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Can Multi Criteria Decision Analysis (MCDA) help assist in the successful uptake of Integrated Urban Water Management (IUWM)?

By Anna Tsitsis

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It is hope that this report will be of assistance to Richard Clark and his drive to help South Australia engage in more sustainable urban water management practices.

From the The University of Adelaide I would like to thank my academic mentor, Douglas Bardsley for his advice and guidance.

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Abbreviations

IUWM: Integrated Urban Water Management

MCDA: Multi Criteria Decision Analysis

KSG: key stakeholder group

CBA: Cost Benefit Analysis

USHO: Urban Stormwater Harvesting Option

UWSRA: Urban Water Security Research Alliance

UN: United Nations

NWI: National Water Institute

DEW: The Department of Environment, Water

MAUT: Multi- attribute utility theory

AHP: Analytical Hierarchy process

ANP: Analytical Network process

SA Water: South Australia Water

SA: South Australia

The abstract

South Australians have inherited three sets of water service networks dealing separately with;

1) The importation and supply of fresh water

2) The collection and discharge of wastewater

3) The drainage and removal of stormwater generated from rainfall on the urban areas.

Systems 2 and 3 are not priced and there is little incentive for individuals to make wise use of these latter two sources of water. Adelaidians also have access to ground water which is used by some industries, many organisations, businesses interested in maintaining sporting fields and also by a significant number of households with large gardens.

It has been widely shown that, with increasing demands on the services and advances in water storage and treatment technologies, it is now possible to develop systems that promote the more efficient use of each of these water sources and/or start combining elements of the three separate systems into a single multi-purpose system. Combining elements of the three separate systems into a single multi-purpose system which, if the coordinating entity has a full understanding of values costs and opportunities, has the potential to generate large reductions in costs and environmental impacts. How far the combination process can be taken will depend on many considerations, but all indications are that the benefits will be large and proportional to the innovation brought into the systems integration process.

Unfortunately, the integration process inherently requires a central lead agency which has the vision and trust to establish the full cooperation of the large number of parties with stakes in the operation of the three separate systems and the services they provide. One reason may be because it is unclear how the different stakeholder's views on Integrated Urban Water Management (IUWM) can be resolved, making such leadership very problematic. This project is to see if Multi Criteria Decision Analysis (MCDA) can support change in this area.

Methodology

This report draws upon academic literature and official government documents, mostly from The Department for Environment and water, and SA Water. To develop a greater understanding of how decision tools could be used to assist the successful uptake of IUWM in South Australia comparative case studies were studied and where possible comparisons and contrasts made**.** The findings of this report have been influenced by the conduct of informal interviews with stakeholders from different institutional backgrounds. Refer to appendix 1 for the interview template used. This information was used to inform the direction and conclusion of the report.

INTRODUCTION

1.1 Background of research

Traditionally, Urban water management has involved the provision of water supply, wastewater and storm water to customers through a network of pipes (Marlow et al., 2013). Regardless of the global variances in organisational and governance arrangements (Baietti et al., 2006) it has been standard practice that these water services have been managed as separate entities (Mukheibir et al., 2014). It is suggested that this conventional approach simplifies the planning process by allowing planners to monitor supply and demand trends for each water service separately, investing in infrastructure only when necessary (Closas et al., 2012).

According to Richard Clark (2018) three sets of 'traditional' water service networks exist in South Australia to deal with water supply, wastewater and stormwater. Respectively they consist of;

1) A network of big water supply pipes bringing water into the city from reservoirs and now, as a result from recent investment, the desalination plant and a network of smaller pipes distributing this water to each service location.

2) Sewer pipelines removing sewage from each location. These pipelines join together to take the sewage to 4 treatment plants near the seafront.

3) A network of small drains taking stormwater as rainfall from the streets into bigger drains, channels and existing creeks. These networks take this storm water to the sea where it is discharged.

Systems 2 and 3 are not priced and there is little incentive for individuals to make wise use of these latter two sources of water (Young. Pers. comm.).

Mitchell (2006) states that this separation of entities has led to their being little interaction between the three water services. Coombes and Kuczera (2002) found this compartmentalization; both physical in terms of infrastructure and institutional in terms of who is responsible for provision, operation and maintenance, has led to suboptimal outcomes with adverse effects on society, the economy and the environment (Butler and Maksimovic, 1999). For example, academic literature cited by Vlachos and Braga (2001) draws on the economic costs of replacing these networks as they become old and degraded if the opportunity to rethink their purpose is not taken, while research by Mouritz and Newman (2000) investigates the harm these water management systems have on aquatic habitat through their impact on environmental flows.

Further, concerns about how this conventional water management will deal with the challenges of climate change, population increase and urbanisation has led to a paradigm shift

in the Urban water industry. The key characteristics of this are evidenced in Figure 1 (Pinkham, 1999). As a result, cities have begun to reconsider the way they plan and manage their water systems (Maheepala et al., 2010).

Figure 1: Characteristics of 'old' and 'emerging' paradigms of urban water systems. Source:

The Old Paradigm	The Emerging Paradigm
Human waste is a nuisance. It should be disposed of after treatment.	Human waste is a resource. It should be captured and processed effectively, used to nourish land and crops.
Stormwater is a nuisance. Convey stormwater away from urban area as rapidly as possible.	Stormwater is a resource. Harvest stormwater as a water supply, and infiltrate or retain it to support aquifers, waterways and vegetation.
Demand is a matter of quantity. Amount of water required or produced by different end-users is the only parameter relevant to infrastructure choices. Treat all supply side water to potable quality, and collect all wastewater for treatment.	Demand is multi-faceted. Infrastructure choice should match the varying characteristics of water required or produced for different end-users in terms of quantity, quality, level of reliability, etc.
One use (throughput). Water follows one-way path from supply, to a single use, to treatment and disposal to the environment.	Reuse and reclamation. Water can be used multiple times, by cascading from higher to lower quality needs, and reclamation treatment for return to the supply side of infrastructure.
Gray infrastructure. Infrastructure is made of concrete, metal or plastic.	Green infrastructure. Infrastructure includes not only pipes and treatment plants, made of concrete, metal and plastic, but also soils and vegetation.
Bigger/centralised is better for collection system and treatment plants.	Small/decentralised is possible, often desirable for collection system and treatment plants.
Limit complexity and employ standard solutions. Small number of technologies by urban water professionals defines water infrastructure.	Allow diverse solutions. Decision makers are multidisciplinary. Allow new management strategies and technologies.
Integration by accident. Water supply, wastewater and stormwater may be managed by the same agency as matter of historical happenstance. Physically, however, three systems are separated.	Physical and institutional integration by design. Linkages must be made between water supply, wastewater and stormwater, which requires highly coordinated management.
Collaboration=public relations. Approach other agencies and public when approval or pre-chosen solution is required.	Collaboration=engagement. Enlist other agencies and public in search for effective solutions.

