper describes a decision-making process for meeting the water supply-demand balance in urban centres. This is a complex sustainability issue, with strong elements of risk and uncertainty, resource and ecological limits, economic constraints, the potential for conflict and an over-arching need for the community to be engaged in the decision-making process. A worked example is used to illustrate the process, which employs several different component methods, each of which has been applied before, but not in combination. This decision-making process is likely to have relevance to a wide variety of other applications, in particular those relating to urban infrastructure.

Integrated resource planning is used in the analysis of supply- and demand-side options for meeting the long-term supply demand balance for water supply systems. These options can all be costed on the basis of their relative capital and operating costs and their contribution to reducing the supply-demand deficit within the planning horizon. An essential prior step is scoping the ecological boundedness of the system. In the case of urban water supply a major focus is the consideration of environmental flows and their impact on supply availability. Greenhouse gas emissions are also an important externality of water supply systems, and attributing a cost to these emissions is an appropriate planning response. The process of decision-making also needs to consider a range of issues which do not lend themselves to easy quantification, which in this process are categorised under the headings: environment; social; risk and feasibility.

To accomplish this, a process was developed that used modified multi-criteria decision-making within a deliberative space. The unique characteristics of the process were the fact that it did not attempt to mix the relatively easily quantified economic criteria with the other, less readily quantified criteria. The qualitative criteria were weighted, scored and ranked by stakeholders in a deliberative process, and these results used to filter or 'screen' options from the portfolio, thus deriving the cost impact of decisions to include and exclude options, based on the qualitative multi-criteria decision process.

The exercise was successfully used as an adjunct to the economic ranking of options within a portfolio, and it avoids the risk of moving beyond a reasonable 'monetisation frontier' associated with methods that attempt to quantify all environmental and social costs, and usual multi-criteria analysis where economic factors are often double counted and 'gaming' the process is a risk.

Case studies from a number of urban water planning studies undertaken by the authors have been used in the elaboration of an example process. Much of the data derives from Sydney, Australia but other data is used to illustrate the more general case. The aim of this paper is to provide researchers and practitioners with a practical example of a decision making process that incorporates a number of principles important for sustainability, and uses a selection of well-tested methodologies in combination. The outcome resulting from the application of this process should be more transparent, improved decision-making.

## INTRODUCTION

The objective of this paper is to describe a sequential process for meeting water demand in an urban area, taking into consideration the range of issues that impact on this task.

The process combines several existing methods, including:

- integrated resource planning
- adaptive management for drought response, incorporating real options analysis
- multi-criteria analysis
- deliberative processes

with the objective of meeting the water related service needs of the city's inhabitants, providing a balance between supply and demand at least cost and with minimum impact. The use of deliberative processes ensures fairness and equity, and brings in the necessary subjective or social dimension to the consideration of appropriate solutions.

This process, and the methods it uses, quantifies and 'builds in' the known constraints and the ecological 'bounds' of the system. For example, yield should be a function of the environmental flow requirements. Similarly, the selection of options for meeting the supply-demand balance should include an appropriate economic value for greenhouse gas emissions.

The consideration of options for meeting the supply-demand balance should treat on an equal footing those options that reduce demand, and those that increase the supply availability. This is an important principle of integrated resource planning.

The portfolio of options should be selected in a way that minimises risk associated with uncertainty. Rain-fed water supply systems are subject to occasional severe drought which is the major source of uncertainty. Trying to deal with this through investment in additional supply options can result in a significant over-investment. An approach which uses adaptive management, and one which diversifies the range of options and avoids single large investments will help reduce risks. The application of the principles of real options analysis, with its recognition of the importance of delaying large irreversible investments as late as possible, is consistent with this approach.

Another aspect of urban water supply systems is that its impacts are varied, and are difficult to compare and aggregate. A process is required that recognises that these are multi-dimensional problems, and in many cases the solutions require value judgements and trade-offs that in turn require deliberative input from a representative group of citizens, rather than the 'usual suspects' of experts, stakeholders with an interest in the issue—i.e. the 'articulate and the incensed'. A combination of a modified multi-criteria analysis process and representative and deliberative participatory methods is proposed, in order to screen, or filter, options in the development of a portfolio.

## BACKGROUND

This paper describes an example process, based on real case studies from a large body of research and practice that has been undertaken in Australia (e.g. Turner, White and Bickford 2005, White et al. 2006) and internationally (Turner et al 2005). Not all of these studies have incorporated all of the aspects and methods as described above, due to constraints in time or scope. However, taken collectively, they allow the key principles and processes to be illustrated sufficiently to provide guidance and to invite reflection from practitioners and researchers.

All these case studies use the underlying principles of integrated resource planning (IRP) as a basis. The application of IRP, a comprehensive process for planning, assessing, implementing and evaluating water supply- and demand-side options has been extended in some cases through the addition of other methods. This paper describes what is regarded as an ideal combination of methods for a planning and decision making process, with the goal of improving the level of sustainability of water service provision in urban areas.

## OVERVIEW OF THE PROCESS

The example process to develop a sustainable portfolio of water supply- or demand-reduction options will be illustrated with a series of graphs and tables. The estimates of costs, savings and other data do not relate to a specific location, but the option types, unit costs and percentage of water use are broadly indicative of actual experience and many of them are consistent with the experience in Sydney, supplied by Australia's largest water utility, Sydney Water Corporation, which supplies 4.2 million people.

The criteria used for the multi-criteria analysis tend to be quite context specific, but those used here are also broadly indicative. Weightings and scoring of options against these criteria are, of course, dependent on the preferences of the participants in such processes.

