WATER SERVICES ASSOCIATION OF AUSTRALIA

Sustainability Framework

PART A: Methodology for evaluating the overall sustainability of urban water systems

Prepared by:

Centre for Water & Waste Technology,
University of New South Wales

Authors: Sven Lundie, Nicholas Ashbolt, Daniel Livingston, Elizabeth Lai, Erik Kärrman, Jennifer Blaikie and John Anderson

PART B: A review comparing the WSAA Sustainability Framework to the Gold Coast Waterfuture process

Prepared by:

Centre for Water & Waste Technology,
University of New South Wales

Authors: Sven Lundie, Greg M Peters and Nicholas J Ashbolt

WSAA Occasional Paper No.17
February 2008

ISBN 1 920 760 25 3

CENTRE FOR WATER AND WASTE TECHNOLOGY
School of Civil and Environmental Engineering

THE UNIVERSITY OF NEW SOUTH WALES

WATER SERVICES ASSOCIATION OF AUSTRALIA
http://www.wsaa.asn.au
email info@wsaa.asn.au

School of Civil and Environmental Engineering
Centre for Water and Waste Technology
University of New South Wales
Building H22, Vallentine Annex
Botany Street, Gate 11
Kensington NSW 2033

MELBOURNE OFFICE
Level 8
469 La Trobe Street
Melbourne
Victoria 3000

SYDNEY OFFICE
Level 11
91 York Street
Sydney
NSW 2000

Contact details of the authors are on page 120

Acknowledgements

The authors would like to thank the WSAA Steering Committee for its contribution.

Special thanks to Bob Humphries, Trish Drioli, Dragan Hranisavljevic, Eric Ligtermoet, Brett Myatt, Francis Pamminger and Natalie Reilly. Claude Piccinin and Peter Donlon

Further acknowledgement needs to be made to our internal reviewers, Hal Colbatch and Stephen Healy, for their many useful comments on the framework.

Overview of WSAA

The Water Services Association (WSAA) is the peak body of the Australian urban water industry. Its 30 members and 27 associate members provide water and sewerage services to approximately 15 million Australians and to many of our largest industrial and commercial enterprises.

WSAA was formed in 1995 to provide a forum for debate on issues important to the urban water industry and to be a focal point for communicating the industry's views. WSAA encourages the exchange of information and cooperation between its members so that the industry has a culture of continuous improvement and is always receptive to new ideas.

The functions of WSAA are:

- be the voice of the urban industry at the national and international level and represent the industry in the development of national water policy,
- facilitate the exchange of information and communication within the industry,
- undertake research of national importance to the Australian urban water industry and coordinate key national research for the industry,
- develop benchmarking and improvement activities to facilitate the development and improved productivity of the industry,
- develop national codes of practice for water and sewerage systems,
- assess new products relating to water, sewerage and trade waste systems on behalf of the water industry,
- jointly oversee the Smart Approved Watermark Scheme for products and services involved in conserving water use
- coordinate annual metric benchmarking of the industry and publish the National Performance Framework with the Federal and State Governments.

Foreword

When proposing a project in the urban water industry, in the planning phase, several potential options are developed and then evaluated before a decision is made on which of the options delivers the optimal outcomes.

Traditionally, economic and engineering considerations have dominated the project option evaluation process. Times have changed and the community now demands that all options under consideration are assessed in the broader sense including their environmental and greenhouse gas emission footprints to ensure that they deliver a sustainable outcome.

Traditional project evaluation methodologies mainly dealt with analytical and objective parameters. However, many of the environmental impact aspects of projects are more subjective in nature and do not lend themselves to analytical assessment.

This sustainability assessment framework has been developed to assist urban water utilities to work with their communities and key stakeholders to undertake processes where assessment of subjective matters such as environmental impacts are included in the decision making process. Such processes are imperative if the final project solution is to be viewed as sustainable and acceptable to the community.

This occasional paper provides a framework for evaluating projects in a holistic manner and the framework is then applied to a hypothetical project and a real life project (Gold Coast Water Waterfuture Process) to demonstrate how the framework can be applied in the real world.

Ross Young, Executive Director, WSAA

Contents

Contents
continued

PART B - A review comparing the WSAA Sustainability Framework to the Gold Coast Waterfuture process

Chapter 1 - Executive Summary

Background

A consortium representing members of the Centre for Water and Waste Technology (UNSW, Sydney), Sustainable Water Division of the NSW Department of Commerce (Sydney) and CIT Urban Water (Chalmers University, Sweden) won the WSAA tender to develop a *Methodology for Evaluating the Overall Sustainability of Urban Water Systems*.

The need for this methodology has been growing for several years, and was recently spurred on by the Intergovernmental Agreement for a National Water Initiative, which identified the need to create water sensitive cities and specifically called for the development of “national guidelines for evaluating options for water sensitive urban developments, both in new urban subdivisions and high rise buildings”.

To assist the urban water industry to achieve sustainable use of scarce water resources, the industry needs to develop a methodology for evaluating the sustainability of the various supply and demand options taking into account economic, environmental, human health, technical and social considerations.

The project brief indicated that the urban water industry wants to develop a common methodology for evaluating the overall sustainability of alternative options for urban water systems. This includes large-scale options for cities as well as configurations of water sensitive urban developments or single high rise developments. In particular the brief called for a common methodology for evaluating overall sustainability of alternative options for urban water systems, noting the range in alternative tools and approaches currently being used.

Project summary

Stakeholder involvement and iterative procedures of activities were identified as critical activities to capture attributes essential to developing more sustainable options for the water industry.

The level of stakeholder involvement is however, dependent on the scale of the project. As such, the proposed framework consists of six phases (Figure 1), each highlighting two components, i.e. one section addressing the procedure *‘how to carry out each phase’*, while another section focuses on the needs for *participation of stakeholders* (see Table 1).

This sustainability framework is intended to be flexible to allow its application for systems varying in each of:

1) scale of participation necessary;

2) financial requirements;

3) system boundary of the project; and

4) asset life-time.

Hence, it is applicable to varying temporal and spatial scale, economic impacts, number and degree of impacted people, sensitivity of and potential impact on the receiving environment, political considerations, availability of resources for assessment and urgency etc.

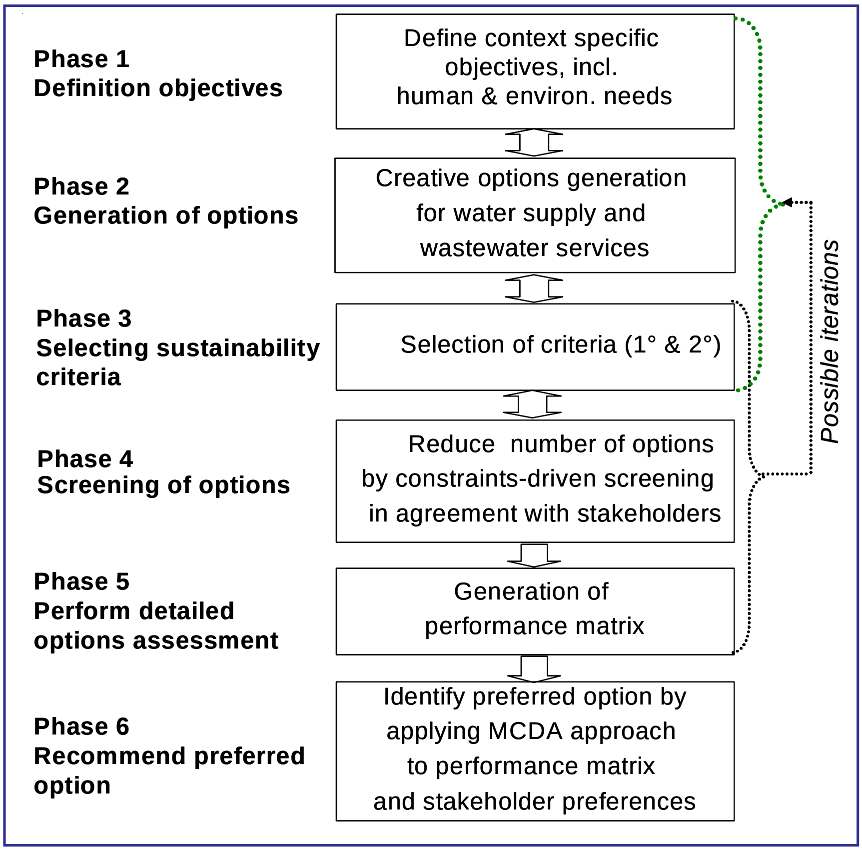
Three main categories of scale are suggested and presented in Table 1, i.e. small-, medium- and large-scale. Recognising that the effect of many ‘small projects’ can be substantial, this should be addressed at the strategic level within an organisation.

An example small-scale decision (replacement of a screen in a small sewage treatment plant) is provided to illustrate each phase of the framework. A large-scale case study (four options to increase a large city supply for 100 000 people) is presented in Chapter 15 - Hypothetical Case Study. This latter case study is provided to specifically illustrate the application of various tools (such as Life Cycle Analysis and Microbial Risk Assessment for environmental impact and human health respectively) during Phase 5, where the quantitative ranking of options occurs, prior to deliberations for the final recommendation of options (Phase 6). The results of the case are circumstance specific and should not be taken as a general rule.

An important strategy during Phases 4 and 5 is to identify the effects of each option by criteria so that mitigation options can be perused if desired before moving onto the next phase. A good example is desalination, where the environmental impact from CO_2 emissions from non-renewable energy sources is identified, but can be mitigated by revisiting options which include, say, changing to a renewable energy source with minimal environmental impact.

The type of consultation process used will depend upon several factors, including, but not exclusively the nature of the relevant stakeholders (within and external to the responsible agency), the types of the potential impacts and the resources available for consultation. While many methods have been and can be used with success to engage stakeholders, for large-scale undertakings requiring considerable public dialog, considerable attention is required in determining the engagement strategy, particularly in relation to public meetings. This is because public meetings give much more exposure to the "incensed and articulate" than to the unengaged, and also give the impression that a decision has already been made (a "decide, announce, defend" strategy). Hence several more 'deliberative designs' for consultation have appeared in recent years, such as the citizens' jury (discussed in the separate literature review undertaken for this project [Kärrman *et al.*, 2000]).

Figure 1 Schematic diagram of the sustainability framework



The above six Phases are described in detail on the following page.

Chapter 1 - Executive Summary

continued

Table 1 Objectives, processes, participants (by scale) for each phase in sustainability assessment for urban water systems

Phase	Objectives	Processes	Participants and	Scale[3]
1. Define problem and objectives	• Determine objectives that are in harmony with (or at least acceptable to) the project proponent, broader policy framework, stakeholder groups, and local community	• Steering committee· • Value management study • Market surveys· • Public conversations· • Reference to other studies, policies, planning controls, organisational goals, etc· • Document all assumptions and value sets used	• Owner/developer • Water authority • Consent authority • [Future] resident community • Relevant government departments • Relevant politicians • Relevant community or environmental	• A • A • M-L • M-L • M-L • L • M-L
2. Preliminary options	• Provide a reasonably diverse and comprehensive set of possible solutions • Any proposed option should be included at this stage	• Brainstorming • Lateral thinking • Backcasting • Workshops • Expert consultants • Collaboration of diverse group	• Any of the Phase 1 participants with an interest in participating • Water management experts (from industry / academia)	• A • M-L
3. Determine sustainability criteria & weightings	• Arrive at a consensus (or aggregate) of stakeholder values • Within the five primary criteria, aim to reduce the total number of secondary criteria, to limit complexity of assessment process	• Citizens' Jury • Deliberative Panel • Expert panel • 'Value-tree analysis' • Public conversations • Etc.	• All stakeholders (i.e. see Phase 1)	• A
4. Screen options	• Reduce the number of options down to a number that can be thoroughly assessed (e.g. 4 or 5)	• Simple absolute yes/no decision based on qualitative assessment (or quantitative if values already known) against objectives and criteria already established • Identify if mitigation is possible, reassess	• Technical experts in consultation with the wider stakeholder group	• A (refers to tech. experts)
5. Detailed assessment	• Assess the impact of each of the options according to each of the criteria selected • Determine preferences on criteria	• Use whatever assessment tools are available: LCA, LCC, MFA, etc. • Surveys &/or focus groups • Identify if mitigation is possible, reassess • Ranking & normalisation of criteria	• Only local engineers • Broader technical experts • Community participation for social impact assessment	• S • M-L • L
6. Recommend preferred option	• Arrive at one preferred option which is either implemented or recommended, depending on the degree of authority	• Critical review of options & uncertainties, which for M-L projects may utilise multi-criteria decision add tools, such as SMART and STRAD	• Senior engineer • Representative stakeholders well informed in the whole process (i.e. see Phase 1)	• S-M • M-L

[3] Scale letters refer to: S – small-scale decision (such as pump or valve replacement) within an organisation; M – medium-scale decision (such as a major trunk main) involving external stakeholders; L – large-scale decision (such as a new subdivision with water/wastewater services in a large city); A – common to any scale.

A quick synopsis of the six phases in the proposed framework is given below. Overall, all assumptions and value sets used need to be documented for each phase.

- **Phase 1 Framing the problem and objectives**. It is quite probable there may be a wide variety of perspectives on the problem(s). There will also be multiple and often competing objectives even from a single stakeholder's perspective. Adequate attention needs to be given to 1) problem framing and 2) the objectives for its solution that all stakeholders are willing to buy into the relative assessment of the sustainability of the various options. Definition of the context-specific objectives of the project (scale-dependent) should include affected stakeholders, selection of participants and the intended use(es) of the results, as well as including discussion on the initiator/driver(s) of the project.
- **Phase 2 Generation of preliminary options**. Stakeholders should develop numerous preliminary options which will be further investigated in Phase 4 and if 'kept', in Phases 5 and 6. These options will consist of conventional as well as alternative options that may not be commonly accepted currently, but which may become attractive in the future under changed conditions. The options should be specified with enough detail so that there is sufficient understanding of each option to enable the subsequent culling phases. It may help to consider what is not wanted, prior to any brainstorming of options. Phases 1 and 2 will both draw out the values of the various parties represented in the process, which may be documented to facilitate discussions in subsequent phases.
- **Phase 3 Selecting sustainability criteria.** The selection of criteria to be used for screening options (Phase 4) and for assessing the performance of prioritised options in detail (Phase 5). The selection of criteria is critical, it should cover the five primary criteria (economic, human health, environment, technical and social) and it needs to encapsulate the various context-specific objectives identified in Phase 1. However the number and types of secondary criteria depend very much on the actual project planned.
- **Phase 4 Screening of options.** Pragmatism (costs, time and other constraints) allows only a few options to be developed and assessed in detail (Phase 5). The purpose of Phase 4 is to reduce with stakeholder agreement the list of options to a number that can feasibly and thoroughly be assessed. It is important to identify which aspects of a less favourable option could be improved by mitigation. This may allow the reframing of the option during a second iteration of Phases 2-4.
- **Phase 5 Perform detailed options assessment**. Performing an assessment of the options should provide reasonably accurate quantitative and/or qualitative comparisons of each option shortlisted in Phase 4 based on criteria chosen in Phase 3. If participation has been adequately undertaken in previous phases, relevant experts should be tasked by the stakeholders to undertake the detailed assessment and bring back data for the final option recommendation (Phase 6). It is during Phase 5 that various tools (such as LCA, LCC, MRA, CRA etc.) are used to provide data on each of the agreed criteria that required quantification. The indicator results should be normalized in terms of selecting a reference point and weighted, or compared to aspiration goals set by the organisation or by the government. This will minimise any bias during the evaluation in Phase 6.
- **Phase 6 Recommend preferred option:** In Phase 6, the final recommendation is made for the preferred option(s) to go ahead. All of the previous information collected during Phases 1-5 are clearly presented to a more limited number of key stakeholders involved in Phase 6. In addition to the consolidated information provided on the five primary criteria from Phase 5, the stakeholders in Phase 6 should work through the data, possibly by way of a transparent multi-criteria decision aiding tool, such as SMART or STRAD. The goal here is not only to 'rediscover' the direct criteria ratings from Phase 5, but to understand the impacts caused by variations in rankings, uncertainty, and if necessary, weightings, so providing further insight for the final recommendation by covering each of the criteria and options.

Chapter 1 - Executive Summary
continued

To the degree tested, the proposed framework addresses the complex topic of sustainability of Urban Water Systems in a structured way. Consideration of *procedure* ('how to carry out each phase') and *participation of stakeholders* is explicitly assessed. This proposed sustainability framework should evolve over time as indeed does our view of sustainability. Recommendations are made in Section 3 for future research in order to further improve the framework and test it more vigorously.

The MCDA methodology outlined, however, does not inherently lead to a sustainable decision. Yet the adoption of sustainability criteria, comparing alternative options to traditional solutions can assist in making decisions that are more sustainable than "business as usual" decisions that rely on a simple financial analysis alone.

If utilities are aiming to make decisions which are sustainable in absolute terms, it is important for them to adopt the principles of sustainable management. Utilities will need to establish their "sustainability context" to guide such an approach. Useful criteria for describing high level sustainability are those outlined in the book, Natural Capitalism, which includes four forms of capital:

- Human capital, in the form of labour and intelligence, culture and organization;
- Financial capital, consisting of cash, investments and monetary instruments;
- Manufactured capital, including infrastructure, machines, tools and factories; and
- Natural capital, made up of resources, living systems and ecosystem services *(Hawken, Lovins and Lovins; 1999. Natural Capitalism. The Next Industrial Revolution, p.4)*.

Chapter 2 -Abbreviations

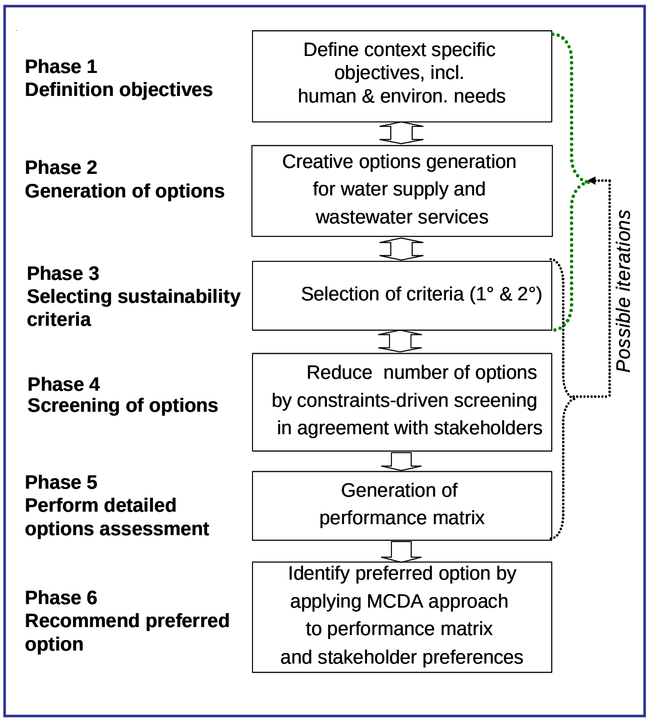
AHP	Analytical Hierarchy Process
BWR	Basic Water Requirements
CAC	Citizen advisory committees
CRA	Chemical risk assessment
DALY	Disability adjusted life year
DM	Decision Maker
DMP	Decision making process
DtT	Distance to target
EF	Ecological Footprint
ELECTRE	*Elimination et Choix Traduisant la Réalité*
ESD	Ecological Sustainable Development
FMEA	Failure mode and effect analysis
GRI	Global Reporting Initiative
IAP2	International Association for Public Participation
IPCC	Intergovernmental Panel on Climate Change
LCA	Life-cycle assessment
LCC	Life-cycle costing
L/p.d	Litres per person in a day
MCA	Multi-criteria analysis
MCAP	Multi-criteria aggregation procedures
MCDA	Multi-criteria decision aiding
MCDM	Multi-criteria decision making
MFA	Materials flow analysis
MIPS	Materials Intensity Per unit Service
MRA	Microbial risk assessment
MTBF	Mean Time Between Failures
NAIADE	Novel Approach to Imprecise Assessment and Decisions Environment method
NPV	Net Present Value
PMF	Probability mass function
PDF	Probability density function
PROMETHEE	Preference Ranking Organisation Method for Enrichment Evaluations
PWWF	Peak wet weather flow
ORWARE	Organic Waste Research model
QMRA	Quantitative microbial risk assessment
RfD	Reference dose
ROC	Rank Order Centroid
SCA	Strategic choice approach
SCADA	Supervisory Control and Data Acquisition
SCR	Screening capture ratio
SFA	Substance flow analysis
SIA	Social Impact Assessment
SMART	Simple Multi-Attribute RaTing method
STRAD	STRategic ADvisor (software package)
SWARD	Sustainable Water Industry Assets Resource Decisions
SWOT	Strengths, weaknesses, opportunities and threats
TMRO	Total material requirement and output
TBL	Triple Bottom Line Reporting
UNEP	United Nations Environment Programme
URWARE	Urban Water Research model
UWS	Urban Water System
WACC	Weighted average cost of capital
WHO	World Health Organization

Chapter 3. Key elements of the sustainability framework

This section introduces the key elements of the *iterative procedural sustainability framework*. The proposed framework consists of 6 phases as depicted in Figure 2. Each phase is split into two components, i.e. one addressing the procedure *'how to carry out each phase'*, while another is separated to highlight the *participation of stakeholders*.

This sustainability framework is intended to be flexible to allow its application for systems varying in characteristics, such as temporal and spatial scale, economic effect, number and degree of people affected, sensitivity of and potential impact on the receiving environment, political considerations, availability of resources for assessment and urgency etc. Therefore, a small scale example, i.e. replacement of a screen in a small sewage treatment plant, is used throughout all Phases to illustrate the application of the framework. A large-scale case study is given in the Appendix 5 that only focuses on Phase 5 in detail, i.e. application of the quantitative tools for detailed options assessment and initial ranking of options.

Figure 2 Schematic diagram of the sustainability framework



The MCDA methodology outlined in this document does not inherently lead to a sustainable decision. However, through the adoption of sustainability criteria, comparing alternative options to traditional solutions can assist in making decisions which are more sustainable than "business as usual" rather than relying on a simple financial analysis alone.

If utilities are aiming to making decisions which are sustainable in absolute terms it is important for them to adopt the principles of sustainable management. Utilities will need to establish their "sustainability context" to guide the use of this approach.

Useful criteria for describing high level sustainability are those outlined in the book Natural Capitalism (see below).

Framing the Decision-making Context to Assess Sustainability

For any activity to be truly sustainable in the long term, it is imperative that the overall value of all forms of capital is enhanced, and not degraded. The four forms of capital are:

- Human capital, in the form of labour and intelligence, culture and organization;
- Financial capital, consisting of cash, investments and monetary instruments;
- Manufactured capital, including infrastructure, machines, tools and factories; and
- Natural capital, made up of resources, living systems and ecosystem services (Hawken *et al*., 1999, p.4).

The traditional approach to choose the lowest cost option taken by most companies in the past has often resulted in the degradation of natural capital.

Through the application of sustainability principles, a water utility may choose to adopt a position of environmental stewardship, leading to protection and enhancement of the natural environment by minimising the direct and indirect effects of its operations, and rehabilitating disturbed areas and providing environmental offsets to compensate for unavoidable losses.

True sustainability understands the long term interdependence between natural and financial capital and aims to protect and enhance environmental capital so

Chapter 3 - Key elements of the sustainability framework *continued*

at to ensure maximum long term economic value to other stakeholders.

With this model in mind, an urban water utility could maximise the sustainability of any proposed project, policy or strategy provided that the competing options are assessed against a rigorous set of sustainability principles, and that options that fail to pass the test are rejected, or modified to achieve congruence with the principles. Once this is done the costs (and, in many, cases benefits) of the mitigations to protect or enhance natural capital are assessed for their affordability and social acceptability.

The Water Corporation's working set of sustainability principles are provided as an example of a high level definition of sustainability. These principles are supportive of the Corporation's business mission, which is *"sustainable management of water services* to *make Western Australia a great place to live and invest"*. These principles will be applied initially to all stages of the capital investment decision making process from the earliest conceptualisation of the need for a capital project, then progressively to procurement, operations and all other areas of the business.

The intention is to change the conventional mind sets of people – to engage them in thinking differently about the decisions they make for the business, and beyond that in their personal lives.

The Water Corporation's Sustainability Principles

The value we deliver

1. Economic - we deliver intergenerational value to the community of Western Australia and our shareholder
We will:

- Make decisions which demonstrate highest shareholder and stakeholder value to WA over the long term

2. Environment – we actively protect and restore the natural environment
We will:

- Protect all ecological processes
- Protect and enhance biodiversity
- Work to reduce waste and emissions
- Maximise resource use efficiency

3. Society - we respect, nurture and develop people and communities
We will:

- Build stronger communities
- Respect diversity of culture and heritage
- Promote equity and equal opportunity
- Promote learning and skills development
- Promote health and safety
- Consider social and economic impacts of our decisions on our customers and employees

4. Governance - we seek the right solutions and do them in the right way
We will:

- Maintain best practice business systems that ensure we will meet or exceed our legal and regulatory compliance requirements
- Accept responsibility for our actions and transparently report our performance
- Make decisions informed by best technical and scientific information and managed for adaptation

5. Engagement - we openly consult stakeholders as part of our decision making
We will:

- Recognise the role and importance of the community, employees and other stakeholders to be involved in our decision making

6. Water for the future
We will:

- Ensure healthy water for all
- Limit abstraction of water sources within their renewable yield
- Promote the value of water and water efficiency practices with our customers

Chapter 4 - Stakeholder participation

Stakeholder participation is crucial for successful application of any sustainability framework. Therefore a brief introduction of stakeholder participation is given below and before each of the six Phases of the framework.

The importance of participation to sustainable outcomes

Moving towards sustainability means a paradigm shift among all water users (i.e. among the entire population), and this is both cognitive (what people believe) and behavioural (what they do). One single technocratic decision, such as arrived at by following this document, will not be so important for ensuring transition towards sustainability, compared to a cumulation of small decisions and changing patterns of 'normal practice'[1].

However, there are critical points when innovations are proposed for introduction. Innovations are vulnerable to veto from outside the 'expert collective', and at these points, the decision process is critical: how people with a capacity to make the proposal stall, or go forward, relate to the process of considering it. Here, the critical point about assessment technologies is not whether they convince the experts, but whether the use of it forms part of a broad mobilisation of understandings and practices among both users and providers, as opposed to a short cut to a 'decision'. Decision tools outlined here both inform and support changing beliefs and practices as they interact. This document includes a strong emphasis on engaging stakeholders throughout the decision-making process and technical details on how to use the available tools to inform such a decision. These broad principles of participation described here are supported with further explanation of their application through each of the phases.

Principles for effective stakeholder participation

Consultation of stakeholders (including – even especially – the public) is increasingly recognised as vital to ensuring successful implementation of water management systems (Morrison, 2003). As explained in Chapter 13.2 of the literature review, stakeholders are part of the system itself – so must inevitably play a role in ensuring sustainable outcomes. Consultation strengthens social capital (Taylor, 2004) for dealing with the water management problem – which is, of necessity, increasingly a shared problem. Engaged and empowered stakeholders and public communities enable stronger commitment to and ownership of problems and their solutions (Carson and Gelber, 2001).

There are degrees to which the public can be engaged in any decision-making process (Arnstein, 1969). The International Association for Public Participation (IAP2) have developed a more recent continuum of participation. It is not necessarily appropriate to assume that maximum participation is always the most appropriate path for all projects, however the continuum does provide project managers and other stakeholders with a clear range of options for what might be expected in terms of participation in a decision making process.

Participation should not be restricted to feeding survey results of 'what the community thinks' into a decision-making process. Community opinion is not a static phenomenon independent of social action. While it is true that public opinion is typically against such innovations as potable recycling, experience of past projects shows that opinions change during the course of a project (Stenekes *et al.*, in press). Thus engaging the community at an earlier stage in a project is more likely to promote trust rather than antagonism toward innovation.

The concept (or construct) of sustainability should not be limited to a technical-expert defined end product, but rather conceived as a snapshot of consensus of a diverse range of values and knowledge at any one time (Colebatch, 2005). Sustainability is not a state to be arrived at, but a broad evaluative framework for understanding and justifying social practice. While this may appear to be weakening the construct of sustainability, nonetheless recognition of the social construction of this discourse will facilitate greater stakeholder buy-in. Such an approach will foster greater flexibility to adapt to new knowledge and values as further problems and opportunities come into light.

The importance of supportive and adaptive institutions

Current thinking on integrated urban water management is that supportive institutional arrangements and policies are required, along with engagement of a wide variety of stakeholders (Hatton MacDonald and Dyack, 2004; Mitchell, 2004; Stenekes *et al.*, 2004; Taylor, 2004). This is quite different to the traditional technically driven nature of water management solutions. This document assumes that implementation of the process recommended herein is supported through organisations that are prepared to adapt and develop their institutional capacity (Brown, 2004) for undertaking innovative and integrated urban water management.

Table 2 presents an overview of stakeholder participation through each of the phases, reflecting the above principles.

---

[1] A comparable example would be the change in acceptance of smoking in public places between 1970 and 2000 in Australia, when it changed from being mainstream and normal to being problematic. There was no 'decision' (by government or anyone else) to delegitimise smoking (although governments at various levels supported moves which had this effect).

Table 2 Objectives, processes, participants (by scale) for each phase in sustainability assessment for urban water systems

Phase	Objectives	Processes	Participants and	Scale[3]
1. Define problem and objectives	• Determine objectives that are in harmony with (or at least acceptable to) the project proponent, broader policy framework, stakeholder groups, and local community	• Steering committee· • Value management study • Market surveys· • Public conversations· • Reference to other studies, policies, planning controls, organisational goals, etc· • Document all assumptions and value sets used	• Owner/developer • Water authority • Consent authority • [Future] resident community • Relevant government departments • Relevant politicians • Relevant community or environmental organisations	• A • A • M-L • M-L • M-L • L • M-L
2. Preliminary options	• Provide a reasonably diverse and comprehensive set of possible solutions • Any proposed option should be included at this stage	• Brainstorming • Lateral thinking • Backcasting • Workshops • Expert consultants • Collaboration of diverse group	• Any of the Phase 1 participants with an interest in participating • Water management experts (from industry / academia)	• A • M-L
3. Determine sustainability criteria & weightings	• Arrive at a consensus (or aggregate) of stakeholder values • Within the five primary criteria, aim to reduce the total number of secondary criteria, to limit complexity of assessment process	• Citizens' Jury • Deliberative Panel • Expert panel • 'Value-tree analysis' • Public conversations • Etc.	• All stakeholders (i.e. see Phase 1)	• A
4. Screen options	• Reduce the number of options down to a number that can be thoroughly assessed (e.g. 4 or 5)	• Simple absolute yes/no decision based on qualitative assessment (or quantitative if values already known) against objectives and criteria already established • Identify if mitigation is possible, reassess	• Technical experts in consultation with the wider stakeholder group	• A (refers to tech. experts)
5. Detailed assessment	• Assess the impact of each of the options according to each of the criteria selected • Determine preferences on criteria	• Use whatever assessment tools are available: LCA, LCC, MFA, etc. • Surveys &/or focus groups • Identify if mitigation is possible, reassess • Ranking & normalisation of criteria	• Only local engineers • Broader technical experts • Community participation for social impact assessment	• S • M-L • L
6. Recommend preferred option	• Arrive at one preferred option which is either implemented or recommended, depending on the degree of authority	• Critical review of options & uncertainties, which for M-L projects may utilise multi-criteria decision add tools, such as SMART and STRAD	• Senior engineer • Representative stakeholders well informed in the whole process (i.e. see Phase 1)	• S-M • M-L

[3] Scale letters refer to: S – small-scale decision (such as pump or valve replacement) within an organisation; M – medium-scale decision (such as a major trunk main) involving external stakeholders; L – large-scale decision (such as a new subdivision with water/wastewater services in a large city); A – common to any scale.

Chapter 4 - Stakeholder participation
continued

Consultation Processes

There are a number of different consultation processes that may be appropriate for any given project[2]. Table 2 provides a synopsis of the six phases in the framework and includes relevant participation and scale of project considerations. Citizen and/or stakeholder participation for sustainability is a new and developing field (Kasemir *et al.*, 2003) with limited history in water management in Australia (Robinson, 2002). The most commonly used forms of consulting communities so far have been public meetings, community liaison committees, focus groups, printed information and market research (e.g. see Carson and Gelber, 2001; Cole-Edelstein, 2004). There have been several other more innovative participatory approaches tried both in Australia and overseas, such as citizens' juries (Carson *et al.*, 2003). Other key stakeholders (such as government departments) have been involved through steering or advisory committees (e.g. Gold Coast Water, 2003). Consultative processes require skills that can be learnt, but generally reside outside the domain of current water agencies (McKenzie-Mohr & Smith, 1999).

The type of consultation process used will depend on several factors, including the nature of the relevant stakeholders, the nature of the project's potential impacts, the resources available for consultation, etc. While all methods have been and can be used with success, public meetings have several drawbacks and may be used with caution. They give much more exposure to the "incensed and articulate" than to the unengaged, and also give the impression that a decision has already been made (a "decide, announce, defend" strategy; Carson, 2005). Hence several more 'deliberative designs' for consultation with the public have appeared in recent years, such as the citizens' jury.

The planning process outlined in this document is based on the use of a steering (also known as advisory committee, working group, etc.), as this is already widely used and understood, and is also inexpensive. This is not intended to rule out other approaches. In fact, additional methods for informing and consulting a wider community may be necessary. These may include public information displays, websites, newsletters, fact sheets and phone info lines. For alternative or additional approaches, any of the publications referenced in this section may be used to guide selection, timing and application of an appropriate consultation approach.

Establishing a Steering Committee

A steering committee should be established for the duration of all six planning and evaluation stages, and its size and scope of players is project specific (Table 2). A consistent approach to involving stakeholders should maximise trust, ownership, buy-in, social capital and thus manifest a shared responsibility in implementing the resultant system for a more sustainably managed urban water system. Ideally the steering committee will take on ownership of the entire planning and decision-making process, consummating with a credible and acceptable decision (or recommendation to make to the decision-making body).

The size of the committee, degree of formality, the frequency and duration of meetings will vary by project. It is better (though not as important for minor projects) to have an independent chairperson. The chairperson should not have any personal interest in any one particular outcome, and could be a respected community leader or a private consultant.

The chairperson should aim to bring the committee to consensus through deliberation rather than bring closure early through voting, which may foster greater antagonism and discontent. Voting should be used only when consensus cannot be reached otherwise. Consensus does not necessarily mean everyone has to achieve a 'win' outcome, but it means the parties are able to live with the concessions necessary to achieve a workable solution.

Depending on the nature of the project, the committee may consist of a few to up to 20 members, comprising representatives of all key stakeholder groups. For the larger committees, it may be worthwhile to allow plenty of lead-time for stakeholder groups to elect their own representatives, thus increasing the legitimacy that each committee member has as an effective representative of their constituents' viewpoints. The proponent together with the chairperson should preside over the selection process to ensure that no groups are over or under-represented on the committee.

The proponent should determine the overall objectives and scope of such a committee, with clear terms of reference. The project objectives (see Phase 1) should be left for the committee to determine, but the committee should know up-front what it is being asked to do, and the extent of its powers.

[2] See, for example, www.coastal.crc.org.au/toolbox/index.asp or Carson and Gelber (2001).

Chapter 4 - Stakeholder participation *continued*

The following list provides a starting point for stakeholder selection (for medium-large-scale projects, Table 2):

- Water authority
- Owner/developer
- Consent authority
- Local Government
    - o Councillors
    - o Relevant council officers (environment, engineering, planning, etc)
- [Relevant] State (or Federal) Government departments
    - o E.g. Environment, Natural Resources, Local Government, Planning, Public Works, Health, etc.
- [Future] Residents
- Community groups
- Environmental groups
- Small businesses / industry groups
- Consumers groups
- Indigenous groups
- Catchment management groups
- Farmers' groups
- Etc.