Pinkham (1999)

Reflecting these views of the paradigm shift, Integrated Urban water management (IUWM) has emerged as an alternative planning framework to assist the development of a more resilient[1] water management system. According to the Global water partnership (2012) the IUWM planning framework facilitates, through emphasizing the importance of integrating water sources, water use sectors and water management, a more coordinated, responsive and sustainable resource management practice (Furlong et al., 2017). Through assessing the social, economic and environmental dimensions of water there is increased awareness

[1] "the capacity of linked social-ecological systems to absorb recurrent disturbances ... so as to retain essential structures, processes and feedbacks ... and the degree to which the system can build capacity for learning and adaptation" (Adger et al. 2005:1036).

about the wider societal context of water. Ujang and Henze (2006) suggest that IUWM balances both human and environmental needs alongside economic growth.

According to a report by the Global Water Partnership Technical Committee (TEC) (2012, pg12) IUWM is defined by the following characteristics.

1. *"The recognition of the need for alternative water sources*

2. *IUWM Differentiates the qualities and potential uses of water source*

3. *IUWM Views water storage, distribution, treatment, recycling, and disposal as part of the same resource management cycle*

4. *IUWM Seeks to protect, conserve and exploit water at its source*

5. *Accounts for non-urban users that are dependent on the same water source*

6. *Aligns formal institutions (organisations, legislation, and policies) and informal practices (norms and conventions) that govern water in and for cities*

7. *Recognises the relationships among water resources, land use, and energy*

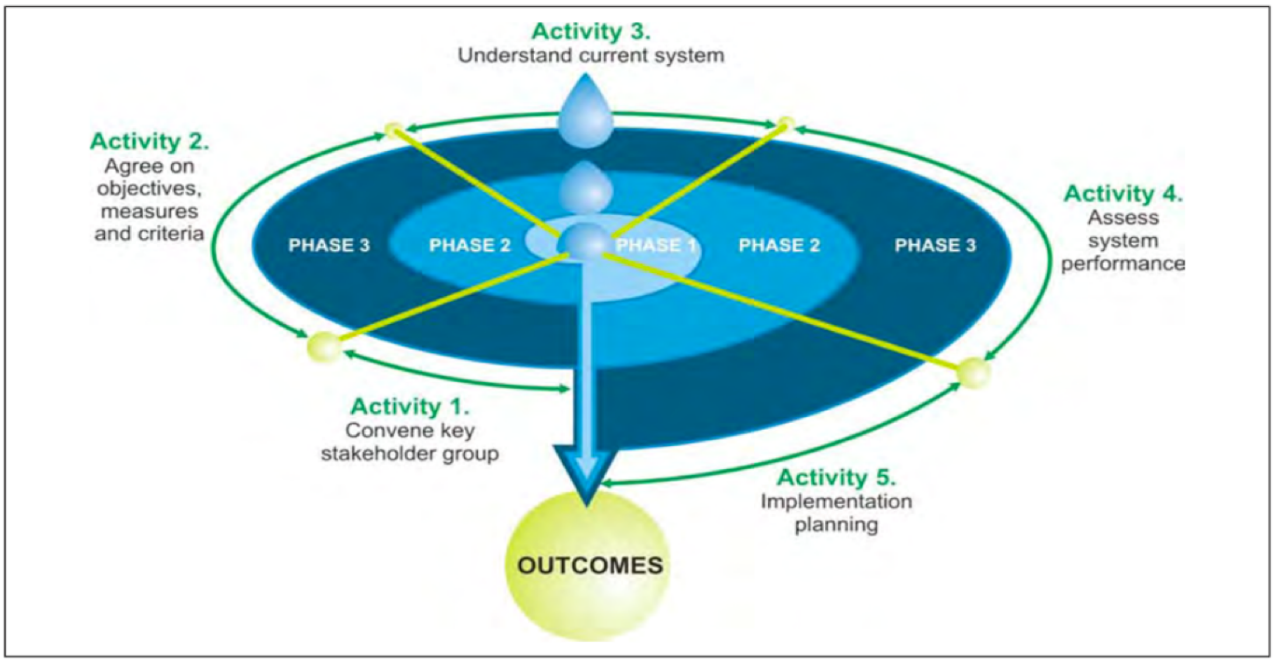
8. *Simultaneously pursues economic efficiency, social equity, and environmental sustainability*

9. *Encourages participation by all stakeholders."*

1.2 The significance of this research

The IUWM planning framework (Figure 2) was created by Maheepla (2010) to help assist with the uptake of IUWM.

FIgure 2: The IUWM Planning Framework (Maheepala, 2010)



According to Maheepala (2010) the process for adopting IUWM generally progresses through three phases. During the first phase a strategic direction for intended urban water management is set in the second, a short list of portfolios is presented and then in the final stage a preferred portfolio chosen. Within these three stages there are six activities;

- *"**Activity 1**: Establishing the key stakeholder group (KSG). The KSG, representatives of critical organisations are responsible for overseeing the whole IUWM planning process*
- ***Activity 2**: Agree on a set of IUWM objectives and how to measure how successful the projects are.*
- ***Activity 3**: Ensure all participant shave full understanding of the current system*
- ***Activity** 4: Assess the system performance in terms of the agreed measures. Stakeholder preferences are taken into account and multi-objective decision processes are used to select preferred portfolios*
- ***Activity 5**: Implement the outcome" (Maheepla, 2010)*

There is currently no standard set of methods to support the IUWM management plan. The significance of this research is to see if MCDA, a decision support analysis tool, can assist in the stage three of the IUWM planning framework: the choosing of a portfolio, and aid the successful uptake of IUWM in South Australia.