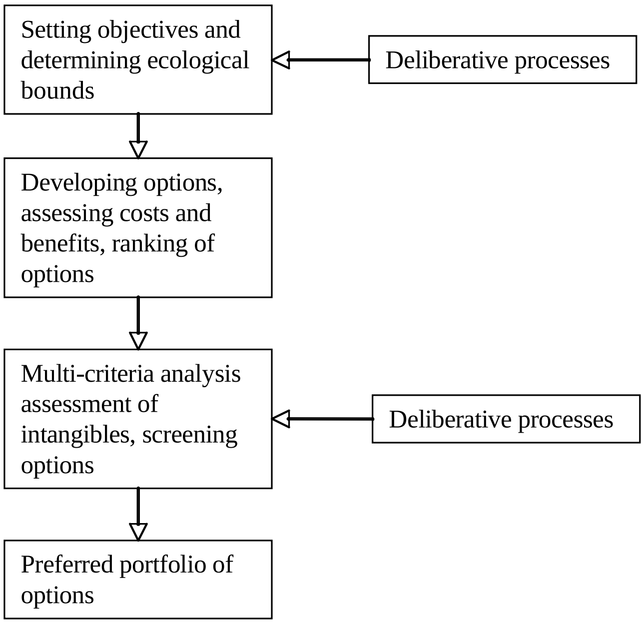


FIGURE 1: A summary of the example process

**Setting objectives and determining ecological bounds**

This stage involves determining several parameters, which impact on the supply-demand balance and on the cost and yield of options. For example, the supply availability, which is the amount of water that can be safely drawn from the system each year on average, is dependent on many factors, including:

- The depth, frequency and trigger level of water restrictions[1] or other elements of a drought response strategy
- The trigger level for inter-basin transfers or other supply options
- The level of environmental flow releases or the regulated water allocation

[1] Water restrictions, also called ‘hosepipe bans’ or ‘drought orders’ in the United Kingdom, refer to the rules that are often used to regulate water use during a drought, for example, banning the use of water for garden irrigation during the day, or for hosing down hard surfaces or washing motor vehicles. Such regulations are often introduced in stages of increasing severity as storage levels drop, and utility levels of service requirements often dictate the maximum average frequency and duration of restrictions.

- The extent to which environmental flows can be offset by discharge of recycled effluent, or reduced extraction by irrigators
- The impact of long term climate change or other changes in system yield due to a pattern of reduced rainfall or runoff
- Improvements or changes in the accuracy of the modelling of system yield.

For the case of Sydney, Australia all of these factors are relevant and have had a major impact on supply availability in the last several years (White et al, 2006)

**Ecological bounds: environmental flows**

The establishment of appropriate environmental flows can be a major undertaking, requiring significant scientific input (see Arthington 1998) and benefiting from community engagement or *at minimum* engagement with stakeholders. In the Sydney case, this was undertaken through a major scientific and technical investigation, a 2-3 year process, involving a stakeholder-based River Management Forum. This Forum, in the final stages of its work, used a multi-criteria assessment process for determining the appropriate flow regime for the Hawkesbury-Nepean River (NSW Government 2004) as have others. This process was undertaken using the stakeholder members of the Forum, rather than citizen engagement.

Establishing an environmental flow regime sets a limit on, or reduces, the supply availability. In the case of Sydney, allocation of environmental flows from the smaller dams in the system (Avon, Upper Nepean) reduces yield by approximately 25 GL/a, from a base of approximately 600 GL/a. The impact of the recommended releases from Warragamba Dam, the largest storage, will reduce yield by a further 70-80 GL/a (White, S. et al 2006). Thus, the externalities associated with water abstraction from the environment, including impacts on for example, river health, water quality, weed growth, oyster and prawn farming, can be considered to be internalised through the cost of the reduction in supply availability that arises from the environmental flow regime. This assumes that the required environmental flow regime is well designed, and that it will provide the appropriate level of river health.

**Ecological bounds: carbon emissions**

In the same way that an agreed level of environmental flow, or a regulated level of water allocation provides a boundary solution to the supply availability, other bio-physical or social constraints can be established that will have an impact on the preferred set of options. For example, it is now recognised that energy use, and associated greenhouse gas emissions represent a key externality of the urban water industry. With increased levels of inter-basin transfers; advanced sewage treatment and reuse; potable substitution through rain tanks and private bores; and the increase in the use of desalination, the average energy intensity of water supply and sewerage systems is increasing. Different options have greatly differing energy and greenhouse gas emission intensity, depending on their operating regime. However, there are now carbon trading markets[2], and a considerable literature on an appropriate 'price' of carbon emissions. This value, and other values for externalities that can be quantified with confidence, can be used to add to the direct economic costs of options to obtain an improved value for the societal cost of options. Other, less easily or less appropriately monetised impacts or externalities can be dealt with through deliberative processes as described later in this paper.

**Values and trade-offs: the need for deliberative processes**

While the factors listed earlier, that impact on supply availability, can be characterised in technical and scientific terms, there is always some degree of uncertainty, and in many cases trade-offs are involved that are too complex to be dealt with through technical analysis or they impact on different stakeholders or on different regions or eco-sheres. For example, it may be possible to achieve an improvement in river health either by releasing water from storages, or by reducing the discharge of nutrient laden effluent into rivers by diverting treated effluent to irrigate agriculture. Similarly, environmental flows in one catchment could be rendered possible through increased transfers from another. This latter example is a real trade-off in the Sydney system, where increased inter-basin transfers from the Shoalhaven River system south of Sydney are likely to be increased to meet environmental flows in the Hawkesbury Nepean. The resolution of these and other trade-offs require the establishment of deliberative decision-making spaces, which are truly representative (i.e. require random selection of citizens) as described later in this paper.

**The supply-demand balance**

Ensuring a balance between supply availability and demand over the period of analysis is the goal of the processes described in this paper. As shown in Figure 2, this can be achieved in two ways, by increasing the supply availability (increasing system yield) and also by decreasing demand. The objective is to be as close to a supply-demand balance as possible, while maintaining adequate security. Since the required level of security should be built in to the estimated supply availability in each year, maintaining a level of supply availability in excess of the projected demand is not economically prudent. In systems such as the Sydney system, which regularly

[2] See, for example http://www.pointcarbon.com/ [accessed 30 October 2006].

spills, this means that all the water supplied by non-rain fed means or inter-basin transfers prior to such spills will flow over the top of the dam wall, reducing the effectiveness of the investment and the greenhouse gas emissions that were required to produce or save that water.