Water management experts (from industry or academia) may, and in some cases should, be added to the committee in an advisory or voting capacity. Examples may include ecologists, environmental scientists, water/wastewater engineers, political scientists, social scientists, etc.

Other (previously unidentified) stakeholder groups may be sought through public notices in relevant media or other public forums.

Some stakeholder groups are well organised and have effective processes of representation established (e.g. trade unions). However others are merely categories rather than established organisations or cohesive groups, such as the public community of water users. This means that the process of representation needs to be given more attention for such groups or categories that are not so good at representing themselves. There is a danger that the steering committee meetings can become the 'process' themselves apart from members consulting with their constituents – which is just as important as the steering committee meeting of key stakeholder representatives. It will probably be necessary, therefore, to check in the latter stages to ensure that the community is still being carried with the steering committee.

Merely appointing and convening a steering committee is not enough. It is necessary to pay attention to how each committee member represents their constituency. Some will need more attention than others. For example, where there are community representatives who may not have strong connections with their community, it may be beneficial to convene open days, public meetings or information displays where the elected community representatives can make presentations or otherwise interface with their constituents.

Chapter 5 - Phase 1: Definition of objectives

It is quite probable that for any decision making context where improved water management is desired, there will be a wide variety of perspectives on what problem(s) warrant solutions. There will always be multiple and often competing objectives even from a single stakeholder's perspective. Adequate attention needs to be given to frame the problem and objectives for its solution so that all stakeholders are willing to buy into and hence be able to achieve the broader policy goal of sustainability.

5.1 Background - sustainability in the water industry

Assessing the overall sustainability of water utilities brings into focus the desire for an industry specific definition of sustainability. The widely used definition of sustainable development proposed by the Brundtland Commission stated that (WCED, 1987):

> Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs.

Despite leaving a legacy of international consensus about environment and sustainable development (Adams, 1987:95), this mainstream definition has proved problematic within the industries that are charged with implementing its ideals. The lack of consensus on the broader notion of sustainable development makes it difficult to discuss this notion in more operationalised terms. Further insight was provided by Gleick (2000), who suggested that sustainable water use is:

> The use of water that supports the ability of human society to endure and flourish into the indefinite future without undermining the integrity of the hydrological cycle or the ecological systems that depend on it.

Current discussion over what sustainability means for the water industry is premised upon the above notion for sustainable water use. However, urban water management has in the past been interpreted the notion of "sustainable" as only having an ecological dimension, including environmental protection and minimisation of the use of natural resources (Ødegaard, 1995; Harremoës, 1997; Larsen and Gujer, 1997; Otterpohl *et al.,* 2003). However, more recent literature appears to follow Gleick's holistic perspective, suggesting that sustainable water management involves more than simply ecologically sustainable development. Some definitions of sustainability for water utilities that synthesise and incorporate many of the above principles have been suggested, for example:

- A sustainable urban water system should over a long time perspective provide required services while protecting human health and the environment, with a minimum of scarce resources (Lundin, 1999); and
- Every human being has a right to clean, 'fit-for-purpose' water. For urban areas, our vision is water management where water and its constituents can be safely used, reused and returned to nature (Malmqvist, 1999).

In short, participants should not get caught up in trying to define 'sustainable water use', as there is no one single overall decision to 'adopt sustainability' or to provide for 'sustainable water system', from which all else flows. Rather, sustainability is about a cumulation of small decisions and changing patterns of 'normal practice' (Colebatch, 2005).

The primary concerned for advancing more sustainable urban water systems, is that the proposed framework should move all stakeholders along a pathway towards more sustainable practices.

5.2 Goals for improved sustainability

For any urban water system (UWS) project, goals for improving sustainability will be dependent on the specific circumstances in which the project is embedded. Nonetheless, context-specific objectives should consider the needs of humans and the environment. While specific objectives must be defined for every project, human and environmental needs take on increasing importance with increasing scale of application.

5.2.1 Context-specific objectives

At the commencement of a project, context-specific objectives should be described along with the intended use of the results, i.e. its application. It should be made explicit on who initiated the project, which stakeholders will be affected by the project and who will participate in the course of the project.

5.2.2 Human needs

In the Guidelines for Drinking-Water Quality, WHO defines domestic water as being:

> "water used for all usual domestic purposes including consumption, bathing and food preparation" (WHO, 2004).

The above definitions for water utilities do not necessarily require water utilities to provide water to cater for all the services that in the past have been perceived as crucial to the functioning of an urban water system. Rather, these definitions require the water service provider to revisit the needs of human society, representing a change in focus from the provision of established domestic water and sanitation services to the provision of water for sustainable livelihoods. Broadening the approach in this way results in novel opportunities to be explored that may improve sustainability. For example, this approach reveals that if water is required at all for toilet flushing, it is not necessarily to be of potable quality. While adequate water supply for health and hygiene purposes should remain paramount we also need to look further at the different needs for urban water.

In summary, for developing regions an overall basic water requirement of 50 L/p.d is essential (15 L/p.d for hygiene, 10 L/p.d for food preparation and 20 L/p.d for sanitation services; Gleick, 1996). In developed regions, were laundry and bathing requirements are also considered essential, the WHO (2004) proposes that the optimal level for water quantity service is achieved at about 100 L/p.d. At this level all consumption and hygiene needs are met, and the level of health concern is rated as 'very low'. In contrast, Australians currently use over three-times this amount (Radcliffe, 2004).

Water used for drinking, hygiene and cooking comes into primary contact with humans during its use. Accordingly, these needs all require water of drinking water standard. Sanitation or removal of wastes, along with garden irrigation may employ a lower water quality standard. In Australia, Class A recycled water is of sufficient standard for such purposes (with NHMRC guidelines under development setting a benchmark health minimum of 10^{-6} DALY[3]/y for any system employed).

5.2.3 Environmental needs

Most major cities in Australia rely upon rivers or estuaries to be healthy and working in order to sustain the demands of the population. For rivers and estuaries in the catchments of major Australian cities and towns, Jones (2002) defines a healthy working river as a river that has been brought into service for the benefit of human kind, while retaining an 'ecological character' that is generally accepted as being 'healthy'.

The health of major river systems depends upon factors at the local scale, such as floodplains and forests, and at the whole-of-river scale, such as flow volume, distribution, variability and quality. An expert group at the CRC for Freshwater Ecology has suggested (Jones, 2002):

> "There is a substantial risk a working river will not be in a healthy state when key attributes of the flow regime are reduced below two-thirds of their natural level."

This scenario, called the "two thirds working scenario" is considered an 'interim flow guidance value' for a healthy working river. Following a risk assessment of the likelihood of an Australian river being healthy under specified flow regimes, the following risk categories provided in Table 3 were derived (Jones, 2002), representing a most basic interpretation. Such a classification is consistent with the intent of the ANZECC (2000) guidelines, but it is as important to note that river regulation and excessive consumptive water use threaten the viability of freshwater and estuarine systems by significantly reducing both the amount and variability in flow. Much of the focus on environmental flow management to date has been limited to ensuring only a minimum baseflow is provided (e.g. Table 3), generally by releases from an upstream dam. However, there is increasing evidence to show that this is not sufficient and that the variations in flow-magnitude, timing, duration, frequency and rate of change are critical in sustaining the biodiversity and integrity of aquatic ecosystems (Stanford *et al*., 1996). Various methods to establish river-specific flow and variability are presented in ANZECC (2000) guidelines, with the most promising methods being those that involve a detailed analysis of the hydrologic regime (e.g. Range of Variability method; Richter *et al*., 1997), together with some form of scientific panel to relate flow characteristics to specific ecologic, geomorphologic and water quality objectives for the particular river.

The guidelines (ANZECC, 2000) also provide considerable detail to enable water quality objectives for other environmental stressors (e.g. nutrients, salts, turbidity and temperature) to be derived for a specific river. Biological indicators and rapid methods for the assessment of biological impact (e.g. AUSRIVAS) are also described at depth, to identify acute and chronic effects to receiving water ecology.

[3] The disability adjusted life year is a summation of the years lived with a disability (scaled by severity) due to some ill effect, and the years of life expectancy lost (compare to the norm in that society). See Mather *et al*. (1999) for DALY estimates for Australians.

Chapter 5 - Phase 1: Definition of objectives
continued

Table 3 - Impact on the aquatic ecosystems depending on the natural flow (Jones, 2002)

% of Natural Flow (for critical indicators	Probability of having a healthy working river
Greater than two-thirds	HIGH
Greater than half	MODERATE
Less than half	LOW

5.3 Participation of stakeholders

The importance of early stakeholder participation

Stakeholders do participate in schemes for changing the way water is used. As a minimun (and the worst outcome), by forcing the abandonment of a proposal or refusing to take up or use innovations that are made available to them. So the question is not *whether* stakeholders will participate but *how* they will participate. Participation should be seen in terms of how the experts allow the inexpert public into the discussion, and there are several reasons for this, including:

a. *Cognitive*: opening the door to wider participation allows for a wider range of knowledge to be brought to bear on a complex process;

b. *Strategic*: consulting stakeholders at an early stage makes it less likely that they will oppose the project at a later stage; and

c. *Behavioural*: sustainability calls for a realignment of attitudes and practices by water users, and participation in the planning process is part of this realignment.

Participation aims

It is thus very important to achieve a shared problem definition in order to promote stakeholder buy-in to the eventual solution. The aim of stakeholder participation in this Phase 1 is to establish a shared understanding of both the problem to be solved, and the objectives that should be met by the solution. This shared understanding will ideally be in harmony with (or at least acceptable to) the project proponent, the broader policy framework, the stakeholders groups and the local community.[4]

Participation processes

How participation is conducted during this phase will vary significantly depending upon the nature of the project. If a *steering committee approach* is used, e.g. for large- scale projects, the proponent (e.g. the water service provider) in conjunction with the independent chair of the steering committee should limit the scope of the meeting such that it only includes objectives and problems within the purview of the water service provider. Other issues can be referred to relevant authorities (rather than simply dismissed). Small-scale projects may involve brief phone calls to affected parties to ensure shared understanding is reached.

Other approaches to *community consultation* could include market surveys or public conversations (see Cole-Edelstein, 2004).

For those guiding the process of arriving at a shared understanding of objectives and problems, a useful starting point is the definition of human and environmental needs as described in Sections 5.2.2 and 5.2.3 on pages 18 and 19..

Phase 1 could take less than a day for projects of small significance. However larger projects may require more elaborate consultative processes that span over several weeks with several meetings of all stakeholders involved in planning and negotiating. However most of the time would be lead-time to give stakeholders a chance to engage themselves and their own constituents[5] rather than constant intensive deliberation; e.g. if a steering committee is set up, the process of selecting the committee may take a few weeks, and then the committee may need to meet during a full or half day to deliberate.

By way of example for each phase of the proposed framework, we have provided the same worked example; a small-scale issue, which is the selection of a raw sewage screen to be used in the first stage of a sewage treatment plant. Hence, for Phase 1, the example looks at issues of project definition and consultation (see Box 1).

[4] If such a shared understanding cannot be reached at the early stages of a project, it may call for one or more of: abandonment of the project; building institutional capacity within and between organisations to reduce fragmentation; waiting for more favourable circumstances; or redesigning the approach taken to ensure consensus can be reached. We do not recommend 'going it alone' as an alternative in this case. There are many examples of projects that have failed when vocal minorities have not been engaged in the process, or have become disengaged due to a lack of shared understanding or values (Stenekes *et al.*, 2003).

[5] Some stakeholders are more organised than others, and the organizations that do exist may be unstable and weakly connected to their constituents. The process of participation may be about creating structures for giving voice and enabling feedback, and this does not happen overnight.

Chapter 5 - Phase 1: Definition of objectives *continued*

5.4 Key outcomes of Phase 1

- Definition of the context-specific objectives of the project including the initiator of the project, affected stakeholders, selection of participants and the intended use(es) of the results.
- Additionally human and environmental needs may be addressed depending on the scale of the project, such as
  - o Water use – maximum quantity of freshwater / groundwater extracted versus recycled, considering human health and social implications; and
  - o Environmental stressors with location-specific water quality objectives for flow volume and variation, nutrients, turbidity as well as biodiversity targets and measures. Impacts via greenhouse gas and air toxic emissions capturing most issues relating to energy use.
- Participation: Regardless of the scale of the assessment, a statement of the problem(s) the project seeks to address, along with the project objective(s), should be produced. This should not be very detailed, but provide a brief and clear statement as to why the project is being undertaken and what are the overall objectives.

Box 1: Case Study – Screen Selection

Project description

Selection of a more sustainable screening option for a small-scale sewage treatment plant.

Background

The existing inlet work in a small town's sewage treatment plant consists of a manual rake screen in the bypass channel and a drum screen. A rapidly growing population in the small town has placed stress on the screening system and the existing system frequently breaks down. The water service provider had decided to upgrade the system to accommodate the projected peak flow of 100 L/s for the next 25 years.

Phase 1. Definition of Objectives

Participation of stakeholders

The aim of stakeholder participation is to achieve a consensus-oriented definition of the objectives and establish an understanding of the problem that needs to be solved (i.e. insufficient capacity of the existing screenings system). In this particular case, there are two major stakeholders in play:

- Water Service Provider; and
- Plant Operator, i.e. end users of the upgraded system.

The stakeholder participation was taken in a form of an informal meeting between the plant operators and representatives from the water service provider, most likely one or two engineers who were assigned to manage this project. The plant operators were consulted on the problem they were experiencing with the existing system and expressed their expectations for the upgraded system.

There are three main objectives for this case study which address the key concerns or outcomes that need to be achieved:

Context Specific Objectives - technical needs: The sewage treatment plant was designed to handle the wastewater from the projected population over the next 25 years. The new screenings system must account for greater population growth over the same 25 years.

Context Specific Objectives - economics needs: The sewage treatment plant has to function properly as a business entity to serve its purpose in the wider economy.

***Human needs*:** To meet the basic human requirement by providing sanitation service in the form of processing sewage generated by the projected population in 25 years. The increasing population posts a greater demand on wastewater services and drives for an upgrade of the screening system.

***Environmental needs*:** The final effluent from the sewage treatment plant discharges into a local river. The environmental need is a healthy river that would sustain the demands of the population. Thus, more screenings being captured in the inlet works is an important step to ensure the downstream treatment process functions well and henceforth the discharge effluent would create less impact on the river. If there were high residual screenings in the downstream flow, it would create stress on the grit system or secondary treatment process as they are designed to capture smaller sized deposits. The solid material passing through, over or around inlet screens can damage or block downstream process equipment, increasing works maintenance costs. More screenings, however, generate increased environmental disposal issues.

Chapter 6 - Phase 2: Generation of preliminary options

Failure to give attention to this stage prevents innovation either in the present or future (Mitchell, 2004). It is important not to allow institutions to 'lock-in' to particular habitual solutions rather than innovating to maximise benefit (socially and environmentally as well as financially) and continually improve outcomes delivered.

The aim of Phase 2 is to provide a reasonably diverse and comprehensive set of possible solutions. Those involved in brainstorming and consolidating ideas should consider the key outcomes generated in Phase 1 (Chapter 5). During Phase 2 particular attention is directed toward generating new ideas that are different to current ways of thinking, more akin to what happens during backcasting rather than forecasting change (Mitchell and White, 2003). Some may be impractical or otherwise unsuitable to the particular project constraints, however part of the benefit of thinking broadly at this stage is to continually challenge existing boundaries in pursuit of more innovation toward enhanced sustainable outcomes.

6.1 Brainstorming: thinking outside the square

To provide some guidance on how to start the generation of ideas for novel water and wastewater service provision, it may be worthwhile to first distinguish between piped and non-piped options, on-site and off-site service provision, and level of centralisation possible (see Table 4 and Table 5).

The on-site scenario means the user sources their own water and disposes of effluent on-site. For example, a water utility could supply bottled water to some intermediate point between the source and the user. The right-hand columns (in the two tables) correspond to the water utility delivering and removing water and waste in batch quantities. The centralised provision of water services is currently the state of play in Australian capital cities. This classification may provide a useful point of reference for a water utility/novel agency seeking to generate alternative and possibly more sustainable options. However, one option might also be the '*do-nothing*' option.

Table 4 Examples for water supply options

Water quality	Piped: Centralised	Piped: Decentralised	Non-piped: On-site water collection	Non-piped: Batch supply of water
Potable	Desalination, aquifer storage & recovery (ASR)	Communal rainwater and treatment with ASR		Bottled water
Non-potable	Non-potable reuse	Rainwater, ASR & greywater	Rainwater & greywater	
	…others		…others	

Table 5 Examples for wastewater service options

Water cycle	Large centralised: Separate Sewer & storm	Large centralised: 'Smart Sewer'	Decentralised: Regional	Decentralised: Households
Recycled or Reuse	Stormwater grass swales, wetlands and reuse or groundwater	Vacuum blackwater & food waste for treatment & reuse	Urine-diversion/ vacuum blackwater & food waste treatment for agricultural reuse. Greywater urban reuse/ASR	Vacuum blackwater & food waste treatment by composting
Discharge to receiving water	STP effluent to receiving water	Vacuum or pressure sewer to STP	Greywater to local treatment	Greywater to soil treatment
	…others		…others	

6.2 Approaches for options generations

The *prospective options matrix* approaches illustrated in Tables 3 and 4 should go beyond the classical mechanistic approach to concept generation that consists of a linear (systematic) analysis of the problem. However, the mechanistic approach as outlined by Ashley *et al.* (2004) might be very valuable, by including:

- Identification of the core criteria and requirements for sustainable water systems including the project-specific objectives (Phase 1); and
- Combining those criteria and requirements to possible solutions.

Several approaches can be taken in order to come up with relevant options, all of which utilise *Participatory* methods to facilitate the exchange of ideas, experiences and knowledge of all relevant stakeholders and to create a basis for implementation of the final results. Such approaches include:

- *Brainstorming*: random ideas are expressed and latter associated pros and cons discussed. The matrices proposed in Tables 3 and 4 may be useful as a way of formalising the process of generating options without involving a lot of technical innovation. Such a matrix may aid in the generation of options using alternative schemes to the conventional 'centralised' scheme.
- *Brainstorming with SWOT*: combination of a brainstorming session with strengths, weaknesses, opportunities and threats (SWOT) analysis with a heterogeneous group of stakeholders may provide a useful tool to further evaluate and identify relevant issues for sustainable UWS.
- *Negative brainstorming*: the worst possible outcome is imagined; then each negative aspect is improved to generate acceptable options.
- *Lateral thinking*: use of experience from other fields to help solve the problem. In order to transfer novel solutions to this problem. For example the electricity industry uses decentralised approaches, and now the water industry is considering this approach.
- *Creative thinking / systematic inventive thinking*: There are different approaches to creative thinking, such as disordered thinking and idea generating methods, versus systematic inventive thinking and idea-focusing methods. Each complements traditional approaches such as brainstorming or lateral thinking, although not meant to replace them can through courses for inventive thinking provide a skill that can be learned and enhanced (Barak, 2004).
- *Pragmatic design*: using previous experience and methods with or with innovative combinations (generally following a forecasting approach, that propagates ideas centred on thinking and approaches used today; Mitchell and White, 2003).
- *Backcasting*: starting from a hypothetical time well in the future and describing what is considered a sustainable UWS, the backcasting approach then works through how we might get there, so challenging existing assumptions that may otherwise have 'locked' people's thinking into our systems and problems of today.

All options generated in this phase are at a *conceptual level only*; no detailed information is required.

6.3 Participation of stakeholders

Participation aims

The aim in this phase is to ensure that all relevant voices are engaged in the process, and that those who show an interest are taken seriously. Making it possible for stakeholders (not only users, but other technical people e.g. public health officers) to have an input at this stage strengthens their engagement in the process and reduces the chances of subsequent obstruction.

Participation processes

Generating options should be fairly open-ended – limited only by time and money constraints. Brainstorming is typically the approach used, sometimes in a 'café' small group/table format. Divergent thinking should be encouraged (Mitchell, 2004), before it converges in subsequent phases.

As a starting point for brainstorming options, the *prospective options matrices* (see Table 3 and Table 4) may be used by the participants. For our screen example, see Box 2 on the next page.

Typically one meeting of a steering committee may suffice, where members are briefed beforehand to come with ideas. Water management experts may be invited to the committee to guide in the development of options. It may be worthwhile in the case of more significant projects to allow further time after an initial brain-

Chapter 6 - Phase 2: Generation of preliminary options
continued

storming meeting for a wider (e.g. public) response to add any further conceivable options. This may also be an opportunity for community representatives on the steering committee to lead out in public meetings with their constituent groups.

For minor projects, the project manager may develop the list of options through informal consultation with other experts and/or stakeholders.

6.4 Key outcomes of Phase 2

- Stakeholders should develop numerous preliminary options which will be further investigated in Phase 4 and possibly in Phases 5 and 6 of this framework. These options will consist of conventional as well as future-oriented options that may not be commonly accept at the moment, but which may become attractive in the future under changed conditions. The number of preliminary options may be higher than 10.
- *Participation*: The steering committee (or project manager for minor assessments) should prepare a long-list of possible options. The options should be specified with only enough detail such that there is sufficient understanding of each option that the subsequent culling phases may proceed. This may mean anything up to one page of text and/or graphical explanation of each option.
- Phases 1 and 2 will both draw out the values of the various parties represented in the process. It may be useful to document these explicitly, as this will facilitate the discussions in subsequent phases.

Box 2: Phase 2. Generation of preliminary options

Participation of stakeholders

The aim of Phase 2 is to generate a list of all possible solutions. The level of expertise required of the stakeholder should not be excessively high, otherwise more general stakeholder groups could be prevented from participating.

The plant operators and the water service provider project team are the key contributors to this phase. The plant operators are engaged because they are the end users of the system and contribute unwritten expertise.

Preliminary options

The project team held an internal brainstorming session and generated a reasonably diverse set of options. The following is the list that covered the most basic non-mechanical screens to the most high performance mechanical screen design.

- ***Option 1. Manual bar screen*** - It is a coarse screen with aperture of 20 mm and above. It requires an operator to manually rake the screen on a regular basis.
- ***Option 2. Drum screen*** - This is a rotary type of screen with the influent fed internally. Wash water is required for cleaning of screen mesh.
- ***Option 3. Step screen*** - Step screen is a fine-bar screening device for fully-automated removal of coarse solids from both municipal and industrial wastewater. Aperture ranging from 2 mm to 6 mm is available. Capacity is up to 2000 L/s.
- ***Option 4. High flow screen*** – The Hi-Flow screen is an elongated form of drum screen with high capacity to handle large flow. The whole flow enters the inside of the drum and the solids are captured by the continuous travelling screen mesh. Maximum capacity of the Hi-Flow screening systems is up to 3000 L/s. Aperture is 6 mm. It also has a built in bypass feature. Wash water is required for cleaning of screen mesh.
- ***Option 5. Screw Screen compactor*** - This type of fine screen is suitable for a Membrane Bioreactor (MBR) plant because of its fine aperture – 0.25mm to 10 mm. It combines several processes by removing screenings from the wastewater, washing and dewatering the screenings prior to disposal. It is more suitable for small-scale municipal wastewater treatment plant.
- ***Option 6. Screw screen compactor with tank*** – the same screen as described above but comes with a tank as a package. For this option, a concrete channel is not required for the placement of the screen.

Table 6 - Prospective options matrix

	Coarse screen	Fine Screen
No dewatering	manual screen	step screen drum screen high flow screen
Dewatering		screw screen compactor screw screen compactor with tank

Chapter 7 - Phase 3: Selecting sustainability criteria

In Phase 3 sustainability criteria are selected that are used for screening options (Phase 4) and for assessing the performance of prioritised options in detail (Phase 5). The selection of criteria is critical, given their significant impact on the decision(s) to be made, and they need to encapsulate the various context-specific objectives identified in Phase 1. The key stakeholders, e.g. the steering committee, should agree upon this set of criteria.

7.1 Generic set of sustainability criteria

To provide a starting point, a generic set of criteria has been developed based on the literature review (Kärrman *et al.*, 2005), grey literature and consultation with representatives from the Australian water industry, i.e. project Steering Committee of the Water Service Association Australia. The set of sustainability criteria presented here may be used as a template for any application in the water industry. However, this set of criteria is not a default set which has to be used in all circumstances. It may be used as a starting point which should be adjusted to the specific circumstances of the decision that has to be made.

A transparent hierarchy of criteria consisting of *primary* and *secondary criteria* is proposed (see Table 7). *Primary criteria* reflect the core areas relevant to measuring the sustainable performance of an urban water system, i.e.

- Economic
- Human health
- Environmental
- Technical and
- Social.

Each of these *primary criteria* consists of one or more *secondary criteria*. *Secondary criteria* are specified by quantitative or qualitative indicators. Primary and secondary criteria indicators are listed in Table 7 (see also Chapter 14 on page 62 for a detailed description of indicators).

We suggest that all five primary criteria categories should be considered so as to comprehensively address the sustainable performance of an urban water system. While others have covered the five areas, often social and health are lumped together, such as in Taylor's (2004) economic, ecological and social aspects in the case of Urban Stormwater Management Measures to Improve Waterway Health, and Ashley *et al.* (2004) use of four primary criteria (economic, environmental, social and technical). Separation of health and social criteria is preferred due to the different tools of assessment and clarity of information relayed on to the decision-making phases.

Chapter 7 - Phase 3: Selecting sustainability criteria

continued

Table 7 List of example primary and secondary criteria for sustainability assessment and examples of mitigations to achieve sustainability (literature with * is available to download from the WSAA website)

Primary criteria	Secondary criteria	Examples of mitigations to achieve sustainability	References to assessment tools
Economic	Life cycle costs including capital and operational expenditure [$]	Ensure that the total life cycle costs are affordable.	
Human health	Risk of infection (DALY; e.g. [years of life loss/year])	Ensure that exposure probability to pathogens remains within acceptable limits to humans or the environment.	Ashbolt *et al.* (2005)*
	Exposure to harmful substances (eg toxic, carcinogenic or endocrine-disrupting compounds).	Ensure that environmental concentrations remain below those harmful to humans or other organisms.	Ledin *et al.* (2005)*
Environmental	Extraction of freshwater and groundwater resources [kL/year]	Ensure that environmental flow requirements (or for groundwater minimum water level requirements) are met.	Guineé *et al.* (2002)
	Land use and disturbance [ha/year]	Offset harm by purchase of substitute land, or rehabilitate degraded land off-site.	Lenzen and Murray (2001), Guineé *et al.* (2002)
	Resource input [t/year]	Purchase products with the highest resource-use efficiencies and with 'cradle-to-grave' recycling guarantees by their manufacturers.	Guineé *et al*. (2002)
	Biodiversity	Offset temporary losses by rehabilitiation ; offset permanent losses by purchasing natural habitats for long-term protection, rehabilitate degraded land elsewhere or create new habitats (eg wetlands).	Guineé *et al.* (2002)
	Greenhouse gas emissions [t CO2-eq./year]	Low carbon intensity sources of power ; renewable energy and/or carbon sequestration to offset emissions	Guineé *et al.* (2002); IPCC (2005)
	Eutrophication [t Phosphorus/year]	Ensure that nitrogen and phosphorus loads remain within the assimilative capacity of the receiving environment.	Kärrman and Jönsson (2001), Guineé *et al.* (2002)
	Photochemical Oxidant Formation	Remove from or reduce concentrations in emissions to the atmosphere.	Guineé *et al.* (2002)
	Ecotoxicity including terrestrial, marine and[6] freshwater aquatic	Ensure that environmental and tissue toxin concentrations remain below those harmful to terrestrial, freshwater and marine organisms.	Lundie *et al*. (2005)*, Guineé *et al.* (2002)

[6]The environment-specific effect factor is equal to $E_{j,s} = \frac{\partial msPAF_j}{\partial C_{j,s}} \approx 0.7 \cdot \frac{1}{HC50_s}$ (Van de Meent and Huijbregts, 2005)

where $E_{j,s}$ represents the effect factor of substance *s* for compartment *j* (year.m^{-3}), ∂msPAF$_j$ is the marginal change in the Potentially Affected Fraction of species due to exposure to a mixture of chemicals in compartment j, and HC50$_s$ is the Hazardous Concentration of substance s where 50 percent of the species is exposed above an acute or chronic toxic value (kg.m^{-3}). All HC50s are based on acute aquatic toxicity data.

Chapter 7 - Phase 3: Selecting sustainability criteria *continued*

Table 7 List of example primary and secondary criteria for sustainability assessment and examples of mitigations to achieve sustainability (literature with * is available to download from the WSAA website)

Primary criteria	Secondary criteria	Examples of mitigations to achieve sustainability	References to assessment tools
Technical	Performance potable water and wastewater quality	Quality remains within the limits specified in Customer Charter or the discharge licence.	Time-series analysis, compliance comparisons
	Reliability	Design and manufacture of the product provides an acceptable frequency of failure.	Western Consortium for Public Health (1997), Vasquez *et al.* (2000)
	Resilience/vulnerability	Ensure that the system is robust, and that it can recover rapidly after upsets by: preventative maintenance; multiple barriers; purchasing resilient or "shock-resistant" equipment.	Teoh & Case (2004)
	Flexibility	Redundancy and/or flexibility should be "designed in" to ensure capacity to adapt to foreseeable contingencies.	Expert opinion
Social	Affordability	Basic water services (i.e. 'water for life') are affordable for the community.	
	Employment	Long-term employment opportunities are created.	
	Acceptability to community	Timely and open engagement of the community is essential to maximise acceptability of proposals, as is establishing an agreed framework for assessing sustainability.	STRAD
	Distribution of responsibility	A clear, fully accountable and fully funded governance model is essential for the good ongoing management of new assets.	
	Organisational capacity and adaptability	Recruit and retain the best staff; run the business at a profit; develop and maintain trust and credibility; invest in strategic and scenario planning; invest in emergency preparedness.	Guitouni and Martel (1998)
	Public understanding and awareness	Timely and open provision of information to the community is essential to maximise acceptability of proposals.	STRAD

Chapter 7 - Phase 3: Selecting sustainability criteria
continued

7.2 Principles for selecting sustainability criteria

When selecting primary and secondary criteria several *principles* should be considered in order to ensure a comprehensive and consistent sustainability assessment of the system(s) under study.

- ***System boundaries***: The system boundaries delineate the system under study, i.e. the options, from the remaining environment and economy. For all comparisons the system boundaries should be made explicit (Guinee *et al.*, 2002). It should be ensured that the system boundaries cover all relevant economic, human health, environmental, technical and social impact. The risk of leaving out significant impacts of one of the options should be minimised. Therefore, the *system boundaries* have to be defined *consistently across all options and criteria*. Ideally, the system boundaries should be identical for all primary and secondary indicators. However, if system boundaries can not be identical for all criteria, it has to be assured that the boundaries are identical for all options and each indicator. The system boundary definition should also be consistent with the objectives of the assessment.
- ***Comprehensiveness***: The selected indicators should allow for sufficient performance monitoring and measurement of the options under study. Importantly, the selected indicators should be able to detect any possible *problem shifting* within each primary criterion or between primary criteria. A good example of this may be leaving more water for environmental flows by utilising desalination, which may increased greenhouse gas emissions when non-renewable energy sources are used. Further, it has to be ensured that the selection of criteria avoid double counting wherever possible.
- ***Applicability***: Selected criteria should be examined the same way for all options under study, i.e. quantitatively or qualitatively. The results of each indicator have to be in a format that is used by MCDA methods (see Chapter 9 on page 37).
- ***Transparency***: A clear statement of justification for excluding any primary criterion and why each secondary criterion is chosen will aid in transparency and communication during the consultation processes.
- ***Data quality***: High quality data or data with reported uncertainty is crucial for the correct interpretation of each criterion used to assess options. Therefore, data quality requirements should be explicitly defined at the beginning of the analysis. However, data quality varies significantly in practice, so as far as practical ensure that data quality is homogeneous across all options in order to make meaningful conclusions. In the case of heterogenous data quality it has to be assured that the quality is consistent for each criterion.
- ***Practicability***: The criteria chosen need to reflect the specific decision making context. Furthermore, the criteria chosen have to be in line with the assessment tools used. In general the number of criteria selected should mirror the complexity of the options. Small scale projects may require less criteria than assessments of large scale project. However, it has to be ensured that the criteria appropriately cover all dimensions of sustainability.
- ***Temporal-spatial aspects***: Some tools are focused on assessing the full life-time of systems (e.g. LCA, LCC) while others may not (e.g. NPV). As a general rule and according to what is described above for the system boundaries, each comparing criterion should cover the same time period and spatial domain.

7.3 Recommendations on tools and approaches to address sustainability criteria

The underlying principle for *all criteria* is a systems analysis approach taken into account all stages of the entire life cycle (so-called 'cradle-to-grave') of the options under study, including extraction of raw materials, production of materials, assembly and installation of capital equipment, its operations as well as the 'after use phase' with all its economic, human health, environmental, social and technical implications (Guinee *et al.*, 2002); what is known as a *life cycle approach*.

The following synopsis of assessment tools (for use in Phase 5) is provided here to illustrate what and how criteria can be measured.

7.3.1 Tools for assessment of economic performance

Life cycle costs (LCC) including capital and operational expenditure are the total expenses needed over the life of the system. This includes the cost of all:

1. initial equipment;
2. expected replacement equipment;
3. construction, maintenance and refurbishment personnel;
4. construction, maintenance and refurbishment tools, vehicles and plant;
5. operational materials; and
6. emissions to air, water and soil if discharge licence fees apply).

The LCC are currently calculated using the *Net Present Value* (NPV). The NPV is the amount in today's dollars that reflects all future costs. To turn future costs into today's dollar values a discount rate is used. The discount rate that should be adopted is the weighted average cost of capital (WACC)[7] which applies to the particular utility in question. In the case of Australian water utilities, this discount rate will be determined by the relevant economic regulator (in the event that the water utility is not subject to economic regulation, the utility should adopt the WACC imposed by its shareholder). It is important to determine whether the WACC set by the regulator (or its equivalent) is a real/nominal discount rate; as this will also determine whether the values in the calculation ought to be expressed in real or nominal terms. When utilities undertake these analyses they also tend to consider costs after tax (i.e. the impact on the utility). As the sustainability assessment is meant to consider societal rather than private costs and benefits, it is important that the cash flows (and discount rate) reflect pre-tax considerations. Equation 1 is used to describe the NPV, where *y* = the year (where year 0 is this year, 1 is next year and n is the final year), e is the expense incurred in that year, *i* is the WACC.

Equation 1: $$NPV = \sum_{y=0}^{n} e_y \left(\frac{1}{1+i}\right)^y$$

7.3.2 Tools for assessment of human health

Tools for human health assessment typically start at what are called screening-level assessments for key hazard groups[8]; the goal being to use conservative assumptions and see which hazards are of potential concern and therefore requiring more detailed analysis with more locally derived data. For example, the NSW-EPA Schedule 10 compounds (some 121 chemicals possible in sewage identified in the 1994 Corporation Act of Sydney Water) may be used to select potential chemical hazards in sewage-impacted Australian waters. A hazard quotient (per chemical) is then derived by dividing the expected environmental concentration by what is considered a safe dose (e.g. US-EPA [1998] IRIS database reference doses, *RfD*), any hazard quotient greater than about 0.3 may be considered a chemical of potential concern (Winton *et al.*, 1995) and warrants further investigation.