1.3 Decision making

Decision making is a cognitive process of selecting between alternatives based on the preferences of the decision maker/ maker's (Ahmed and Omotunde, 2012). In such a case the decision maker's choice is hoped to best fit with their goals, objectives and values (Harris, 1980). There are various kinds of decisions; decisions of whether (e.g. deciding whether to go ahead with something or not), decision on which (deciding between alternatives) and conditional decisions (decisions only made when certain conditions are met). Decision making is a dynamic process rather than a static action (Harrison, 1999). There are many different process' which can be used to inform decision making, of which is the best is dependent on many factors for example; the decision makers themselves, the available time frame, the availability of information and resources available (Donnelly et al., 1998).

Decisions theory is the study of how and why we make decisions. Decision theory draws on the academic disciplines; psychology, statistics, philosophy and mathematics to provide reasoning for agent's choices. There are three main branches of decision theory; descriptive decision theory, prescriptive decision theory and normative decision theory.

Descriptive decision theory is concerned with categorising and explaining the regularities apparent in individual's choices (Chandler, 2017). Prescriptive decision theory is concerned with prescribing methods and guidelines for decision makers to follow to ensure they make optimal decisions when faced with an uncertain decision framework. Normative decision theory explains how decision should be made with respect to a certain set of values.

Decision theory provides us with the knowledge of how people might approach decisions without assistance and thus why decision choices may not always be optimal. Methodologies have been established to support effective decision making in complex situations. Decision analysis methods have thus been used to help guide decision makers to make optimal decisions.

There are many methods used to support decision making. Three commonly applied methods considered herein are;

- ***Multi Criteria Decision analysis***
- ***Cost Benefit Analysis (CBA)***
- ***Game Theory***

1.4 Public participation

The ability of authorised decision makers to come to comprehensive decisions which account for the complexity and interconnectedness of many problems has been questioned (Fung, 2006). There has been widespread recognition about the importance of including citizens in the formal decision processes. It has been suggested by scholars that the involvement of citizens leads to better decision making as the information used to inform decisions is more complete and locally relevant.

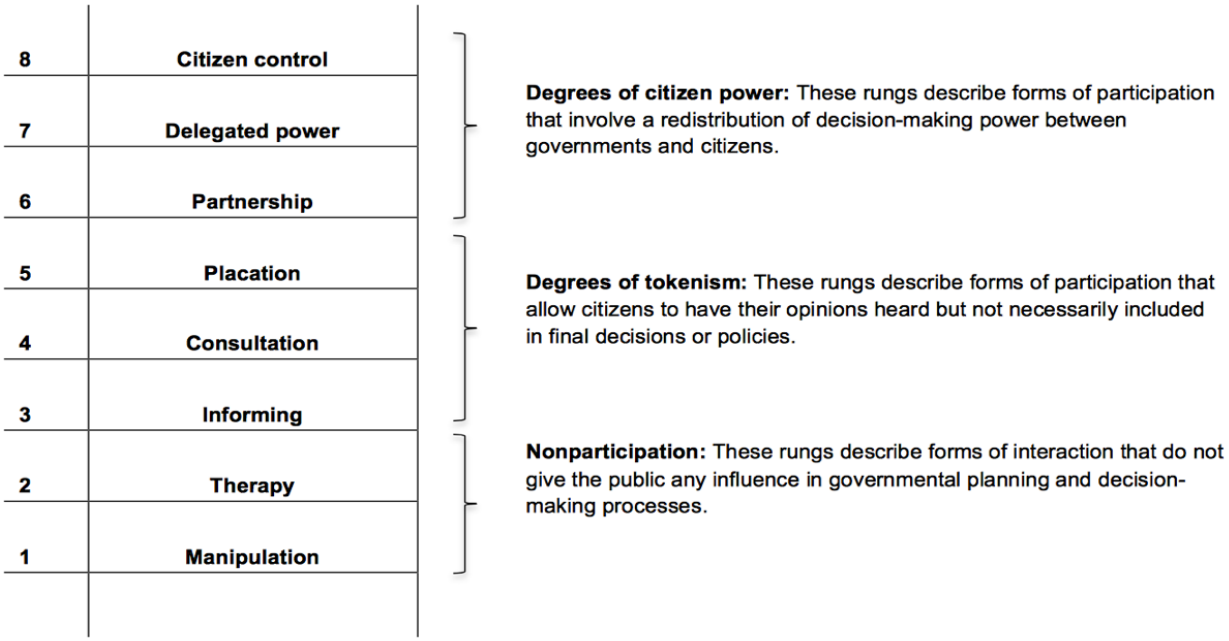
Participation is sometimes criticized as being a vague term, to some, a much abused and a potentially expensive process if unqualified participants have influence. To others

participation is an essential activity to gain a breadth of stakeholder views. It is necessary therefore to be clear on what is desired through participation and how best to incorporate wider views into planning in a defendable and useful way (Leake Pers. Comm).

Arnstein's (1969) ladder of participation characterises different forms and degrees of participation. Each step of the ladder reflects a different level of power a citizen can exert in the decision process (Figure 3).

An empirical investigation into public participation by Tawfik (2016**)** found that there was little community engagement within the Australian urban water sector. Participatory approaches were found to only be used in specific urban water management issues such as water recycling (Hurlimann and Dolnicar, 2010). Public participation was being used to encourage change through persuasion rather than as a platform to spark discussion and debate. It is suggested by Bochel et al. (2008) that a decision support methodology that facilitates dialogue between stakeholders, including citizens is needed to support robust decisions making.

Figure 3. Ladder of Citizen participation (Arnstein, 1969)



CASE STUDY

This part of the report will now draw on the South Australian Context. It has been found that there will be considerable price reductions in water costs for consumers if a more Integrated Urban Water Management approach is adopted (Goyder, NA). Such benefits are expected to

be realised through the investment in the less traditional water sources; waste and stormwater. It is suggested that MCDA will be able to assist in the the successful uptake.