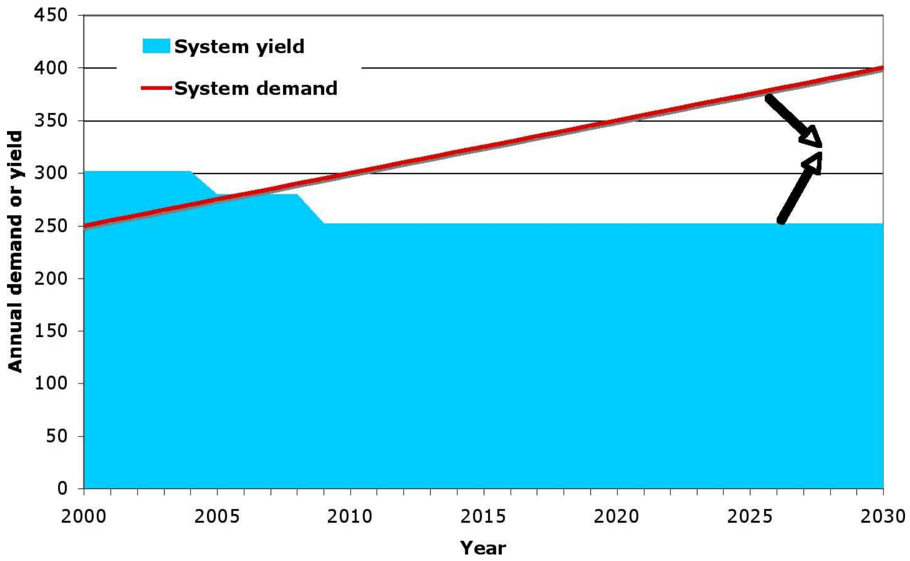


FIGURE 2: The supply demand balance over time can be ensured by increasing supply availability as well as reducing demand.

Table 1 shows a range of options and factors that increase supply availability or decrease demand. Note that water restrictions are listed as a ‘supply-side option’. The role of water restrictions, and the fact they are different to demand management measures that act to reduce the demand for water permanently is often misunderstood. Water restrictions increase the yield of the supply system because they act as a feedback process, reducing demand as dam levels drop, slowing the rate of decline and increasing the likelihood that new rains will replenish the system before dams reach dangerously low levels.

| Supply-side (influences yield) | Demand-side (influences demand) |
|---|---|
| New dams, pipelines, groundwater, desalination | Improve system efficiency (leakage, pressure management) |
| Changed environmental flow regime | Improve water use market<br>- metering, billing and pricing<br>- education and advisory services |
| Reuse schemes for environmental flows | Improve residential water use efficiency (incentives, retrofit, regulation)<br>- appliances and fixtures<br>- landscapes and irrigation |
| Indirect potable reuse into storages | Improve business water use efficiency (incentives, retrofit, regulation) |
| Changed drought response strategies<br>- restrictions regime<br>- emergency supply readiness<br>- drought pricing | Substitute potable use (on-site or larger scale)<br>- rain tanks and stormwater<br>- greywater and effluent reuse<br>- groundwater |

TABLE 1: Factors or policy actions which influence supply availability by increasing or decreasing system yield (supply-side options), compared with others that decrease demand (demand-side options).

As indicated earlier, the baseline yield forecast is a complex function of a number of factors, many of which are determined using technical means (hydrological modelling for the most part) as well as environmental flow requirements, but also other factors that are best established through deliberative means, for example the appropriate frequency and depth of restrictions. The demand forecast is also a complex matter, also subject to great uncertainty, related to demographic and land use change, technical characteristics of the stock of water using equipment and appliances (eg toilets, cooling systems, washing machines) and water using practices as well as the integrity of the supply system itself. The methodology and associated complexity of this process is beyond the scope of this paper, but it is worth recognising that best practice demand forecasting needs to consider the *end use* of water, that is, it should result in the analytical disaggregation of water use to the maximum extent possible, in order to increase the accuracy of demand forecasts. This is consistent with an approach which asks ‘how can we best meet water related needs?’ rather than ‘how can we best increase the supply of water?’ (see e.g. White, Milne & Riedy 2004).

**Developing options and estimating costs and benefits**

The next stage in this process is to develop as comprehensive as possible a list of options that can increase supply or decrease demand. In terms of the supply side options, this would need to include both rain-fed and non rain-fed supplies, and should include options of all sizes and types, no matter how small. In terms of the reduction of risk, and using the principles of adaptive management to manage risk, smaller options are valuable in a diverse portfolio. In the case of demand reduction options, the most useful means of ensuring comprehensiveness is to check that every water-using customer sector (e.g. the water supply system itself; single residential dwellings; multi-unit residential dwellings; industrial and commercial customers) and water end-use (e.g. toilet, shower, washing machine, kitchen, taps, outdoor water use) are considered and that options are developed that can tap into the conservation potential in all these sectors and end-uses.

It is an important principle of integrated resource planning, the methodology that this work fits within (White and Fane 2002) that there is an equivalence between reducing demand and increasing supply, both of them are reducing the supply-demand deficit and their impact can be measured in terms of the deficit reduction potential, or the impact on yield or reduction in demand.

Another important principle is that the task of a water utility shifts from being a water supplier, to being a provider of water services. After all, it is the services that customers want (clean clothes, clean bodies, sanitation) and not the water itself. The services can be provided with differing levels of water use intensity (efficiency), and different levels of water quality (such as less than potable grade water for toilet flushing and clothes washing) and in some cases no water at all (as in the case of waterless urinals, or in-ground heat pump cooling systems).

In this case study, a range of options has been developed for illustrative purposes. In some cases options have been clumped together for simplicity, for example, the indoor residential option would combine the following two sub-options:

- a residential retrofit program, in which householders are offered a heavily discounted service in which a plumber comes to the house to install a water efficient shower head, tap flow regulators, toilet cistern flush arrestors and to repair any miscellaneous leaks
- a cash rebate at point of sale to encourage the purchase of a more efficient clothes washing machine (in the Australian context this means a front loading machine in preference to a top loading machine)

In both cases, these options are designed to rapidly increase the proportion of water efficient appliances in households, pending the implementation of regulated standards for the efficiency of new appliances, which would act to ensure that the entire stock is changed over time. In the modelling of the savings from these programs, the potential for double counting the savings needs to be dealt with.