As discussed in the literature review (Kärrman et al., 2005), however, there is neither *RfD* data on the possible toxicity of the many xenobiotic compounds found in urban societies nor the chemistry to estimate very low environmental concentrations. Hence, in the Urban Water Programme, a novel screening procedure: *CHIAT – Chemical Hazard Identification and Assessment Tool*, was developed to select the most critical chemical pollutants when handling storm- and wastewater (Ledin *et al.*, 2005). In short, CHIAT consists of a decision tree in which hazardous and problematic compounds are identified. To visualize the sorting of these chemicals the decision tree can be described as a funnel fitted with several filters. The filters have been set according to specified criteria based on sorption, volatility, persistence to biodegradation, potential for bioaccumulation and toxicity. There is also one on/off filter for technical/aesthetical problems, and a long-term chronic effects-filter considering cancer, mutagenic and reproduction hazards, endocrine disruption effects and allergenic effects. The output is a classification of the compounds in three categories (white, grey and black) depending on their priority as possible pollutants.

For pathogen risks, a screening-level assessment would be to follow the risk ranking approach provided in

[7] In ideal circumstances, a discount rate reflecting the risk associated with the specific project would be used. However, economic regulators have not adopted this approach and have relied upon average portfolio risk.

[8] Key hazard groups can be as general as *E. coli* representing potential pathogens, trihalomethanes representing disinfection by-products etc. through to *E. coli* representing enteric bacterial pathogens, rotavirus representing all human enteric viruses and estrogen representing all endocrine disruptors.

Chapter 7 - Phase 3: Selecting sustainability criteria
continued

AS4360 (Standards Australia, 1999) and the Australian Drinking Water Guidelines (NHMRC, 2004), where each hazard is ranked on likelihood and severity to give a risk score. Ashbolt (2005) has also described a quantitative microbial risk assessment (QMRA) tool that takes a stochastic description of reference pathogen[9] numbers from sources, through each system barrier and describes their probability density function (likelihood distribution of numbers) at various points of exposure, and characterises the effects in terms of disability adjusted life years (DALYs). There is also an attempt to provide DALYs spanning the performance and reliability over the whole life of each system structure assessed.

7.3.3 Tools for assessment of environmental performance

There are several existing "physical economy" approaches for quantifying the material demands of the human economy upon the natural environment. Commonly used tools are total material requirement and output (TMRO), material flow analysis (MFA), substance flow analysis (SFA), ecological footprint analysis (EF), materials intensity per unit service (MIPS), life cycle assessment (LCA) and company level MFA. All tools measure one, few or many substance, material and / or energy flows throughout the systems under study.

Despite methodological differences, there are underlying characteristics of the physical economy approaches that are addressed differently by each tool. In this context Daniel and Moore (2002) mention (amongst others):

- The primary purpose of each tool is to track, quantitatively, the physical flow of materials and energy between the ecosphere and the technosphere;
- System boundaries are at a "high level" delineating the natural environment and the technosphere monitoring crossovers of relevant substance, material and / or energy flows. The human economy (or any smaller system within the economy) is considered as an "open" subsystem located within the ecosphere (Baccini and Brunner, 1991);
- "Physical economy" approaches are based on a holistic and integrated perspective, i.e. cradle-to-grave approach (Guineé *et al.*, 2002)[10]; and
- The material balancing approach is an underlying principle that is governed by the laws of conservation of matter and energy (Baccini and Brunner, 1991).

In Figure 3 available tools are assessed against the above mentioned characteristics. Company level MFA is probably most convenient approach for water service providers. However, this approach falls short in many aspects, such as coverage of metabolic flows, system boundaries and cradle-to-grave approach. More accurate approaches are MFA/SFA and LCA. MFA/SFA seems to the most useful if only *specific substances* are considered in the analysis, by fulfilling many of the underlying principles to a very high degree. However, LCA tends to take a more holistic view including quantification of *all material and energy flows* and also prediction of diverse, *potential environmental impacts*.

7.3.4 Tools for assessment of technical performance

Technical performance evaluation is largely an in-house activity, each using their own development approaches, but increasingly relying on SCADA systems to plot key indicators. As such, over time records from operators or operator experience builds up, and externally performance of water or wastewater treatment systems are reported against agreed key (licensed) parameters. For example, percent of the time that waters do not comply with the licensed values.

System *Reliability*, *Resiliency* and *Vulnerability* are parameters that are largely utilized in-house. To a large degree such information comes from the logs of operators and SCADA systems. For water systems generally, *Reliability* (the probability that the system will remain in a non-failure state), *Resilience* (the ability of the system to return to non-failure state after a failure has occurred) and *Vulnerability* (the likely damage of a failure event) have been well investigated, but the data resides in company hands. Nonetheless, analysis of these parameters' behaviour is generally investigated from time-series of data. Estimation of the start and end of

---

[9] Pathogens representative for each major taxonomic group, such as rotavirus for human enteric viruses, *Campylobacter jejuni* for bacterial pathogens, *Cryptosporidium* oocysts for parasitic protozoa, and *Ascaris* ova for helminths.
[10] Therefore these tools are often labeled as "integrated chain management" tools for environmental problem solving (Udo de Haes *et al.*, 1997).

system problems, however, is not as straight forward as first imagined. Apart from clear total failures of a system component, partial failures may go unrecognised, particularly when minor instrument drifts and spikes also occur, particularly in SCADA-recorded measurements. Moreover, the strong correlation between resilience and vulnerability may suggest that resilience should not be explicitly accounted for (as double counting). A further parameter, system *Flexibility* (which is not routinely assessed) is implicit to a system component and is also important to solicit expert opinion on.

Reliability and even *Resiliency* are more generally assessed by engineers by measures such as the *Mean Time Between Failures* (MTBF), and for example, have been applied to system failure assessment of the San Diego water reuse project (Western Consortium for Public Health, 1997). In other areas of manufacturing system *Vulnerability* can be measured by failure mode and effect analysis (FMEA), which is a related and widely used quality improvement and risk assessment tool in manufacturing (Teoh & Case, 2004).

In recent years, genetic algorithms (GAs) have been shown to have advantages over classical optimization methods and have become one of the most widely used tools for solving a number of hydrology/water resources and water quality problems (Vasquez *et al.*, 2000). Because GAs are not based on objective function gradient estimates, they may be used for complex, discontinuous, and nonlinear problems. The applicability of GAs for identifying reliable management solutions for water quality systems in the face of natural variability in the system inputs and parameter uncertainty was described by Vasques *et al*. (2000) and appears to have

Figure 3 Major approaches for quantifying the metabolism of systems (after Daniels and Moore, 2002)

	Total material requirement	MFA/SFA	Ecological footprint	Material intensity Per service unit	Life Cycle Assessment	Company Level MFA
1. Metabolic flows						
Specific substances	+	+/+++			++	+
Materials	+++	++/+	++	+++	++	+
Energy	+	+/	++	+	++	+
Outputs to environment	++	++/++	+	+	+++	+
Stock changes	+	+++/++				
2. Socio institutional entity	National, Regional economy	National, Regional, local Economy & activities	Consumption on national, regional level or individual	Service	Good or service	Enterprise
3. Geographical scale	Global, Nation (Region)	Global, Nation, Region, Local	Global, Nation, Region	Global, Nation	Global, Nation, Region	Global, Enterprise
4. Temporal scale	Year	Year	Year	Life cycle	Life cycle	Year
5. Cradle-to-grave	++	++/++	+	++	+++	
6. Mass balancing	++	++/+++		++	+	++

+++ = is a core feature of the approach
++ = is typically included
+ = is occasionally be included in the analysis

Chapter 7 - Phase 3: Selecting sustainability criteria
continued

advantages over several other approaches for evaluating the minimum total treatment cost-reliability trade-off for environmental quality problems, including chance constrained programming (CCP), combined simulation-optimization, and multiple realization-based approaches.

7.3.5 Tools for assessment of social performance

In recent years a number of tools have emerged for assessing social performance of companies or agencies, although few have been applied to the water industry. For example, Dejean *et al.* (2004) provide an analysis of how measurement tools influence the legitimacy of an industry and the systemic power within it. A recent example from the forestry industry, illustrated how stakeholders' valuations were compared cross-culturally and intra-culturally, which indicated that technical, financial and environmental issues were perceived as the most relevant elements of the acceptability of operations, and thus of corporate social performance (Mikkilä *et al.*, 2005).

As described by Mikkilä *et al.* (2005), well described tools such as the acceptability model (based on Saaty's 1980's hierarchical decision-making process), have been used in the form of an analytic hierarchy process. Their acceptability model described multi-criteria problems with multiple actors, the latter being defined in terms of the characteristics of two theories related to corporate social performance (CSP): the theory of business values and stakeholder theory. The theory of business values refers to judgements, including the process involved in making judgements and the standards and criteria brought to bear in this process. Stakeholder theory was employed to identify judges for the acceptability model.

7.4 Participation of stakeholders

Participation aims

The values of each stakeholder group are fed into the decision-making process by translating them into a set of criteria from which options will be assessed.

Participation processes

The list of sustainability criteria outlined (see Section 5.1) provides a starting point for determining criteria appropriate to the particular assessment at hand. Some may be added or removed from this list.

Stakeholders need to collaboratively determine a set of criteria through a deliberative, consultative process. In the case of (socially, environmentally or politically) sensitive assessments, it may be worthwhile using an additional consultative approach for this phase. In some situations, a citizens' jury is an expensive but effective way of coming to democratic consensus (e.g. Robinson, 2002). Other less expensive methods, such the steering committee are also adequate for deriving an appropriately diverse set of criteria which reflects how many stakeholders agree with each criterion and how important they think each is. For smaller projects where no formal steering committee is established, such a list of criteria may be established by the project manager in informal consultation with other relevant key players.

Box 3 provides an example of criteria for the sewage screens decision for Phase 3.

7.5 Key outcomes of Phase 3

- Selection of a manageable number of *primary* and *secondary criteria* for screening and detailed performance assessment of the options, i.e. Phases 4 and 5 respectively. The criteria should fulfil the principles outlined in Section 6.2 on page 23. However the number and types of secondary criteria depend very much on the actual case study. Limiting the number of criteria also helps with the final decision-making phase, as too many criteria are difficult to mentally integrate without the aid of 'black-box' software packages. Information on criteria weightings may also be attached, although these will more than likely be re-adjusted/constructed during Phase 6.
- The selection of criteria should ideally be reached through consensus of participating stakeholders.

Box 3: Phase 3. Selecting sustainability criteria

Participation of stakeholders

The key player in this exercise was the project team from the water service provider who possesses the expert knowledge in designing screenings system and who has a detailed understanding of STP operation. The members of the project team agreed on the criteria selected.

Sustainability Criteria

The selected sustainability criteria form the basis for screening options in Phase 4 and for assessing the performance in Phase 5. The primary criteria are the five generic sustainability dimensions. The secondary criteria chosen primarily rely on the expertise of the project team. The principle in choosing the secondary criteria is that they should be practicable (i.e. reflect the specific decision making context) and comprehensive (i.e. cover all dimensions of sustainability).

Table 8 Sustainability criteria

Primary Criteria	Secondary Criteria
Economic	• Whole life cost of up to 25 years using NPV @ 7% that takes into account: o Capital cost – the capital cost may reoccur over the 25 years depending on the design life years of the machine; and o Operational cost – operational cost involves the electricity costs to run the system and maintenance costs.
Environmental	• Reduced pollution loading in downstream effluent and air: o Poor screen performance allows more solid material passing through and impacts on treatability and ultimately the health of the receiving water; and o Potential for release of air toxics.
Technical	• Designed life years o This is a measure of durability of the machine. • Mechanical reliability o Poor reliability increases screen maintenance cost • Degree of enclosure for odour extraction o How well is the screen sealed to allow for odour extraction
Human health	• Risk of infection via contact with raw sewage during operation of the screenings system o Example of this risk includes the exposure to the raw sewage through the nozzle spray used to clean the screen mesh; and o Operator raking the manual screen has a higher chance of contacting raw sewage.
Social	• Acceptance by operator, i.e. ease of operation; and • Odour potential to residence.

Chapter 8 - Phase 4: Screening of options

Pragmatism (costs, time and other constraints) allows only a few options to be developed and assessed in detail. The purpose of Phase 4 is to reduce the list of options down to a number that can be feasibly and thoroughly assessed with stakeholder agreement. The total number of options for detailed investigation (see Chapter 9) should be well below 10 (see Taylor, 2004, p. 13; Lundie, 1999).

8.1 Principles for screening preliminary options

This screening of options requires a quick and crude assessment of preliminary options. This assessment is going to be based on coarse data quality, i.e. no detailed information will be available. However, the screening should consider the objectives as defined in Phase 1 inclusive of human and environmental needs. Additionally the options have to fulfil primary and/or secondary criteria, i.e. economic, human health, environmental, technical and social (see Chapter 7). It has to be stated that only a subset of criteria (as defined in Phase 3) might be used for screening. This *constraints-driven screening* should be based on qualitative and/or rough quantitative information (back-of-envelop calculations).

Examples of objectives for human and environmental needs are:

- Basic water requirements for human society needs are assured;
- The remaining average freshwater flow has to be >50% of the natural flow after extraction of freshwater for human needs; and/or
- Nutrient releases will not increase the number of eutrophication events in receiving waters.

Examples for screening criteria are:

- Life-cycle costs of each option should not exceed x $M;
- Human health risks are not perceived to get significantly worse;
- Water consumption must be lower than Y L/d.person; and
- The system will be acceptable to the community.

The consideration of objectives and the *constraints-driven screening* should identify those options that are clearly violating objectives or criteria, resulting in a reduced number of options. Each aspect (objectives and criteria) should be assessed individually in terms of whether or not each option fulfils a criterion. In principle three *decision making situations* are possible:

- *Situation 1*: an option fulfils both objectives and screening criteria,
- *Situation 2*: an option fulfils objectives, but not all criteria, and

Table 9 Decision making context and possible outcomes of the screening process

Situation	Screening situation outcomes 1	2	3a	3b
Objectives				
• context - specific	Fulfilled	Fulfilled	Fulfilled	One or more not fulfilled
• human needs	Fulfilled	Fulfilled	Fulfilled	
• environmental needs	Fulfilled	Fulfilled	Fulfilled	
Criteria	All criteria are fulfilled	Some criteria are fulfilled	No criteria are fulfilled	Criteria are (not) fulfilled
Decision	Detailed option assessment in Phase 5	Iteration to Phase 2, i.e investigate if and how the option might be modified in order to fulfil the criteria	Option is excluded from further assessment	Option is excluded from further assessment

- *Situation 3*: an option neither fulfils the objectives nor the criteria.

The consequences for each situation are quite different. At the end of this phase all preliminary options should be classified and documented as described in Table 9.

However, the documentation of the screening process will result in an implicit check of the quality and robustness of Phases 1 to 3. As a consequence some aspects of the previous phases might be further developed or revised [11]

8.2 Participation of stakeholders

Participation aims

The aim of participation during Phase 4 is to make sure that the process of reducing options for consideration does not produce an 'us and them' (divisive) scenario. There may be the situation in which an option is technically weak but has strong popular support.

Participation processes

The involvement of water management (technical) experts is necessary in this phase, as they will have good insight into the likely design and impacts of the options put forward. However for larger projects, the steering committee should take responsibility for the process to ensure the continued engagement of stakeholders, even if it eventuates that technical experts are appointed to do the screening. The important thing is that there is a discourse between the expert and the non-expert: that the process of selection is transparent and commands support. Furthermore, non-technical stakeholders may well assist in proposing mitigation strategies, to 'lift' certain option(s) up to Phase 5 evaluation.

8.3 Key outcomes of Phase 4

- The steering committee (or other person/group responsible for screening options) should provide a written report outlining the rationale used to screen each option.[12]
- Decisions are made with regard to all preliminary options whether the options are further investigated in Phase 5, excluded from the assessment or revised

[11] However, as part of the screening process it might be possible that additional objectives are identified, additional options are generated or further criteria are added.
[12] The Gold Coast Pimpama Coomera Waterfuture Master Plan Options Report (Gold Coast Water, 2003) gives an example of documentation of this step.

Chapter 8 - Phase 4: Screening of options
continued

Box 4: Phase 4. Screening of options

Participation of stakeholders

The project team from water service provider undertakes this phase without external input.

Screening options matrix

There are six options (see Box 3 on page 33) that might be possible solutions to the problem formulated in Phase 1. Not all are suitable, however, as some of the options may not meet the objectives or certain criteria imposed on by the water service provider. Based on the specification of requirements for screen performance, some options are eliminated.

The following specifications were derived by the water service provider. In addition to the human and environmental needs, a context specific constraint on the budget and technical constraints were provided, giving the following screening criteria:

1. **Human**: minimal health risk and odour problems;
2. **Environmental**: reduce likelihood of d/s pollution, SCR > 50%;
3. **Economic**: capital costs less than $60,000; and
4. **Technical**: ease for servicing, and capable of handling a peak wet weather flow (PWWF) of 100 L/s.

The water service provider decided that the social criteria is not sufficiently important for the overall decision making. The options were assessed against the four basic criteria (Table 10).

Table 10 Preliminary screening option matrix

Options	1	2	3	4	5	6
Human	yes	yes	yes	yes	yes	yes
Environmental	**x**	yes	yes	yes	yes	yes
Financial	yes	yes	yes	yes	yes	**x**
Technical	yes	yes	yes	yes	yes	**x**
Decision	Option excluded	Detailed analysis (Phase 5)	Detail analysis (Phase 5)	Detail analysis (Phase 5)	Detail analysis (Phase 5)	Option excluded

According to the matrix, Options 1 and 6 are screened out because not all of the preliminary criteria were fulfilled. Option 1, is unacceptable on the basis of not meeting the required reduce screening loading to downstream effluent (SCR = 0.4 for manual screen). Option 6 (screw compactor screen with tank) exceeded the budget and therefore it is excluded from further assessment (i.e. capital cost is $75,000) as also no technically appropriate (poor access to the screen brush for servicing). Thus, the list is now trimmed down to the following for further assessment in Phase 5:

Option 1. Drum screen;

Option 2. Step Screen;

Option 3. High flow screen; and

Option 4. Screw Compactor.

via an iteration back to Phase 2.

- The screening of options is ideally achieved in consensus with all stakeholders.

Chapter 9 - Phase 5: Perform detailed options assessment

Detailed assessment should provide accurate quantitative and/or qualitative comparisons of each option shortlisted in Phase 4 based on the criteria chosen in Phase 3. If participation has been adequately undertaken in previous Phases, relevant experts should be trusted by the stakeholders to undertake the detailed assessment and bring back data for the final decision-making phase. However, iterations of Phases 2, 3 and 4 might be required, if mitigation strategies (as proposed in this Phase) are pursued (see Section 9.3).

Technical experts will be required for selected primary and secondary criteria, such as health, environmental, and economic indicators. Social indicators may require trained social scientists undertaking additional forms of community consultation, or more basic expertise, depending on the scale of assessment undertaken. The technical experts engaged should be acceptable to the steering committee (or the project manager depending on the project scale). External consultants may be required in addition to the in-house staff, particularly if options put forward are not in the expertise area(s) of the proponent.

In this section an approach is presented to generate a detailed performance matrix of the options under study, normalise absolute results into relative figures, rank sustainability criteria and propose an overall sustainability 'raw' score. An introduction to decision support methodologies is given below, which may be necessary to aid in the ranking of options and identification of where mitigation strategies could prove useful.

9.1 Generation of a performance matrix

For each sustainability indicator selected in Phase 3 (see Chapter 7 commencing on page 25), and each option that undergoes a detailed analysis (see Chapter 8 commencing on page 34), data has to be collected for quantitative assessment of options. It is highly recommended to follow the principles as outlined in Section 7.2 on page 28, particularly the ones on system boundaries and comprehensiveness, and to use the tools as recommended in Section 7.3 on page 28.

The generation of reliable results can be a very time consuming process if the indicators are addressed in-depth. Hence, the level of detail has major implications on the scale of the assessment. Taylor (2004) proposes to define aspects of consideration, such as capital cost of the project, potential maintenance concerns, potential impacts to the wider community and the on ecosystems etc. For each of these aspects three levels of assessment are defined, i.e. "basic", "intermediate" and "high". The options under study are then classified for each aspect into one of the three levels of assessment. However, for simplicity reasons it is recommended to decide on *one level of assessment* for all options and criteria under study (see Taylor (2004, 16-19) for more details). This level is then pursued for the entire project. By doing so, it is aimed for homogenous data quality across all options and criteria. However, it is unlikely that such consistent data quality will be available. Therefore, the quality of data and possible sources of uncertainty should be documented. A simple way of flagging data quality and uncertainty is by assigning "high", "medium" and "low" labels to each result y_{ji}.[13]

At the end of data collection, the quantitative and qualitative results of the criteria are given in different units, such as "tonnes of CO_2-eq" or "high reliability". The results should be document and summarised in a performance matrix (see Table 11).

[13] There are more sophisticated ways of quantitatively addressing data quality and uncertainty. However, these are not described here.

Chapter 9 - Phase 5: Perform detailed options assessment
continued

9.2 Benchmarking of indicator results

The indicator results for each criterion should be converted in terms of normalisation and selecting a reference point before ranking and/or adding weighting factors on criteria.

The main aim of normalisation of criteria results is to better understand the relative importance and magnitude of their effect. Normalisation is also required if additional procedures, such as summing or weighting, are carried out (Guineé *et al.*, 2002). Normalisation converts the criteria results with varying units into uniform, dimensionless numbers for further analyses.

Normalisation can be applied to quantitative and qualitative criteria results if:

1. No additional information is available on each criterion;
2. Information is available on each criterion; and
3. Aspirational targets[14] have been set for each criterion, such as the options under study should be carbon neutral or options shall not cause any loss of biodiversity.

Quantitative indicator results: There are three approaches for converting indicator results into scores:

- ***Min-max approach***: The best indicator result gets the highest score of 100, while the worst indicator result scores lowest (i.e. 0). All indicator results inbetween are scaled in a linear manner.[15]
- ***Ranges approach***: For each indicator minimum and maximum boundaries might be defined if more sophisticated information (from previous projects) is available on what is technically achievable. For example, options under consideration may perform better than worst case, but they might be inferior to the best available technology. In that cause, the options under study will score higher 0 and less than 100 when applying the value function.

Table 11 Schematic of a performance matrix

		Options				
		X_1	X_2	....	X_n	Units
Criteria	Y_1	y_{11}	y_{12}	....	y_{1n}	u_1
	Y_2	y_{21}	y_{22}	....	y_{2n}	u_2
	.....					.....
	......					......
	Y_m	y_{m1}	y_{m2}	....	y_{mn}	u_m

X_i option $_i$
Y_j criteria $_j$
Y_{ji} criteria result $_{ji}$
U_j unit of criteria $_j$

[14] Aspirational target is the value set as a goal to achieve (possibly in the long-term). Hence the relative meeting of this target provides a simple means to compare against the estimated criterion for an option.

[15] There are however infinite possibilities for the value functions, and some other common examples of an exponential function and a linear function with internal maxima are provided in Ashley *et al.* (2004) and Edwards and Barron (1994). In most cases, this linear value function produces a conversion of high accuracy (Ashley *et al.*, 2004).

- ***Distance-to-target approach***: Distance-to-target (DtT) model was developed in the early 1950s by Paul M. Fitts, an experimental psychologist. DtT weighting method ranks criteria performance as being more important the further away the performance is from achieving aspirational targets. Finnveden and Lindfors (1997) point out that these methods are suitable if the targets of impact categories have the same significance. The DtT-approach can be applied if unambiguous aspirational targets are defined by decision makers.

Qualitative indicator results: Some of the indicator results, such as reliability, robustness, acceptance by the customer etc., are qualitative. The results are expressed as "high", "medium" and "low" or may be rated in classes ranging from 1 to 5. In such a situation the rating scale is translated into the uniform scale the same way as it is done with quantitative situations, i.e. min-max or ranges approach.[16]

While min-max approach does not require any additional information on any indicator, it may overstate the differences between options when the options may actually be quite similar. Therefore, the ranges and DtT-approach are preferable as they reflect better the actual criteria performance of an option relative to a reference figure. However, additional information is required for both approaches, i.e. ranges and DtT. The ranges approach is most widely applied in practice.

When comparing options it is helpful for the analysis to select one option as a reference. Often the reference point is the current operations, such as the given infrastructure system ("business-as-usual" or "do-nothing" option). However, more progressive reference points can be chosen, such as a prospective option that accounts for upcoming innovation or options that preserve the four forms of natural capital (Hawken *et al.*, 1999).

9.3 Reducing the number of sustainability criteria required

There may be a large number of sustainability criteria for assessment in the performance matrix. Such a large number may be problematic as decision makers usually cannot deal with more than seven criteria at the same time (Lundie, 1999).[17] Further, some criteria may cancel out others or be neutral between options. Therefore, consideration should be given as to which criteria should be removed before any weighting and/or ranking (see Section 9.4 on page 40) and results summarised (see Section 9.5 on page 40). There are various ways to reduce the number of criteria, such as:

- *Exclusion of criteria with similar performance across all options*: A criterion can be excluded from further analysis if the performance of all options is identical or very similar for that particular criterion; and
- *Mitigation of impacts by modification of options*: As a result of the normalised performance matrix an option may be preferable for most criteria, while it may not perform best for remaining criteria. This opens the opportunity to modify this option in such a way that the impacts are improved or even mitigated, e.g. renewable energy might be used to eliminate impact on climate change. This requires a modification of that particular option in Phase 2 (see Chapter 6 on page 22) in order to improve its weak

Table 12 Options for normalisation of quantitative and qualitative criteria results

Criteria results	No information on criteria results available	Information on criteria results available, i.e.	
		from past experience	by aspirational targets
Quantitative	Min-max approach	Ranges approach	Ranges or distance-to-target approach
Qualitative	Min-max approach	Ranges approach	Ranges or distance-to-target approach

[16] For example, a qualitative indicator result ranging from 1 to 5 can be converted into scores, such as 20, 40, 60, 80 and 100, using a linear approach. However, such a transformation of qualitative information into quantitative information pretends information to be accurate than they actually are.
[17] The number of criteria a decision maker can deal with at the same time may range from 5 to 9, i.e. 7 plus/minus 2, depending on the skills of the person being involved.

Chapter 9 - Phase 5: Perform detailed options assessment
continued

performance for certain criteria. This option will then be reassessed in Phases 3 to 5. Such an approach may then result in a situation that all options under study have a similar performance for one or more criteria, which allows their exclusion from the performance matrix. To achieve mitigation of criteria, several iterations to previous phases may be required.

9.4 Preference elicitation and rating/ ranking methodologies

Preferences may be expressed on criteria by direct rating, i.e. weighting, pairwise comparisons or ranking.

Direct weighting

A straight forward approach is to weight primary and secondary criteria directly. A weight is assigned to each criterion. The sum of all weights equals 100%. However, such weighting may best wait, if applied at all, to Phase 6, when recommending the preferred option(s).

Ranking

Each criterion is ranked according to its importance. However, if both the number of criteria and the number of stakeholders are large, it may be difficult to determine a consensus-based rank order. In this case pairwise comparison can be applied, i.e. each criterion is compared individually with all other criteria. This is done for all possible pairs of criteria. Once this pairwise comparison is completed a rank order is generated according to the frequency criteria ranked most important. The resulting rank order can be transformed into a weighting set.

9.4.1 Recommendations

Direct weighting seems to be more preferable to express preferences compared with ranking. This is one reason why the simple linear additive weighting model is the most widely applied technique to calculate an aggregated indicator result. However, some decision makers may find it easier to rank criteria rather than weight them (Lundie and Huppes, 1998).

While ranking of criteria may require less time compare with direct weighting, SMART tends to give the criterion with the highest rank an overriding importance due to the application of the Rank Order Centroid (ROC) method used.[18] This may *not* reflect the true preferences of stakeholders.

9.5 Analysis of the results

When looking at the data used in any analysis, it is important to identify data variability and uncertainty (possibly combined) for each technical criterion. *Variability* is the intrinsic variation of a particular parameter measured (such as the amount of energy required by a certain pump) and is not be changed by further measurement; whereas *Uncertainty* is our lack of precise knowledge of the input values or the lack of knowledge of the system being modelled, which can be reduced by further measurements.

Both variability and uncertainty can be described as ranges (possibly descriptively by expert opinion) or stochastically (as distributions). Distributions are used in analyses to model three conceptually different things:

---

[18] E.g. the weight of the 1st rank is four times higher than the 2nd rank if 2 criteria are ranked and approximately two times higher if up to 6 criteria are ranked. However, Edwards and Barron (1994) suggest, on the basis of simulation studies, ranking the options using ROC procedure will successfully locate the best available option between 75 and 85 per cent of occasions. More importantly, when the best option is ***not*** located, the average loss of score is only 2 per cent. Given the likely inaccuracies in the data, this suggests that the ROC procedure can be a very effective short-listing device.

Chapter 9 - Phase 5: Perform detailed options assessment *continued*

- The variability of individuals in a population (frequency distribution);
- The value of a random variable (probability distribution); and
- The uncertainty we have about a fixed, but imprecisely known parameter in nature (uncertainty distribution).

Distributions are of two basic types, discrete (e.g. when values are integers only)[19] or continuous (e.g. when values fall along a continuum)[20]. The outputs for discrete and continuous distributions are respectively: the probability mass function (PMF) (relates the possible value of a discrete variable to its' probability of occurrence), and the probability density function (PDF) (can be integrated to obtain the probability that a continuous random variable takes a value in a given interval). When the probabilities are described from 0-1 (or 0-100 %) (value of *X*) in a plot, it is called a cumulative distribution function, and it is a function giving the probability that the random variable *X* is less than or equal to x, for every value x.

The advantage of using PMFs or PDFs to describe variability and uncertainty is that the final result (potentially for each criterion) comes with this additional information when reporting/aggregating results (during Phases 5 and 6). Such distributional information is typically obtained through Monte Carlo simulations[21], which randomly selects a value from each distribution many hundreds if not thousands of times to generate a final output distribution of variability and uncertainty.

Expert opinion is an important source of information for quantifying modeled criteria, parameters and variables. Expert estimates can produce unrealistic distributions but they are often the only source of information available. Vose (2004) suggests that you need to follow the following broad principles to get the most reliable and unbiased expert estimate:

- Select your expert carefully for knowledge and lack of bias. Include, if possible, the expert in the original model design;
- Collate any information and find a good way of presenting that information to help the expert orient his/herself;
- Explain the reason for requiring the estimate. This will improve cooperation and also help the expert to comment on other factors that need consideration (correlations, etc.);
- Hold a brainstorming session with several experts and restrict their conversation to discussing information only, and avoid any estimation within the group if possible. Then ask each expert in private for their estimates. This allows you to determine whether the information is well understood and will result in consistent estimates;
- Allow the expert to describe the reasons for uncertainty about the parameter in his/her own way, and make the model match the expressed opinion. Too often, an expert is asked to confine his/her opinion to a statement of minimum, most likely and maximum. Disaggregation methods are particularly helpful. Make full use of the range of distributions normally used to model expert opinion;
- Model any correlations that the expert expresses;
- If the expert's estimate is based on quantifiable data, consider performing a statistical analysis of the data rather than relying on the expert to provide the interpretation. People tend to believe that a small data set tells us more than it actually does;
- Be aware of sources of bias and error in the estimation process, including the misunderstanding of probabilistic terms;

---

[19] Example of a discrete distribution is the *Binomial* distribution (such as the results from tossing a coin, where the number of successes from n independent trials where there is a probability p of success in each trial). In Excel, the function BINOMDIST(s,n,p,**0**) returns the binomial probability mass function, and BINOMDIST(s,n,p,**1**) returns the binomial cumulative distribution function.

[20] Example of a continuous distribution is the *Normal* or *Gaussian* distribution (which. addresses variations of many naturally occurring variables, such as peoples' height). The normal distribution is described by two parameters, the mean and standard deviation, and in Excel, the function NORMDIST(x,*m*,*s*,**0**) returns the probability density function for the Normal(*m*,*s*) distribution, whilst NORMDIST(x,*m*,*s*,**1**) returns its cumulative distribution function.

[21] Monte Carlo simulation is a computer-based method of analysis developed in the 1940's that uses statistical sampling techniques in obtaining a probabilistic approximation to the solution of a mathematical equation or model. It is a method of calculating the probability of an event using values, randomly selected from sets of data repeating the process many times, and deriving the probability from the distributions of the aggregated data.

Chapter 9 - Phase 5: Perform detailed options assessment
continued

- Generate a plot of the modelled opinion, check this matches the expert's opinion. Fine tune as necessary. When it does, get him/her to sign and date it;
- Offer the possibility of revision if the expert has a rethink;
- If you have two or more expert estimates, make a combined distribution. If the estimates disagree strongly, check that there has not been a misunderstanding of the information, assumptions (especially for conditional distributions), or the quantity being estimated; and
- Test whether the model output is sensitive to the estimated parameter/variable. If it is, you may consider fine-tuning the estimate.

In summary, to capture variability and uncertainty of criteria values, the following aspects should be considered during the analysis steps:

- *Consistency check* whether assumptions, methods, models and data are consistent with the objectives of the project;
- *Completeness check* to ensures that all relevant information and data needed for the interpretation phase are available and complete;
- *Error check* can identify false assumptions, model choices and data; and
- *Sensitivity and uncertainty analysis* to assess the influence on the results of variations in process data, model choices, weighting and other variables. As a first attempt to this last point, it may be easiest to run minimum and maximum values through any model to see how much effect changes have, then work on gaining higher quality data on the most sensitive parameters.

9.6 Participation

Participation aims

The aim of participation in this phase is merely to ensure that stakeholders are going to accept the results of whatever detailed technical assessment is done.

Participation processes

It is most likely that stakeholder representatives will not be involved in this phase beyond the initial step of engaging the relevant experts, e.g. one steering committee meeting may be necessary to appoint a list of trusted experts. These may be in-house or external consultants subsequently engaged by the proponent. Stakeholder representatives, however, may well swing back into action to assist with suggestions for mitigation strategies raised by poor performance with certain criteria.

Furthermore, some of the criteria (e.g. the more qualitative ones) may best be determined within a meeting of the steering committee, without the need to engage experts/consultants.

9.7 Key outcomes of Phase 5

- The output of the initial participation of this phase is the approval and engagement of the experts to undertake the remainder (and significant majority) of the work in this phase – the detailed technical/ social assessment of options according to the established criteria using were possible quantitative tools.
- Detailed quantitative, qualitative and normalised criteria results for each criterion by option studied. The results shall be described and summarised in the performance matrix.
- Selection of a reference point against which the options are benchmarked.
- Rank order or weighting on primary and/or secondary criteria which has been agreed on by stakeholders.

Box 5: Phase 5. Perform detailed options assessment

Participation of Stakeholders

The project team was responsible for the assessment because they had the technical expertise to interpret and evaluate the results. A senior engineer from the water service provider checked the results. The remaining options were assessed using the following procedure:

1. Generation of a performance matrix;
2. Normalisation of performance scores;
3. Assign weighting to primary & secondary criteria; and
4. Aggregation into final score.

Step 1. Generation of a performance matrix

The following table shows the performances of each option for each criterion that is selected in Phase 2.

Table 13 Performance index for all options

Primary	Secondary Criteria	Option 1 Drum Screen	Option 2 Step screen	Option 3 High flow screen	Option 4 Screw Compactor	Boundary Min	Boundary Max
Environ-mental	Reduced screening loading in d/s effluent	60%	65%	75%	75%	50%	90%
Economic	Capex	$25,000	$30,000	$45,000	$42,000		
	Opex (per year)	$700	$550	$600	$600		
	Whole life cost (NPV 7%)	$52,327	$55,644	$86,497	$64,215	$40,000	$100,000
Technical	Designed life	10	12	10	15	7	20
	Mechanical reliability	2.75	4	3.5	3.75	1	5
	Degree of enclosure for odour extraction	3.5	2	2	4	1	5
	Ease of operation	4	4.5	4.5	4.5	1	5
Health	Risk of infection	2.5	4	3	4.5	1	5
Social	'Not studied'						

Step 2. Normalisation of performance scores by min-max and ranges approach

In this approach the normalised scores for each criterion were calculated on a linear scale with the specified boundary in Table 14 as the maximum and minimum (see also Figure 8 in Chapter 16.4.1 for visualisation). At the far right hand of the table, there are two columns which specify the boundary for that criterion. It generally refers to the acceptable range that this particular criterion is capable of performing. The boundaries were used for the range approach in step 2 of phase 5, i.e. normalization of performance scores.