2.1 The South Australian Context

On 24th September 2012 the Treasurer of South Australia referred, to the Essential Service Commission, an inquiry into pricing reform for drinking water and sewerage services provided by SA Water. Richard Clarks "SUBMISSION TO ESCOSA ON SA WATER PRICING AND EXTERNALITIES" (2013) suggests that long term price reform will not be sustainable until the government adopts the alternative planning framework of IUWM and integrates the underlying concepts into the future design and management of the current water sources. Without these changes it is possible that SA Water customers, who are already subject to the highest cost for water supplies in Australia will be subject to even higher prices as aging infrastructure is replaced and increasing demand is fulfilled by the use of high cost desalinated seawater (Clark, 2013).

Clark (2013) suggests the reasons for these high water prices include; the lack of consumer choice for low cost water supplies, the existence inefficient water structures and lack of attention to the use of storm water as an additional resource (Clark, 2013).

There are difficulties in changing the existing situation. SA water has inherited a system that, with little exception, only has the capability to deliver one type of water- a quality which is of 'drinking water' standard. It has been identified in a study conducted by Urban Stormwater Harvesting Option (USHO) that 50GL/a of stormwater could be harvested from wetlands in Adelaide for non-potable uses at a lower cost than the water current water supply. Thus, by acknowledging that stormwater and wastewater resource is not a nuisance (Pinkham, 1999) there is scope for, with the appropriate further investment, an alternative lower cost water supply to be made available to SA customers.

In response to a recent drought the SA government invested in a desalination plant. On top of the initial costs of this investment and the associated running costs of the plant, the desalination plant produces water at a higher quality than required drinking water and at a higher cost (Clark, 2013). In a study conducted by the Urban Water Security Research Alliance (UWSRA) it was found that the desalination plant under the expected population growth and predicted climate change, would not be able to carry supplies through the expected once every 25-50 year droughts. It was found that if the appropriate investment was made into stormwater and wastewater, these water sources would be able to sustain water supplies in Adelaide even through a one in a one-hundred-year drought (UWSRA, 2010)., and at a cheaper cost than the desalination plant. Thus with the appropriate investment, Stormwater could provide a more sustainable and cheaper alternative to desalinated seawater. These examples both exemplify how long run sustainable price reform can be brought about by aligning urban water management with the the paradigm shift intrinsic to IUWM.

It is evident that there is a clear distinction between the inefficiencies of the present water system and the greater efficiencies that could be achieved through the appliance of IUWM concepts. Despite the acknowledgement of 'the emerging paradigm' (Pinkham, 1999) and its endorsement by United Nations (UN) and the National Water Institute (NWI) as a best practice principal (UWSRA, 2010), SA Water customers are still subject to urban water planning which has not kept alignment with the improved planning strategies of IUWM.

2.2 The scope of the problem

The Key reasons for lack of uptake in South Australia are noted by Clark (2013) to be;

The lack of a single 'lead- shop'

Integration relies on the leadership of a 'lead – shop' as well as cooperation between the 'players'. There is thus need for an existing body such as The Department of Environment, Water (DEW) or an alternative new body to step up and take this leadership role. A possible reason for the lack of willingness for the uptake of this leadership position is the suggested difficulty in aligning stakeholder's views. It is widely recognised that cooperation between stakeholders is necessary to facilitate the successful up take of multi-objective decisions intrinsic to IUWM. As Young suggested the institutional models and approaches to be used in a IUWM investigation for South Australia requires careful consideration (Young Pers Comm.)

Stakeholder involvement

Customers of the water supply at present have little or no input in the decision process for water management. To become involved they need to be able to contribute effectively. They now have inadequate information about the possible changes and opportunities arising for IUWM. It terms of Arnstein's ladder of participation (Arnstein and Sherry, 1969), the involvement of at least some of the stakeholders has been suggested to been no more tokenism (e.g. Leake Pers. com). As customers may be subject to initial higher costs to fund the infrastructural adjustments required by IUWM, it is important that customers are well informed in the decision process. Effective planning requires committed participation from all involved stakeholders (Maheepala, 2010).

A division of motives

SA Water's drive for short term profit disincentives SA Water to engage in research or the planning of practices which might threaten its profit base. If adequate resources were available, the local governments whom, are responsible for stormwater and wastewater, may be more persuaded to invest in the appropriate infrastructure needed to engage with the harvesting and storage of these two water sources[2], providing South Australians with a cheaper alternative water source but SA Water may consider it's income base to be thus under threat. This and the fact they don't know what the outcome of IUWM might be, suggests why SA Water may be resistant to engage with the implementation of IUWM with respect to stormwater and wastewater.

The extent to which MCDA could assist South Australia in the uptake of IUWM will be assessed over the following sections.

[2] As occurred with the Playford Council in planning for their aquifer injection project, see http://www.playford.sa.gov.au/page.aspx?u=1306 who were able to attract federal finance for their project to achieve this end of mobilising additional water supplies.

Multi- Criteria Decision Analysis

3.1 The Theory

MCDA is used to assist decision makers in prioritising or selecting one or more alternatives from a finite set of available alternatives with respect to multiple decision criteria. Hajkowicz and Collins (2007) state that MCDA has been heavily used for water policy evaluation, strategic planning and infrastructure.

After the necessary stakeholders have been acknowledged, according to ***Howard (1991) the MCDA process genuinely follows the following processes;***

1. *"The defining of the decision options*
2. *Choosing the evaluation criteria by which the decision options will be judged on*
3. *Assigning an appropriate weighing of importance to each criteria to reflects the importance of each criteria in the decision process*
4. *The combining of the weights and scores given by participants to rank or score the different options*
5. *The performance of a sensitivity analysis to see where the MCA model needs strengthening and to test the robustness of results given the input assumptions.*
6. *The use of the results to inform decision."*

3.1 General motives for adopting MCDA

3.2.1 Transparency

MCDA increases the transparency of decision procedures (Dunning et al., 2000) which may otherwise have been characterised by unclear motives and rationale (Brown et al. 2001). This is achieved through the direct integration of stakeholders into multiple phases of the decision process. Stakeholders are consulted over which criteria should be chosen to judge the chosen portfolios and the weights assigned to each criterion. The process is transparent as the evaluation criteria and respective weightings are explicitly stated. This means that once the weights and scores have been combined the rationale for choosing one decision over another is clear and logical (Dunning et al., 2000). For example, this transparency was found to be of great assistance to road engineers in Myanmar by making the decision process quite clear to stakeholders accustomed to lack of transparency, leading to some decisions being more useful in improving livelihoods (Leake Pers. Comm.)