Table 2 describes a series of options considered in this example process. The costs and yield estimates shown in Table 3 (deficit reduction potential) are based on real examples, although in some cases, particularly the supply options, they will vary significantly with locational context.

| **Category** | **Name** | **Short description** |
|---|---|---|
| Demand | Appliance performance standards | The introduction of national standards for the efficiency level of water using appliances manufactured, imported or sold. The US Federal Energy Act (1992) is an example. |
| Demand | Non-residential program | The provision of advice to businesses on opportunities for water saving equipment and practices and financial support to encourage uptake. |
| Demand | Pressure and leakage reduction | Reducing excess pressure in the water supply system which reduces leaks and bursts, and a program of active leakage control which reduces leakage and other unauthorized use to a minimal level. |
| Demand | Residential outdoor program | Provision of targeted advice and support, including equipment or resources, to householders to assist in improving the efficiency of outdoor water use. This includes landscaping, species selection, mulching, maintenance, irrigation equipment and practices and soil treatment. |
| Demand | Residential indoor program | Discounted or free installation of water efficient equipment in houses, and rebates on the purchase of water efficient clothes washers. |
| Demand | New developments (Smart Growth) | The application of innovative approaches to servicing new developments (greenfield or infill) that first minimise water demand through water efficient appliances, fixtures and landscaping. Secondly, they maximise the use of available water from the lot or neighbourhood, through roof water and stormwater capture and reuse. The principles of water quality cascade are used, maximising the potential for treatment and reuse of wastewater for lower grade uses. Reductions in the cost of reticulation can be used to offset increased treatment costs. |
| Demand | Effluent reuse | The use of treated effluent from sewage treatment plants, reticulated to large users, households and agricultural use or environmental flow returns. This will only provide a benefit in terms of yield if there is an offset in the required environmental or agricultural flow releases. The avoided cost of sewage treatment upgrades which may not be required e.g. for nutrient removal can be deducted from this cost. |
| Supply | Emergency supply readiness | The ability to build capacity to supply additional water in an emergency. This might, for example, include the ability to construct bores to access groundwater, or to transfer water from a neighbouring catchment, or to use advanced recycling to supplement supplies to a reservoir. The yield that is provided is based on the fact that the existing water supply system can be drawn down further knowing that there is an option available to supplement supplies. The risk-weighted cost of the option is dependent on the probability of the need for it being triggered. |

| Category | Name | Short description |
|---|---|---|
| Supply | Accessing dead storage | This describes an option involving extending dam intakes to increase the effective capacity of storages. This allows for an increase in the safe yield as described above. |
| Supply | Agriculture efficiency transfers | The use of improved efficiency in agriculture to save water and thereby reduce flow releases from water storages which can then be allocated to urban use. Water savings in irrigated agriculture can be very low cost relative to urban water savings. |
| Supply | Weir raising | This involves the increase in the wall of weirs, allowing greater levels of storage. |
| Supply | Desalination | The construction of a desalination plant to operate continuously, rather than in the 'readiness mode' as described above. |
| Supply | New dam | The construction of a new dam, generally further from the centre of demand than existing storages, often in neighbouring catchments. In most cases there are significant transfer pipeline and pumping costs involved. |

TABLE 2: Short description of supply- and demand-side options considered in this example process.

| Category | Name | Deficit reduction potential in 2015 (GL/a) | Deficit reduction potential in 2030 (GL/a) | Present value cost ($m[3]) | Unit cost ($/ML) | Typical net greenhouse gas intensity (kg/ML) |
|---|---|---|---|---|---|---|
| Demand | Appliance performance standards | 16 | 30 | 8 | 50 | -20,000 |
| Demand | Non-residential program | 38 | 38 | 148 | 350 | -600 |
| Demand | Pressure and leakage reduction | 34 | 34 | 154 | 400 | -250 |
| Demand | Residential outdoor program | 24 | 24 | 118 | 450 | -250 |
| Demand | Residential indoor program | 12 | 12 | 71 | 500 | -20,000 |
| Demand | New developments (Smart Growth) | 22 | 57 | 156 | 600 | 0 |
| Demand | Effluent reuse | 33 | 37 | 278 | 900 | 1,000 |
| Supply | Emergency supply readiness | 40 | 40 | 25 | 59 | 50 |
| Supply | Accessing dead storage | 30 | 30 | 60 | 190 | 0 |
| Supply | Agriculture efficiency transfers | 17 | 17 | 50 | 300 | -100 |
| Supply | Weir raising | 20 | 20 | 147 | 700 | 0 |
| Supply | Desalination | 45 | 45 | 616 | 1,300 | 5,000 |
| Supply | New dam | 120 | 120 | 1395 | 1,500 | 1,000 |

TABLE 3: Estimates of key parameters for the supply- and demand-side options considered in this example process.

[3] All costs shown here are in Australian Dollars. Currently (30 Oct 2006) 1 AUD = 0.60 EUR = 0.77 USD. All water volumes are in kL/a, ML/a or GL/a where 1 kL = 1 $m^3$, 1 ML = 1,000 $m^3$ and 1 GL = 1,000,000 $m^3$.

**The unit cost of options**

The capital and operating costs that are used to determine the unit costs represent the net total resource cost. In other words it is the total private costs to all stakeholders, including the utility, customers, government and any other parties, less any benefits that might accrue from implementing the option, also from a total resource cost perspective. Thus, for example, in the case of the effluent reuse option, the total unit cost of the option may be in excess of $1,500/ML, however, there may be significant avoided costs associated with the reduced need to upgrade sewage treatment plants for nutrient removal, which need to be deducted from the cost, reducing it to $900/ML. Similarly, the cost of water saving, rainwater capture and effluent reuse in new developments (Smart Growth) has avoided cost implications relative to the base case, or business-as-usual due to the avoided cost of reticulation and infrastructure needed for supply or water and sewerage services in the conventional way (for more discussion of these emerging possibilities see Mitchell and White 2003, White 2005).

In the case of the agriculture efficiency transfers option, this is modelled (based on estimates for the Sydney context) as the improvement of the efficiency of agricultural water use (irrigation) with the associated savings resulting in reduced need for flow releases from storages for allocation to irrigators. In this case, no additional water transport infrastructure is needed, however in many proposed rural-urban transfers there are significant capital costs associated with pipelines. This represents an irreversible capital investment (sunk cost) that alters the marginal cost of supply, and can result in 'lock-in' of such transfers.

There are several possible metrics that can be used to calculate unit cost. Annualised cost is often used where the annual volume of water saved or supplied is constant, and the annual operating costs is also constant. Unit capacity cost, for example, expressed as $/ML/a can also be used, but the year in which the water volumes are delivered must be specified. The preferred metric, which takes into consideration the more general case where both the stream of net costs are varying over time, as well as the water volumes, is the *levelised cost* or *average incremental cost* (see Fane, Robinson and White 2003).