Box 5 is continued over the page

Chapter 9 - Phase 5: Perform detailed options assessment
continued

Box 5: Phase 5. Perform detailed options assessment - *continued*

Table 14 Performance index for all options using ranges approach

Primary	Secondary Criteria	Min Max Approach Option 1	Option 2	Option 3	Option 4	Ranges Approach Option 1	Option 2	Option 3	Option 4
		Drum Screen	Step screen	High-flow screen	Screw Com-pactor	Drum Screen	Step screen	High flow screen	Screw Com-pactor
Economics	Whole life cost (NPV 7%)	100	90	0	65	79	74	23	60
Environmental	Reduced screenings load in d/s effluent	0	33	100	100	25	38	63	63
Technical	Designed life	0	40	0	100	21	26	77	40
	Mechanical reliability	55	80	70	75	44	75	63	69
	Degree of enclosure for odour extraction	70	40	40	80	63	25	25	75
	Ease of operation	80	90	90	90	75	88	88	88
Health	Risk of infection	50	80	60	90	38	75	50	88

Step 3. Weighting for primary and secondary criteria

The four primary criteria, i.e. environmental, economic, health and technical, were directly weighted according to their perceived importance by the assessor. Economic received the highest rank base followed by environmental, technical, and health.

Table 15 Criteria weighting distribution by Direct Method

Primary	Weighting	Secondary	Weighting	Overall weighting
Economics	48%	Whole life cost (NPV@7%)	100%	48%
Environmental	28%	Reduced screenings loading in d/s effluent	100%	28%
Technical	18%	Durability (design life)	50%	9%
		Mechanical reliability	30%	5%
		Degree of enclosure for odour extraction	10%	2%
		Ease of operation	10%	2%
Health	6%	Risk of infection	100%	6%

Chapter 10 - Phase 6: Recommend preferred option

In Phase 6, the final recommendation is made for the preferred option(s) is delivered. All of the previous information collected during Phases 1-5 are clearly presented to the more limited number of key stakeholders involved in Phase 6, which should include some Board members for large-scale projects. In addition to the consolidated information provided on the five primary criteria from Phase 5, the stakeholders in Phase 6 should be worked through the data, possibly assisted by way of a transparent multi-criteria decision aiding tool, such as SMART or STRAD. The goal here is not only to 'rediscover' the direct criteria ratings from Phase 5, but to understand the impacts caused by variations in weighting and uncertainties, so providing further insight for the final recommendation by covering each of the criteria and options.

The idea of this 'rediscovery' phase is to provide greater insight into the various pros and cons of each option remaining from Phase 4. Critical to the success of Phase 6 is the level of prior knowledge of both the processes used and background material (from Phases 1-5). Hence, by default Phase 6 participants should largely be a subset of people involved in Phase 5.

10.1 Introduction to appropriate decision support methodologies

The principal objective of some sort of multi-criteria decision analysis is to support which option is preferred (Phase 6) (Roy, 1990). As described in the literature review (Kärrman *et al.*, 2005), the multi-criteria decision aiding (MCDA) methodology can be seen as a *non-linear recursive process* consisting of the following steps: Structuring the decision problem; articulating and modelling the preferences; aggregating the alternative evaluations; exploiting the aggregation; and making recommendations. The application of methodologies to support decision takes place in the preference modelling and aggregation steps, where an overall assessment of each alternative is made based on the aggregation of each alternative's performance across all the criteria. The application of methodologies should be applied in a structured and transparent way.

Guitouni and Martel (1998) proposed a set of guidelines to match a decision-making situation with available methodologies based on several theoretical and pragmatic aspects of comparison between the selection of most popular methods. These points of comparison are divided into:

1. *Input capabilities*: the information and the criteria accepted or required by the methodology;
2. *Preference modelling*: each model assumes a preference structure of the decision makers, and accepts the preferences in certain forms; and,
3. *Aggregation procedure*: the algorithmic and mathematical procedures used to combine results from separate criterion.

Guitouni and Martel (1998) report among their findings that their study reveals how difficult it is to identify all the important aspects associated with methodologies to support decision because of the complexity of classifying the behaviours of a decision maker who influences and transforms all the decision processes. One pragmatic approach to classify the different methodologies is to simply consider what type of information is available, and then consider the range of methodologies that support such types of information. That is, to only consider the 'input capabilities', and to ignore the preference modelling and aggregation aspects (see Kärrman *et al.*, 2005, Chapter 14 commencing on page 62 for more details); these are:

1. Data collection to evaluate each of the different criterion across the alternatives;[22] and,
2. Preference elicitation, to determine the relative importance of each of the criterion.[23]

Table 16 classifies several of the common methodologies to support decisions based on the characteristics of the information available.

[22] The data collected could be strictly cardinal, ordinal, strictly (non-)deterministic or contain various elements of each of these.

[23] The preferences may be expressed as a direct rating of each of the criterion, or as an expression of the relative rating of each pair of criteria.

Chapter 10 - Phase 6: Recommend preferred option
continued

Table 16 Classification of selected methodologies to support decisions

	Preferences elicitation mode	
	Direct rating	**Pair-wise comparison**
Cardinal only	Linear additive method SMART	Analytical hierarchy process
Ordinal only		REGIME
Cardinal & ordinal		PROMETHEE, ELECTRE
Cardinal & ordinal & non-deterministic	STRAD	NAIADE

Participants of decision making processes usually emphasis the importance of transparent, relatively simple methods that take the decision maker(s) through the entire procedure step-by-step rather than 'black box' approaches (see Lundie (1999); Healy and Ascher (1995). The steering committee of this project supports this view; therefore the preference is towards direct rating as opposed to more complex preference elicitation, such as pair-wise comparisons.

10.2 Aggregation of information to an overall score

In this step the normalised results from the performance matrix (see Section 9.1 on page 37) is combined with the weightings (see Section 9.3 on page 39) in order to aggregate the various indicator results into a single score for each option. The method is also known as the weighted sum method of aggregation. It assumes that all criteria scores are directly substitutable. This assumption is rarely held in environmental projects (e.g. a project that is highly flexible may cancel out a bad performance in risk of infection), which is a shortcoming of this simplified methodology. The calculation of the overall score is shown in Table 17, and if considerable time and resources are required to elicit weightings, direct weightings or the Rank Order Centroid (ROC) method may prove useful.

Linear additive method

A straight forward approach is to weight primary and secondary criteria directly. The linear additive method aggregated normalised criteria scores and preferences into an overall value. This is done by multiplying the value score on each criterion by its weight and adding all products together. These widely applicable methods provide robust results and effective support to decision-making.

Simple Multi-Attribute Rating Method (SMART)

If criteria are ranked, the rank orders can be applied on 1) primary and secondary criteria separately or 2) all secondary criteria at the same time. One way of expressing the preferences is to construct a value tree of primary and secondary criteria (see Table 7 for an example). Ranking may be required for both the primary and secondary criteria.[24] Once the rank order for primary and secondary criteria is established, the rank order is converted into weights. There are several other techniques to elicit the weightings of different criteria (Hokkanen and Salminin, 1995; Simos, 1990; Edwards & Barron, 1994).

Ranking can also be applied to secondary criteria only. This approach is preferred if the total number of primary criteria is relatively small.

More complex methods than the weighted sum approach may utilse decision support tools, like STRAD, to combine stakeholders uncertainties as well as tool uncertainties for each criterion assessed. The reasons for undertaking the final aggregation in Phase 6 is so the process of aggregating results is well understood by the final set of stakeholders who recommend the final option(s).

[24] Preferably there is consensus among decision makers when assigning rank orders to the criteria; however, if there is disagreement with regard to the ranking, several rank orders might be considered for further analysis.

Table 17 Schematic of calculation of the aggregated score for each option

		Options		
		X_1	.....	X_n
Criteria	Y_1	$w_1 \cdot y_{11} / y_{1,ref}$	...	$w_1 \cdot y_{1n} / y_{1,ref}$
	...	...		...
	Y_m	$w_m \cdot y_{m1} / y_{m,ref}$	...	$w_m \cdot y_{mn} / y_{m,ref}$
		$\sum_{i=1}^{m} w_i \cdot y_{i1} / y_{1,ref}$		$\sum_{i=1}^{m} w_i \cdot y_{in} / y_{n,ref}$

X_i	option $_i$
Y_j	criteria $_j$
Y_{ji}	criteria result $_{ji}$
Yj,ref	reference for criteria i
w_j	weighting factor for criteria $_j$

Chapter 10 - Phase 6: Recommend preferred option
continued

Strategic Advisor (STRAD)

STRAD is based on the principles of strategic choice approach (Friend and Hickling, 2005). At the beginning of a project (problem definition, Phase 1) it is common practice to invite participants to compile a list of issues of concern in a brainstorming session. The main incentive of this process is to build a shared view of the main decision areas faced by the decision maker in that particular planning situation.

However, it is commonly found that some of the concerns expressed by participants cannot be easily formulated as decision areas. There might be matters which have little or no direct influence, or they are of more generic nature, such as strategic preferences, values or goals which are not directly related to the decision making context. Areas of concern of the former kind can then be expressed as *uncertainty areas* – and then classified in terms of three categories: uncertainties about the working environment (UE), uncertainties about guiding values (UV) and uncertainties about related agendas (UA). Concerns about preferences can be expressed as *comparison areas*. The procedure is carried out for all decision areas separately. The options are ranked and the distance between the options is determined. STRAD then assesses all aspects and provides a prioritisation between all aspects.[25] There is a possibility to give a larger weight to a certain criteria by enlarging the distance between decision options. This is done graphically and not by giving exact weighting values.

The main incentive for using the STRAD process is to build a shared view of the main decision areas faced by the decision makers. The strength of STRAD is the highly interactive participation of stakeholders in the decision making process. However, stakeholders' concerns may not be easily formulated into decision areas.

[25] STRAD estimates the aggregate impact level by calculating the sum of the squares of the individual impact levels, then taking the square root of the result.

10.3 Participation

Participation aims

Stakeholders need to deliberatively and collaboratively decide on an option which they will recommend to the final decision-makers (e.g. Council or the board of directors).

Participation processes

The output of the detailed assessment should be sufficiently simplified and displayed such that any (unqualified) person should be able to get a feel for the relative merits of each option. If one option clearly outranks the others, then a decision may be arrived at simply. The decision may also be arrived as quickly and simply with brief informal consultation if the project is of minor significance, even if more than one option shows potential.

However if two or more options have shown similar or contrasting advantages, then it may be necessary to guide the decision through more detailed decision aiding tools such as multi-criteria decision aiding (MCDA). Sensitivity analysis and/or variations to weightings are also typically done at this stage. However whatever tools are used, they should be understood as tools to *aid* not *make* decisions, otherwise buy-in to the decision will be diminished, i.e. the output of the tool should still be subject to further deliberation of the committee. Further, any black-box tool will also diminish buy-in to a decision, so it is important that even if a software tool is used, that comparable justification for a particular ranking of options can be shown on a one-page table or document.

This is another stage where a citizens' jury or other consultative/deliberative approach (Carson *et al.*, 2003; Taylor, 2004) may be used for particularly sensitive projects. However such tools will typically extend the time (due to lead-time of consultative process) and cost of a project considerably.

10.4 Key outcomes of Phase 6

- Calculation of an overall score for each option by using MCDA and rank order of options. Any weightings used should be documented.
- The final recommendation should be documented along with the decision-making process used. If the decision goes contrary to that recommended by strict adherence to the summation of criteria by respective weightings (or other MCDA approach), such a departure should be clearly justified.

Chapter 10 - Phase 6: Recommend preferred option
continued

Box 6: Aggregation

The sewage screen case study results were aggregated by both the Min-Max Method using direct weighting (case 1, see Section 15.4.2 on page 112 for detailed calculation) and the Ranges Approach using direct weighting (case 2, see Section 15.4.2 on page 113 for detailed calculation). Rank 1 indicates the preferred option.

The results from both methods demonstrated similar results except that the range of the aggregated scores was reduced using the Ranges method. This would prevent over exaggeration of any single option's prevalence over the others. The results showed Options 1, 2 and 3 as being compatible and worth considering even if Option 1 and 2 did not rank the highest. For the Ranges method, the final scores between Options 2 and 4 are very close (i.e. 59 and 62 respectively) and indicate there was no absolute preference considering possible errors made in the assumptions for the performance data and method of determining distribution of weights. The differences between the two methods is illustrated by Table 21.

Table 18 Overall performance min-max vs. ranges approaches

	Min Max		Ranges	
	Final Score	Rank	Final Score	Rank
Option 1	57	3	54	3
Option 2	68	2	59	2
Option 3	38	4	44	4
Option 4	81	1	62	1

Box 7: Phase 6. Identify preferred options

Participation of Stakeholders

Before the final recommendation was made, a scenario testing exercise was undertaken to test the effects of different criteria weight distributions on the final outcomes. Recommendations were then made to the decision maker in the water service provider.

Scenario Tests

Three scenarios with different rankings were examined to test the influence of weights on the final results. The three scenarios were developed based on the importance of the two key primary criteria, environmental and economic:

1. Base Case: Economics is more important than Environment (Econ > Environ);
2. Economic is equally important as Environment (Econ = Environ); and
3. Environment is more important than Economic (Environ > Econ).

Table 19 shows the weighting for each scenario:

Table 19 Weighting sets for Scenarios 1, 2 and 3

Primary Criteria	Secondary Criteria	Scenario 1 Econ > Environ Weighting by direct	Scenario 2 Econ = Environ Weighting by direct	Scenario 3 Environ > Econ Weighting by direct
Environmental	Reduced screenings loading in d/s effluent	48%	36%	28%
Economic	Whole life cost (NPV@7%)	28%	36%	45%
Technical	Durability (design life)	9%	9%	11%
	Mechanical reliability	5%	6%	6%
	Ease of operation	2%	4%	2%
	Degree of enclosure for odour extraction	2%	3%	2%
Health	Risk of infection	6%	6%	6%

Chapter 10 - Phase 6: Recommend preferred option
continued

Box 7: Phase 6. Identify preferred options (continued)

Table 20 Overall performances for the three scenarios using min-max approach

	Scenario 1 Econ > Environ		Scenario 2 Econ = Environ		Scenario 3 Environ > Econ	
	Final Score	Rank	Final Score	Rank	Final Score	Rank
Option 1	57	3	48	3	38	4
Option 2	68	2	62	2	57	2
Option 3	38	4	48	3	56	3
Option 4	81	1	84	1	87	1

For the three scenarios as shown in Table 20, Option 4 still ranked the highest amongst the others. This indicated that Option 4 was equally robust for both Economic and Environment criteria. Option 2 ranked second for all three scenarios.

The scores for both Option 2 and Option 4 did changed little across the scenarios as both options had strong performance in the two key primary criteria. However, the ranking for Option 1 and 3 shifted for Scenarios 3. Option 1 dropped to the lowest in Scenario 3 when the environmental criterion was valued higher than economics.

The difference in scores between Option 2 and 3 was minor for Scenario 3 (i.e. Option 2's final score in Scenario 3 was 57 compared to Option 3's 56). Again this suggests the two options are quite compatible in the 3rd ranking order when environmental prevails. In Scenario 2, Options 1 and 3 ranked the same. Option 1 and 3 were compatible in the 3rd rank order when environmental was valued the same as economics.

Table 21 Overall performances for the three scenarios using Ranges Approach

	Scenario 1 Econ > Environ		Scenario 2 Econ = Environ		Scenario 3 Environ > Econ	
	Final Score	Rank	Final Score	Rank	Final Score	Rank
Option 1	54	3	49	3	44	4
Option 2	59	2	55	2	52	2
Option 3	44	4	48	4	52	2
Option 4	62	1	63	1	62	1

The results using the ranges approach were similar to the min-max method. The major difference being that the final scores were closer, meaning the gap between the highest score and lowest was brought closer together.

Summary of Assessment

- Option 4 screw screen compactor was the preferred option as demonstrated by the analysis for both cases, whether economics or environmental criteria prevailed. The second best choice was Option 2, followed by Option 1 and Option 3 when economics were more emphasized.
- The results from both ranges and min-max approaches were similar. However, the results were amplified when using the min-max approach.

Differentiating between options may be difficult in some cases when the final scores are close. For example in Table 20, the final scores between Options 2 and 3 in Scenario 3 differ by only 1 point. When results like this appear, both options should be considered carefully. Throughout an assessment many assumptions are made and data used may be biased. All these factors need to be considered when evaluating options with similar final scores. The other issue to consider is when are the final scores for each option significantly different to make a judgment that the option with the highest score is indeed the best?

It is difficult to set a fixed rule because the ranges in final scores vary from case to case. Hence, further interpretation and evaluation of the results by the decision maker may be necessary.

Chapter 11 - Summary

This report consists of three key components, i.e. synopsis of the literature review, sustainability framework and case studies. In the synopsis key aspects are presented of previous research on sustainability assessments in the water industry from both Australia and overseas. The findings were taken into account when developing the Methodology for Evaluating the Overall Sustainability of Urban Water Systems, i.e. the sustainability framework described in this document.

The managing or governing of water use reflects the understandings and practices of the participants – including the organisations responsible and the users. The relatively recent pursuit of sustainability represents a shift in these understandings and practices. The framework addresses this complex, multi-disciplinary topic of sustainability of urban water systems in a structured way. It aims to outline a process for supporting community-informed steps towards improved sustainability in urban water management projects by the intensive participation of stakeholders throughout the process. Therefore, each of the 6 Phases consists of a procedural (*'how to carry out each phase'*) part with an integrated participatory component:

- ***Procedure***: The procedural component of each Phase gives detailed instructions on how the assessment of options is carried out including definition of objectives (Phase 1), generation of options (Phase 2), selection of criteria (Phase 3), screening of options (Phase 4) and generation of performance matrix (Phase 5) in order to recommend the most sustainable option (Phase 6). The procedure should be applicable to various types of options ranging from small- to large-scale projects with largely differing ramifications to stakeholder(s).
- ***Participation***: For each Phase the objectives of participation are presented as well as which stakeholder should be involved and how.

However, the application of this framework is *not* the making of a single decision, but the continuing work of aligning the understandings and practices of the participants with a developing understanding of what sustainability means in terms of their own practice and environment. Because sustainability is a broad term, there are questions about the most appropriate way to collect and process data, and also how to structure the decision process. Therefore, just as the framework and indicators of sustainability are constantly being reviewed and contested, so also must this framework evolve.

The framework has been illustrated and tested at two levels, i.e. all Phases of the framework have been applied to a small-scale case study (see Chapters 5 to 10), while application of specific quantitative tools (Phases 5) was tested with a large-scale case study (see Chapter 15).

It can be concluded that incorporating emerging sustainable urban water management knowledge into practice is a challenge due to the complexity of the problem. However, many promising ideas and options have been and will continue to be put forward. Such ideas, however, are most effective when they find an organisational home. Conventional engineering knowledge about water management has an established organisational home. In contrast, current emerging knowledge of what is considered sustainable urban water management is somewhat divergent, at least from the established norm. It may also continue to diverge. We do not support the conception of sustainable urban water management as a desired rationally (expert) defined end product, but rather a 'work in progress' that may take further cognitive, normative and regulative twists that no one can presently foresee. Thus ongoing review of this framework is vital.

Chapter 12 - References

Adams, W. M. (2001) Green Development 2nd edition: Environment and Sustainability in the third world. London: Routledge.

Al-Shemmera, T., Al-Kloub, B. and Pearman, A. (1997) Model Choice in multi-criteria deciaion aid *European Journal of Operational Research* 97:550-560.

Arnstein, S. (1969) The Ladder of Citizen Participation, *Journal of the Institute of American Planners* 35(4):216-224.

Ashley, R., Blackwood, D., Butler, D. and Jowitt, P. (2004) *In* Sustainable Water Services, a procedural guide (SWARD) IWA Publishing, Milton Keynes, UK.

Ashbolt, N.J. (2001) Advances in risk assessment approaches to waterborne disease: outbreak and occurrence. *In* Craun, G.F., Hauchman, F.S. and Robinson, D.E. (Eds.), Microbial Pathogens and Disinfection By-Products in Drinking Water: Health Effects and Management of Risks, pp:149-164. Washington D.C. International Life Science Institute.

Ashbolt, N.J., Petterson, S.A., Stenström, T.A., Schönning, C., Westrell, T. and Ottoson, J. (2005) Microbial Risk Assessment (MRA) Tool. Urban Water Report 2005:7. Gothenberg: Chalmers University of Technology.

Australian and New Zealand Environment and Conservation Council (ANZECC) and Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ) (2000) Australian and New Zealand Guidelines for Fresh and Marine Water Quality, Volume 2, Aquatic Ecosystems - Rationale and Background Information (Chapter 8), http://www.deh.gov.au/water/quality/nwqms/volume2.html

Baccini, P., Brunner, P. (1991) Metabolism of the anthroposhere, Springer Verlag, Berlin, Germany

Barak, M. (2004) Systematic approaches for inventive thinking and problem-solving: Implications for engineering education. *International Journal Engineering Education* 20(4):612-618.

Beavis, P., Lundie, S. (2003) Extension of Greenfield Scenarios in Sydney Water Corporation's Water Plan 21 Review. Final Report to PENGOS, Sydney, June 2003

Brown, R. (2004) Local institutional development and organisational change for advancing sustainable urban water futures. Keynote presentation at the *International Conference on Water Sensitive Urban Design: Cities as Catchments*, November 21-25, Adelaide.

Carson, L., & Gelber, K. (2001). *Ideas for Community Consultation: A discussion on principles and procedures for making consultation work*. (report prepared for) NSW Department of Urban Affairs and Planning, Sydney.

Carson, L., Hendriks, C., Palmer, J., White, S. and Blackadder, J. (2003) *Consult your community: A guide to using citizens' juries*, Department of Planning, Sydney.

Carson, L. (2005) *Building sustainable democracies*, New Matilda, downloaded 9/2/2005 from http://www.newmatilda.com/policytoolkit/policydetail.asp?PolicyID=28&CategoryID=10.

The Catchment Modelling Toolkit. http://www.toolkit.net.au/cgi-bin/WebObjects/toolkit

Chauret, C., Springthorpe, S. and Sattar, S. (1999) Fate of *Cryptosporidium* oocysts, *Giardia* cysts, and microbial indicators during wastewater treatment and anaerobic sludge digestion. *Canadian Journal of Microbiology* 45(3):257-262.

Colebatch, H. K. (2005). Governing the use of water: The institutional context. In, Conference Proceedings, *Integrated concepts in water recycling*, 14-17 February 2005, Wollongong: University of Wollongong.

Cole-Edelstein, L. (2004). Consult, deliberate or empower? Water, *Journal of the Australian Water Association* 31(8):72-75.

Crockett, C.S., Haas, C.N., Fazil, A.A., Rose, J.B. and Gerba, C.P. (1996) Prevalence of shigellosis in the U.S.: consistency with dose-response information. *International Journal of food Microbiology* 30(1-2):87-99.

Daniel, P. L., Moore, S. (2002) Approaches for Quantifying the Metabolism of Physical Economies - Part I: Methodological Overview. *Journal of Industrial Ecology* 5(4):69-93.

Deere, D. and Davison, A. (2005) The Ps and Qs of risk assessment. A straightforward explanation of the concepts. *Water - Journal of the Australian Water & Wastewater Association* 32(2):84-93.

Dejean, F., Gond, J.P. and Leca, B. (2004) Measuring the unmeasured: An institutional entrepreneur strategy in an emerging industry. *Human Relations* 57(6):741-764.

Edwards, W. and Barron, F. H. (1994) SMARTS and SMARTER: Improved simple methods for multiattribute utility measurement. *Organisational Behaviour and Decision Processes* 60:306-325.

Falkenmark, M., and Lundh, G. (1974) How can we cope with the water resources situation by the year 2015?" *Ambio* 13(3-4)114-122.

Fernando, K. and James, V. (2004) personal communication with Jennifer Blaikie, Sydney 20/12/2004

Finnveden, G., Potting, J. (1999) Eutrophication as an Impact Category: State of the Art and Research Needs. *Journal of LCA* 4(6):311-314.

Fitt, P. M. (1954) The *information* capacity of the human motor system in controlling amplitude of movement. *J. Exper. Psych.* 47:381–391.

Friend and Hickling (2005) Planning Under Pressure - The Strategic Choice Approach. 3rd Edition, Elsevier Butterworth-Heinemann Publisher.

GaBi (2004) http://www.gabi-software.com/

Gantzer, C., Gillerman, L., Kuznetsov, M. and Oron, G. (2001) Adsorption and survival of faecal coliforms, somatic coliphages and F-specific RNA phages in soil irrigated with wastewater. *Water Science and Technology* 43(12):117-124.

Gibbs, R.A., Hu, C.J., Ho, G.E. and Unkovich, I. (1997) Regrowth of faecal coliforms and salmonellae in stored biosolids and soil amended with biosolids. *Water Science and Technology* 35(11-12):269-275.

Gleick, P.H. (1996) Basic Water requirements for Human Activities Meeting Basic Needs, *Water International* (21):83-92.

Gleick, P.H. 2000. The World's Water 2000-2001: The Biennial Report on Freshwater Resources. Island Press, Washington, D.C.

Chapter 12 - References
continued

Gold Coast Water (2003) Pimpama Coomera Water Futures Master Plan Options Report. Gold Coast: Gold Coast City Council.

Guinee, J. F., Gorree, M., Heijungs, R., Huppes, G., Kleijn, R., de Koning, A., van Oers, L, Wegener Sleeswijk, A., Suh, W. and Udo de Haes, H. (2002). Handbook on Life Cycle Assessment. Operational Guide to the ISO Standards. Dordrecht, Kluwer Academic Publishers.

Guitouni, A. and Martel, J-M. (1998) Tentative guidelines to help choosing an appropriate MCDA method. *European Journal of Operational Research* 109:501-521.

Haas, C.N., Crockett, C.S., Rose, J.B., Gerba, C.P. and Fazil, A.M. (1996) Assessing the risk posed by oocysts in drinking water. *Journal of American Water Works Association*, 88(9):131-136.

Haas, C.N., Rose, J.B. and Gerba, C.P. (1999) Quantitative Microbial Risk Assessment. New York: John Wiley & Sons, Inc.

Haas, C.N., Thayyar-Madabusi, A., Rose, J.B. and Gerba, C.P. (2000) Development of a dose-response relationship for *Escherichia coli* O157: H7. *International Journal of Food Microbiology* 56(2-3):153-159.

Harremoës, P. (1997) Integrated water and wastewater management. *Water Science and Technology* 35(9):11-20.

Hatton MacDonald, D. and Dyack, B. (2004) Exploring the Institutional Impediments to Conservation and Water Reuse - National Issues. CSIRO Land and Water Client Report.

Hawken, P., Lovins, A.B. and Lovins L.H. (1999) Natural Capitalism. 396 pp. The Next Industrial Revolution. Earthscan Publications Ltd. ISBN 185383 763 6

Healy, R.G. and Ascher, W. (1995) Knowledge in the policy process - Incorporating new environmental information in natural-resources policy-making, *Policy Sciences*, 28(1):1-19.

Heiijungs R., Guinee J.B., Huppes G., Lankreijer, R.M., Udo de Haes, H.A., Wegener Sleeswijk A., Ansems, A.M.M., Eggels P.G., van Diun R. and de Goede H.P. (1992) Environmental Life cycle Assessment of Products: Backgrounds and Guide, Centre of Environmental Science (CML), Leiden.

Höller, C. (1988) Long-term study of occurrence, distribution and reduction of *Campylobacter* sp. in the sewage system and wastewater treatment plant of a big town. *Water Science and Technology* 20(11-12):529-531.

Hokkanen J. and Salminen, P (1995) Choosing a solid waste management system using multi criteria decision analysis. *European Journal of Operational research* 98:19-36.

IPCC (2005) http://www.ipcc.ch/

Jones, G. (2002) Setting environmental flows to sustain a healthy working river. Watershed February: 1-2. <http://freshwater.canberra.edu.au/Publications.nsf/273fdcbd0ec0f908ca256f0f001eccc4/3e87d45560552a60ca256f0b001f0677/$FILE/Final%20watershed%20feb%2002.pdf>

Kärrman, E.; Jönsson, H. (2001) Including oxidisation of ammonia in the eutrophication impact category. *International Journal of Life Cycle Assessment* 6(1):29-33.

Kärrman, E., Söderberg, H., Lundie, S., Ashbolt, N.J., Kazaglis, A., Lai, E., Livingston, D. and Anderson, J. (2005) Literature Review. Methodology for Evaluating the Overall Sustainability of Urban Water Systems. Report by the Centre for Water and Waste Technology, University of New South Wales for the Water Services Association of Australia, Melbourne.

Kain, J.-H. (2003) Sociotechnical Knowledge: An Operationalised Approach to Localised Infrastructure Planning and Sustainable Urban Development. Department of Built Environment and Sustainable Development. Chalmers University of Technology. Göteborg.

Kasemir, B., Jäger, J., Jaeger, C. C. and Gardner, M. T. (Eds.) (2003) *Public Participation in Sustainability Science*, Cambridge University Press, Cambridge.

Larsen, T., and Gujer, W. (1997) The concept of sustainable urban water management. *Water Science and Technology* 35(9):3-10.

Ledin, A., Aabling, T., Baun, A., Eriksson, E. and Mikkelsen, P.S. (2005) [CHIAT - Chemical Hazard Identification and Assessment Tool] En metodik för utvärdering av kemiska risker i samband med hantering av dag- och avloppsvatten. Göteborg: VA-forsk rapport, Chalmers University.

Lenzen, M. and Murray, S.A. (2001) A modified ecological footprint method and its application to Australia. *Ecological Economics* 37 (2):229-255.

Lundie, S., Huijbregts, M. and Feitz, A (2005) Australian human and eco-toxicity life cycle impact assessment characterisation factors. Submitted to *International Journal of Cleaner Production*

Long, J. and Ashbolt, N.J. (1994) Microbiological Quality of Sewage Treatment Plant Effluents. *AWT Science & Environment report number 94/123*. Sydney: Sydney Water Corporation.

Lundie, S., Peters, G., Beavis, P. (2004) Life Cycle Assessment for Sustainable Metropolitan Water Systems Planning. *Environmental Science and Technology* 38 (13):3465-3473.

Lundie, S., Beavis, P., Peters, G. (2004) LCA for Waterplan 21 Review - Base Case & Scenarios. Final Report to Sydney Water. Sydney, September 2004.

Lundie, S. and Peters, G. (2005) Life Cycle Assessment of the Hope Valley Reservoir Water Supply. Final Report to SAWater, Sydney, March 2005.

Lundie S, Huppes G. (1999) Environmental assessment of products - the ranges of social preferences method. *International Journal of Life Cycle Assessment* 4(1):7-15.

Lundie, S. (1999) Oekobilanzierung und Entscheidungstheorie: praxisorientierte Produktbewertung auf der Basis gesellschaftlicher Werthaltungen, ISBN 3-540-65042-3, Springer Verlag, Berlin.

Lundin, M. (1999) Assessment of environmental sustainability of urban water systems. Licentiate thesis, Department of Technical Environmental Planning, Chalmers University of Tech-

Chapter 12 - References
continued

nology, Göteborg, Sweden.

McKenzie-Mohr, D. and Smith, W. (1999) Fostering Sustainable Behaviour - An introduction to community-based social marketing. Gabriola Islands, BC, Canada: New Society Publishers.

Malmqvist, P.M. (1999) Sustainable Urban Water Management. Vatten 55(1):7-17.

Market Equity (2004) Community Opinions on Desalination and the Proposed Plant, (presentation for Water Corporation).

Mathers, C., Vos, T. and Stevenson, C. (1999) Burden of Disease and Injury in Australia. Australian Institute of Health and Welfare, Australian Government, Canberra.

Medema, G.J., Teunis, P.F.M., Havelaar, A.H. and Haas, C.N. (1996) Assessment of the dose-response relationship of *Campylobacter jejuni*. *International Journal of Food Microbiology*, 30(1-2), 101-111.

McKenzie-Mohr, D. and Smith, W. (1999) *Fostering Sustainable Behaviour - An introduction to community-based social marketing*. Gabriola Islands, BC, Canada: New Society Publishers.

Mikkilä, M., Kolehmainen, O. and Pukkala, T. (2005) Multi-attribute assessment of acceptability of operations in the pulp and paper industries. *Forest Policy and Economics* 7(2):227-243.

Mitchell, C. and White, S. (2003) Forecasting and backcasting for sustainable urban water futures, *Water, Journal of the Australian Water Association*, 30(5):25-30.

Mitchell, V. G. (2004) *Integrated Urban Water Management: A review of current Australian practice*. CSIRO Urban Water.

Morrison, K. (2003) Stakeholder involvement in water management: necessity or luxury? *Water Science and Technology* 47(6):43-51.

NHMRC (2004) Australian Drinking Water Guidelines (ADWG). Canberra: National Health and Medical Research Council.

Otterpohl, R., Braun, U. and Oldenburg, M. (2003) Innovative technologies for decentralised water-, wastewater and biowaste management in urban and peri-urban areas. *Water Science and Technology* 48(11-12):23-32.

Petts, J. (1999). Public participation in environmental impact assessment. *In*: Petts, J. (ed.) Handbook of Environmental Impact Assessment. Volume 1. Blackwell Science, Oxford, pp. 145-177.

Richter BD, Baumgartner JV, Wiginton R & Braun DP (1997) How much water does a river need? *Freshwater Biology* 37:231.-249.

Radcliffe, J. (2004). Water Recycling in Australia. A review undertaken by the Australian Academy of Technological Sciences and Engineering, Canberra

Robinson, J. J. (2002) Environmental value transfer: an application for the South East Queensland waterways, *Water Science and Technology* 45(11):91-100.

Roseth, N. (2003) Community Views on Alternate Water Supply, In, *Proceedings, Water Recycling Australia, 2nd National Conference,* 1-3 September, AWA, Brisbane.

Roy, B. (1990) Decision-Aid and Decision Making, *European Journal of Operational Research* 45:324-331.

Simos J. (1990) Évaluer l'impact sur l'environement. Lausanne: Presses Polytechniques et Universitaires Romandes.

Söderberg, H. and Kärrman, E. (2003) MIKA Methodologies for Integration of Knowledge Areas. The Case of Sustainable Urban Water Management. Göteborg: Dept. of Built Environment & Sustainable Development, Chalmers University of Technology.

Stanford J.A., Ward J.V., Liss W.J., Frissell C.A., Williams R.N., Lichatowich J.A. and Coutant C.C. (1996) A general protocol for restoration of regulated rivers.' *Regulated Rivers: Research and Management* 12, 391.413.

Standards Australia (1999) Australian/New Zealand Standard for Risk Management AS/NZS 4360:1999. Sydney: Standards Association of Australia.

Starkl, M. and Brunner, N. (2004) Decision aid systems for evaluating sustainability: a critical survey *Environmental Impact Assessment Review* 24 pp. 441-469.

Stenekes, N., Waite, T. D. and Colebatch, H. K. (2003). Water recycling and policy-making. In, *Proceedings 2nd National Conference, Water Recycling Australia, Sept 1-3*, Brisbane: AWA.

Stenekes, N., Colebatch, H. K. and Waite, T. D. (in press). Risk and governance in water recycling: 'public acceptance' revisited. (Submitted) *Science, Technology and Human Values*.