3.2.2. Accountability

Through involving the stakeholders in the defining of the evaluation criteria and their respective weightings, stakeholders are more accountable for the outcome of the decision.

This is because their inputs have directly influenced the final outcome of the decision analysis. This increases the likelihood that the stakeholders involved will be supportive of the outcome even if the chosen portfolio wasn't their top preference.

3.2.3 Weightings of the decision criteria and sensitivity testing

To consider the varying importance of evaluation criteria, weightings are assigned to criterion. This is very important to enable effective decision making as stakeholders may have stronger preferences over some evaluation criteria being met by the chosen portfolio than others. When the weighting is higher the associated scoring of the evaluation criteria will have a larger impact on the overall score and rank of the portfolio. Conversely, when the weighting is smaller the scoring will have a lower impact on the overall scoring.

These weightings thus have a direct impact on the results of the MCDA. Chosen by the stakeholders, the subjectivity that often pervades can be a matter of concern to some, especially when there are multiple stakeholders with conflicting views involved. However, sensitivity testing has been used to examine the extent to which vagueness about weightings and disagreement between stakeholders effects the overall result. Sensitivity testing allows one to manipulate the weighting system and examine how the ranking of options might change under different weightings. If there is little difference between the best options under different weighting systems, there may be little loss in overall benefit falling back on your less preferred portfolio options. Sensitivity analysis can thus facilitate conflict resolution between interest groups with conflicting views on which portfolio should be chosen. It also facilitates stakeholder learning about the relative importance of their views in comparisons with others.

3.2.4 Auditability

MCDA uses formal axioms of decision support methodology to inform choice. Refer to section 3.3.2 For more information about the specific decision support methodologies. Hajkowicz and Collins (2007) state the use of these formal axioms makes the analysis more logical and robust. An auditor can use the formal rules to logically recreate decision problems from the past. This facilitates effective post-implementation evaluation where the performance of the chosen portfolio can be compared to the overall objectives and decision criteria.

3.2.5 Conflict resolution

When there are multiple stakeholders involved in a decision process it is highly likely that there will be conflict between stakeholder's views (Cai et al. 2004). Mimi and Sawalhi (2003) used MCDA to solve conflicting views about the allocation of Jordan River water amongst Palestine, Israel, Syria, Lebanon and Jordan. As all parties were required to state their preferences, areas of agreement and disagreement were recognised. Through acknowledging where disparities and similarities existed a shared solution space was identified (Cai et al. 2004). MCDA thus facilitates conflict resolution through evoking compromise and negotiation between the stakeholders involved (Pohekar, 2004). As there are multiple stakeholders with conflicting interests involved in the planning process implicit to IUWM, it is necessary that the decision support methodology supports conflict resolution.

3.2.6 The inclusion of multiple objectives

MCDA provides us a way to balance multiple objectives in a logically robust way. With sustainability being one of the main objectives of IUWM it is critical that the multi facets of sustainability are encompassed in to the decision process. MCDA establishes preferences between decision options through scoring and weighting the chosen evaluation criteria. As there are multiple evaluation criterion, multiple objectives are taken into account in the decision process and thus the different components of sustainability can be accommodated. MCDA thus supports the analysis of alternatives in complex decision problems which are seldom guided by a single objective.

3.2.7 Citizen involvement

Public participation and stakeholder engagement has been recognised as a valuable component of urban water management (Wondolleck and Yaffee, 2000) laying the groundings for future communication, dialogue, and negotiation (Gregory and Keeny, 1994). MCDA facilitates the active involvement of the general public in the decision making process which conforms to what Arnstein (1969) refers to as Partnership, Delegated power and citizen control. Decisions are thus thought to be more comprehensive (Fung, 2006).

3.3 The generic shortcomings of MCDA

3.3.1 The evaluation criteria

Evaluation criteria are chosen by the stakeholders involved. The evaluation criteria reflect the interests of each stakeholder. After each stakeholder has scored each evaluation criteria, the score is combined with the weighting to rank the decision options against each other. The defining of the evaluation criteria will thus greatly impact the result of the decision analysis.

According to Lai, Lundie and Ashbolt (2008) the robustness of the results is questionable when;

1. There is preferential interdependency between the Decision Criteria.
2. The choice of Decision criteria and insufficient resulting in double counting and under counting

Preferential independency

Preferential independency occurs when the preference for a decision criterion is dependent on another or the alternatives available in the decision analysis. Saaty (1996) states that if the problem of dependency is not dealt with one can not be sure about how good the results from MCDAs are. This problem has been overcome through the application of the assumption: utility independency **(Fishburn 1965)**. This assumption assumes one's preference for a decision criterion is independent from the others. However, it is recognised by Saaty (1996) that this assumption does not always hold and thus there must be a methodology to ensure there is as little independency between criteria as possible.

Double counting and under counting

Problems with the weighting of criteria exists when the decision criteria accounts for unnecessary attributes or when key criteria are not included.

Double counting can also occur when the weights of interdependent criteria are considered separately (Schankerman 1981). Keeney (1996) suggests double counting occurs because the structuring of MCDA does not require one to distinguish between fundamental and means-end criteria. Fundamental criteria accounts for criteria which is important because it is required by the decision methodology. Means-end criteria describe the criteria which is only important because they have implications on other criteria. The weightings of the fundamental decision criteria should be acknowledged as discrete values whereas the weightings for the means-end criteria should not. This is because means-end criteria are defined by multiple attributes, which can encompass fundamental criteria. Undercounting happens when the compiled list of criteria is unrepresentative of the multiple objectives hoped to be achieved.