**The cost of greenhouse emissions**

The greenhouse gas intensities shown in Table 3 are indicative, although based on real examples in the case of most of the demand-side options. These should always be expressed as net greenhouse emissions, relative to the base case. The contributions to greenhouse gas emissions results arise from increased energy intensity of water production (desalination, advanced wastewater treatment and recycling and additional pumping from new dams which are generally a greater distance from the demand centres). The reductions in greenhouse gas emissions from the demand-side options arises from avoided water pumping and treatment as well as avoided emissions associated with reduced hot water use, which are significant in the case of water efficiency programs involving showers, taps, clothes washers and some industrial processes. In terms of the unit cost of options, these greenhouse gas emission intensities can be used to calculate a revised figure for social cost, based on agreed estimates of the cost of carbon. For example, a cost of carbon of $30/tonne would add approximately $7m/a to the operating cost of a 100 ML/d desalination plant. This would add approximately $200/ML to the $1,300/ML unit cost of desalination in this example. Conversely, in the case of the indoor residential efficiency program, where hot water savings reduce the greenhouse gas emissions relative to the base case, the addition of the (avoided) cost of carbon at this value reduces the unit cost of water saved from $500/ML to -$125/ML, that is, to become a net benefit. While this social unit cost has not been shown in this worked example process in the interests of simplicity, it can change the ranking of options, particularly where hot water savings are involved. In this example process, the indoor residential water efficiency option is the only option that would change its rank order.

**Risk and uncertainty**

Infrastructure generally, and water supply systems in particular, operate in a highly uncertain environment. Demand is difficult to forecast, even when more detailed, end-use based, modelling is undertaken. Perhaps the most significant uncertainty, particularly in countries such as Australia is the impact of drought on water supply systems that are predominantly reliant on surface water. Increasingly, there is uncertainty regarding the implications of groundwater extraction, and the future impact of environmental flow requirements which have not yet been characterised fully. Overlaid on all of this is the impact of long term climate change on the yield of storages which is the subject of modelling that is highly uncertain and spatially coarse.

Traditionally, many utilities have attempted to deal with this uncertainty by building storages that can compensate for the 'worst drought on record' or for the worst simulated drought using stochastic modelling to synthesise many more years than are usually available in continuous record[4]. As can be imagined, this leads to a significant additional investment in infrastructure to cope with the worst drought on record, a large investment to deal with a statistically improbable event.

[4] In Australia, the length of rainfall records and particularly streamflow records, rarely exceed 100 years.

This means that there is significant value in finding solutions that can be made available during drought. Water restrictions are one such method, which are routinely used to cope with drought. As the potential for restrictions is exhausted, or there is resistance from elected decision-makers to imposing more severe restrictions, other options become relevant, including desalination, groundwater, inter-basin transfers, effluent reuse. These options are less dependent on rainfall in the local area. What is important is not the pre-emptive construction of new capacity to deal with severe droughts, but the ability to do so within sufficient time, should that prove necessary. Such 'virtual supply' options can contribute to a net increase in yield by allowing storages to be drawn down to a greater extent while maintaining appropriate levels of security. These options have a far lower cost, which should be calculated as the risk-weighted (i.e. probabilistic) cost of the option. This logic[5] is based on the principles of real options analysis (see McDonald and Siegel 1986). These principles make it clear that it is preferable to delay investment in large irreversible capital works until the very last point at which it is needed. This is consistent with an adaptive management approach, which allows a continuous re-assessment of the environment and the level of knowledge of key parameters, including demand and inflows and therefore the available yield.

**Assessment and ranking of options**

The options that have been modelled for this case study are represented in a supply curve in Figure 3, showing the unit cost of each option relative to the cumulative contribution to reducing the supply-demand deficit, in a specific year (in this case 2015). Note that the options, when ranked in order of increasing unit cost, combine demand-side and supply-side options. In the first iteration of assessing and ranking options and development of a supply curve, the optimal timing of options is not known. Option timing should be optimised to ensure that the demand is kept below the yield at any given time (to ensure security criteria are met), while minimising the surplus of supply over demand (to limit over-investment). This highlights the benefits associated with preferencing options that increase yield incrementally at a reasonable unit cost, in terms of avoiding the risk of over-investment.

[5] The authors are indebted to David Campbell of ACIL Tasman Australia [http://www.aciltasman.com.au/ accessed 30 Oct 2006], joint author of the 2006 Review of the Metropolitan Water Plan (White et al. 2006) for this concept, and for the term 'virtual desalination plant'.

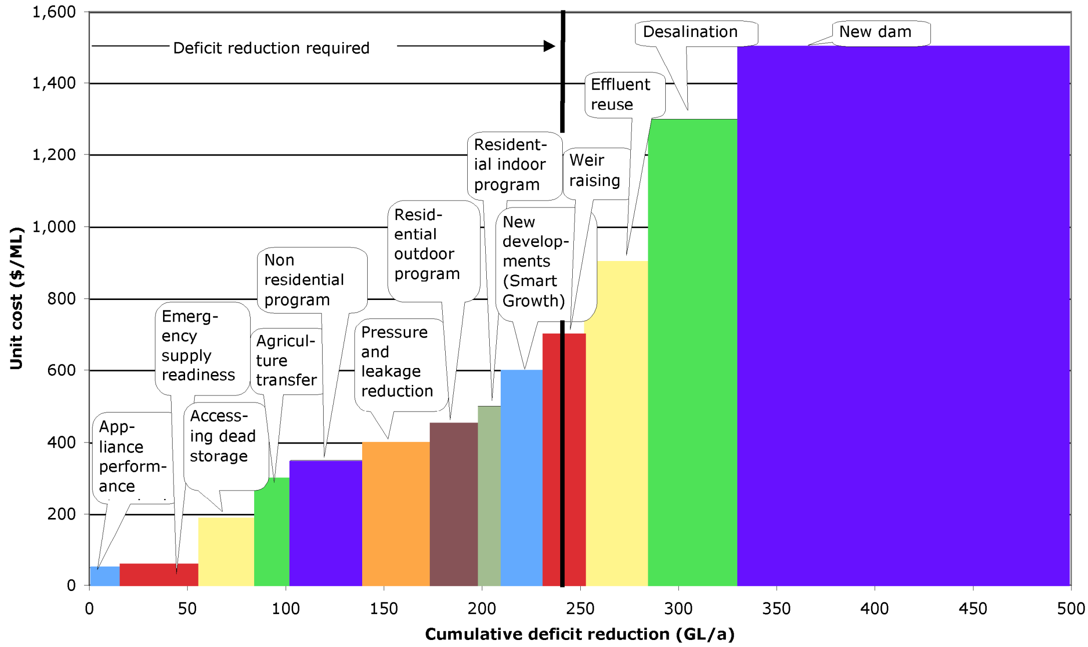


FIGURE 3: The unit cost of supply- and demand-side options in rank order, relative to the cumulative reduction in the supply-demand deficit that would be expected from those options in 2015. Also shown is the target deficit reduction needed in that year.