Stenekes, N., Livingston, D., Colebatch, H.K., Waite, T.D. and Ashbolt, N.J. (2004) Sustainable water management in Australia: an institutional analysis. Proceedings, Good Water Governance for People and Nature: Water Roles for Law, Institutions & Finance August 29-September 2, 2004, Dundee, Scotland.

Taylor, A. (2004) Draft Guidelines for Evaluating the Financial, Ecological and Social Performance of Urban Stormwater Management Measures to Improve Waterway Health. Cooperative Research Centre for Catchment Hydrology,

Teoh, P.C. and Case, K. (2004) Failure modes and effects analysis through knowledge modelling. *Journal of Materials Processing Technology* 153-54(Part 1 Sp. Iss.):253-260.

Teunis, P.F.M., van der Heijden, O.G., van der Giessen, J.W.B. and Havelaar, A.H. (1996) The dose response relation in human volunteers for gastro-intestinal pathogens. Bilthoven, the Netherlands: National Institute of Public Health and the Environment (RIVM), The Netherlands.

Udo de Haes, H., van der Voet, E. and Kleijn, R. (1997) From quality to quantity: Substance flow analysis (SFA), an analytical tool for integrated chain management. In Regional and national material flow accounting: From paradigm to practice of sustainability. Proceedings of the ConAccount Workshop. Wuppertal special 4, edited by S. Bringezu *et al* Wuppertal, Germany: Wuppertal Institut

Udo de Haes H.A., Jolliet O., Finnveden G., Hauschild M., Krewitt W., Mueller-Wenk R. (1999) Best available practice regarding impact categories and category indicators in life cycle impact assessment. *International Journal of Life Cycle Assessment* 4(2):1-15.

US-EPA (1998) Integrated Risk Information System (IRIS). Cincinnati, OH: Office of Research and Development, National Center for Environmental Assessment.

Vasquez, J.A., Maier, H.R., Lence, B.J., Tolson, B.A. and Foschi, R.O. (2000) Achieving water quality system reliability using genetic algorithms. *Journal of Environmental Engineering* 126(10):954-962.

Van de Meent D. and Huijbregts M.A.J. (2005) Calculating LCA effect factors from PAF-based ecotoxicological response functions. *Environmental Toxicology and Chemistry* 24 (accepted).

Vose, D. (2004) Model Assist™ for @ Risk® Advanced version 1.0. Vose Consulting, http://www.risk-modelling.com.

Weidema B.P. (2000) LCA developments for promoting sustainability. Presentation for 2nd National Conference on LCA, Melbourne, 2000.02.23-24. (Download at http://www.ipt.dtu.dk/~bow/publ/austr.html)

Western Consortium for Public Health (1997) Total Resource Recovery Project, Aqua III San Pasqual Health Effects Study. *In* Cooper, R.C., Olivieri, A.W., Eisenberg, D.M., Soller, J.A., Pettegrew, L.A. and Danielson, R.E. (Eds.): 131. San Diego: Western Consortium for Public Health.

WHO (2004) *Guidelines for drinking-water quality*, Third edition, WHO, Geneva Switzerland.

Winton, R., Hansen, J. and Cardwell, R. (1995) Assessing aquatic ecological and human health risks from coastal sewage treatment discharges. Paper presented at the National Environmental Engineering Conference, Sydney.

Chapter 13 - Synopsis of literature review

Various state-of-the-art international approaches for urban water sustainability assessment are covered in the accompanying project literature review (Kärrman, *et al.*, 2005). The purpose of the review was to highlight and consolidate important components potentially applicable to this WSAA project developing a framework for sustainable urban water management.

The Literature Review was split into six main sections, for which a brief synopsis is presented below.

13.1 Statement of the Problem

The problem of integrating different sustainability aspects is discussed based on the experience gained from the Swedish Urban Water programme and associated MIKA project (Methodology for Integration of Knowledge Areas), given its status as one of two of the most developed programs internationally (see Söderberg and Kärrman, 2003; Ashley *et al.*, 2004). In the Swedish program, five main sustainability criteria are used to assess urban water management options: health and hygiene, environment, economy, socio-culture aspects and technical function. The MIKA project was started to address the complicated issue of integrating these different sustainability aspects (how to add 'apples' and 'oranges'), and it is analogous to the SWARD process described by Ashley *et al.* (2004). The Swedes go further, however, in that they seek to find a balance between the product-oriented approach – which places an emphasis on expert knowledge and has a fixed goal, versus the process oriented approach, where the goal is set as a part of the process with negotiations and 'good enough' are values in focus. Usable and supportive methodologies for planning and decision-making are not to be mixed up with more "decision-machine" tools based on multi-criteria analysis (MCA).

13.2 Sustainable Development and Infrastructure Change

This section reviews the various definitions of sustainability that have evolved through time. International Union for the Conservation of Nature (IUCN) was the first to present the well-known triple bottom line of economic, social and environmental sustainability concept, but the mainstream sustainability notion emerged later through the Brundtland Commission. However, despite the wide acceptance of the definition, there is an inherent vagueness that makes it difficult to discuss this notion in more operationalised terms. More recently, the Swedish Urban Water programme has adopted a conceptual framework that includes the technical structure, the organisations and the users of the system into the picture associated with the five broad sustainability criteria described in section 13.1; forming the Urban Water System (UWS). This prevents the inclination to measure sustainability on a quantitative scale and requires consideration to its surrounding. In this context, sustainability has to be focused on changing understandings and practices (since present practice is not considered sustainable), with the available technologies (like recycling) and decision-tools (like the forms of analysis discussed in section13.3) as a component of this change, both informing it and supporting it: beliefs and practices interact with one another. With the pressure placed on the UWS by water scarcity, the challenge is to change the paradigm for water management. This also implies change for the institutions that manage them.

In essences, sustainability is not a state to be arrived at, but a broad evaluative framework for understanding and justifying social practice. Moving to sustainability means a paradigm shift among all water users (i.e. among the entire population), and because it is both cognitive (what people believe) and behavioural (what they do) it is imperative to incorporate the participation of stakeholders throughout the process. Final consensus in selecting the desired option has therefore moved from MCA to a multi-criteria decision aided (MCDA) approach (section 13.4 on page 58).

13.3 A Process-orientated Approach to Infrastructural Change

The strategic choice approach (SCA) developed by Friend and Hickling (2005) is based on the assumption that there is "no clear cut stance of advising the manager". SCA is a learning and process-orientated approach that deals with complex realities by facilitating a creative management of multiple uncertainties. To facilitate a way through the range of uncertainties, the decision making process is based on a model that is made up of four modes, namely: shaping, designing, comparing and choosing. The emphasis of this model is the continuous cycle between the complementary modes of decision making which is in contrast to a traditional linear decision making process.

There are various tools available to assess the technical criteria of sustainability that are discussed in the literature review includes Life-Cycle Assessment, Ecological Footprint, Microbial Risk Assessment, Chemical Risk Assessment, Life Cycle Costing and Urban Water Research Model. Triple Bottom Line (TBL) Reporting is a reporting tool that describes the performance of organisations under consideration of economic, environmental and social aspects.

Life Cycle Assessment

Environmental life cycle assessment (LCA) is a tool to calculate and evaluate environmentally relevant inputs (resources demand) and outputs (emission to air, water & land) and their potential environmental impacts of a product or service system over its entire life cycle. LCA is an iterative process that produces quantifiable potential environmental impacts associated with products or services. LCA has been applied successfully to the strategic planning process for the overall business of many water service providers around the world. The life cycle approach has been used as an underlying principle for shaping legislation, such as EU-directives for the waste management sector in the European Union.

Ecological Footprint

Ecological Footprint (EF) is a comparative tool for assessing the consumption patterns of populations or economic entities. The output of the assessment is a single index showing the area of land and water that is required to provide the energy and material consumed by a person, a population, an organisation or an economy. Further models were developed to improve on the original measurement which address only the land used directly by the producer and omitted impacts of suppliers further up the entire production chain. There are four prominent EF approaches that had evolved through time.

Microbial Risk Assessment

Microbial Risk Assessment (MRA) emerged as an analogue to chemical risk assessment that focuses on exposure assessment and a linked dose-response model to ascertain potential risks from waterborne pathogens. The review highlights the two fundamental issues associated with MRA: an inadequate database to compare MRA predictions against, and what is tolerable risk. Available statistics on the occurrence of waterborne outbreaks do not represent the true incidence of outbreaks or illnesses as most go unrecognized or unreported. As for tolerable risk, the benchmark of one infection per 10 000 people (1 in 10^4) for the annual risk of infection from microbial pathogens in a drinking water supply has been adopted by the US EPA. However, in Australia, the Disability Adjusted Life Years (DALYs) approach developed by WHO has been adopted. The DALY accounts for the years lived with a disability plus the years of life lost due to exposure to a hazard, that is, to assess any ill effect by severity and loss of expected life years.

The review also covers the paradigm shift in MRA development. The current paradigm shift in MRA relates to the fact that drinking water sampling is too late and of limited use to control human microbial hazard exposure. Hence, the starting premise is now a community/ political question as to whose safety do we design a water system.

The quantitative MRA process commences with a problem formulation to identify all possible risks and their pathways from sources(s) to recipient(s). Next, a screening-level risk assessment is applied to identify hazards of potential concerns using conservative data and assumptions. Detail assessment of the environmental concentrations and dose-responses of the selected hazard follows to characterize risks. Based on the outcomes, further iterations may follow to better define risks and their uncertainties.

Chapter 13 - Synopsis of literature review
continued

Chemical Risk Assessment

There is little or no information on many anthropogenic organic compounds (xenobiotic organic compounds, XOCs) in the environmental/recycled water fractions, which has limited the application of the quantitative risk assessment approach to urban water chemical risk assessments (CRA). Also, in contrasts to pathogens, we are exposed to a vast array of compounds from many different types of products on the market. An initial screening methodology has been proposed to identify compounds that might pose a threat in connection with the use of non-potable and potable waters. This method has been developed for the Swedish Urban Water programme, the method also includes chemical analyses; specifically developed analysis methods; toxicity measurements, hazard and problem identification, and a qualitative risk assessment.

Life Cycle Costing

Life Cycle Costing (LCC) methodology quantifies the costs over the life cycle of a product or a service system. LCC attempts to quantify costs that occur throughout the entire life cycle to *all* stakeholders affected, such as manufacturers, retailers, users and waste managers. Therefore, LCC goes far beyond traditional financial assessments with very narrow systems boundaries, such as costs to a corporation. With regard to its application LCC is at a relatively early stage of development compared with environmental LCA. The structured approach allows all the elements of costs to be addressed via specification of types of LCC, *viz*: cost categories, cost models and type of aggregations. The resulting spending profile generated helps to assists with the economic criterion in the decision making process.

Urban Water Research Model

In the Urban Water research programme, LCA is used together with material flux analysis (MFA) and energy analysis to calculate the environmental impact of the elements tracked by MFA. The urban water system is simulated using an extended version of ORWARE (Organic Waste Research model) called URWARE (Urban Water Research model) – a computer-based material flow simulator using evaluation techniques from life-cycle assessment. The URWARE simulator combines, for example for households, drinking water production, transport, wastewater treatment, digestion, incineration and landfill, into an overall model of the household system.

Triple Bottom Line Reporting

Triple Bottom Line (TBL) Reporting is itself not a tool to assess environmental impacts, but covers indictors that reflect the sustainability performance of an institution including economic, environmental and social aspects. TBL guidelines have been developed by the Global Reporting Initiative (GRI) designed to enhance the quality and to ensure the uniformity of sustainability reporting. Started in 1997, GRI became independent in 2002, and is an official collaborating centre of the United Nations Environment Programme (UNEP) and works in cooperation with UN Secretary-General Kofi Annan's Global Compact.

13.4 Multi-criteria decision aids (MCDA)

As with most complex decisions, the outcome is seldom made on the basis of a single measurement or by an individual. The philosophy of multi-criteria analysis (MCA) addresses this issue by allowing the stakeholders to use several criteria at the same time. The oldest field in MCA is multi-criteria decision making (MCDM), which involves a search for the alternative that is most attractive with respect to all criteria. The current evolution of MCDM is multi-criteria decision aiding (MCDA), as advocated in the Swedish MIKA project (Söderberg and Kärrman, 2003).

The process of structuring the decision making process is a critical part of MCDA, as this phase is likely to have consequences throughout the rest of the process. Differences in MCDA approaches largely evolve around how the stakeholders express their preference and how these preferences are captured in mathematical terms to make an assessment possible. An overall assessment of each alternative is performed in the aggregation phase, which utilizes a number of 'educated' stakeholders in the process. There are different methods described for aggregating the preferences, including Linear Additive model, Simple Multi-Attribute Rating Method (SMART), Strategic Advisor (STRAD), Analytical Hierarchy Process (AHP), Single Synthesising criterion approach and Synthesising using an outranking approach.

In the exploitation phase, results are exploited in order to clarify why an alternative is better ranked than the other. Sensitivity analysis is then required to test the influence of the various parameters to the final results.

In the last step of the MCDA process, recommendations are made on whether a selection of the best alternative can be made, or sorting the alternatives into different categories or ranking of the alternatives.

MCDA tools available

Six MCDA tools are discussed including ELECTRE III, PROMETHEE, REGIME, NAIADE, SWARD and STRAD:

- ELECTRE is a system that is capable of including the imprecise and uncertain nature of decision making by using thresholds of indifference and preference. It makes use of a threshold to make a more realistic comparison between two alternatives. ELECTRE III is one of the versions of the ELECTRE family; it is useful as it allows quantification of the relative importance of criteria.
- In PROMETHEE, the degree of preference between alternatives is expressed through a linear scale from 0, over a zone of weak preference to 1, indicating strict preference. In another word, PROMETHEE calculates how much an alternative is dominating over the other ones.
- In some situations it is impossible to model on the basis of quantitative information; REGIME is designed to evaluate the qualitative issues. The fundamentals of the method are the regime vector, the ordinal ranking of the criteria and the probability score of each alternative.
- NAIADE is a discrete multi-criteria method where the performance matrix can include precious, stochastic or fuzzy measurements, and allows the use of information affected by different types and degrees of uncertainty. No traditional weighting of criteria is used in this method.
- SWARD (Sustainable Water Industry Assets Resource Decisions) is a process that aims to help decision maker to make better decisions in terms of consistency, openness and auditability by analysing options through seven phases. It is developed by the UK academics in collaborations with water service providers.
- STRAD (STRategic ADvisor) is a general MCDA software tool that enables you to build a clearer view of the decisions ahead of you, to agree on a strategic focus for closer examination, and within this, to explore options and consequences in more depth. It therefore allows you to arrive at a balanced view of important sources of uncertainty and to build an agreed action plan for making decisions and managing uncertainty through time, and to extend, review and modify your plans as circumstances change.

13.5 Sustainable Development and Participation: Why and When, by Whom and How?

There are different definitions of public participation and the differences generally relate to the purpose and perceived potential participants. Not only do the definitions vary, but the level of participative settings also differ substantially, as illustrated by the "ladder of citizen participation" (Kain, 2003; Arnstein, 1969 and Petts, 1999). Furthermore, the purpose of participation also varies and the specific outcomes are seldom clear until the process has been undertaken. For example, public participation is used for generating sustainability indicators, creating social support and promoting openness to increase likelihood of a successful project.

Four methods for enhancing participation are discussed. They include citizen advisory committees (CAC), planning cells, citizens' juries and the Varresbecker Bach participatory process. CAC is a generic term describing several techniques for small groups of citizens to represent ideas and attitudes of various groups or communities. This allows public participation in an early stage before any preliminary decision takes place. Planning cells are the forums for communication and learning for citizens to enable to discuss and evaluate the options. A citizens' jury is a method to enhance partnership between citizens and elected official by randomly select member of citizens to represent their community and participate by means of expressing their preference. The Varresbecker Bach participatory approach was developed following a difficult decision-making in relation to a possible contaminated residential site. The model emphasises joint problem solving between the authority and the public by early involvement of the public and an independent facilitator. The public being authorised to make recommendation but the overall agenda is set by the authority.

Chapter 13 - Synopsis of literature review
continued

Contrast to public participation, Social Impact Assessment (SIA) is about finding the effects of a human activity on the health, well-being, and quality of life of individuals and communities as opposed to seeking opinions from the public on the proposed human activity.

Four cases studies are presented to demonstrate the applicability of different MCDA methods and relation to the four modes of decision-making process. The first three cases adopt NAIADE as the supporting tool and the last one uses the strategic choice approach. The MCDA models are evaluated with respect to stakeholder participation.

13.6 The State of play in Australia

The last section documents the applications of the decision making support tools described in section 13.3 as in current use by the water industry across Australia.

Life Cycle Assessment and Costing

There are four LCA case studies in the context of Australia discussed. One of the case applied LCA to examine the potential environmental impacts on Sydney Water's operation in the year 2021. LCA was applied to the three main scenarios, namely "pushing it", "population growth" and "doing it differently" scenario on top of the base case. The next two LCA case studies were on the wastewater system and the assessment of biosolids process options. The last case study focused on rainwater tanks and other water-saving technologies, and was undertaken to examine the environmental benefits of demand management devices.

Ecological Footprint

One case study published on Ecological Footprint was calculated for Sydney Water Corporation. The case study uses output-input analysis additional to land disturbance which makes it an innovative approach that overcomes traditional problems identified in original EF concept. The EF was also calculated for other water service providers; however, the results have not been published.

In an ongoing ARC Linkage Grant project the Centre for Water and Waste Technology at the University of New South Wales, the School of Physics at Sydney University and Water Service Association Australia aim to develop a novel Ecological Footprint concept to be applied at the company level, i.e. any urban water services provider. The project addresses major methodological limitations of the existing national EF concept by using regionalised input-output analysis and multimedia fate modelling. This new method will be an effective environmental reporting and communications tool. Its value is greatly increased by the fact that it will be a generic approach to environmental reporting for any economic entity.

Chemical and Microbial Risk Assessment

Sydney Water Corporation had conducted several ecological risk assessment for chemicals listed in Schedule 10 of the Act, with a view to assess the potential impact of wastewater services in metropolitan coastal areas. The effects to aquatic life, wildlife and human health were also assessed with respect to recreational activities. Microbial risk assessment has been undertaken for Sydney, examining the bather risk following the commissioning of the deepwater ocean outfalls and with the Rouse Hill dual reticulation scheme.

MCDA

Applications of MCDA within several states are reviewed. The case study in Queensland is in Brisbane's Roachdale development area. A Master Plan for a new urban village was prepared and as part of the plan, multi-criteria analysis was employed to compare the options for the integrated water management of this development. The Pimpama Coomera case study demonstrated a broad community consultation and engagement process by means of involvement of an advisory committee. The Brisbane Heathwood case study analysed options for providing sustainable water services for a mixed residential and industrial Greenfield development ranged from current conventional practice through to site-scale self-sufficiency.

In Victoria, South East Water has developed a sustainability assessment tool that incorporates some of the principles of multi-criteria and TBL analyses. Sustainability principles were developed and criteria were selected for achieving these principles for a particular project.

In New South Wales, Sydney Water Corp. has developed a list of tools to assess the economic, social, technical and environmental areas of a proposal. These tools lie within a broader model for sustainable decision-making which defines the stages of a project from conception to implementation. Another case study in the New South Wales is BASIX, developed by Planning NSW. BASIX is a web-based planning tool that measures the potential performance of new residential dwelling against a range of sustainability indices. A case study on a citizens' jury is the Bronte Catchment Project. The project facilitated a community-based participatory process in the form of a citizens' jury to enhance stormwater quality within the micro-catchment of Bronte, in Sydney.

In South Australia, an innovative model namely the Sustainability Space Model was developed. It improved an existing model that only contained economic, social and environmental components, by time, political and technological dimensions.

In Western Australia, the Water Corporation has devised a sustainability assessment which incorporates the three basic sustainability components (environmental, economic and social), time and space aspects.

In addition, the Water Corporation have developed an approach which converts a triple bottom line analysis into a NPV and compares the results with a conventional NPV. The Water Corporation's literature survey on sustainability assessment tools also provided valuable input into their approach.

Nationally, the CRC for Catchment Hydrology has been developing the Catchment Modelling Toolkit, a repository of software and supporting documentation intended to improve the efficiency and standard of catchment modelling (CRC-CH). Of these tools, Aquacycle is most relevant to the WSAA project, in that it is a tool that produces daily, monthly, and annual estimates of water demand, stormwater yield, wastewater yield, evaporation, imported water use, stormwater use, and wastewater use, as well as performance measures of any water management strategies selected.

Chapter 14 - Sustainability criteria

14.1 Economic criteria

The effect of the NPV equation is that expenses this year are valued 100% but expenses in the future are discounted and do have a lower value. These values are outlined as follows:

Interest Rate	Value of dollar spent in year 20	Value of dollar spent in year 30
1%	$0.82	$0.74
2%	$0.67	$0.55
3%	$0.54	$0.40
4%	$0.44	$0.29
5%	$0.36	$0.22
6%	$0.29	$0.16
7%	$0.23	$0.11
8%	$0.19	$0.08
9%	$0.15	$0.06
10%	$0.12	$0.04

Therefore, given that the usual rates used in NPV are usually 4%, 7% and 10%, the costs beyond year 30 is not included as they are worth only a small amount.

14.2 Human Health Criteria

Human health criteria were limited to pathogens, given the lack of data available for chemical risk assessment. A single criterion was used, the relative Disability Adjusted Life Year (DALY) (Deere and Davison, 2005) between each system for eleven major pathways of exposure to waters. It was considered that a relative measure better reflected the differences between systems than the estimated absolute values, which are difficult to compare to relatively, given there is insufficiently insensitive epidemiologic data available for that purpose.

Microbial risk assessment is most sensitive to the pathogens selected and the environmental exposures humans have to them (Ashbolt, 2001). All pathogens that are excreted in faeces could potentially be found in wastewaters and source waters. A selection of reference pathogens was therefore made for the hygiene risk assessment, with representatives from each microbial group (bacteria, viruses and protozoa). The case study included pathogens that mainly cause gastroenteritis (*Campylobacter jejuni*, *Giardia*, *Cryptosporidium*, rotavirus), although milder respiratory infections (adenovirus) and pathogens that can cause more severe disease, such as haemolytic uremic syndrome (enterohaemorrhagic *E. coli* O157:H7, EHEC) could be included in future iterations. All of these pathogens have been causes of waterborne disease, are know to occur in Australia and have all been detected in sewage.

14.3 Environmental criteria

Some of the indicators listed in Table 7 on page 26 are explained below

Fresh- and groundwater extraction: This indicator quantifies freshwater extracted from the ecosystem. However, the total quantity is not a robust indicator for river health. The ANZECC (2000) guidelines note that river regulation and excessive consumptive water use threaten the viability of freshwater and estuarine systems by significantly reducing both the amount and variability in flow. Much of the focus on environmental flow management to date has been to ensure that a minimum baseflow is provided, generally by releases from an upstream dam. However, there is increasing evidence to show that this is not sufficient and that the variations in flow-magnitude, timing, duration, frequency and rate of change are critical in sustaining the biodiversity and integrity of aquatic ecosystems (Stanford *et al.*, 1996). Various methods to establish river-specific flow and variability are presented in ANZECC (2000) guidelines, with the most promising methods being those that involve a detailed analysis of the hydrological regime (e.g. Range of Variability method; Richter *et al.*, 1997), together with some form of scientific panel to relate flow characteristics to specific ecological, geomorphological and water quality objectives for the particular river.

Primary energy input is strictly *not* an environmental impact category. However, energy use is a useful indicator for analysing the energy intensity of processes and water management systems as well as the energy contained in avoided products. Total energy use provides useful explanatory data when analysing climate change. Additionally, the over use of non-renewable resources could be considered as an Ecological Sustainable Development (ESD) issue related to the intergenerational equity.Energy use covers renewable and non-renewable energy sources.[26] Renewable energy sources are, in this study, biogas and hydropower, while now-renewable sources are black and brown coal, crude oil and natural gas. Total energy use can be considered as a measurement of the efficiency of the system and as an indicator for the depletion of energy resources. The figures quantifying the total energy use show a breakdown from different contributing processes. The total energy use is expressed in MJ.

Climate change

Climate change[27] is obviously of international and local interest, given Australia's status as a major per capita emitter of greenhouse gases. This category considers releases of greenhouse gases into the atmosphere as a result of human activities and natural sources. Main quantitative contributors to climate change are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and, to a lesser degree, halocarbons (halons, chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs) and hydrofluorocarbons (HFCs)). Climate change is usually evaluated on a 20, 100 or 500 year timescale. For this study, the most commonly used timescale has been selected - 100 years. The equivalence factors are set by the Intergovernmental Panel on Climate Change (IPCC).

Eutrophication potential:

Eutrophication is very relevant to the water industry due to the regulatory imperative associated with discharging effluent, particularly in those inland plants that discharge to sensitive receiving waters. Like all indicators used in LCA, eutrophication models are aimed at providing a quantitative measure of the incremental additional likelihood of an environmental problem occurring on the regional or global scale. They do not answer the question of whether an algal bloom or an anoxic condition will occur at a particular part of a riverine or marine environment. The intention is to compare alternative developments and report on the relative risk among different options, rather than the risk in an absolute sense. Site-specific problems associated with eutrophication potential as an indicator have been discussed by Finnveden and Potting (1999). Eutrophication covers aquatic environmental impacts and is caused by a high level of macronutrients. Nitrogen and phosphorus are the most important substances contributing to eutrophication. Enrichment in these macronutrients may cause a shift in the composition of species, an increase of biomass production in aquatic and terrestrial ecosystems, and high nutrient concentrations in surface water. In Heijungs *et al*. (1992) eutrophication due to an abundance of N, P, and C is aggregated by quantifying the contribution of these elements to biomass formation. Eutrophication potentials are used as characterisation factors to calculate the total indicator.In this project a newly developed eutrophication model created by Kärrman and Jönsson (2001) is applied. It takes the original approach by Heijungs *et al*. (1992) further by differentiating between freshwater and marine aquatic environments. This indicator estimates the total potential oxygen depletion as suggested by Udo de Haes *et al.* (1999). In inland waters, Kärrman and Jönsson (2001) assume phosphorus is usually the substance which most severely limits the growth of algae, while in marine waters nitrogen or a combination of nitrogen and phosphorus limits the growth.

Photchemical Oxidant Formation Potential: *Photochemical oxidant formation potential* addresses the formation of reactive substances that can damage human and ecosystem health. Usually photo-oxidant formation takes place in the troposphere, but it can also take place in urban areas. The photo-oxidants are formed by oxidation of volatile organic compounds or by carbon monoxide in the presence of nitrogen oxides and the influence of ultraviolet light. Formed photo-oxidants can significantly differ in concentration depending on the location and time. High concentrations of photo-oxidants are called photochemical smog. This category is relevant because of the urban situation that is modelled in this study.This category considers releases of organic compounds contributing to photochemical oxidant formation (mostly hydrocarbons, ie. ethylene, propene, higher alkenes, ethane, propane, butane, benzene, toluene, xylene, formaldehyde and aromatic aldehydes, acetone and acetylene; Derwent *et al* 1998). Three components are required in order to generate photochemical smog, ie. NOx, hydrocarbons and sunlight. In metropolitan areas smog is limited by sunlight and hydrocarbon supply, so NOx is not included as a smog precursor despite its role in the production of smog.

---

[26] This indicator is also known as embodied energy or as cumulative energy demand.

[27] Climate change is also know as global warming potential. Both terms are used interchangeable in this report.

Chapter 14 - Sustainability criteria
continued

Ecotoxicity including terrestrial, marine and freshwater aquatic potential: In this study newly developed Australian human and eco-toxicity factors have been used (see detailed description in Huijbregts *et al.* 2001). Equivalence factors for relevant substances are listed in Huijbregts *et al.* 2001 and the basic mechanisms of human, aquatic and terrestrial eco-toxicity is described below. The impact category human toxicity accounts for the effects of toxic substances on humans. The potential effect on humans depends on the actual emissions, the fate of the specific substance emitted to the environment and the time of exposure. This category is difficult to model because of the fate of toxic substances and their intermedia transport (Jensen *et al* 1997). In Guinée *et al* (1996a and b) separate characterisation factors have been defined for emissions of toxic substances to the environmental media *air* (human toxicity to air (HTA)), *water* (human toxicity to water (HTW)) and *soil* (human toxicity to soil (HTS)). These effect scores for the media air, water and soil can be added to provide a single medium-independent effect score for human toxicity:

$$Human\ Toxicity = \sum_i ((HCA_i \times m_{a,i}) + (HCW_i \times m_{w,i}) + (HCS_i \times m_{s,i})$$

with m_i = emitted quantity of substance i to air (a), water (w) and soil (s). Eco-toxicity deals with effects of toxic substances on terrestrial and aquatic ecosystems. The potential effects on ecosystems depend on the actual emission, the exposure to these emissions and the fate of specific substances in terrestrial and aquatic ecosystems. This category is as complex as human toxicity. Reasons for this uncertainty are the large number of mechanisms, identifying affected species and intermedia transport of substances in the ecosystem (Udo de Haes *et al* 1999). In Guinée *et al* (1996a and b) emissions to water and soil are taken into account. Emissions to water are considered to be toxic only for aquatic ecosystems, emissions to soil are considered to be toxic only for terrestrial ecosystems. Separate characterisation factors have been defined for emissions of toxic substances to the environmental media water (ECA) and soil (ECT), and these are used to calculate the effect score for aquatic and terrestrial ecotoxicity:

$$Aquatic\ Ecotoxicity = \sum_i (ECA_i \times m_{w,i})$$ and

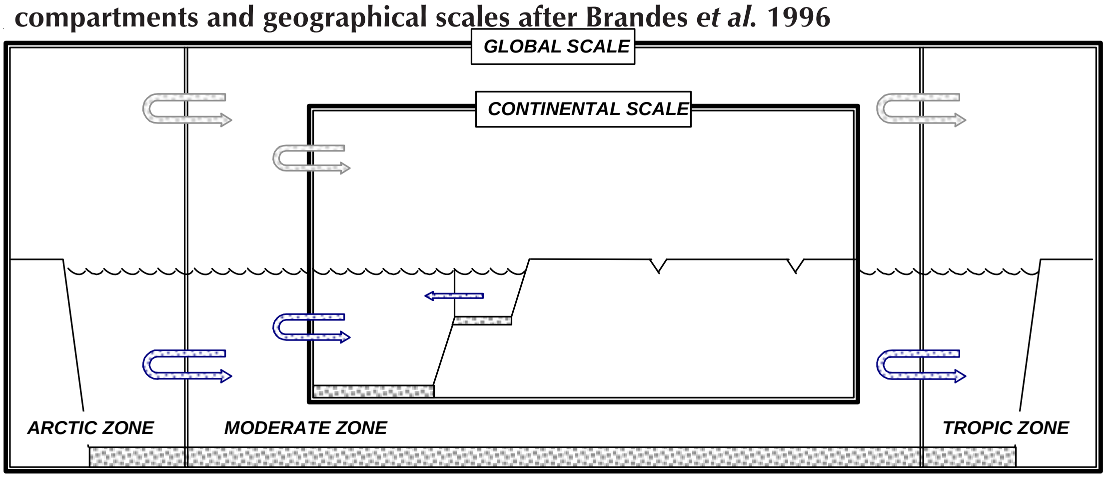
$$Terrestrial\ Ecotoxicity = \sum_i (ECT_i \times m_{s,i})$$

with m_i = emitted quantity of substance i to water (w) and soil (s). Human and eco-toxicity indicators have developed further sophistication with the concept of multi-media modelling. Substance emissions may occur in other environmental compartments and geographical areas prior to their final destination compartment. For instance, aquatic ecotoxicity may be an aggregation indicator of substances which are emitted to the initial compartments of land, air and/or water. Multimedia modelling attempts to account for the emission, transport and fate of substances and consequently tracks exposure pathways (see Figure 4 for schematic representation of transportation routes).

The steps involved are as follows:

- The concentration of the substance emitted into a specific environmental compartment is measured based on Predicted Environmental Concentration (PEC);

Figure 4 Schematic representation of transportation routes between different compartments and geographical scales after Brandes *et al.* 1996



- A Predicted No–effects Concentration (PNEC) based on eco-toxiological data for that substance in that compartment is assessed;
- The Risk Characterisation Ratios (RCR) are calculated for each substance in each compartment based on PEC divided by PNEC;
- These RCRs are weighted in their effect to the compartment of interest and summed, i.e. freshwater aquatic, or terrestrial. This step takes account of regionally specific factors such as rainfall, and soil condition or, for the human toxicity indicator, human consumption (predicted daily intake). The scale of the emission is also considered, i.e. emissions on a global, continental or regional scale[28]; and

Finally the impact category is calculated by taking aggregated, weighted RCRs and dividing them by a common reference substance RCR for that compartment. In the case of toxicity, the reference substance is 1,4-dichlorobenzene. This step calculates equivalency factors to be applied for each impact category for a given process inventory of emissions. For instance, once these equivalency factors are established, an environmental impact of stack emissions from a plant may then be characterised for human, aquatic and/or terrestrial eco-toxicity. This can be compared with the characterisation of potential impacts of alternative products or services to determine which is preferable.

14.4 Technical criteria

Reliability is defined to be the expected percentage down time of the equipment or the expected rate of events where the system operates in a way that stops it meeting the design criteria, for example if a new surface water source is designed so that water restrictions are needed one summer in 10, but there is the potential for the conditions to change so that this becomes 1 summer in 3, then the reliability would be lower than desalination where there is no reliance on climate.

Durability is defined to be the expected lifetime of the equipment with adequate maintenance.

Flexibility is defined to be the expected ability of the design to be changes to meet future volume and water quality requirements as well as the opportunity for change in system type in the future, this includes the amount of infrastructure and expense required for the current system that may reduce the ability of future decision makers to choose more expensive options.

14.5 Social criteria

Affordability: This criterion evaluates the ability of customers to pay for the service provided. Thus the emphasis is on measuring relation between cost and income rather than merely assessing project cost, which is already taken into account through other (economic) indicators.

Employment: This criterion values job creation (or loss) as a result of the project for its social impact on the community, rather than treating the cost of employment as purely an economic (or financial) factor. It may be measured in the total number of jobs provided and any net change.

Acceptability to community: This criterion is based on indicators of user attitudes to the type(s) of services provided. It may be measured by customer surveys, or for greater salience, by the number of complaints received.

Distribution of responsibility: This criterion looks qualitatively at the distribution of responsibility and risk between users, operators and managers of a system. What is considered a healthy distribution of responsibility may be different between projects and cultures.

Organisational capacity and adaptability: This criterion qualitatively compares the current institutional arrangements, and the ability to adapt, with the institutional arrangements required for a new system to work effectively. The factor which varies between options will therefore be the capacity of the existing organisation to manage or adapt to each particular option.

Public understanding and awareness: This criterion is based on indicators of how much public education will be required for a proposed system to work. The number of existing users of similar services may be a good guide, or market surveys may be needed.

[28] For modelling purposes there are 21 environmental compartments to be scaled in their magnitude of effect to toxicity potential: Each of the regional and continental scales have 6 compartments (freshwater, seawater, natural soil, agricultural soil, industrial soil and air. The global scale has 3 zones – arctic, moderate and tropical. Each of these zones is given 3 compartments. This categorisation allows for the calculation of sinks, and chemical conversion (Huijbregts, 1999).

Chapter 15 - Hypothetical Case Study

In this section a hypothetical case study is provided that illustrates how various tools as described in Section 7.3, commencing on page 28, might be used in the sustainability framework. Due to the nature of this project, this case study is not applied to the entire sustainability framework, but only to selected tasks of Phases 5 and 6 (see Sections 15.2 on page 73 and 15.3 on page 89). Further, it is important to note that the results of this case study are dependent on the local conditions considered, and should not be taken as generic. This section starts with a detailed description of the four scenarios .