3.3.2 The stakeholders

Eliciting judgments from stakeholders and defining the evaluation criteria is a subjective task (Proctor and Drechsler, 2006). It is thus crucial to consider who is involved in setting priorities and assigning weights. If the stakeholders involved are unrepresentative of key groups, then critical evaluation criteria may not be included in the MCDA. This would lead to, from the perspective of some, to sub-optimal decisions which are favoured towards some and not others.

According to the Integrated Urban Water Management Planning Manual sponsored by the Water Research foundation the possible key members of key stakeholder groups are listed in Figure 4.

Figure 4: Possible members of key stakeholder group. Sourced: The Integrated Urban Water Management Planning Manual

Type of organization	Possible representatives
Water wholesalers, utilities and managers	• Utility managers • Utility operators • Local government stormwater managers/operators • Wastewater treatment plant managers/operators • City Councils • Private water purveyors outside city
Regulators	• Regulators (water quality, public health, supply) • Federal, state, local • Regional water quality control board • Public health officials • County stormwater (septics)
Industry	• Local industry (existing and new) • Energy industry • Chamber of commerce • Developers
Planners	• Local government planning • Upstream and downstream cities • Port representative
Funding groups	• State (grants for recycled water)
Users and special interest groups	• Rate payers/residents • Tribes • Species protection groups • Wetland champions • Recreational users • Agricultural users • Environmentalists • Downstream users • Fishery groups • Greenhouse gas groups

Through the serotyping of different stakeholders, it has been presumed that institutions representing water consumers (for example city councils) would highly prioritise the effect a certain decision portfolio would have on the cost of water. Institutions such as environmentalists whom are more concerned about the environmental impacts would be more concerned with how this portfolio would impact on the environment through greening and the subsequent health benefits. Water wholesalers have been shown to prioritise their own profit base irrespective of the other potential benefits.

To ensure that the final decision is robust and unbiased, a wide range of views and opinions should be taken into consideration. To do this it is essential that a variety of stakeholders from different backgrounds are included in the decision process.

3.3.2 The decision support methodologies

A critical concern of MCDA is how to prioritise the different portfolios against each other. At the heart of every MCDA is a Decision support methodology (DSM). Different DSM introduce priorities in different manners and lead to different results. Decision support methodologies are very technical and mathematical and will effect the auditability of the decision analysis. This report will draw on the main perceived benefits the following DSM;

- Multi- attribute utility theory (MAUT)
- Analytical Hierarchy process (AHP) and,
- Analytical Network process (ANP)

Multi- attribute Utility theory (MAUT)

MAUT has been commonly been used in water management planning (Velasquez and Hester, 2013). MAUT is a "rigorous methodology that incorporate[s] risk preferences and uncertainty into multi criteria decision support methods" (Loken, 2007, p. 1587). Decisions are made through the derivation of a utility function, applying it to each possible outcome, and then choosing the outcome with the highest utility (Konidari and Mavrakis, 2007). The major advantage of this method argued by Velasquez and Hester (2013) is its ability to, through the encompassment of uncertainty in to the utility function, allow for the decision process to take uncertainty into account which many other MCDA methods can not. Uncertainty occurs when the decision maker can not list all the possible outcomes.

Analytical Hierarchy Process (AHP)

Analytical hierarchy Process (AHP) is a theory that uses the judgement of experts to derive priority scales through pairwise comparison (Saaty, 2008). Pairwise comparison occurs when two portfolios are placed against each other and direct judgement is made between them. This allows one to create a ranking between decision options.

Due to its hierarchical structure, AHP is scalable and can adjust to accommodate a wide range of decision making problems. Inconsistencies in judgement and ranking may occur when additional alternatives are proposed at the end of the process. This could cause the final rankings to flip or reverse. However, this problem is nullified when the alternatives are limited from the beginning of the process. Conclusively, AHP's main strength is to handle larger problems through the derivation of a priority scale. Okeola & Sule (2012) used AHP to study urban water supply systems in Nigeria.

Analytical network Process

Analytical network process accounts for the potential dependencies and interdependencies that can arise between the decision evaluation criteria and the decision options (Tsai *et al*., 2010). For more information about the potential dependencies and interdependencies that can arise in the evaluation criteria review section 2.3.2. However, this can also be seen as a disadvantage where the ANP has be found to "ignore the different effects among clusters" (Wang, 2012, p. 931). The main advantage of ANP is that is does not require independence of the evaluation criteria.

Other decision analysis tools

There are many other tools which could be used to assist decision making**.**

4.1 Cost Benefit Analysis

CBA is a pragmatic tool for aiding decision making. Thampapillai (1991) states the main strength of the tool is its ability to aggregate the costs and benefits of each alternative in to one single result. From this one result direct comparisons are made between the different alternatives allowing for clear and comprehensive decisions to be made.

Thampapillai (1991) identifies the main limitation of CBA to be the requirement of all outputs to be expressed in monetary units. As water management planning decisions are normally

made with respect to both financial and non-financial factors, there is a high level of incommensurability (Aldred, 2006) when translating non-financial factors in to monetary values. A technique that does not require the monetization of impacts is more appropriate for aiding the decision process behind the implementation of IUWM. The MCDA framework allows for a robust analysis to be made whilst permitting non-financial issues to be incorporated.

CBA is an analytical tool. It is not a framework which requires stakeholder participation (Pearce et al., 2006). In accordance to the discussions at the Åhrus convention stakeholder participation has been recognised as an integral component to any decision-making process related to water management. Unlike CBA, MCDA requires direct involvement and active participation by all stakeholders.

CBA is recognized as an outcome driven procedure. CBA gives decision makers a single monetary estimate of the net costs and benefits of each project under consideration. From this it is presumed the option which is most economically efficient will be chosen. MCDA takes on a more process driven approach. MCDA aims to guide decision makers to make the right decisions through educating the decision maker about the alternative options, the key trade-offs, uncertainties and preferences expressed by stakeholders (Gregory et al., 2012). The decision process is therefore "a dynamic process of social learning" (Kompas and Liu, 2013, pg 19). A dynamic, integrative decision making process is more desirable as it engages stakeholders throughout the whole process.