Figure 4 shows the cumulative present value cost of investment in the options assuming they are implemented in rank order. This kind of representation can be used as a heuristic device to determine the investment required (vertical axis) to ensure supply and demand are in balance (horizontal axis). For example, in this case, by 2015, it is expected that base case demand and yield will differ by 240,000 ML/a (240 GL/a). In other words, a combination of supply and demand options totalling 240,000 ML/a would need to be implemented before 2015 to ensure the supply demand balance.

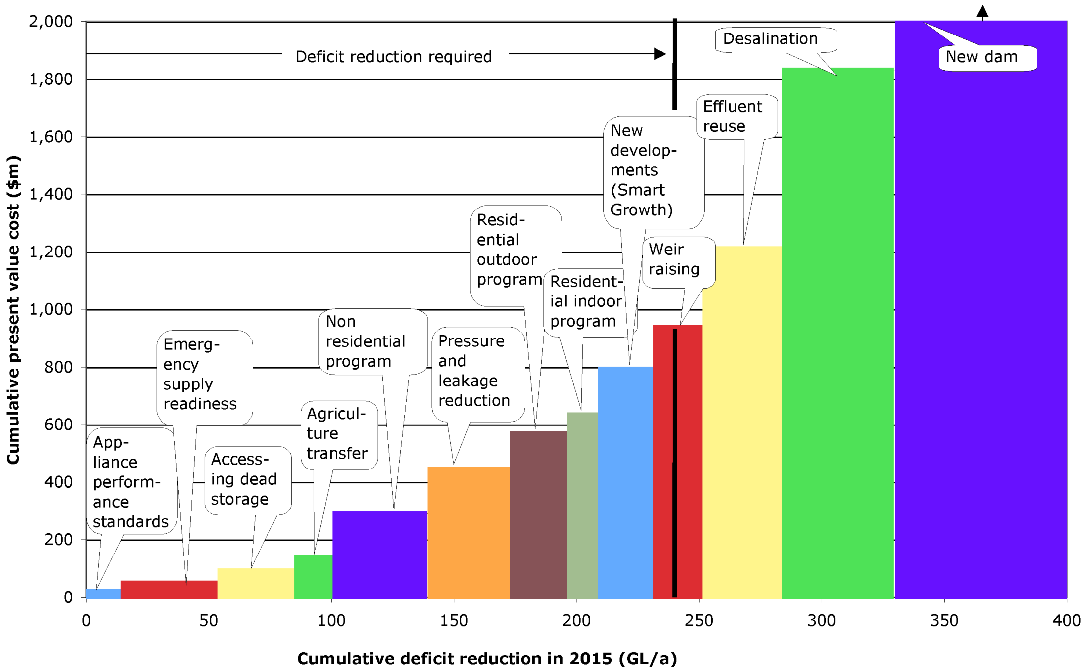


FIGURE 4: The cumulative present value net cost of implementing options in rank order of unit cost, relative to the cumulative reduction in the supply-demand deficit that would be expected from those options in 2015. Also shown is the target deficit reduction needed in that year.

These options, when implemented u the point of the effluent reuse, would result in the demand and supply being in balance, as shown in Figure 5. If options are excluded through the multi-criteria analysis screening and filtering process, described later in this paper, then higher cost options will need to be implemented. Figure 5 illustrates this, showing the weir raising excluded and the effluent reuse taking its place.

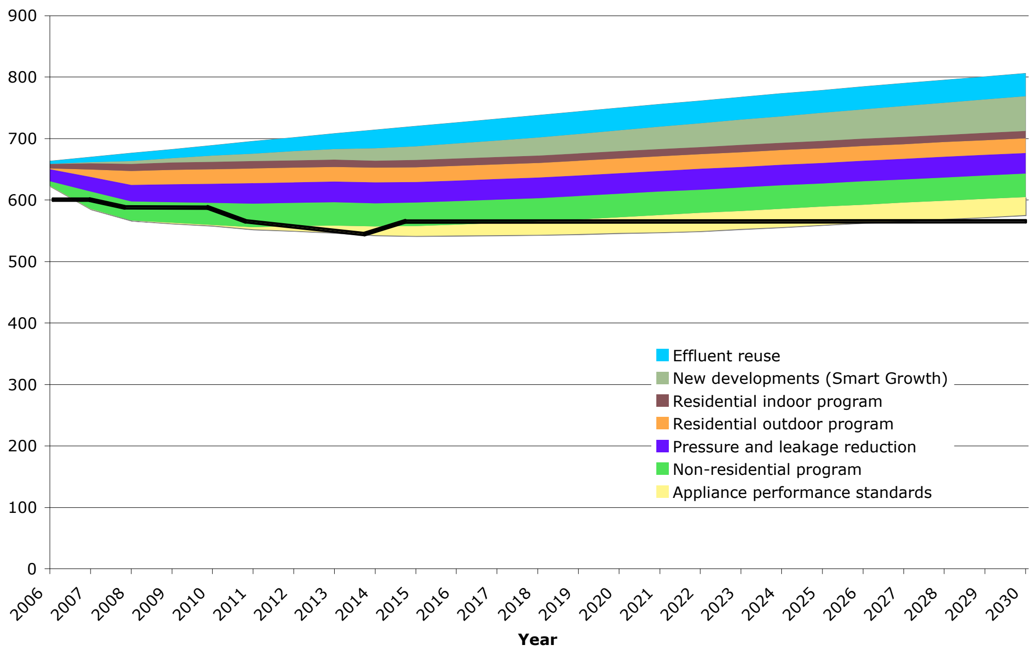


FIGURE 5: Time series water supply and demand showing the demand-side options in detail. The black line is the yield, or available supply, with the lowest cost supply-side options implemented at the appropriate time.