15.1 Detailed description of the scenarios

An imaginary Australian regional city was specified for this case study. It currently has 600 000 people living in 200 000 dwellings and is expecting to release 100 000 new lots over the next 25 years. The scenarios cover four different ways of providing water and sewerage services to these dwellings. The scenarios are:

Scenario 0 – Reservoir Expansion

In this scenario the extra water is provided by reservoir expansion and the sewage is treated and released locally. There is no move to reduce the consumption of the existing city and all demands for the new dwellings are supplied by the reticulated potable system.

Scenario 1 – Desalination

In this scenario the extra water is provided by a desalination plant and the sewage is treated and released locally. Again there is no move to reduce the consumption of the existing city and all demands for the new dwellings are supplied by the reticulated potable system.

Scenario 2 – Third Pipe

In this scenario the extra water is provided by a reservoir expansion and the sewage is treated and released locally. The demands from the Greenfield development are reduced through the use of a reticulated non-potable supply Again there is no move to reduce the consumption of the existing city.

Scenario 3 – Rainwater Tank+

In this scenario the extra water is provided by a reservoir expansion and the sewage is treated and released locally. The demands from the Brownfield area are reduced by the use of water efficient appliances and the demands of both the Greenfield and the Brownfield developments through the use of rainwater tanks and the demands.

15.1.1 Scenario 0 – Expanded outer reservoir

15.1.1.1 Description – Existing Urban Areas (Brownfield)

The water and sewage systems in a large regional city provide service for 200 000 single residential lots in existing suburban areas. The following area assumptions have been made for existing areas:

- Average 670m^2 existing lot size.
- Subdivision density 10.7 lots/ha including roads and footpaths.
- Gross development density 800 lots/km^2 including non-residential and public open space areas.
- Average 3 persons per dwelling in existing suburban residential areas.

There are associated public, commercial and industrial facilities. Water use in the non-residential sector is 20% of the residential demands.

Table 22 Summary of key technical aspects of scenarios 0 – 3

Scenario	Existing City water supply	New City water supply
0- Reservoir Expansion	Existing Reservoirs	Existing Reservoirs and expanded outer reservoir
1- *Desalination*	Existing Reservoirs	Existing Reservoirs and desalination plant
2- Third *Pipe*	Existing Reservoirs	Existing Reservoirs and expanded outer reservoir and reticulated recycled water
3- *Rainwater Tank+*	Existing Reservoirs, internal retrofit of showerheads & taps, rainwater tanks to half of dwellings	Existing Reservoirs and expanded outer reservoir and rainwater tanks to all new dwellings

Water Supply – Existing Dwellings

- Baseline indoor appliances and fittings as per NSW BASIX schedule.
- Baseline garden water demands with average annual rainfall of 800mm/year (based on western Sydney).
- Single residential house demands kL/y.house:
  - Toilet 38.5
  - Laundry 55.1
  - Other Indoor 94.6
  - Garden 95.9 average year, 127.6 drought year
  - Pools 10.3
  - **Total 294.4 average year, 326.1 drought year**
- Peak day demands 3.0kL/d.house.

Wastewater System Flows – Existing Dwellings

- Average dry weather wastewater flows including infiltration = 220kL/y.house (assumed average infiltration = 17% of residential flow).

15.1.1.2 Description – New Urban Areas (Greenfield)

Expansion of the city is proposed by providing 100 000 single residential lots in new release areas in a new outer urban satellite city over a 25-year period. The new releases will take place in five parcels of 20 000 lots each.

The following new release area assumptions have been made:

- Average 450m^2 lot size.
- Subdivision density 16 lots/ha including roads and footpaths.
- Gross development density 1200 lots/km^2 including non-residential and public open space areas.
- Average 3 persons per dwelling in new residential housing areas.

The new release areas will have associated public, commercial and industrial facilities. Water use in the non-residential sector will be 20% of the residential demands.

The following new residential water, wastewater and recycled water demand assumptions have been made for new dwellings:

Water Supply – New Dwellings

- BASIX indoors with 3A rated indoor appliances and fittings.
- Baseline garden water demands with average annual rainfall of 800mm/year.
- Single residential house demands (kL/y.house):
  - Toilet 21.9
  - Laundry 34.6
  - Other Indoor 59.6
  - Garden 72.0 average year, 95.7 drought year
  - Pools 10.3
  - **Total 198.5 average year, 222.2 drought year**
- Peak day demands 1.8 kL/d.house.

Wastewater System Flows

- Average dry weather wastewater flows including infiltration = 136kL/y.house.

15.1.1.3 Water and Sewerage Systems

Water Supply

The water supply headworks obtain supply from two branches of the main river in the region. The inner catchment has a 125 GL storage and an average annual discharge of 620 GL/y. The outer catchment has an average annual discharge of 420 GL/a and a 32GL storage.

Water is delivered to the 750 ML/d central water treatment plant from a water source 30km away with a pumping lift of 120m head. At present about 20% of the supply is obtained by transferring water from an outer catchment with an additional pumping lift of 150 m.

An alternative proposal to expand supply from conventional river sources would require

- Enlargement of the outer catchment storage from 32 GL to 92 GL inundating 250 ha of forest.
- A 200 ML/d increase in the capacity of the water treatment plant.
- A 200 ML/d increase in the capacity of the transfer pipeline to the central water treatment plant by adding pumps at the major pump station, requiring an 8.3 MW increase in the power supply.

Water supply will be delivered into the new release

Chapter 15 - Hypothetical Case Study
continued

areas by pipeline from the central water treatment plant about 20 km away. The first 20 000 lots can be supplied from the existing distribution system by extending an existing distribution pipeline. New pipelines and pumping stations will be required to serve the remaining 80 000 new lots. To supply the satellite city's projected peak demand of 225 ML/d, it is proposed to provide a total delivery capacity of 191 ML/d and 270 ML of service reservoir capacity.

Sewerage

Two centralised wastewater treatment plants of 440 000 EP and 360 000 EP capacity serve the existing suburban areas respectively. There is a surplus capacity available to cater for about 80 000 EP additional load from the new development. These treatment plants provide secondary biological treatment, and tertiary nutrient removal and disinfection before discharge to the local inland waterway.

The waterway has a natural annual discharge of about 160 GL/y before the addition of urban stormwater runoff and treated discharges. The plants are required to reduce phosphorus levels to below 1 mg/L TP (90^{th} percentile) before discharge. The waterway is a downstream tributary of the rivers from which the water supply is obtained.

The first 20 000 lots of the new satellite city can be connected to the existing 440 000 EP centralised wastewater treatment plant about 10km away. It is proposed to cater for the remaining 80 000 new lots by constructing a new wastewater treatment plant in 4 stages each of about 75 000 EP capacity. This new treatment plant will also provide secondary treatment, nutrient removal and disinfection before discharge to the local inland waterway.

Biosolids from the treatment plants are stabilised and transported 30km for use in the downstream irrigation area.

Urban Stormwater

Stormwater from both the existing urban areas and the new development areas discharge to the same local inland waterway. It is assumed that there are no significant sewer wet weather overflows.

Stormwater runoff in the new urban areas will be reduced through the use of semi-pervious pavements, grassed swales and detention basins.

Catchment, Environmental Flow and Water Quality Issues

The assessed yields of the existing water storages and proposed enlargement include allowance for release of environmental flow requirements.

Water quality in the river downstream is affected by both the water supply diversions and the treated discharges. Water quality is monitored downstream of the wastewater treatment plant discharges, and upstream and downstream of the main river junctions.

There would be some environmental benefits associated with reducing water diversions in both of the existing catchments and in reducing sewage treatment plant discharges.

There is an 8 000 ha downstream agricultural irrigation area which draws around 48 GL/y or about 4% of the natural annual average discharge. This area operates on run-of-river flows with no regulating storage, but water access is reasonably assured by the upstream discharges. There is some off-river storage and on-farm storage to assist in supplying peak watering demands in the irrigation season. About 20% of the irrigation area grows salad crops for consumption by the local community.

To improve downstream water quality, consideration could be given to supplying recycled water to the agricultural area by pipeline *in lieu* of releases to the river.

There is a public recreation area including swimming and water skiing in the river which reaches further downstream of the water storages.

15.1.2 Scenario 1 – Desalination

15.1.2.1 Existing Urban Areas (Brownfield)

Identical to the Scenario 0 Reservoir Expansion.

15.1.2.2 New Urban Areas (Greenfield)

Identical to the Scenario 0 Reservoir Expansion.

15.1.2.3 Water and Sewerage Systems

Water Supply

Expansion of the headworks system will be required to cater for the new satellite city. The preferred solution is to construct an 80 ML/d desalination plant to provide the additional system yield. The desalination plant would be about 20km from the existing central water treatment plant. The desalination plant will require construction of seawater intake and 5 km rising main to the desalination plant. A 10km brine disposal pipeline will be required. A 120 ML/d expansion of the central water treatment plant and delivery capacity from the nearer storage dam would also be needed to supply peak summer demands.

Sewerage

Identical to the Scenario 0 Reservoir Expansion.

Urban Stormwater

Identical to the Scenario 0 Reservoir Expansion.

Catchment, Environmental Flow and Water Quality Issues

Identical to the Scenario 0 Reservoir Expansion except that the construction of a desalination plant will keep water supply diversions at existing volumes resulting in higher downstream flows and better water quality than the base case.

Scenario 0

15.1.3 Scenario 2 – Water Recycling in the Greenfield development (Third Pipe)

Description

All new urban release areas will have a recycled water reticulation to supply recycled water for garden watering, toilet flushing and clothes washing. There will be a significant reduction in both annual and peak day potable water demands and requirements for potable water delivery capacity.

A new water reclamation plant will cater for the remaining 80 000 new lots and associated non-residential development. The water reclamation plant will be built in 4 stages, each of about 75 000 EP capacity. The plant will incorporate secondary biological treatment, plus advanced water treatment incorporating coagulation, deep bed dual media tertiary filters and chlorine disinfection to meet Class A recycled water quality with a target 5 log virus reduction.

To supply sufficient recycled water during peak garden watering periods, extra recycled water will be delivered from the existing 440 000 EP centralised wastewater treatment plant about 10km away. Additional tertiary filtration and disinfection facilities will be required at that plant to meet recycled water quality requirements.

There will be environmental benefits from the reduction in discharges to the local inland waterway.

Water System Parameters

Dual Reticulation Water System Flows (kL/y.house)

- Potable 76.9
- Recycled 121.6 average year, 145.3 drought year
- Overall residential reuse system demands = residential use + 10% for commercial/open space.
- Total recycled water demands = 133.8 kL/y.house average year, 159.8 kL/y.house drought year

Table 23 Projected Urban and Residential Recycled Water Demands

	Average Year GL/y	Drought Year GL/y
Total	**13.3**	**16.0**

Chapter 15 - Hypothetical Case Study
continued

Residential Reuse System Details

The following residential reuse system sizing has been adopted:

- Service reservoirs at about 4 km spacing;
- Delivery rate from STPs to reservoirs = 85% of drought year peak day; and
- Reservoir capacity = 120% of drought year peak day.

A simple simulation analysis was undertaken to identify:

- How much of the recycled water demand can be supplied from the local treatment plant;
- How much recycled water is delivered from the centralised wastewater treatment plant in average and drought years;
- How much potable water top-up is required in peak periods; and
- How much residual recycled water is discharged in winter and wet weather.

The adoption of smaller (450 m^2) lot sizes in new subdivisions will reduce the cost of third-pipe recycled water systems. Provision of a third-pipe recycled water system is estimated to reduce potable water reticulation costs (Apostolidis, 2003).

Drinking Water System

Expansion of the drinking water supply will be required to cater for the new satellite city. This will be provided through the expansion of the outer reservoir to a volume of 55 000 ML.

Projected Water Savings

Assumptions:

Water Supply = [residential water use + (0.7 × Scenario 2 new non-residential) + (Scenario 1 old nonresidential)]×(1+Losses)

= [residential water use + (0.7 × Scenario 2 new nonresidential) + (Scenario 1 old nonresidential)]×1.1

Wastewater Flows = residential flows + 20% non-residential + 10% wet weather flow

Recycled Water Demands

= [residential non-potable water use + (0.3 × Scenario 2 new nonresidential)]×(1+Losses)

= [residential non-potable water use + (0.3× Scenario 2 new nonresidential)]×1.1

Dual Reticulation versus Water-Efficient Conventional Subdivision

- Reduction in annual water diversions 13.3 GL/y
- Reduction in annual wastewater discharges 13.3 GL/y

Dual Reticulation versus 100 000 Existing Houses with Baseline Demands

- Reduction in annual water diversions 25.9 GL/y
- Reduction in annual wastewater discharges 24.3 GL/y

15.1.4 Scenario 3 – Demand management and rainwater tanks

Scenario Description

15.1.4.1 Brownfield Area

It is projected that water use in existing houses will be reduced by 12% (30 kL/y.house) over 10 years through a demand management program targeting indoor water. Measures may include:

- Residential audits to fit water saving shower roses, dual flush toilets, tap aerators and to fix leaks.
- Purchase of water efficient washing machines and dishwashers by householders when old machines are replaced.
- Installation of 6L/3L or 4.5L/3L dual flush toilets for any new or replacement installations.

In addition, 10 kL rainwater tanks would be retrofitted to existing houses to supply water for garden use. Potable water top up will be needed to meet peak garden water needs in summer. For houses with these systems, garden water needs will be reduced by about 40 kL/y.house on average. It is assumed that the take-up rate will be 2% of houses per annum, so that at the end of 25 years, 50% of existing houses will have a system fitted, giving average savings of 20 kL/y.house in outdoor water use for the total Brownfield area.

It is assumed that matching demand reductions will be achieved through water audits and other measures in the non-residential sector.

There will be reductions in water supply system operating costs and river water quality benefits from reductions in diversions at the main water supply intake

There will be reductions in wastewater system operating costs through reductions in wastewater flows and environmental benefits from the reduction in discharges to the local inland waterway.

15.1.4.2 Greenfield Area

10 kL rainwater tanks would be installed in new houses in the Greenfield areas to supply water for garden use, toilet flushing and laundry. Potable water top up will be needed to meet peak garden water needs in summer. For houses with these systems, garden water needs will be reduced by about 50 kL/y.house on average.

Water System Parameters

Rainwater Tank System Details

The following residential tank system details have been adopted:

- Tank volume 10 kL.
- Water supply outlet 100 mm above bottom of tank
- Mains water top-up if tank less than 1 kL storage above outlet, top-up rate 2.5 L/min. (limiting the top-up rate reduces peak demands on the reticulated water system in dry weather.)

Drinking Water System

Extra water supply capacity will be required to a smaller extent than in Scenarios 0 and 1. This capacity will be provided through the expansion of the outer reservoir to a volume of 45 000 ML.

The water savings in the existing residential areas will reduce the extent of headworks expansion required.

To supply peak summer demands will require:

- A 100 ML/d increase in the capacity of the central water treatment plant.
- A 100 ML/d increase in the capacity of the transfer pipeline to the central water treatment plant by adding one pump to the major pump station at the nearer storage, requiring a 3.7 MW increase in the power supply.

Sewerage

Sewage flows reduced as a result of indoor water saving measures in the existing houses

Urban Stormwater

Urban runoff reduced as a result of installing rainwater tanks in new and existing dwellings.

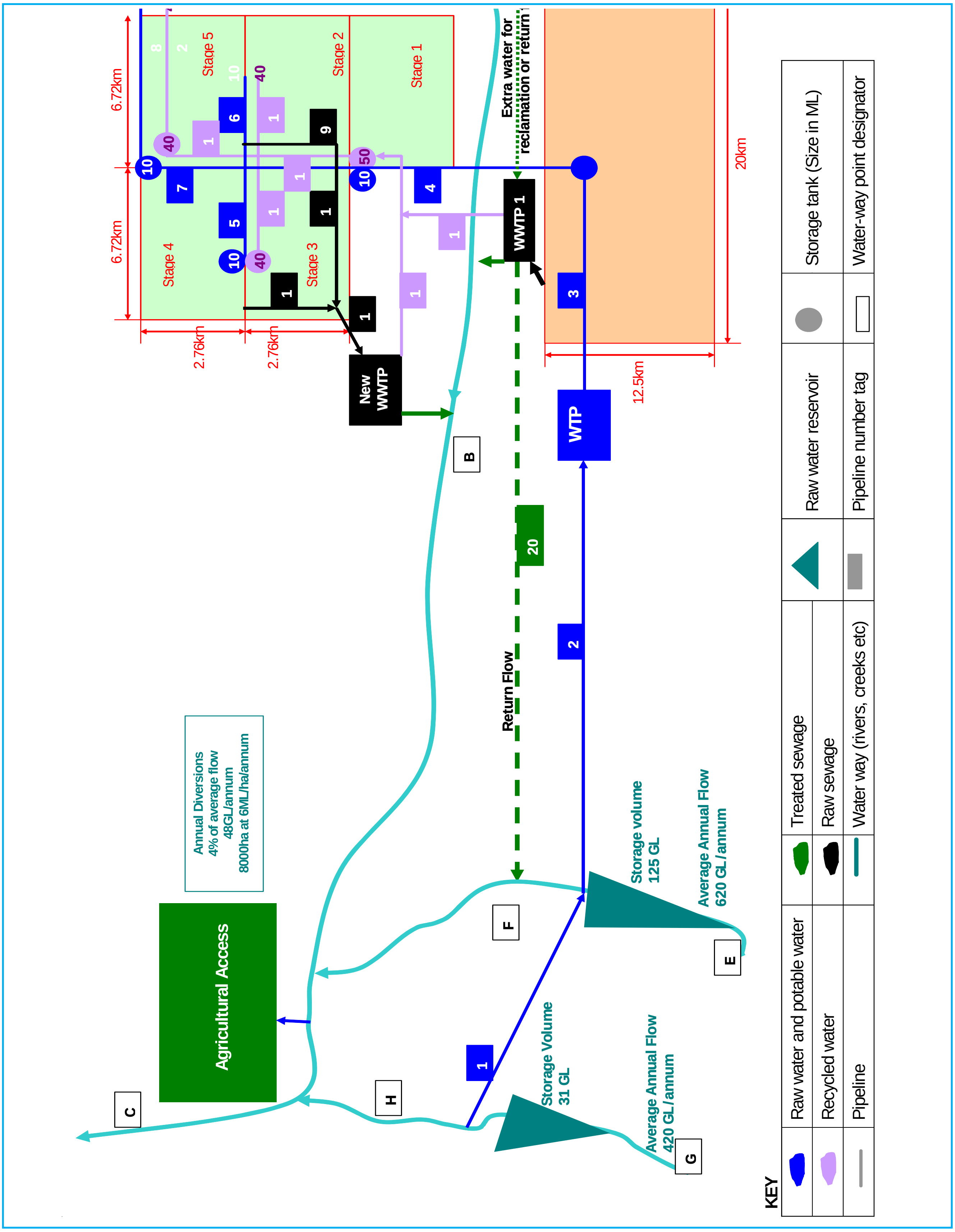
Projected Water Savings

Assumptions:

- Water Supply = residential water use + 20% non-residential + 10% system losses; and
- Wastewater Flows = residential flows + 20% non-residential + 10% wet weather flow.

Chapter 15 - Hypothetical Case Study
continued

Figure 5 System boundaries for the scenarios under study



Existing Development Demand Management versus Base Case

- Reduction in annual water use 19.8 GL/y
- (200 000 x 50 kL/house average + 20% non-residential + 10% system losses)
- Reduction in annual wastewater discharges 8.0 GL/y
- (200 000 x 30 kL/house average + 20% non-residential + 10% wet weather flows)

The system under study is illustrated in Figure 5.

15.2 Perform detailed scenario assessment

Phase 5 of the sustainability framework, i.e. detailed scenario assessment, was carried out for the four options under study, including:

- Generation of a performance matrix;
- Normalisation of the performance matrix;
- Weighting of criteria; and
- Calculation of an aggregated indicator score (see also Section 16.2.9 on page 107).

15.2.1 Performance matrix - economic assessment

A NPV spreadsheet for CAPEX and OPEX was developed to evaluate the economic performance of the options. Consumer costs were included in this analysis, for example the cost of a rainwater tank.

Environmental externalities were not included, but there was some agreement that externalities could be included as a 5% levy as per Victorian and ACT governments.

New developments are staged over the 25 years. Staging the development has impacts on both the environmental effects and economic costs.

The economic assessment based on NPV at 7% indicate that the total life cycle cost range from $690 million for scenario 0 to $812 million for scenario 2.

A detailed cost break down can be found in Table 45 in Section 15.4.3 on page 94.

15.2.2 Performance matrix - human health assessment

15.2.2.1 Background

The analysis was undertaken using the MRA Tool (Ashbolt *et al.*, 2005) for possible exposure points given in Table 24, which includes our assumptions for the distributions of water consumed and frequencies per year with each scenario.

Chapter 15 - Hypothetical Case Study
continued

Table 24 Points of exposure with assumptions on number of persons affected, contact volumes and frequencies per year

Type of Exposure	Proportion of population exposed	Water Source: Scenario 0	Scenario 1	Scenario 2	Scenario 3	Volume (mL)	Frequency (year^{-1})
1. Drinking water	1	WG	DS	WG	WG	N*(650,500)	365
2a. X-connection with sewage to potable supply	0.001	Diluted sewage entering distribution system				N(650,500)	T**(21,30,90)
2b. X-connection with non-potable to potable supply	0.001	-	-	WR	-	N(650,500)	T(21,30,90)
2c. X-connection with raintank supply	0.001				RT	N(650,500)	T(21,30,90)
3. Rainwater tank ingestion (intentional connection to potable supply)	0.015	-	-	-	RT	N(650,500)	365
4. Toilet Flushing aerosols	1	WG	DS	WR	RT	T(0.01, 0.1,0.5)	N (1095, 120)
5a. Garden irrigation – aerosols	0.33	WG	DS	WR	RT	T(0.01, 0.1,0.5)	N(100, 20)
5b. Garden irrigation – ingestion (hand to mouth)	0.33	WG	DS	WR	RT	T (0.1,1,10)	N (100, 20)
5c. Garden irrigation – ingestion	0.1	WG	DS	WR	RT	T (1, 20, 100)	N (100, 20)
6. Accidental ingestion stormwater	0.1	Stormwater				T (0.1, 1, 3.0)	N(10, 3)
7. Recreational swimming at home	0.2	WG	DS	WR	WG	T(5, 25, 50)	N(30,20)
8. Recreational swimming in river	0.1	River water quality impacted by Treated effluent discharge and stormwater				T(5,25, 50)	N(30,20)
9. Public Irrigation Aerosols	0.33	WG	DS	WR	WG	T(0.01, 0.1, 1)	N (150, 20)
10. Biosolids on market garden crops	0.33	Biosolids stored for 30 days prior to application. Cops consumed 30 days following application				T(0.01, 0.1, 1)	N (150, 20)
11. Sewage Maintenance workers	0.00005	Possible exposure to raw sewage				T(0.1,1,2)	T(300, 400, 500)

Water source:

WG- Warragamba; DS – Desalinised water; WR – reclaimed water; RT – Rain Tank.
* Normal distribution defined by (mean, standard deviation);
**Triangular distribution defined by parameters (minimum, mode, maximum)

Further assumptions included:

- Drinking water quality from Warragamba Dam (assume, following treatment viable mean *Giardia*, *Cryptosporidium* 1/10 000 L, and viruses & campylobacters 1/100 000 L)
- Sewage ingress into distributed water (potable and non-potable options) results in 1/100 000 dilution of our pathogen numbers in sewage. Ingress events assumed to affect 0.1% supply.
- Unintentional cross connections between potable and non-potable (reclaimed or raintank) water assumed to occur at a frequency of 1 in 1 000 households per year. The duration of the cross-connection was assumed to have a minimum of 21, mode of 30 and maximum of 90 days.
- Reclaimed water quality assumed to be at the class A limit, currently with < 1 virus, protozoan or campylobacters/50 L.
- Rainwater assumed to contain no viruses, but *Cryptosporidium* and *Giardia* at 1/50 L and *Campylobacter* at 1/L.
- Stormwater microbiology; assume Table 25 data, and *C. perfringens* (Cp) give a good measure of dilution of sewage, i.e. raw sewage contains about 10^5 Cp/100mL. Dilution factor assumed to follow a triangular distribution (100,1000,2000)
- Average dry weather wastewater flows including infiltration = 220 kL/y.house (assumed average infiltration = 17% of residential flow).
- Tertiary-treated wastewater discharged to river (1:1 dilution) were downstream recreation occurs (including swimming/skiing 8 months of the year).
- Stormwater collected and directly discharged to same river. Run-off coefficient 0.6 for total area and storm event frequency for 55 mm/h 10-times per year.

Table 25 Adjusted Geometric Mean Densities (cfu/100 mL) of Faecal Bacteria in Coastal Stormwaters

Stormwater site	FC	FS	*Clostridium perfringens*	*Salmonella*
Whale (NH101)	87,100	2,950	708	7.2
Freshwater (NH41)	16,500	2,630	812	2
Queenscliff (NH51)	6,300	977	166	0.251
Bondi (SH28)	891	436	120	0.15
Malabar (SH70)	204	126	51	0.53
Bellambi (SC11)	295	62	87	0.076
Standard Error of the Mean	1.38	1.26	1.26	1.62

Chapter 15 - Hypothetical Case Study
continued

The overall mean proportion of 50-L stormwater samples containing enteric viruses was 11.1% with 95% CI of 7.01-17.4 (Ashbolt pers. com.)

15.2.2.2 Hygiene Risks

Hazard identification & Hazardous events

All pathogens that are excreted in faeces could potentially be found in wastewaters and source waters. A selection of reference pathogens is therefore made for the hygiene risk assessment, with representatives from each microbial group (bacteria, viruses and protozoa). It included pathogens that mainly cause gastroenteritis (*Campylobacter jejuni*, *Giardia*, *Cryptosporidium*, rotavirus), All of these have been causes of waterborne disease, are know to occur in Australia and have all been detected in sewage.

The hazardous exposures were identified by a systematic assessment of each system structure and its surroundings. The frequency of exposure, the number of persons exposed at each point and the amounts likely to be ingested per exposure were determined (summarised in Table 24). The numbers and distributions can be varied according to the prevailing conditions at each site, but are assumed to be roughly equal in this screening-level risk assessment.

The doses of pathogens for each exposure were estimated from the concentrations in raw sewage based on Adelaide sewage data, except for campylobacters, which came from a German study (Höller, 1988) (Table 26).

The reduction in the wastewater treatment was based on previous studies at Australian wastewater plants (Long & Ashbolt, 1994) (Table 27). The recreational water was assumed to be fully mixed and under steady-state conditions and first-order pathogen inactivation equations were used.

Table 26 provides example output from the MRA tool illustrating spread in the pathogen PDF's when estimating sewage numbers from occurrence datasets.
The concentration of the pathogens in the raw sludge was based on measured concentrations in sewage and

Table 26 Pathogen densities in Australian raw sewage

Parameter	Enteric virus (Rotavirus)	Bacterium (C. jejuni)	Protozoan (*C. parvum*)	Protozoan (*G. lamblia*)
Mean (per L)	1.53´10^{7}	3.38´10^{6}	1.27´10^{4}	2.13´10^{4}
50th percentile (per L)	8.97´10^{5}	1.87´10^{5}	8.97´10^{2}	1.24´10^{3}
95th percentile (per L)	4.55´10^{7}	1.03´10^{7}	4.13´10^{4}	6.29´10^{4}

Table 27 Removal rates of pathogens by water reclamation treatment processes

	Enteric virus (Rotavirus)	Bacterium (*C. jejuni*)	Protozoan (*C. parvum*)	Protozoan (*G. lamblia*)
Primary *	20%	80%	55%	55%
Secondary*	75%	99.90%	99%	99%
Tertiary*	99.99%	100.00%	99.80%	99.80%
Microfiltration	50%	100.00%	100.00%	100.00%
Disinfection (Chlorine)	99.99%	99.00%	0%	0%
TOTAL REMOVAL (Log)	9	>17 (complete)	10	10

Data from Long and Ashbolt (1994)

Table 28 Inactivation rates of pathogens in faeces and soil expressed as days for 90% inactivation, (compiled for Schönning *et al*. submitted)

	T_{90} faeces (mean ± stdv)	T_{90} soil (mean ± stdv)
Salmonella	30 ± 8	35 ± 6
EHEC	20 ± 4	25 ± 6
Rotavirus	60 ± 16	30 ± 8
Hepatitis A	55 ± 18	75 ± 10
Giardia	27.5 ± 9	30 ± 4
Cryptosporidium	70 ± 20	495 ± 182
Ascaris	125 ± 30	625 ± 150

ratios between various microbes in raw sewage and sludge (Chauret *et al.*, 1999). The inactivation of pathogens during the anaerobic digestion was assessed from literature data [e.g. (Chauret *et al.*, 1999) (Gantzer *et al.*, 2001)]. In the dewatering processes fifty percent of the pathogens were assumed to attach to sludge particles. No inactivation was assumed for protozoa and viruses before exposure to the sludge. The die-off of EHEC and *Salmonella* can be rapid in sludge (same assumed for *Campylobacter*) but large regrowth may also occur (Gantzer *et al.*, 2001; Gibbs *et al.*, 1997)]. We therefore assumed that the concentration was back to initial levels at the time of sludge collection.

On agricultural land the biosolids was assumed to be homogenously mixed into the top 25 cm of soil according to current practices, with harvest of crop taking place one month after application. As an example of crop likely to be eaten raw we used celery where sludge-soil mixture could contaminate the stalks especially during episodes of heavy rains.

Table 29 Median and range of removal in $\log_{10}$ of microorganisms in drinking water treatment processes. Modified from Westrell (2004)

Process	Bacteria	Viruses	Protozoa
Coagulation/flocculation	1.7 (0.5-3.9)	1.9 (0.2-4.3)	2.0 (0.4-3.7)[a]
Rapid sand or GAC[b] filtration	1.0 (0.3-1.5)	(0.7-1.2)	0.6 (0-1.4)
Slow sand filtration	2.2 (1.3-3.4)	2.1 (0.9-3.5)	n.d.[c] (0.3->6.5)[a]
Chlorination	3.5 (2.5-5.0)	2.0 (1.5-3.0)	0.4 (0-1.0)

[a] *Cryptosporidium*. Lower removal reported for *Giardia*.

[b] GAC = granular activated carbon.

Chapter 15 - Hypothetical Case Study
continued

15.2.2.3 Risk characterisation

Quantitative risk of infection were calculated from the doses by each pathway (exposure concentrations x frequency x volumes of exposures) described in Table 24 and applied in the dose-response models for each reference pathogen (Table 30). Either the exponential:

Equation 1:

$$P^{*}_{\inf} = 1 - e^{-r\mu} \text{ or } P_{INF} = 1 - e^{-\left(\frac{D}{k}\right)}$$

Equation 2:

or β-Poisson: $$P_{\inf}(D;\alpha,\beta) = 1 - \left(1 + \frac{D}{\beta}\right)^{-\alpha}$$

models were used to estimate the probability of infection (P_{inf}) with dose (D).

The intention of the quantitative microbial risk assessment is to provide relative comparisons between system structures, with the uncertainties aiding interpretation between pathways and reference pathogens. Table 31 provides a summary of the DALYs for each pathway by scenario.

To compare between scenarios against each other, only the dominant exposure pathways and reference pathogens were compared (Table 32).

Table 30 Dose-response parameters for the pathogens used in the MRA Tool

Reference pathogen	Parameters	Comments
Campylobacter jejuni	α = 0.145, β = 7.59	H.f.t.[a] by Black *et al.* 1988
Rotavirus	α = 0.253, β = 0.422	H.f.t. by Ward *et al.* 1986
Adenovirus 4	k^{c} = 2.397	H.f.t. by Couch *et al.* 1966
Giardia lamblia	r = 0.0199	H.f.t. by Rendtorff 1954
Cryptosporidium parvum	k^{c} = 238.6	H.f.t. by DuPont *et al.* 1995

[a] H.f.t. = human feeding trials. [b] $\hat{a} = N_{50}(2^{1/\acute{a}}-1)$. [c] $r = 1/k$ (see equations 1 & 2)

(Crockett *et al.*, 1996; Haas *et al.*, 1996; Haas *et al.*, 1999; Haas *et al.*, 2000; Medema *et al.*, 1996; Teunis *et al.*, 1996).

Table 31 Total DALY estimates (median) per year for population of 100 000 for each exposure pathway by Scenario

Exposure	Scenario 0	Scenario 1	Scenario 2	Scenario 3
1. Drinking water	1.25	0	1.25	1.25
2a. X-connection with sewage to potable supply	4.62	4.62	4.62	4.62
2b. X-connection with non-potable to potable supply			0.14	
2c. X-connection with rain water to potable supply				1.66
3. Rainwater tank ingestion				65.89
4. Toilet Flushing aerosols with non-potable water	1.02 ´ 10^{-4}	0	1.1	17.82
5a. Garden irrigation - aerosols	3.11 ´ 10^{-5}	0	3.32 ´ 10^{-2}	0.55
5b. Garden irrigation - ingestion	5.56 ´ 10^{-4}	0	0.61	9.61
5c. Garden irrigation – ingestion non-potable	1.91 ´ 10^{-3}	0	1.99	31.12
6. Accidental ingestion stormwater	10.67	10.67	10.67	10.67
7. Recreational swimming at home	7.73 ´ 10^{-4}	0	0.82	7.73 ´ 10^{-4}
8. Recreational swimming in river	63.24	63.24	63.24	63.24
9. Public irrigation aerosols	8.63 ´ 10^{-5}	0	9.33´ 10^{-2}	8.63 ´ 10^{-5}
10. Biosolids on market garden crops	19.95	19.95	19.95	19.95
11. Sewage maintenance worker	0.18	0.18	0.18	0.18

Table 32 Relative differences in median total DALY estimates for each scenario relative to scenario 0

Pathway (pathogen) Versus Scenario	Scenario 1	Scenario 2	Scenario 3
2. X-connection with potable supply	0	0.14	1.66
5. Garden irrigation – ingestion non-potable	-2.45 ´ 10^{-3}	2.58	40.66
6. Accidental ingestion stormwater	0	0	0
7. Recreational swimming-home pool	-7.67 ´ 10^{-4}	0.83	0
8. Recreational swimming in river	0	0	0
Total	**-1.25**	**4.72**	**125.88**

Based on the results summarized in Table 32, further discussion by stakeholders may allow modifications to reduce/control risks in the preferred scenario (based on other sustainability factors) (Phase 4 of the framework).

15.2.3 Performance matrix - environmental assessment

In order to assess the environmental impacts of the four scenarios as described in Section 15.1 on page 66 a streamlined LCA was carried out. Below the key elements of the LCA are presented.

15.2.3.1 Goal of the study

The main aims of this project are to quantitatively evaluate *four scenarios* of a Brownfield residential site with 200 000 dwellings supplied by water from a reservoir, and options for how to cope with an extra 100 000 new dwellings in a Greenfield site over the next 25 years. A detailed description of the four scenarios is given in Section 15.1 commencing on page 66

A life cycle perspective has been chosen for this evaluation. The LCA approach is appropriate for the water and wastewater sector as it considers the impacts of the entire system (cradle-to-grave approach). This approach allows to obtain a holistic perspective of the various impacts of the combined operations and thus offers means to move away from 'end-of-pipe thinking' as the sole criteria for more sustainable environmental outcomes.

The main reasons for carrying out the study are to:

- Quantify the overall environmental impacts from the annual quantity of water consumed and wastewater generated within the system and
- Obtain a detailed picture of environmental impacts of the system, i.e.
  - o water usage,
  - o total primary energy input,
  - o climate change,
  - o freshwater eutrophication,
  - o photochemical oxidant formation and
  - o freshwater, marine and terrestrial eco-toxicity.

15.2.3.2 Scope of the study

The study will use a *prospective* approach[29] which supports strategic planning and sustainability assessment of the systems.