4.2 Game theory

Game theory is an actor analysis method (Hermans and Van der Lei, 2012) which has been used to study the strategic interaction amongst multiple stakeholders.

The aim of a game theorist is to, focusing on the power and interests of actors, predict how player's actions combine, to form a set of possible outcomes and payoffs (Hermans, Cunningham and Slinger, 2014). Through predicting the outcomes of interaction between different players, Game Theory is suggested to aid decision making through educating the players on what decisions they should make to lead to the best outcomes.

Game theory has most commonly been used as a tool to explain observed outcomes (Rasmusen, 2007) and provide insight in to why, in a given situation, the interaction of players led to the observed outcomes (Hermans, Cunningham and Slinger, 2014). It is suggested in this report that game theory would be a more useful tool for ex-ant analyses rather than informing ex-post decision making. This is suggested as it is easier to extract the necessary information required to build a realistic game theory model once the interactions between multiple actors has occurred and the outcomes realized.

The potential use for MCDA in South Australia

4.1Findings

It is recommended that MCDA would be used useful tool to help facilitate the uptake of IUWM in South Australia. Mateo (2012) states that MCDA methods can provide solutions to complex planning problems. A better understanding of the decision making process is achieved through the direct involvement of stakeholders and citizens. Stakeholder involvement is a factor that has been recognised as important to facilitate the successful uptake of IUWM in SA.

MCDA evokes compromise and negotiation between stakeholders through the quantification and communication of preferences (Pohekar, 2004). From this the decision process is more explicit, rational and efficient (Mateo, 2012). With the divergence of stakeholder preferences and views being seen as hindering the uptake of IUWM in South Australia, the potential for MCDA to help align stakeholder preferences is a factor which further verifies its possible use in stage three of the IUWM planning strategy.

MCDA follows a clear and explicit set of rules. This makes it an easy method to be adopted by a 'lead-shop'. With the involvement of stakeholders throughout the whole process, and the reasoning for choice being made transparent and explicit it is more likely that there will be full compliance by stakeholders in the final decision of the analysis. The use of MCDA will help encourage a 'lead-shop' to lead the implementation of IUWM.

However, to ensure the results of the decision analysis are robust and logical, precautions should be taken to address the possible problems discussed in the conclusion.

5.2 Further recommendations

It has been recognised that MCDA would be of great assistance in assisting effective decision and supporting the implementation of IUWM in South Australia. However, the usefulness of this decision analysis tool will only be realised when the portfolios under debate are representative of the necessary changes. The portfolios thus need to reflect the necessary actions needed to transition to use of non-traditional water sources such as waste water management and stormwater.

5.1.1 Decentralisation

Traditional urban water systems have been characterised by large scale centralised operations run by professionals and technical elites (Farelly and Brown, 2011). Decentralised systems provide a more holistic approach, incorporating more factors relevant to the local stakeholders such as the provision of wastewater and stormwater services. These factors of importance may not be shared by wider stakeholders. Decentralised systems are now being used to compliment centralised systems. These systems involve the harvesting, collection and storage of wastewater and stormwater at different spatial scales; from local communities to individual homes. The principles of IUWM are apparent in the planning and design of these systems.

Decentralisation also involves the devolving of power from the government to local governments, private individuals and communities. Through the diversification of responsibilities, water management decisions can be made at a local scale. Decisions can thus be made to meet the needs and desires of the catchment area rather than trying to meet to overall needs of a state. It is suggested that wastewater and stormwater practices would benefit greatly from the adoption of these decentralized concepts (Newland Pers. Comm. & Clark pers Comm.).

Through the adoption of decentralised practices as best practices, it is more likely that storm and wastewater planning will be included in the decision alternatives (Howard, 1991).

Conclusion

6.1 Findings and Conclusion

It is suggested that South Australia could, through further uptake of IUWM practices, benefit from considerable reductions in water price and an improvement in wider stakeholder satisfaction (Clark pers. comm). Widespread adoption of IUWM requires a set of methods to aid planning and assist in the incorporation of stakeholders. To date there are no standard sets of methods or tools to support the planning process implicit to the adoption of IUWM. It is concluded that MCDA has great potential to assist South Australia with the uptake of IUWM.

This report has drawn on MCDA because of its capacity to involve stakeholders (including the general public) throughout the whole process. This is necessary as it has been suggested that the main stakeholders involved in the planning process e.g. SA Water, have failed to take into consideration the wider societal benefits e.g. water price reductions that could realised through the adoption of IUWM principles as they jeopardize their own objectives e.g. profit. It is thus necessary that a wide range of views are taken into consideration in the decision process.

The explicit and transparent nature of the MCDA methodology increases the auditability of decision making, assists with conflict resolution whilst increasing the analytic rigour of water management decisions. These characteristics provide a clear rationale for 'the choosing of the portfolio' easing the role of a 'lead-shop'. Characteristics desirable to ease the uptake of IUWM in South Australia.

Two comparative analysis tools were discussed as alternatives: Game Theory and Cost-Benefit Analysis. It was found that Game theory would be more appropriate to assist with ex-ant policy analysis and CBA with decision problems where the costs and benefits could be standardised to monetary values with ease.

Although concluded that there is great potential for MCDA to assist in the planning process implicit to IUWM, planning and choosing of a portfolio and ultimately assist in the successful uptake of IUWM in South Australia, the results of the decision analysis will only be trustworthy when;

- The correct decision methodology is chosen
- The criteria are all sufficient
- The correct stakeholders are involved though the most appropriate institutional arrangements
- The definition of the decision alternatives represents the needed change

5.2 Recommendations

The DSM

It is recommended that for any meaningful link to be made between output and the assessment, the chosen DSM should reflect the knowledge of the participants. Under the presumption that most stakeholders in SA are not experts in MCDA, simpler DSM such as AHP should be chosen to facilitate effective communication.