## Assessment of intangibles

The costs (and avoided costs) that are included in the assessment that is summarised in Table 3, and Figures 3 and 4, are of direct costs (labour, capital, operating and maintenance costs). The types of costs that are experienced in the urban water supply system can be characterised as a 'spectrum' of costs, with the more easily quantified, direct costs on the left hand side, and the less easily quantified on the right hand side as shown in Figure 6. There is a 'monetisation frontier' where it is counter-productive, or even objectionable to attempt to quantify or monetise costs (O'Connor 2002).

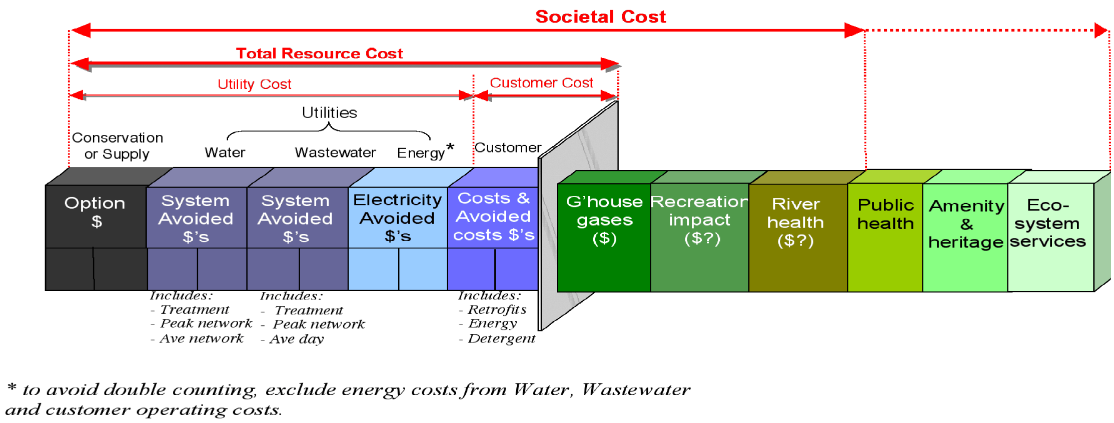


FIGURE 6: A spectrum of costs and benefits for urban water illustrating different cost categories.

This work, as described in the following section, suggests that it is better to re-design the way that the intangible costs are dealt with using a qualitative approach, which recognises the inherent subjectivity and 'value-laden' nature of this kind of assessment. The qualitative, discursive approach can then guide decisions on allocation of resources, which provide a direct input to economic decision making and associated costs. This is reflected in the spectrum in Figure 7.

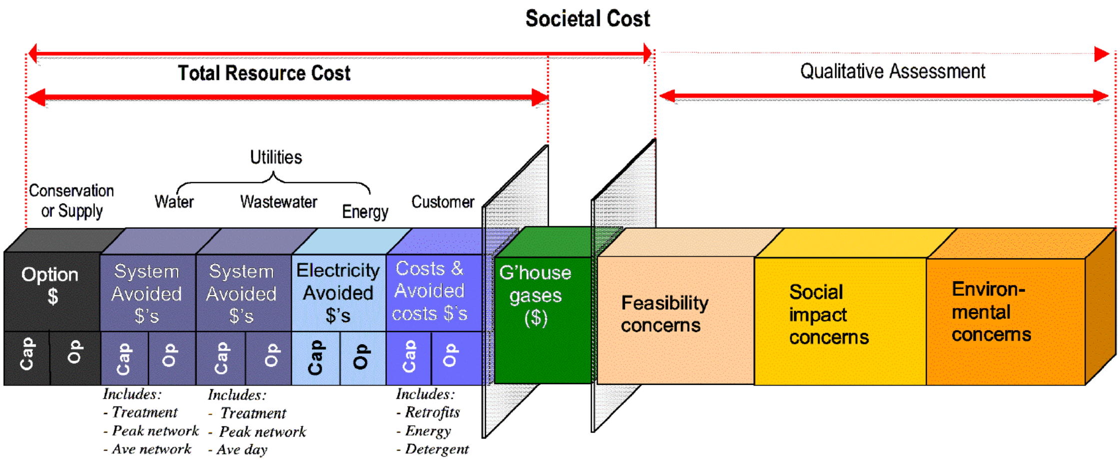


FIGURE 7: A spectrum of costs and benefits for urban water illustrating different cost categories, and illustrating the area where qualitative assessment can play a part in the assessment of options.

**Screening options using multi-criteria analysis**

This stage involves the application of multi-criteria analysis (MCA), using a deliberative process. However, as distinct from many MCA processes, in this case it was not used to rank options, but to interactively and deliberatively screen or filter options and to test the impact of such filtering on the total portfolio cost of meeting the supply demand balance. The cost or the yield of options, or any criteria that is strongly related to the cost or yield, are excluded as criteria from the MCA assessment exercise. This avoids the risk of double counting, and the potential for 'gaming' the process. The process is an iterative cost-effectiveness exercise. It asks the question 'what portfolio of options will meet the supply demand balance, while *considered acceptable* in relation to an agreed set of non-cost criteria?'.

The definition of *considered acceptable* is at the heart of the appropriate choice of deliberative process. This question can be informed by scientific and technical knowledge, and can be subject to suasion by stakeholder or interest group preferences, but the acceptability should ultimately be determined or informed by the collective judgement of a representative group of citizens engaged in informed dialogue. In the case of the two examples of application of this method described here, for two Australian cities, it was beyond the project scope to undertake the full community engagement as outlined above, and the participants in the deliberative process were agency staff. The processes were both undertaken in a half-day workshop.

However, fortunately, there are now many excellent examples of the application of appropriate community engagement processes which do embody the principles of:

- representativeness (using random selection and a stratified sample of participants);
- deliberation (dialogue between participants with sufficient time to move toward consensus—minimum 2 days—with a skilled, neutral moderator, and access to experts and resources); and
- influence (a clear 'charge' for the participants to address, and a contract with the organisers regarding the fate of the outcome of the process).

Some of these example processes are described by Carson and Hart (2005) and Carson and Hartz-Karp (2005).