Functional unit and function

The functional unit (fu) is defined as the annualised provision of water supply and sewerage services to 300 000 dwellings over the next 100 years.

The *main* functions in this study are the supply of water, its distribution from and to the households and the treatment of wastewater. However, there are also supplementary functions within the system, i.e.:

Nutrient recovery: Treatment of biosolids and their application on land which can potentially substitute the production of fertilizer.

Water recovery: Treatment of wastewater to a sufficient standard for non-potable reuse will substitute the effort required to treat water to potable standard for the same use.

System boundary

In LCA methodology usually all inputs and outputs from the system are based on the 'cradle-to-grave' approach. This means that inputs into the system should be flows from the environment without any transformation by humans and outputs should be discarded to the environment without subsequent human transformation (AS/NSZ ISO 14040: 1998 Environmental Management – Life Cycle Assessment – Principles and Framework.). Inputs and outputs at the system boundary are elemental flows.

The system starts with the provision of potable water. The water is pumped from catchments to water filtration plants (WFP) plants. The water is pumped through water system areas to the Brownfield and Greenfield sites. The Brownfield consists of 200 000 residential dwellings, while the Greenfield site is smaller with 100 000 dwellings. A large quantity of the water consumed in each customer area becomes wastewater which is

[29] This looks ahead to examine the effect of a change in the product system in an attempt to predict the effects of this change on the environment. It is "getting away from measuring the effects of products to measuring the effects of changes" (Weidema, 2000). Prospective LCAs study possible future changes between alternative product systems typically applied in product development and in public policy making (Tillman, 1998). This is less about allocation of responsibility and more about optimisation of future actions. In prospective LCA, more attention is given to the marginal effects of increasing or decreasing demand for products, materials and services.

pumped via wastewater system areas to a wastewater treatment plant (WWTP). The treated wastewater is discharged to the environment or reused for non-potable purposes. Biosolids are captured and treated on-site. The biosolids are trucked directly to the application on farms where they partially substitute fertilizer. A detailed description of the technical specification of both the Brownfield and the Greenfield site are given in Section 15.1.

15.2.3.3 Life Cycle Inventory Analysis

Data source

Two main sources of information were used for this hypothetical LCA study, i.e.

- Technical description of the scenarios (see Section 5.1) and
- LCI data from the "LCA for Waterplan 21 Review - Base Case & Scenarios" project (Lundie *et al.*, 2002).

After validation (mass and energy balances) the data were related to unit processes and the functional unit.

These information is combined with Australian LCI data (on electricity, gas, coal, transportation etc.) in order to quantify the environmental profile of the functional unit.

Assumptions

The data collected had to be transformed into a format that allows the allocation of inputs and outputs to the functional unit, i.e. annualised provision of water supply and sewerage services to 300 000 dwellings over the next 100 years. Therefore and because of the quality of data obtained several assumptions had to be made, i.e.

- Capital equipment
  - o The Greenfield site is upgrade over the first 25 years. The material demand for the upgrade is annualised, and
  - o At any time maximum surface water demand is available for extraction, i.e. 101 GL/y.
- Operation
  - o Electricity is supplied from hard coal-fired power plants,
  - o Chemical dosage is based on guidelines (Fernando and James, pers comm.) and cross-check with operational data (Lundie *et al.*, 2002),
  - o Effluent characteristics cover phosphorus, suspended solids, total nitrogen and total Kjeldahl nitrogen only. It is based on averaged data from inland wastewater treatment plants (Lundie *et al.*, 2002),
  - o An average transport distance of 230km is assumed for the distance between biosolids generation and its application, and
  - o The application of biosolids to land reduces the need for synthetic P and N fertilizer production. The calculation of avoided products credit the system with avoided energy and material inputs and substance emissions (Lundie *et al.*, 2004).

Data gaps

However, several data gaps have been identified at both capital equipment and the operational phase. Main data gaps are:

Capital equipment

- Bronze: No LCI data is available on Bronze. This material has been excluded from the analysis due to the small quantity, and
- Installation: Energy demand for construction works has not been quantified.

Operation

- Detailed data on effluent characteristics from wastewater treatment plants are not available except for nutrients

Chapter 15 - Hypothetical Case Study
continued

Table 33 LCI data of all scenarios

		Scenarios			
		0	1	2	3
Materials for infrastructure					
Aluminium	kg/a	0	0	0	1000
Bronze	kg/a	437	437	765	80
Concrete	kg/a	185678	182695	268939	89053
Copper	kg/a	53500	54500	109000	10000
Iron	kg/a	459379	449715	686008	225691
Polyester coating	kg/a	0	0	0	4000
PVC M	kg/a	356315	356315	449456	151235
Stainless Steel	kg/a	12409	12409	12409	955
Steel	kg/a	0	0	77350	320000
Zinc	kg/a	0	0	0	8000
Water flow					
Water extracted	ML/a	101283	93884	75214	71210
Water from Desalination	ML/a	0	7399	3488	2827
Potable Water Provided	ML/a	100779	100779	78019	73378
Non-potable Water Provided	ML/a	0	0	11312	0
Non-potable Top up	ML/a	0	0	0	0
Total water demand	ML/a	101283	101283	90014	74037
Waste Water Treated	ML/a	73896	73896	65531	59432
Chemical usage					
Alum	kg/a	53561	53561	42370	40281
Sodium Hypochorite (@12.5%)	kg/a	4031174	4031174	4340669	3305245
Sodium Silico Flouride	kg/a	167966	167966	130032	122296
Sodium bisulfite (desal)	kg/a	0	24997	11784	9551
Lime (for desal plant)	kg/a	0	719929	310932	246599
Energy demand					
Electricity	GWh/a	92.3	107.6	76.1	72
	kWh/kL	0.9	1.1	0.8	1
Effluent volume					
Effluent volume	ML/a	73896	73896	65531	59432
Phosphorus	kg/a	132771	132771	117740	106783
Suspendid solids	kg/a	738960	738960	655305	594321
Total nitrogen	kg/a	807331	807331	715936	649309
Total kjeldahl nitrogen	kg/a	333143	333143	295429	267936
Biosolids					
Biosolids generation	dt/a	10402	10402	9225	8366
Avoided N-fertilizer	kg/a	81834	81834	72570	65816
Avoided P-fertilizer	kg/a	683368	683368	606007	549610
Transport	tkm	8009623	8009623	7102883	6441874

15.2.3.4 Life Cycle Impact Assessment

Life cycle impact assessment (LCIA) is the third phase of LCA. The purpose of LCIA is to better understand environmental impacts caused by the emissions and environmental interventions of a product or service.

In this section, quantitative impact category results are presented for water usage, total primary energy usage, climate change, eutrophication, photochemical oxidant formation, aquatic and terrestrial eco-toxicity potentials. The impact category results are presented per functional unit.

There are many processes related to the provision of the functional unit that are considered in the life cycle assessment. They include:

- Material production for infrastructure including aluminium, concrete, copper, iron, polyester, PVC, stainless steel and zinc;
- Electricity;
- Chemicals (alum, sodium hypochlorite, sodium silico fluoride, sodium bisulfite and lime);
- Wastewater treatment and effluent discharge;
- Transportation of biosolids from generation to its application; and
- Avoided fertilizer production.

All results are presented in an aggregated manner in Table 34.[30] Extracted surface water is highest for scenario 0 (i.e. 101 GL/y), while it is smaller for scenarios 1-3, i.e. 94 GL/y, 75 GL/y and 71 GL/y respectively.

The eutrophication potential results show a similar trend with highest impacts from scenario 0 and lowest contribution by scenario 3. However, the primary energy input is significantly higher for the option that is utilising a desalination plant for potable water supply, i.e. Scenario 1, due to its high electricity demand.

The performance of the remaining impact categories are determined by the electricity consumption of each scenario: Scenario 3 has the least contribution to climate change, photooxidant formation and all ecotoxicity potentials, followed by Scenarios 2, 0 and 1.

Table 34 Environmental impacts for four scenarios

		Scenarios			
Impact category	**Unit**	**0**	**1**	**2**	**3**
Water Use	[GL/y]	101	94	75	71
Primary energy input	[TJ/y]	1169	1363	836	795
Climate change	[kt CO_2/y]	89	104	63	61
Eutrophication	[kt O_2/y]	20	20	17	16
Photchemical Oxidant Formation	[t ethene/y]	30	34	23	20
Terrestrial Ecotoxicity	[kt DCB/y]	0.79	0.93	0.58	0.53
Marine Aquatic Ecotoxicity	[kt DCB/y]	2519	2939	1797	1680
Freshwater Aquatic Ecotoxicity	[kt DCB/y]	0.04	0.05	0.03	0.03

[30] No further disaggregation per life cycle phase is needed for the application of the LCA results in the sustainability framework.

Chapter 15 - Hypothetical Case Study
continued

15.2.4 Performance matrix - technical assessment

The technical assessment was undertaken in the form of a questionnaire that allowed the scoring of the options on a scale of zero to five. The two experts then discussed the results and agreed upon new scores. Two experts assessed each scenario according to 7 technical sub-criteria, i.e.:

- ***Performance*** including water quality supply (1. compliance with required standards in tests performed throughout the year (%) and number of water quality complaints) and water quality treatment (effluent quality);
- ***Reliability*** including water availability (number of restriction or interruption complaints per year) and system failure (risk of failure to meet consent conditions due to treatment malfunctions);
- ***Durability*** (life time of the system expected to operate successfully for);
- ***Flexibility*** **and** ***adaptability*** including cost of adding or removing from system in response to future changes and level of accommodation in design (potential and ability to accommodate future changes);
- ***Endure seasonal effects*** including number of days where there is insufficient non-potable water (reticulated and tank) stored leading to potable water top up;
- ***Level of experience with technology*** including number of successful projects using similar technology; and
- ***Ease of operation*** including ease of assessment and approval, maintenance and construction.

The rating is summarised in Table 35:

Table 35 Technical rating results (rating out of 5)

	Scenario			
	0	1	2	3
Performance	4	4	4	4
Reliability	4	4	3	4
Durability	5	3.5	3.5	3.5
Flexibility and adaptability	3.5	3.5	3.3	3.5
Endure seasonal effects	5	5	4	4
Level of experience with technology	5	3	3	4
Ease of operation	4.5	3	2.7	3.2

15.2.5 Performance matrix - social assessment

An expert assessed each scenario according to four social sub-criteria, i.e.:

- ***Acceptability to the community*** was determined through a combination of data from previous experience elsewhere (Market Equity, 2004; Roseth, 2003) for each type of option (for salience) and also data from a resident survey of attitudes toward water services. Acceptability tended to be lower for less familiar alternatives.
- **The** ***distribution of responsibilities*** for more centralised water services options was deemed to be unfavourable by the steering committee for engendering change in user beliefs and practices. Hence those innovations involving greater user engagement in managing their own water services were rated more highly for this criterion. The rating was done by deliberation of the expert.
- **The** ***organisational capacity and adaptability*** criterion was also rated by the expert. The expert determined that the more traditional, centralised options are easier for the established centralised water authority to manage due to the more natural fit. Hence the more centralised options were rated more favourably.
- ***Public understanding and awareness*** was determined in the same manner as community acceptability – i.e. through a combination of data from elsewhere (Market Equity, 2004; Roseth, 2003) and also a resident survey. Understanding and awareness is obviously lower for the more innovative options.

The rating is summarised in the Table 36:

Table 36 Social rating results (rating out of 5)

	Scenario			
	0	1	2	3
Acceptability to community	4	3.5	3	3
Distribution of responsibility	1	1	3	4
Organisational capacity and adaptability	4.5	4	3.5	3
Public understanding and awareness	4	2.5	3	3.5

15.2.6 Performance matrix results

Table 37 shows the performances of each option for each criterion:

Table 37 Performance matrix for all scenarios

Criteria			Scenario			
Primary criteria	**Secondary criteria**	**Units**	**0**	**1**	**2**	**3**
Economic	NPV @ 7%	k$	688613	811589	712349	702830
Human health	Relative DALY	Disability adjusted life years	1	-1.25	4.72	125.88
Environmental	Water Use	[GL/y]	101	94	75	71
	Primary energy input	[TJ/y]	1169	1363	836	795
	Climate change	[kt CO_2/y]	89	104	63	61
	Eutrophication	[kt O_2/y]	20	20	17	16
	Photochemical Oxidant Formation	[t ethene/y]	30	34	23	20
	Terrestrial Ecotoxicity	[kt DCB/y]	0.79	0.93	0.58	0.53
	Marine Aquatic Ecotoxicity	[kt DCB/y]	2519	2939	1797	1680
	Freshwater Aquatic Ecotoxicity	[kt DCB/y]	0.04	0.05	0.03	0.03
Technical	Performance	# out of 5	4	4	4	4
	Reliability	# out of 5	4	4	3	4
	Durability	# out of 5	5	3.5	3.5	3.5
	Flexibility and adaptability	# out of 5	3.5	3.5	3.3	3.5
	Endure seasonal effects	# out of 5	5	5	4	4
	Level of experience with technology	# out of 5	5	3	3	4
	Ease of operation	# out of 5	4.5	3	2.7	3.2
Social	Acceptability to community	# out of 5	4	3.5	3	3
	Distribution of responsibility	# out of 5	1	1	3	4
	Organisational capacity and adaptability	# out of 5	4.5	4	3.5	3
	Public understanding and awareness	# out of 5	4	2.5	3	3.5

Chapter 15 - Hypothetical Case Study
continued

15.2.7 Normalisation of the performance matrix

In this case study the min-max approach is chosen due to the lack of data on possible ranges for each criterion. Hence, the option that has the best performance score receives the highest normalised score (i.e. 100) for that criterion, while the worst performance score gets the minimum normalized score using linear value functions. The normalised results from Table 37 are shown in Table 38.

The normalised results highlight the relative strength and weaknesses of the four options under study: Scenario 0 achieves highest scores for economic and human health performances as well as for most of the technical aspects. This scenario seems to be socially well excepted because it is the current way of operations. Scenario 1 is expensive and causes highest environmental impacts, but it is the best option in human health (i.e. slightly better than scenario 0). Scenario 3 is by far the best option with regard to environmental aspects; however, human health results are the lowest. Scenario 2 does not score the highest in any criterion, but it achieves relatively high scores across all criteria.

15.2.8 Weighting of criteria

Two ways of weighting have been presented in Sections 9.3 on page 39. Here the ROC method has been applied that converts the rank orders into weights. A conservative rank order has been chosen for primary criteria assigning the greatest importance to economic performance, i.e.

1. Rank: Economics (46%);
2. Rank: Environmental (26%);
3. Rank: Human health (16%);
4. Rank: Technical performance (9%); and
5. Rank: Social (4%).[31]

Table 38 Normalised performance matrix for all scenarios

Criteria		Scenario			
Primary	Secondary	0	1	2	3
Economic	NPV @ 7%	100	0	81	88
Human health	DALY	98	100	95	0
Environmental	Water Use	0	25	87	100
	Primary energy input	34	0	93	100
	Climate change	35	0	94	100
	Eutrophication	5	0	63	100
	Photchemical Oxidant Formation	32	0	82	100
	Terrestrial Ecotoxicity	33	0	88	100
	Marine Aquatic Ecotoxicity	33	0	91	100
	Freshwater Aquatic Ecotoxicity	33	0	88	100
Technical	Performance	80	80	80	80
	Reliability	80	80	60	80
	Durability	100	70	70	70
	Flexibility and adaptability	70	70	65	70
	Endure seasonal effects	100	100	80	80
	Level of experience with technology	100	60	60	80
	Ease of operation	90	60	53	63
Social	Acceptability to community	80	70	60	60
	Distribution of responsibility	20	20	60	80
	Organisational capacity and adaptability	90	80	70	60
	Public understanding and awareness	80	50	60	70

Similarly rank orders have been given to secondary criteria as well: freshwater use was considered to be the most important aspect from all environmental secondary criteria, followed by climate change, eutrophication, freshwater and marine aquatic ecotoxicity potential. Performance was considered to be more important than reliability, durability, flexibility, level of experience and ease of operation (see Table 39).

These rank orders give the NPV figure an importance that is three times higher than the second most important aspect, i.e. human health (16%). Environmental criteria are of lesser importance, i.e. freshwater usage has an overall weight of only 9%.

[31] For example, if ‘Economic’ is the most important and ‘Environment’ second most important of the 5 primary criteria, then $w_{economic} = \frac{1}{5}(1+\frac{1}{2}+\frac{1}{3}+\frac{1}{4}+\frac{1}{5}) = 0.4567$ and $w_{economic} = \frac{1}{5}(\frac{1}{2}+\frac{1}{3}+\frac{1}{4}+\frac{1}{5}) = 0.2567$.

Table 39 Rank order and weighting sets for primary and secondary criteria

Primary criteria	Rank	Weight	Secondary criteria	Rank	Weight	Overall weight
Economic	1	46%	NPV @ 7%	1	100%	45.70%
Human health	3	16%	Relative DALY	1	100%	15.70%
Environmental	2	26%				
			Water Use	1	34%	8.70%
			Primary energy input	7	3%	0.90%
			Climate change	2	21%	5.50%
			Eutrophication	3	15%	3.90%
			Photochemical Oxidant Formation	8	2%	0.40%
			Terrestrial Ecotoxicity	6	5%	1.40%
			Marine Aquatic Ecotoxicity	5	8%	2.00%
			Freshwater Aquatic Ecotoxicity	4	11%	2.80%
Technical	4	9%				
			Performance	1	37%	3.30%
			Reliability	2	23%	2.00%
			Durability	3	16%	1.40%
			Flexibility and adaptability	4	11%	1.00%
			Endure seasonal effects	5	7%	0.70%
			Level of experience with technology	6	4%	0.40%
			Ease of operation	7	2%	0.20%
Social	5	4%				
			Acceptability to community	1	52%	2.10%
			Distribution of responsibility	2	27%	1.10%
			Organisational capacity and adaptability	3	15%	0.60%
			Public understanding and awareness	4	6%	0.30%
					Total	**100%**

15.2.9 Calculation of an aggregated indicator score

In this section aggregated indicator scores are calculated by multiplying normalized performance scores of each scenario (see Table 38) with the derived weighting set as shown in Table 39 and adding up all products. The results show that Scenario 2 (water recycling in Greenfield) is the most preferred option (score: 82.5). Scenario 0 and Scenario 3 (demand management and rainwater tanks) have very similar scores, i.e. 75.9 and 75.6 respectively. These two options may be considered as equally performing. The desalination option (Scenario 1) has by far the poorest indicator score.

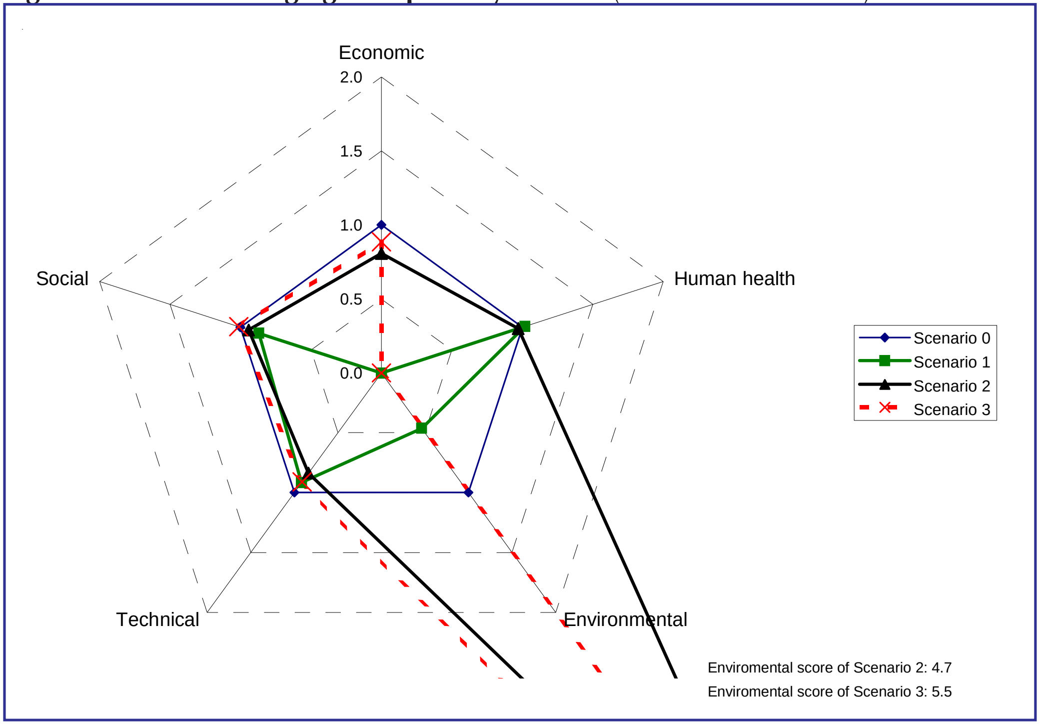
Chapter 15 - Hypothetical Case Study
continued

In Figure 6 Scenarios 1 to 3 are compared with scenario 0 against all primary criteria. The primary criterion score of each scenario is the sum of all weighted secondary criteria scores as listed in Table 40. This comparison highlights the strength and weaknesses of all scenarios relative to Scenario 0; Scenario 1 performs not as good as Scenario 0 in all aspects. Scenario 1 is dominated by Scenario 0. Scenario 2 can be considered to be equally good with regard to human health, social and technical dimension. Scenario 2 is slightly more expensive, i.e. 3% or $24m, but its environmental performance is five times better than Scenario 0. Scenario 3 has similar scores except for human health.

Table 40 Calculation of an aggregated indicator score using normalized performance data and weighting sets

Criteria		Weighted Scores Scenarios			
Primary	***Secondary***	***0***	***1***	***2***	***3***
Economic	NPV @ 7%	45.7	0	36.9	40.4
Human health	Relative DALY	15.4	15.7	14.9	0
Environmental	Water Use	0	2.1	7.6	8.7
	Primary energy input	0.3	0	0.8	0.9
	Climate change	1.9	0	5.2	5.5
	Eutrophication	0.2	0	2.5	3.9
	Photchemical Oxidant Formation	0.1	0	0.3	0.4
	Terrestrial Ecotoxicity	0.5	0	1.2	1.4
	Marine Aquatic Ecotoxicity	0.7	0	1.8	2
	Freshwater Aquatic Ecotoxicity	0.9	0	2.5	2.8
Technical	Performance	2.7	2.7	2.7	2.7
	Reliability	1.6	1.6	1.2	1.6
	Durability	1.4	1	1	1
	Flexibility and adaptability	0.7	0.7	0.6	0.7
	Endure seasonal effects	0.7	0.7	0.5	0.5
	Level of experience with technology	0.4	0.2	0.2	0.3
	Ease of operation	0.2	0.1	0.1	0.1
Social	Acceptability to community	1.7	1.5	1.3	1.3
	Distribution of responsibility	0.2	0.2	0.7	0.9
	Organisational capacity and adaptability	0.5	0.5	0.4	0.4
	Public understanding and awareness	0.2	0.1	0.2	0.2
	Total score	***75.9***	***27.1***	***82.5***	***75.6***

Figure 6 Benchmarking against primary criteria (baseline Scenario 0)



15.3 Identify preferred options

In Phase 6 of the sustainability framework (see Chapter 9) the most preferable scenario is identified. All information from previous phases of the framework are reviewed for consistency etc.

In this case study the relevance of decision makers preferences were further investigated, while performance data were not analysed. In Section 15.2.8, on page 86, economic considerations were given the highest priority followed by environmental, human health, technical performance and social aspects (see Table 39). These preferences might change over time in a carbon constraint economy with increased pressure on water resources. Therefore it seems to be sensible to test influence of preferences on the final rank order to scenarios. Two additional rank orders were applied, i.e.:

- Environmental criteria being more important than the economic criterion; and
- Environmental and economic criteria being equally important.

The rank orders of the remaining primary criteria, i.e. human health, technical and social, and all secondary criteria were unchanged. The transformation of ranks into weighting sets were carried out as described in Section 15.2.8. The weighting sets for the three ranking scenarios are shown in Table 41 (details are given in Table 46 and Table 47). It is worthwhile to mention that the NPV value was always the most important secondary criterion even if the primary environmental criterion had a higher priority than the economic one. This is due to the large number of secondary criteria in the environmental dimension.

Chapter 15 - Hypothetical Case Study
continued

Table 41 Alternative weighting sets

		Rank order		
Primary criteria	**Secondary criteria**	**$ > Env**	**$ = Env**	**Env > $**
Economic	NPV @ 7%	45.70%	35.70%	25.70%
Human health	Relative DALY	15.70%	15.70%	15.70%
Environmental				
	Water Use	8.70%	12.10%	15.50%
	Primary energy input	0.90%	1.20%	1.50%
	Climate change	5.50%	7.70%	9.80%
	Eutrophication	3.90%	5.40%	7.00%
	Photochemical Oxidant Formation	0.40%	0.60%	0.70%
	Terrestrial Ecotoxicity	1.40%	1.90%	2.50%
	Marine Aquatic Ecotoxicity	2.00%	2.80%	3.60%
	Freshwater Aquatic Ecotoxicity	2.80%	3.90%	5.00%
Technical				
	Performance	3.30%	3.30%	3.30%
	Reliability	2.00%	2.00%	2.00%
	Durability	1.40%	1.40%	1.40%
	Flexibility and adaptability	1.00%	1.00%	1.00%
	Endure seasonal effects	0.70%	0.70%	0.70%
	Level of experience with technology	0.40%	0.40%	0.40%
	Ease of operation	0.20%	0.20%	0.20%
Social				
	Acceptability to community	2.10%	2.10%	2.10%
	Distribution of responsibility	1.10%	1.10%	1.10%
	Organisational capacity and adaptability	0.60%	0.60%	0.60%
	Public understanding and awareness	0.30%	0.30%	0.30%

Scenario 2 (water recycling in Greenfield) scored the highest independent of the ranking order applied, while Scenario 1 (desalination) was always the worst option. Scenario 3 and 0 achieved equal overall scores when economic aspects were rated higher than environmental. However, Scenario 3 became clearly second best if the preference was shifted from economic to environmental considerations (see Tables 42, 48 and 49.

Table 42 Overall scores for alternative rank orders

		Scenarios			
Ranking		**0**	**1**	**2**	**3**
$ > Env	*Score*	*75.9*	*27.1*	*82.5*	*75.6*
	Rank	*2*	*4*	*1*	*2*
$ = Env	*Score*	*67.7*	*27.9*	*83.0*	*76.8*
	Rank	*3*	*4*	*1*	*2*
Env > $	*Score*	*59.5*	*28.7*	*83.5*	*77.9*
	Rank	*3*	*4*	*1*	*2*

15.4 Additional information on the case study

15.4.1 Normalisation

Figure 7 Spider Diagram for Min Max Approach Normalised Scores

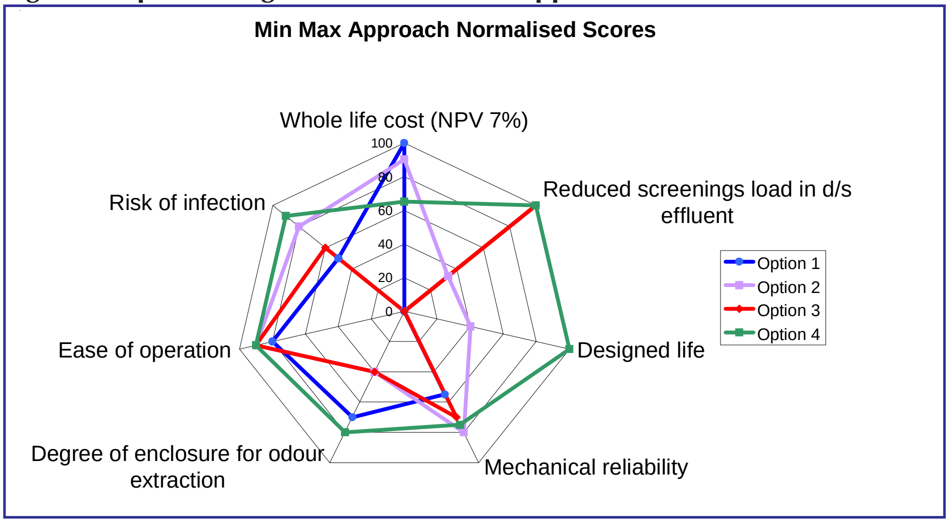
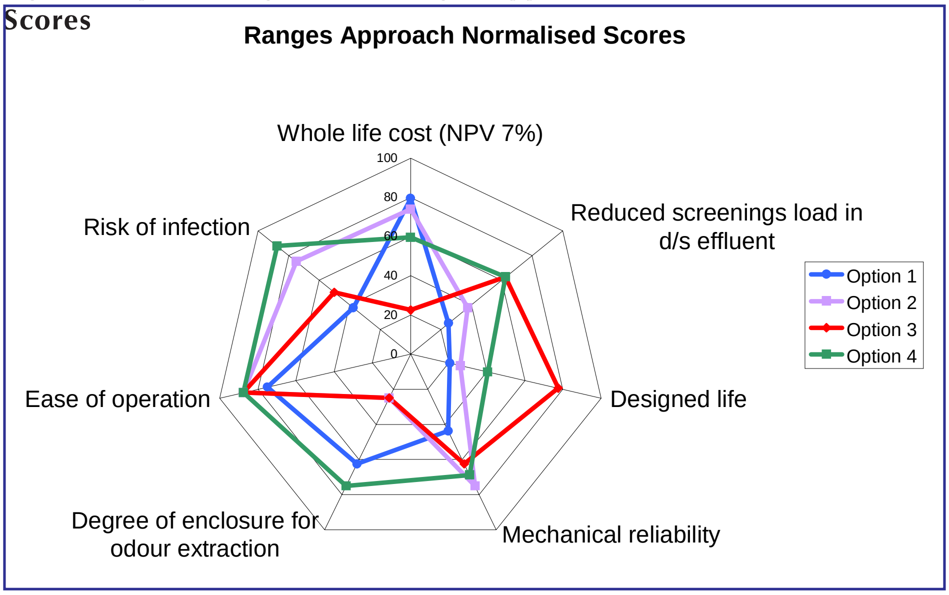


Figure 8 Spider Diagram for Ranges Approach Normalised Scores



Chapter 15 - Hypothetical Case Study

continued

15.4.2 Aggregation

Box 6: Aggregation

Case 1: Min-Max Method using Direct weighting approach

The following table shows the aggregation scores using normalised performance scored obtained from Min-Max Method.

Table 43 Calculation of a single index for each option using min-max method

Primary Criteria	Secondary Criteria	Option 1 Drum Screen	Option 2 Step screen	Option 3 Highflow screen	Option 4 Screw Compactor	Weights by Direct	Aggregated Scores Option 1	Option 2	Option 3	Option 4
Economics	Whole life cost (NPV 7%)	100	90	0	65	0.48	48	43	0	31
Environ - mental	Reduced screenings load in d/s effluent	0	33	100	100	0.28	0	9	28	28
Technical	Designed life	0	40	0	100	0.09	0	4	0	9
	Mechanical reliability	55	80	70	75	0.05	3	4	4	4
	Degree of enclosure for odour extraction	70	40	40	80	0.02	1	1	1	1
	Ease of operation	80	90	90	90	0.02	1	2	2	2
Health	Risk of infection	50	80	60	90	0.06	3	5	4	5
							57	68	38	81
						Rank	3	2	4	1

The results show Option 4 Screw Compactor had the highest aggregated performance score followed by Option 2 Step Screen, Option 1 Drum Screen and Option 3 High Flow Screen. Even though Option 4 Screw Compactor was not the cheapest option, the combination of its superior performance in environmental and technical primary criteria make it the preferred option.

As mentioned previously, using the Min-Max normalised performance scores will result in the best performance score getting a full normalised score of 100 whereas the worst performance score getting a normalised score of zero. However, in some cases, the difference between the best performance score and the worst was not very significant. For example: in Table 13 the environmental criterion between the highest scored option (Option 4, 75%) and the least (Option 1, 60%) is only 15% points. By using the Max Min method, the environmental criterion normalised scores for Option 4 would be 100 and Option 1 would have 0. The influence of this is evident in the large gap between the options' aggregated score. The smallest aggregated score (Option 3) was almost half of Option 4's. That would give the decision maker preference to Option 4 over all other options.

Box 6: Aggregation (continued)

Case 2: Ranges Method using Direct weighting approach

The following table illustrates the aggregation of scores using the Ranges Method to normalised performances scores.