To increase the robustness of the decision analysis, it is suggested that multiple DSM should be used to make up for the deficiencies of a singular method

As there is no methodology to figure out which DSM would be the most appropriate for any given decision problem, a guide should be developed, specific to the South Australian context, to help facilitate the appropriate selection of DSM. It is suggested the South Australian government should fund this

The Evaluation Criteria

A formal analytical process should be established which allows for the identification of dependent criteria, distinguish between fundamental criteria and mean-ends criteria. This can help assist in selection and elimination of criteria to ensure that the final list of decision criteria is comprehensive and allow for decisions to be robust. The more robust the results of the decision analysis are, the more likely the stakeholders involved will fully cooperate with the final outcome. This will increase the likelihood of a 'lead-shop' stepping up in South Australia.

Stakeholder mapping

It is suggested that before the decision analysis is undertaken that the key lead-shop should engage in a process of stakeholder mapping. Stakeholder mapping Involves the identification of each stakeholder, their respective values and perceptions on the matter, their relationships and any apparent conflicts. Stakeholder mapping is a way to visually represent the complicated interaction between multiple actors and can be used to ensure that an appropriate range of stakeholders are included in the decision analysis. This will ensure that the final decision is representative of the wider stakeholder. Lack of Stakeholder interaction has been acknowledged as a hindrance to the successful uptake of IUWM in South Australia.

Educational services on the importance of IUWM

As IUWM is a new alternative planning framework to urban water management, stakeholders may not be fully aware of how IUWM principals could be incorporated into existing and future design and the respective potential benefits. It is suggested that the development of an easy to access, informative training programme would help iron out any fallacies and increase appropriate awareness. The training program should vary in complexity to accommodate those who are advanced in their IUWM understanding and those who are not.

It is suggested that such a training program could incentivise stakeholders in South Australia to realign their motives, increasing the likelihood of planning coherent with IUWM to be undertaken.

The need for an institution to adopt the MCDA planning framework

Pre-existing institutions may be discouraged to adopt a new decision support methodology if they are satisfied with their methodologies currently in place. It is thus recommended that new institution in South Australia could be established who is eager to adopt and utilise MCDA, at least for the planning phase with the results being considered by the Essential Service Commission.

The use of MCDA as an educational tool to educate stakeholders

Many institutions and organisations do not recognise the importance of acknowledging the interactions between other stakeholders when making decisions. MCDA can be used as a tool to facilitate discussion among stakeholders and help develop a decision making culture that values participatory decision making (Brown, 2005). It is suggested that the methodology used in MCDA could be used throughout South Australia in a non-formal manner, perhaps at a classroom level, to example how important holistic decision making.

Further research to be undertake

As decisions are intrinsic to the planning process implicit to IUWM, it is suggested that the urban water industry would benefit from further research into existing and emerging decision analysis methods and tools. From this research gaps can be recognised and the appropriate funding allocated to ensure that South Australians will be subject to even more robust decision analysis in the future.

Appendix one

This Interview Template was sent to a variety of stakeholders from numerous backgrounds. The information gained from these interviews was used to guide the direction of this report.

Background

South Australians have inherited three sets of water service networks dealing separately with; 3)) the importation and supply of fresh water, 2) the collection and discharge of wastewater and the drainage and removal of stormwater generated from rainfall on the urban areas. Systems 2) and 3) are not priced and there is little incentive for individuals to make wise use of these latter two sources of water. Adelaidians also have access to groundwater which is used by some industries, many organisations and businesses interested in maintaining sporting fields and also by a significant number of households with large gardens. It has been suggested that, with increasing demands on the services and advances in water storage and treatment technologies, it is now possible to start develop systems that promote the more efficient use of each of these water sources and/or. combining elements of the three separate systems into a single multi-purpose system, which if the coordinating entity has a full understanding of values costs and opportunities has the potential to generate large reductions in costs and environmental impacts. How far the combination process can be taken will depend on many considerations, but all indications are that the benefits could be large and proportional to the innovation cost brought into the systems integration process.

Unfortunately, the integration process inherently requires a central lead agency which has the vision and trust to establish the full cooperation of the large number of parties with stakes in the operation of the three separate systems and the services they provide. One reason a leader has not emerged may be because it is unclear how the different stakeholders views on Integrated Urban Water Management (IUWM) can be resolved, making such leadership very problematic. Another is that the incentives and government payment and subsidy arrangements prevent this from happening. This project is to see if the use of Multi Criteria Analyses can assist in resolving these differences (Clark, 2013)

Howard (1991) states that the MCDA process generally follows the following processes;

1. Engaging key stakeholders
2. The defining of the decision options
3. Choosing the evaluation criteria by which the decision options will be judged on
4. Assigning an appropriate weighing of importance to each criteria to reflect the importance of each criteria in the decision process
5. The combining of the weights and scores given by participants to rank or score the different options
6. The performance of a sensitivity analysis to see where the MCA model needs strengthening and to test the robustness of results given the input assumptions.
7. The use of the results to inform decisions.

Steps 3 and 4 are significant factors that can be addressed in a preliminary research project of this kind.

Questions;

1. What institutional models and approaches are worthy of careful consideration?
2. What valuation criteria do you think all stakeholders should take into consideration when deciding between decision options? What ranking of importance would you give each factor in influencing the final decision?
3. What valuation criteria do you think LGA's, representing their rate payers, should take into consideration when choosing between decision options? What ranking of importance would you give each criteria in influencing the final decision?
4. Prior to this interview what was your knowledge on MCDA? And what areas was MCDA applied to?

Examples of valuation criteria include;

- Profit
- Return on investment
- Availability of new water supplies (saved from storm water)
- Distributional impacts of water supply charges and sewage treatment charges
- Cost of floods
- Amenity- environmental enhancement
- Reliability
- Other?

We had considered using game theory but decided that that multi-actor analysis tool would be more useful for ex-post analysis.

I will not use your name explicitly in the report however the information and views that you chose to share may be cited in the report as coming from someone from your class of stakeholder. Do let me know if this is a problem.

I am flexible as to interview time, please advise your telephone number that I can contact you on. I can be contacted on 0452570782.

Regards,

Anna Tsitsis

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