In the case of one of the case study MCA processes, the participants were given a primer package 24 hours before the workshop. This package included a description of the tasks to achieve for the workshop, which were:

- To select the five key qualitative criteria for each index category (social; environmental; and risk/feasibility)
- To allocate weights against each criteria to reflect their importance in decision making
- To discuss the scoring for options against the criteria

To achieve the first task participants were provided with a range of example criteria within each index category (i.e. social; environmental; and risk/feasibility). Participants were given the option to contribute additional criteria within each index category, but were required to complete the task of reducing the number of criteria to five within each index[6]. Accompanying the listed criteria was a description (or rationale) behind each criteria, based on a literature review, and some examples of the type of impacts which could be encompassed by individual criteria when screening options. Participants were requested to be ready to contribute to the workshop their preferred criteria which were agreed by consensus following discussion.

The workshop commenced with a presentation, explaining the role of the qualitative assessment process within the overall planning process. Participants then commenced with the first task of shortlisting the criteria to produce an agreed list within each index category as shown in Table 4.

| Environmental | Social | Risk / Feasibility |
|---|---|---|
| Terrestrial impact | Equity between socio-economic groups | Technical |
| Water quality and river health | Inter-catchment equity | Public acceptance |
| Ecosystem values | Landscape, amenity and recreation values | Rick of non-delivery of the option |
| Resource use efficiency | Health | Health and safety risks |
| Environmental sinks – air, land, water | Inter-generational equity | System reliability |
| | | Institutional |

TABLE 4: Shortlisted criteria by index category

6 A sixth criteria was included for risk/feasibility

For the second stage of the workshop, participants were asked to individually assign a weight to each criteria between 0 and 5. This process indicated the relative magnitude of the importance of each criteria for the participants in the decision making process. Participants were able to allocate weights, discuss why they had chosen such weights, and review their decisions following discussion and reflection. The individual weights were collated in a ballot and the aggregate results are shown below in Table 5**.**

| Social index | Aggregate Weighting |
|---|---|
| Equity between socioeconomic groups | 4.0 |
| Inter-catchment equity | 2.4 |
| Landscape, amenity and recreational values | 2.7 |
| Health | 4.7 |
| Intergenerational equity | 2.7 |
| Environmental index | |
| Terrestrial Impact | 2.6 |
| Water quality and river health | 4.5 |
| Ecosystem values | 3.8 |
| Resource use efficiency | 4.2 |
| Environmental sinks | 2.5 |
| Risk / Feasibility index | |
| Technical | 2.9 |
| Public Acceptance | 3.7 |
| Risk of non-delivery | 3.3 |
| Health and safety risks | 4.5 |
| System reliability | 3.7 |
| Institutional | 2.5 |

TABLE 5: Weightings for criteria based on the deliberative process.

The third stage of the workshop began with a discussion about the range of options and the type of impacts that would arise from each option based upon assessment against each of the criteria, relative to a base case. Participants were asked to consider whether the impacts were positive, neutral, or negative for each criteria. A raw score of +1, 0, or –1, indicating the cost or benefit (or neutral) relationship, was allocated for every criteria-option combination. It was observed by some participants that it would have been preferable to have -2,-1,0,+1,+2 scoring system to distinguish some options more clearly from each other.

In this process, the raw score from individual criteria-option combinations was multiplied by the relevant weighting derived for each criteria, providing a weighted score. The weighted scores for each option were then aggregated by index category.

The next stage is to use the results of the scoring to iteratively screen, or filter options. For example, these might be plotted as shown in Figure 8, where there is a preferred zone of acceptable scores resulting from the deliberative analysis. These can be used to screen or filter the options from the portfolio, then re-calculating the total portfolio cost and considering the implications of the increase in cost. For example, with the portfolio shown in Figure 4, should the weir raising be excluded due to being assessed as having a high impact, then the next option, effluent reuse, would be brought into the portfolio instead increasing the total cost by the difference between these two options. In this way, the quantitative economic consequences of the qualitatively based decision to exclude the option can be assessed in a transparent way.

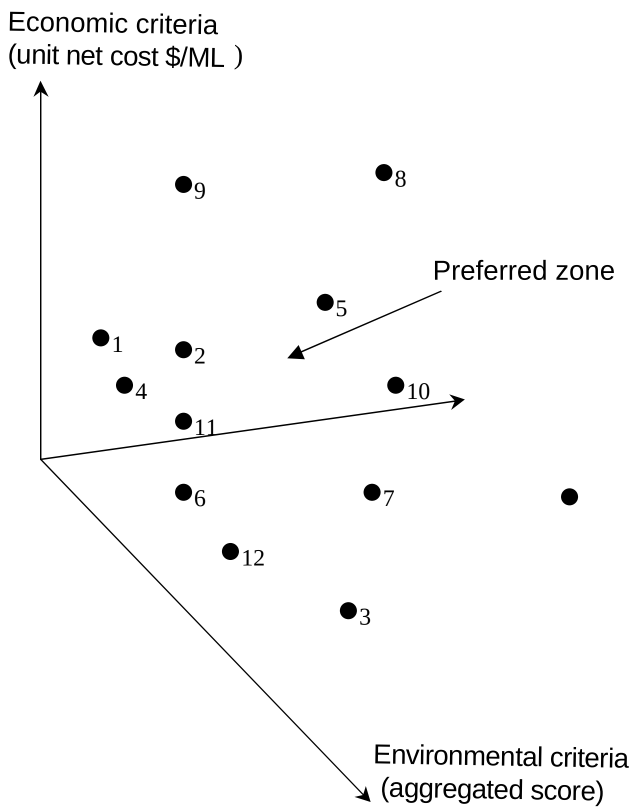


FIGURE 8: A visual representation of the boundary of acceptable impacts that arise from the qualitative assessment process.

## CONCLUSIONS

The example process that has been outlined in this paper combines the principles and practical aspects of several different decision support methods, to enable a more robust and transparent decision-making process for urban water supply. This process is underpinned by integrated resource planning, and uses the principles of adaptive management and real options analysis, as well as utilising a deliberative approach to objective setting and a modified multi-criteria analysis in which the economic criteria are dealt with separately and the results are used for iterative screening and filtering of options in a portfolio. All the components of this process are well characterised, and the combination promises to ensure a greater level of transparency in decision-making in urban water management and a more sustainable outcome.

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