Table 44 Calculation of a single index for each option using ranges method

Primary Criteria	Secondary Criteria	Option 1 Drum Screen	Option 2 Step screen	Option 3 Highflow screen	Option 4 Screw Compactor	Weights by Direct	Aggregated Scores Option 1	Option 2	Option 3	Option 4
Economics	Whole life cost (NPV 7%)	79	74	23	60	0.48	38	35	11	29
Environ-mental	Reduced screenings load in d/s effluent	25	38	63	63	0.28	7	11	18	18
Technical	Designed life	21	26	77	40	0.09	2	2	7	4
	Mechanical reliability	44	75	63	69	0.05	2	4	3	4
	Odour (degree of enclosure)	63	25	25	75	0.02	1	0	0	1
	Ease of operation	75	88	88	88	0.02	1	2	2	2
Health	Risk of infection	38	75	50	88	0.06	2	5	3	5
							54	59	44	62
						Rank	3	2	4	1

Chapter 15 - Hypothetical Case Study
continued

15.4.3 Economic assessment

Table 45 Economic assessment of scenario 0 to 3 using NPV at 7%

ITEM	DESCRIPTION	Scenario 0 Costs $000s	Scenario 0 Present worth 7%	Scenario 1 Costs $000s	Scenario 1 Present worth 7%	Scenario 2 Costs $000s	Scenario 2 Present worth 7%	Scenario 3 Costs $000s	Scenario 3 Present worth 7%
1	WATER SUPPLY SYSTEM								
	Water Storage	$104,000	$84,397	$0	$0	$44,000	$35,741	$24,000	$19,560
	Pump Station	$3,800	$2,366	$3,800	$2,366	$1,900	$1,183	$1,900	$1,183
	Balance Tanks	$3,600	$2,242	$3,600	$2,242	$0	$0	$0	$0
	Rising Main	$0	$0	$0	$0	$0	$0	$0	$0
	Terminal Storage	$0	$0	$0	$0	$0	$0	$0	$0
	Water Treatment Plant	$43,079	$20,176	$30,277	$14,163	$22,952	$10,723	$20,924	$10,081
	Clearwater Pump Station	$32,800	$24,724	$16,900	$10,836	$5,570	$3,781	$13,780	$8,893
	Delivery Trunk Main	$52,000	$38,901	$26,000	$16,191	$13,400	$8,345	$26,000	$16,191
	Major Service Reservoirs	$37,200	$18,922	$37,200	$18,922	$37,200	$18,922	$37,200	$18,922
	Distribution Mains	$13,212	$9,644	$13,212	$9,644	$13,212	$9,644	$13,212	$9,644
	Subdivision Reticulation	$19,209	$9,537	$19,209	$9,537	$192,087	$95,371	$19,209	$9,537
	Desalination plant and associated works	$0	$0	$0	$195,135	$0	$0	$0	$0
	Total	$308,900	$210,910	$150,198	$279,038	$330,321	$183,710	$156,224	$94,012
2	WASTEWATER SYSTEM								
	Subdivision Reticulation	$335,000	$177,970	$335,000	$177,970	$335,000	$177,970	$335,000	$177,970
	Major Carriers	$6,300	$3,418	$6,300	$3,418	$6,300	$3,418	$6,300	$3,418
	Pump stations	$100,000	$53,125	$75,000	$39,844	$75,000	$39,844	$75,000	$39,844
	Sewage Treatment Plants	$75,000	$32,282	$75,000	$32,282	$75,000	$32,282	$75,000	$32,282
	Discharge Pump Station	$0	$0	$0	$0	$0	$0	$0	$0
	Discharge Pipeline	$0	$0	$0	$0	$0	$0	$0	$0
	Offshore Discharge	$0	$0	$0	$0	$0	$0	$0	$0
3	DEMAND MANAGEMENT								
	Demand Management Program	$0	$0	$0	$0	$0	$0	$80,000	$56,189
	Leakage Reduction	$0	$0	$0	$0	$0	$0	$0	$0
4	RAIN TANKS								
	Rain Tank Installation 10kL	$0	$0	$0	$0	$0	$0	$500,000	$233,072
	less Incentive Payment	$0	$0	$0	$0	$0	$0	$0	$0
	plus Incentive Payment	$0	$0	$0	$0	$0	$0	$0	$0
	less Stormwater Benefits	$0	$0	$0	$0	$0	$0	-$60,000	-$27,969
5	RESIDENTIAL REUSE								
	Water Reclamation Plant	$0	$0	$0	$0	$30,000	$28,037	$0	$0
	Dual Reticulation	$0	$0	$0	$0	$162,050	$91,471	$0	$0
	less Incentive Payment	$0	$0	$0	$0	$0	$0	$0	$0
	plus Incentive Payment	$0	$0	$0	$0	$0	$0	$0	$0
	less Distribution System Benefits	$0	$0	$0	$0	-$51,325	-$28,091	$0	$0
	TOTAL	$1,134,099	$688,613	$791,695	$811,589	$1,292,668	$712,349	$1,323,749	$702,830

15.4.4 Alternative weighting sets

Table 46 Alternative weighting set environment > economics

Primary criteria	Rank	Weight	Secondary criteria	Rank	Weight	Overall weight
Economic	2	26%	NPV @ 7%	1	100%	25.70%
Human health	3	16%	DALY	1	100%	15.70%
Environmental	1	46%				
			Water Use	1	34%	15.50%
			Primary energy input	7	3%	1.50%
			Climate change	2	21%	9.80%
			Eutrophication	3	15%	7.00%
			Photochemical Oxidant Formation	8	2%	0.70%
			Terrestrial Ecotoxicity	6	5%	2.50%
			Marine Aquatic Ecotoxicity	5	8%	3.60%
			Freshwater Aquatic Ecotoxicity	4	11%	5.00%
Technical	4	9%				
			Performance	1	37%	3.30%
			Reliability	2	23%	2.00%
			Durability	3	16%	1.40%
			Flexibility and adaptability	4	11%	1.00%
			Endure seasonal effects	5	7%	0.70%
			Level of experience with technology	6	4%	0.40%
			Ease of operation	7	2%	0.20%
Social	5	4%				
			Acceptability to community	1	52%	2.10%
			Distribution of responsibility	2	27%	1.10%
			Organisational capacity and adaptability	3	15%	0.60%
			Public understanding and awareness	4	6%	0.30%

Chapter 15 - Hypothetical Case Study
continued

Table 47 Alternative weighting set environment = economics

Primary criteria	Rank	Weight	Secondary criteria	Rank	Weight	Overall weight
Economic	1	36%	NPV @ 7%	1	100%	35.70%
Human health	3	16%	DALY	1	100%	15.70%
Environmental	1	36%				
			Water Use	1	34%	12.10%
			Primary energy input	7	3%	1.20%
			Climate change	2	21%	7.70%
			Eutrophication	3	15%	5.40%
			Photochemical Oxidant Formation	8	2%	0.60%
			Terrestrial Ecotoxicity	6	5%	1.90%
			Marine Aquatic Ecotoxicity	5	8%	2.80%
			Freshwater Aquatic Ecotoxicity	4	11%	3.90%
Technical	4	9%				
			Performance	1	37%	3.30%
			Reliability	2	23%	2.00%
			Durability	3	16%	1.40%
			Flexibility and adaptability	4	11%	1.00%
			Endure seasonal effects	5	7%	0.70%
			Level of experience with technology	6	4%	0.40%
			Ease of operation	7	2%	0.20%
Social	5	4%				
			Acceptability to community	1	52%	2.10%
			Distribution of responsibility	2	27%	1.10%
			Organisational capacity and adaptability	3	15%	0.60%
			Public understanding and awareness	4	6%	0.30%

15.4.5 Application of alternative weighting sets

Table 48 Calculation of an aggregated indicator score using normalized performance data and weighting set environment > economics (see Table 44)

Criteria					
Primary	*Secondary*	*Weighted Scores*			
Economic	NPV @ 7%	25.7	0	20.7	22.7
Human health	DALY	15.4	15.7	14.9	0
Environmental	Water Use	0	3.8	13.4	15.5
	Primary energy input	0.5	0	1.4	1.5
	Climate change	3.4	0	9.3	9.8
	Eutrophication	0.4	0	4.4	7
	Photochemical Oxidant Formation	0.2	0	0.6	0.7
	Terrestrial Ecotoxicity	0.8	0	2.2	2.5
	Marine Aquatic Ecotoxicity	1.2	0	3.3	3.6
	Freshwater Aquatic Ecotoxicity	1.7	0	4.4	5
Technical	Performance	2.7	2.7	2.7	2.7
	Reliability	1.6	1.6	1.2	1.6
	Durability	1.4	1	1	1
	Flexibility and adaptability	0.7	0.7	0.6	0.7
	Endure seasonal effects	0.7	0.7	0.5	0.5
	Level of experience with technology	0.4	0.2	0.2	0.3
	Ease of operation	0.2	0.1	0.1	0.1
Social	Acceptability to community	1.7	1.5	1.3	1.3
	Distribution of responsibility	0.2	0.2	0.7	0.9
	Organisational capacity and adaptability	0.5	0.5	0.4	0.4
	Public understanding and awareness	0.2	0.1	0.2	0.2
	Total score	*59.5*	*28.7*	*83.5*	*77.9*
	Rank order of options	*3*	*4*	*1*	*2*

Chapter 15 - Hypothetical Case Study
continued

Table 49 Calculation of an aggregated indicator score using normalized performance data and weighting set environment = economic criteria

Criteria					
Primary	*Secondary*	*Weighted Scores*			
Economic	NPV @ 7%	35.7	0	28.8	31.5
Human health	DALY	15.4	15.7	14.9	0
Environmental	Water Use	0	3	10.5	12.1
	Primary energy input	0.4	0	1.1	1.2
	Climate change	2.7	0	7.2	7.7
	Eutrophication	0.3	0	3.4	5.4
	Photochemical Oxidant Formation	0.2	0	0.5	0.6
	Terrestrial Ecotoxicity	0.6	0	1.7	1.9
	Marine Aquatic Ecotoxicity	0.9	0	2.6	2.8
	Freshwater Aquatic Ecotoxicity	1.3	0	3.5	3.9
Technical	Performance	2.7	2.7	2.7	2.7
	Reliability	1.6	1.6	1.2	1.6
	Durability	1.4	1	1	1
	Flexibility and adaptability	0.7	0.7	0.6	0.7
	Endure seasonal effects	0.7	0.7	0.5	0.5
	Level of experience with technology	0.4	0.2	0.2	0.3
	Ease of operation	0.2	0.1	0.1	0.1
Social	Acceptability to community	1.7	1.5	1.3	1.3
	Distribution of responsibility	0.2	0.2	0.7	0.9
	Organisational capacity and adaptability	0.5	0.5	0.4	0.4
	Public understanding and awareness	0.2	0.1	0.2	0.2
	Total score	*67.7*	*27.9*	*83*	*76.8*
	Rank order of options	*3*	*4*	*1*	*2*

Table of Tables for Part A

Table of Figures for Part A

Part B - A review

comparing the WSAA Sustainability Framework to the Gold Coast Waterfuture process

by Sven Lundie, Greg M Peters and Nicholas J Ashbolt

Table of Contents

Synopsis

Background

Gold Coast Water developed a long-term plan for the sustainable management of water resources for the Gold Coast called the "Gold Coast Waterfuture" (GCWF). Independently, the Water Services Association of Australia (WSAA) engaged a consortium lead by UNSW to produce a "Sustainability Framework" to support the water industry in its long-term planning activities. The GCWF was never intended to be based on the Sustainability Framework, indeed, it could not have been. Yet when the two appeared it was clear they had a number of ideas in common.

The scope of this review was to examine the GCWF document and the planning process that led to it. The purpose was to consider the Water Services Association Australia (WSAA) Sustainability Framework and the degree of consistency between it and the process used for the development of GCWF. The Review Team from the Centre for Water and Waste Technology (CWWT) and the School of Civil and Environmental Engineering at the University of New South Wales were commissioned to:

- Describe how the GCWF process was pursued,
- Consider the extent to which GCWF is consistent with and,
- Identify principal differences between the process used by GCWF and the and the WSAA Sustainability Framework, and
- Make recommendations regarding the applicability and future directions in the development of the Framework.

In order to achieve these objectives the authors met with Gold Coast Water officers over two days to discuss the GCWF process, reviewed the relevant documents and carried out several detailed, interactive web-phone conferences with people who were involved in the project (see Section 1).

Project summary

This summary is subdivided into three sections:

General procedure (Section 1),

Stakeholder participation (Section 2) and

Methodological issues (Section 3).

Section 1 General procedure

The procedure taken in the GCWF project was largely consistent with the methodology proposed in the WSAA framework, both from a stakeholder engagement and methodological point of view.

Gold Coast Water (GCW) applied all elements of the WSAA Sustainability Framework. GCW did not choose to name them in the same way nor organise them in the same order as the 6 phases that are proposed in the WSAA framework. An attempt by the Review Team to match the components of the GCWF project with the phases of the WSAA Sustainability Framework reveals that it consisted of four 'stages', i.e. 1) describe strategy, 2) initial screening of options, 3) strategy assessment and scoring and 4) strategy comparison.

The major differences between the two approaches are:

- That 'stage 1' of the GCWF project included the preparatory activities for the project. Terms of reference were established which dealt with the rules of collaboration within the GCWF project. These were considered fixed for the length of the project, but were able to be interpreted as new issues arose. An agreement was generated on how to carry out the project including acceptance of the proposed Multi-Criteria-Analysis process and stakeholder participation. Also a common knowledge base related to water cycle management was generated for further discussions. These tasks are not considered in the WSAA framework. However, they do seem to be vital from an implementation point of view. How much emphasis on developing common knowledge is needed will depend on the scale of the project at hand.
- In the GCWF project, screening of unacceptable options was undertaken at an early stage ('stage 2'). The eventual strategy consists of a bundle of several different options. The WSAA framework provides for screening at a later stage, i.e. stage 4, to ensure the structure allows plenty of room for consideration of unconventional strategies, i.e. strategies 'outside the square' and iterations to evolve ideas. While the GCWF project was successful, as a general procedure the WSAA framework structure may offer a lower-risk means to success in this respect. Of course, if several iterations of the overall process occur, the order of events is less important.

Synopsis
Continued

Section 2 Stakeholder participation

For larger-scale projects or projects with a wide variety of options, both the GCWF-project and WSAA Sustainability Framework highlight the importance of stakeholder engagement that is facilitated by an independent chair:

- The role of chair is crucial for the delivery of high quality project outcomes in time. Anyone fulfilling the role of independent chair has to be highly skilled to deal with the different types of information which arise in such planning activities. The chair has to able to deal with heterogeneous groups and to talk to different stakeholder groups within the Advisory Committee as well as outside. It is job of this person to make sure that there is an outcome, but he or she should not have an influence on the direction of the outcome. By doing so, the chair achieves a thorough agreement on the process, but not necessarily on the outcomes.
- Permanent Advisory Committee: An Advisory Committee oversaw the entire duration of the GCWF project and was a key reason why this large-scale project was successful. The composition of the Committee did not change during the project. This enhanced the participants' confidence in the entire process. This approach seems to generate a high degree of continuity for stakeholders and supports the development of trust between all parties whether inside the Advisory Committee or outside.
- Fair representation of the societal groups: stakeholders have to represent the broader community; the Advisory Committee has to be balanced. In the GCWF project the Advisory Committee included representatives of environmental groups, resident groups, highschool-age youth, industry groups, state government agencies, elected councillors and council officers.
- Additional effort caused by participation: Participation requires time and may cause additional planning costs, but it ensures community ownership. In the GCWF project neither the Advisory Committee members nor the independent chairman were paid. Stakeholder engagement seems to be vital for engendering a sense of ownership of the process, the outcome and the implementation later on. Timing might become problematic when many stakeholders are involved, but we may expect to avoid delays during the more cost-intensive construction process by this means.
- Iterative procedure: Both the WSAA Sustainability Framework and the GCWF-project highlight the importance of an iterative procedure, i.e. having the chance to challenge assumptions and decisions that were made in earlier stages. Several iterations were performed in the GCWF project including adjustments of water strategies towards the end of the project.
- Control of the process: Stakeholder engagement may make it more difficult to predict the direction and outcomes of the process.

Section 3 Methodological issues

The GCWF methodology largely conformed with the methodology proposed in the WSAA Sustainability Framework. Quantitative and qualitative environmental, social and economic criteria were normalised and used for selecting the preferred strategy. However, there was one difference between the approaches:

- The WSAA framework recommends the consideration of economic, environmental and social aspects be undertaken in a similar way. As part of this, economic, environmental and social criteria need to be normalised and aggregated using a common process before the results are used for recommending the preferred strategy. This means explicitly giving each factor, including any cost score, a weight.
- In the GCWF project a different approach was taken. Environmental and social criteria were normalised, weighted and then aggregated into a single index for each strategy, i.e. the "non-cost" score. The whole-life-cycle costs were quantified separately and not normalised. Both costs and non-cost scores were then used for calculating the value for money score which was an impact score per billion dollars.

This separate handling of costs treats the economic aspects of the decision differently to the environmental and social aspects – at least formally. This separate handling of the financial data, and its use as a denominator in the value for money score, effectively forces a person reading the score to simultaneously consider cost and the aggregated non-cost score. Additionally, by normalising non-cost items and not normalising the cost score the variability of the latter relative to the non-cost score may be reduced. Valuably, this method was chosen consciously by the Advisory Committee and reflects their preferences for analysis. People who were not party to all the Committee's discussions on this at the time, and subsequent readers of the docu mentation, might not have access to all the Committee's deliberations and so not fully understand their reasons for using this method. With hindsight, the approach suggested in the WSAA project would be preferable from the point of view of delivering greater methodological transparency and consistency between GCWF and other strategic planning processes in other water service providers.

In providing guidance to other groups engaged in strategic planning, our analysis suggests attention may need to be paid to:

- **'Fair' system boundaries**: The analysis in the GCWF project highlighted the importance of comparable system boundaries for all strategies. In general, system boundaries should be drawn in such a way that the different services offered by different options are all included. However, there seems to be a tendency that the larger the system boundaries get, the more similar the costs become.
- **Criteria selection**: The Project Team for the GCWF project prepared a draft list of environmental, social and economic criteria. Only those criteria were suggested which would differ for the strategies under study. In principle, the authors agree with this approach, but we argue that it is extremely difficult to judge upfront whether criteria will vary for different options without thorough investigation. The application of sophisticated tools, such as Life Cycle Assessment, may help to overcome this problem.
- **Weighting of criteria** was done before any details of different strategies were revealed to the stakeholders in the GCWF process. This is a good way to prevent a 'tactical evaluation' of criteria being used in order to influence the selection process of the preferred strategy. Varying the weights and examining outcomes iteratively can also be a way of making the values of the decision-makers explicit or learning about weighting[1] .
- **Generating quantitative criteria scores**: three methods were discussed for converting quantitative results into scores, i.e. min-max, distance to target and range method. The latter was applied. The choice of method may have a significant impact on the overall recommendations.

[1] Another way to educate decision-makers about the principles behind the establishment of weights could be the use of role-play based on an imaginary decision process requiring little technical knowledge, for example, selecting some common domestic items.

Lessons learned

The WSAA Sustainability Framework provides a practical procedure that allows the evaluation of the overall sustainability of urban water systems. The comparison of the WSAA Sustainability Framework and the approach taken in the GCWF project has shown a high degree of concordance between the two approaches and has given us confidence that the WSAA Framework works. This case-study demonstrates the WSAA Framework in the context of large-scale decision-making, but we see no reason why it would not work when tailored to smaller projects.

GCW should be recognised as having undertaken a very comprehensive sustainability assessment process and encorporating an advanced form of community engagement which leads the way in the Australian water industry. This engagement has lead to a high degree of community support for GCW's plans. The GCWF project gives us substantial confidence that the stakeholder empowerment process is both practical and valuable for its ability to generate public endorsement for a planning process.

The comparison between the WSAA Framework and the GCWF project suggests the following practical advice for future projects:

- Allow sufficient time for setting up the project for establishing terms of reference, agreement on how to carry out the project and the generation of a common knowledge base for all participants.
- Engage an independent chairman who has no personal interest in any one particular outcome.
- Ensure transparency of the process: it is important to show participants the overall process that consists of several steps. Otherwise members may get confused and start questioning the process; mistrust may build up.
- Use tangible terminology that is understood by every Advisory Committee member.
- Decouple the criteria weighting process from the analysis of performance of strategies in order to avoid biased weighting.
- Apply sophisticated tools that cover a large range of issues, and
- Allow for iterations that allow option designs to be reworked on the basis of decision-maker feedback. Iterations ensure ownership, buy-in and high quality outcomes.

Recommendations

The following needs have been identified to progress the uptake of the WSAA Sustainability Framework:

- Encourage the application of the WSAA Sustainability Framework with the external advice from experts who are familiar with the Sustainability Framework in particular, sustainability in general and the water industry.
- Develop training modules for the application of sophisticated tools for quantification, fair system boundaries, normalisation and ranking/ weighting of criteria and for multi-criteria decision aiding (MCDA).
- Develop training modules for stakeholder participation.
- Carry out research to identify appropriate criteria, particularly to avoid 'double counting' of environmental and economic criteria.

1 Objectives of the project

The scope of this project was to examine the Gold Coast Waterfuture (GCWF) project and the planning process that led to it. The project team from the Centre for Water and Waste Technology (CWWT) undertook to:

- Describe how the GCWF process was pursued;
- Consider the extent to which GCWF is consistent with the WSAA Sustainability Framework;
- Identify principal differences between the GCWF and the Framework; and
- Make recommendations regarding the applicability and future directions in the development of the Framework.

In order to achieve the objectives of this project, we met with Gold Coast Water officers and representatives of WSAA over two days (3-4 November 2005) to discuss the GCWF process. We then reviewed the relevant documents that were provided to the project team, i.e.

- GCW (2005) Gold Coast Waterfuture Community Engagement Report. May 2005
- GCW (2005) Water Supply Strategies Development and Assessment Revision 4, Draft. July 2005 and
- GCW (2005) Gold Coast Waterfuture - Ensuring our future is on tap. September 2005.

Additionally, we interviewed people who were involved in the project:

- Pat Nixon (Senior Planning Engineer at SinclairKnightMerz; role in the project: Senior Planning Engineer; member of the Project Team),
- Phil Selmes (Project Manager at Gold Coast Water; role in the project: Project Manager; member of the Project Team) and
- Neil Sutherland (Gilbert & Sutherlands; role in the project: independent facilitator).

In this report the authors took the following approach: firstly the general approach is reviewed (see Section 2 on page 106), followed by a more detailed discussion on stakeholder engagement (see Section 3 on page 112) and methodological issues (see Section 4 on page 115). In each of these sections the Sustainability Framework of the Water Service Association Australia (WSAA) is delineated briefly first, then a description follows of the Gold Coast Waterfuture (GCWF) Project. At the end both approaches are compared and general conclusions are drawn.

2 General procedure

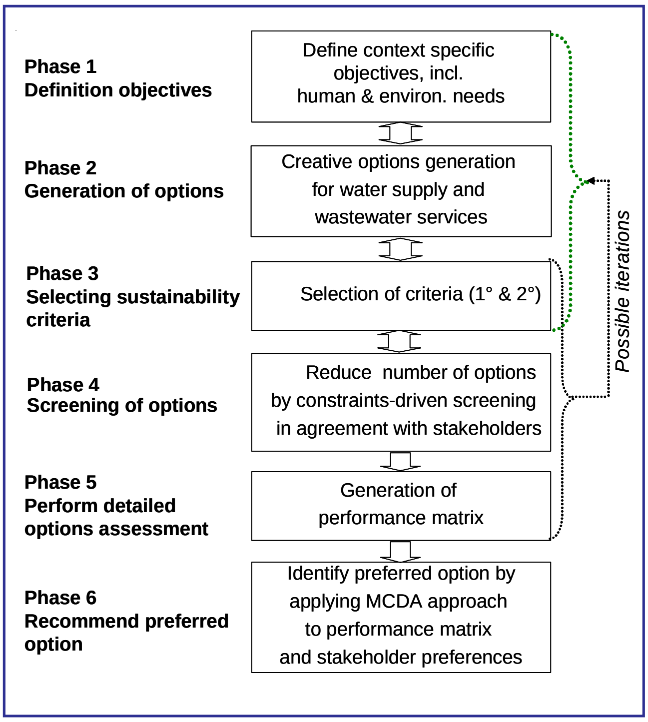
2.1 Water Services Association Australia Sustainability Framework

A consortium of researchers representing members of the Centre for Water and Waste Technology and the School of Civil and Environmental Engineering (UNSW, Sydney), Sustainable Water Division of the NSW Department of Commerce (Sydney) and Chalmers Industriteknik (Chalmers University, Sweden) developed a sustainability framework for the Australian Water Industry. The project was commissioned by Water Services Association Australia (WSAA).

The objective of the project was to develop a common methodology for evaluating the overall sustainability of alternative options for urban water systems. This includes large-scale options for cities as well as configurations of water sensitive urban developments or single high rise developments. In particular the project aimed for a common methodology for evaluating overall sustainability of alternative options for urban water systems, noting the range in alternative tools and approaches currently being used.

A sustainability framework was developed with six principal phases connec¬ted via an iterative process. This framework is summarised in Figure 1.

Figure 1: Conceptual relationships in the Sustainability Framework



To a varying extent, it is important that in each phase, the planning process follows both a participatory and methodological approach (see Table 1). By this Lundie et al., (2005) mean that a methodological framework should be followed because it provides a rigorous structure and a sense of progress towards the ultimate goal of selecting the preferred, sustainable option. But participation is just as important as having a robust framework and tools. The Sustainability Framework emphasises the inclusion of direct engagement with stakeholders from the first phase of project development onwards. Exactly who the relevant stakeholders are and how they may get involved in the planning process has to do with the scale of the problem and its potential solution. This may often include the public.

Table 1: Stakeholder engagement activities by process phase and system scale – WSAA Sustainability Framework (Lundie et al., 2006)

Phase	Objectives	Processes	Participants and	Scale[a]
1. Define problem and objectives	• Determine objectives that are in harmony with (or at least acceptable to) the project proponent, broader policy framework, stakeholder groups, and local community	• Steering committee· • Value management study • Market surveys· • Public conversations· • Reference to other studies, policies, planning controls, organisational goals, etc· • Document all assumptions and value sets used	• Owner/developer • Water authority • Consent authority • [Future] resident community • Relevant government departments • Relevant politicians • Relevant community or environmental organisations	• A • A • M-L • M-L • M-L • L • M-L
2. Preliminary options	• Provide a reasonably diverse and comprehensive set of possible solutions • Any proposed option should be included at this stage	• Brainstorming • Lateral thinking • Backcasting • Workshops • Expert consultants • Collaboration of diverse group	• Any of the Phase 1 participants with an interest in participating • Water management experts (from industry / academia)	• A • M-L
3. Determine sustainability criteria & weightings	• Arrive at a consensus (or aggregate) of stakeholder values • Within the five primary criteria, aim to reduce the total number of secondary criteria, to limit complexity of assessment process	• Citizens' Jury • Deliberative Panel • Expert panel • 'Value-tree analysis' • Public conversations • Etc.	• All stakeholders (i.e. see Phase 1)	• A
4. Screen options	• Reduce the number of options down to a number that can be thoroughly assessed (e.g. 4 or 5)	• Simple absolute yes/no decision based on qualitative assessment (or quantitative if values already known) against objectives and criteria already established • Identify if mitigation is possible, reassess	• Technical experts in consultation with the wider stakeholder group	• A (refers to tech. experts)
5. Detailed assessment	• Assess the impact of each of the options according to each of the criteria selected • Determine preferences on criteria	• Use whatever assessment tools are available: LCA, LCC, MFA, etc. • Surveys &/or focus groups • Identify if mitigation is possible, reassess • Ranking & normalisation of criteria	• Only local engineers • Broader technical experts • Community participation for social impact assessment	• S • M-L • L
6. Recommend preferred option	• Arrive at one preferred option which is either implemented or recommended, depending on the degree of authority	• Critical review of options & uncertainties, which for M-L projects may utilise multi-criteria decision add tools, such as SMART and STRAD	• Senior engineer • Representative stakeholders well informed in the whole process (i.e. see Phase 1)	• S-M • M-L

[a] Scale letters refer to: S – small-scale decision (such as pump or valve replacement) within an organisation; M – medium-scale decision (such as a major trunk main) involving external stakeholders; L – large-scale decision (such as a new subdivision with water/wastewater services in a large city); A – common to any scale.

2 General procedure
Continued

2.2 Gold Coast Waterfuture Project

Gold Coast City Council recognised the need to become smarter about how to use the water available to the community in the future. In doing so, the need was embraced for a diverse, balanced, adaptable and community-focused water supply strategy to provide the best possible solution for the Gold Coast. Four characteristics of a strategy were identified (GCW, 2005a):

- **Diversity**: By introducing a diverse range of water supply sources, it is envisaged that the security of our water supply will be enhanced, i.e. reducing demand, reducing loss, multiple water sources, using non-drinking water where appropriate;
- **Balance**: By embracing a balanced approach, a more sustainable community will be created by considering environmental, social and economic perspectives;
- **Adaptability**: By being adaptable, the GCWF Strategy will have flexibility to respond to future changes in water supply requirements, technological advancements or unexpected events, i.e. new technologies, innovations and information; and
- **Community input**: By incorporating community input, a feeling of joint ownership in the final Gold Coast Waterfuture Strategy decision will be created.

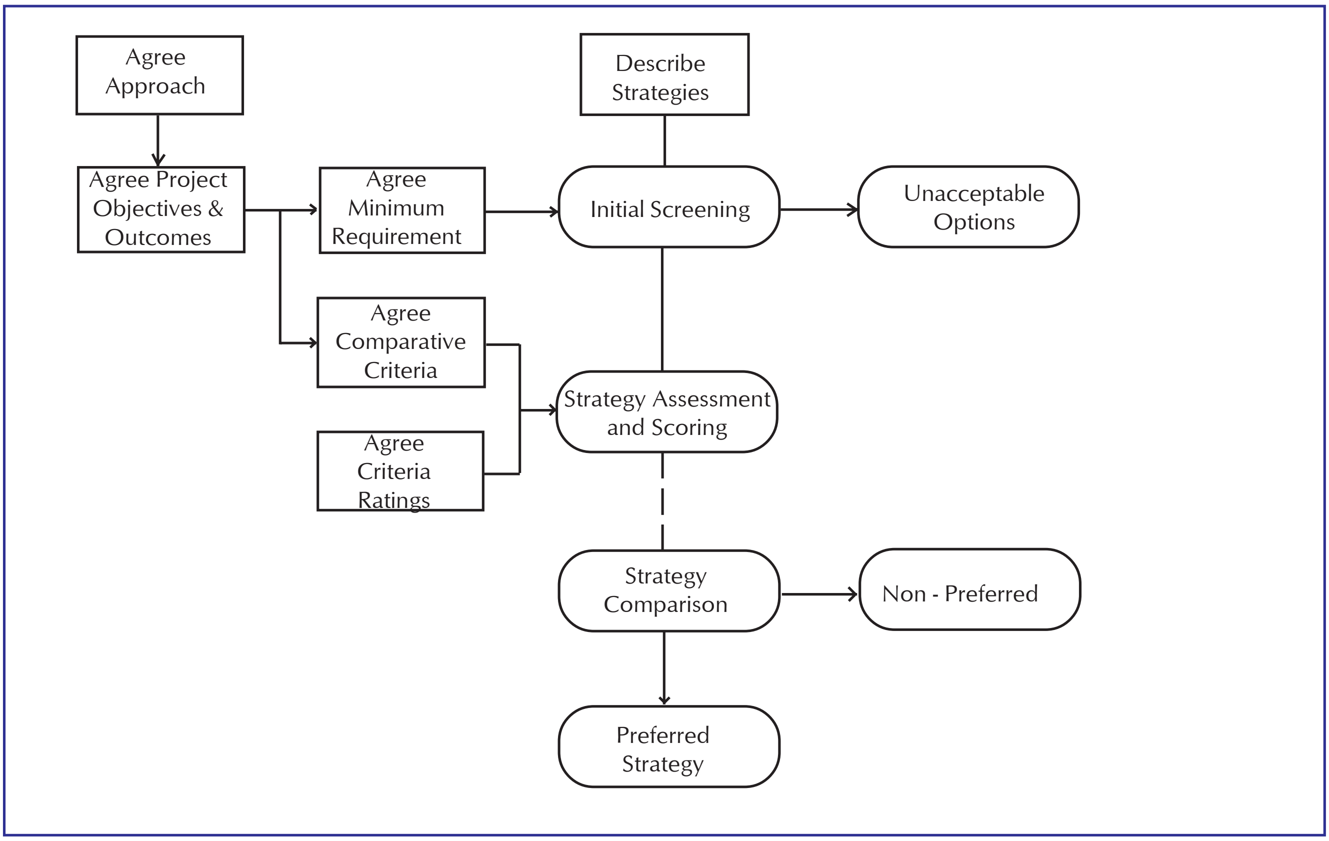
By combining all these elements, the GCWF Strategy made an attempt to create a sustainable community that leads the nation in innovative water supply. The approach is outlined in Gold Coast Water (2005c):

- Describe each strategy in sufficient detail to allow assessment.
- Check that each strategy meets the minimum requirements for the project that all strategies must satisfy.
- Assess and score each strategy against the 'comparative criteria' using a standard rating system. The comparative criteria have been defined as either quantitative criteria or qualitative criteria:
  - Quantitative criteria are those where the performance can be calculated using a standard method of analysis;
  - Qualitative criteria, which must be assessed subjectively by the Advisory Committee.
- Determine the total weighted 'non-cost' score for each strategy.
- Prepare estimates of whole-of-life cost for each strategy.
- Determine the 'value for money' score by dividing the total weighted non-cost score by the whole-of life cost.
- Rank the strategies based on the decision support tools; non-cost score, whole-of-life cost (PV) and value for money score.
- Consider the strategies based on feedback from consultation and comparison of scores.'

A schematic diagram of the process flow is given in Figure 2.

2 General procedure
Continued

Figure 2: Process flow diagram of the strategy evaluation methodology by Gold Coast Water for the WaterFuture project



Between April 2004 and August 2005 the Advisory Committee met monthly to consider the issues affecting the Gold Coast's water supply, including defining our water needs, investigating opportunities, developing and assessing alternative strategies and identifying the preferred GCWF Strategy.

The Advisory Committee was chaired by an independent chairman[2] . The Advisory Committee consisted of environmental groups, resident groups, youth representatives, industry groups, state government agencies, councillors and council officers.

A Project Team from GCW (consisting of 8-9 experts) and external consultants prepared inputs in form of draft documents for the meetings which were used as a basis for decisions. Decisions were passed by majority voting. All decisions made at the meetings were documented.

In Table 2 an attempt is made to match the components of the GCWF project with the phases of the WSAA Sustainability Framework. However, in the GCWF project no such phases were formally defined.

[2] Neil Sutherland, of Gilbert and Sutherland Pty Ltd, Robina, QLD

2 General procedure
Continued

Table 2: GGWF project - stakeholder engagement activities by process stage and system scale

GCWF Stage	GCWF Objectives	GCWF Process(es)	*WSAA Phase*
1. Describe strategy	• Agree on how to carry out the project including 1) acceptance of the proposed Multi-Criteria-Analysis process and 2) stakeholder participation • Generate common knowledge base for further discussions • Describe strategy	• A paper was prepared by the Advisory Committee and passed by the Council in which all rules for the process were described (Terms of Reference)	1. Define problem & objectives
2. Initial Screening of options	• Endorse objectives and outcomes • Define minimum requirements for options • Define options • Filter out unacceptable options according to minimum requirements	• Project Team from GCW prepared a draft set of minimum requirements • Acceptance of minimum requirements and exclusion of unacceptable strategies were passed by majority voting	*1. Define problem & objectives* *2. Preliminary options* *4. Screen options*
3. Strategy Assessment and Scoring	• Identify comparative criteria that differ for the different strategies • Arrive at a set of comparative criteria Agree on a weighting set for the criteria	• Project Team from GCW prepared a draft set of comparative criteria prior to the meeting • Decision on criteria selection was passed by majority voting • Project Team from GCW prepared a proforma weighting that was sent to the Advisory Committee members prior to the meeting • Median and average weights were calculated based on a 'Delphi-type' approach	*3. Determine sustainability criteria and weightings* *5. Detailed assessment*
4. Strategy comparison	• Assess the impact of each strategy according to non-cost scores, costs, value for money scores, financial aspects and community consultation outcomes • Arrive at one preferred strategy which is recommended	• The Project Team calculated the non-cost score, costs for strategies, information on finances (infrastructure and recurrent water charges) • Applied decision support tools for quantifying a value for money score	*6. Recommend preferred option*

2.3 Comparison of approaches and general findings

Prior to stage 1 the GCW Project Team analysed the situation and approached stakeholder groups with regard to their interest to participate in the process. Groups were asked to nominate a representative.

Stage 1 of the GCWF project served the purposes of agreeing on the rules for cooperation and generating a homogenous knowledge base. This stage was time intensive (e.g. 4 meetings were required) and resulted in some participants feeling a degree of frustration with the high level of attention to procedure, but it was considered as being crucial for the success of the project.

Stage 2, i.e. initial screening, consisted of getting agreement on objectives and outcomes, defining minimum requirements, discussing options which were proposed by members of the Advisory Committee or external consultants and filtering out unacceptable options that did not fulfil the minimum requirements. Minimum requirements correspond to outcomes and ensure that community values are maintained, i.e. protecting community health and environmental health, setting minimum water resource requirements.

Everyone was given the opportunity to present their option/proposal to the Advisory Committee in order to ensure that a broad spectrum of options is considered (‘diversity of options’). However, the presentation and discussion requires substantial time resources.

The Project Team identified key words (or key drivers), such as water security, water balance, adaptability, diversity etc. These key words were maintained their significance throughout the entire process. They were needed to bring the discussion to the point and used for describing the objectives. The objectives were discussed on the floor, i.e. during the meetings.

In terms content, stage 2 in the GCWF project is very similar to Phase 1 & 4 of the WSAA Sustainability Framework.

Stage 3, i.e. Strategy Assessment and Scoring, is very similar to Phase 3 of the WSAA framework as it includes identifying and agreeing on a set of comparative criteria and criteria weighting. In order to avoid the risk of bias in the establishment of weights, the evaluation methodology was deliberately determined before any results were presented.

The strategy comparison (i.e. Stage 4) combines two phases of the WSAA framework, i.e. Phase 5 Detailed assessment of options and Phase 6 Recommend preferred option. Here the impact of each strategy is assessed: The non-costs score and the costs are calculated. Both figures feed into the value for money score. This score as well as financial aspects and community consultation outcomes were used for identifying the preferred strategy.

3 Stakeholder participation

3.1 WSAA Sustainability Framework

The WSAA Framework emphasises that stakeholder participation is crucial for successful application of any sustainability framework but that the extent of stakeholder participation may vary depending on the goals and objectives of each phase and the overall scale of the project.

Moving towards sustainability means a paradigm shift among all water users (i.e. among the entire population), and this is both cognitive (what people believe) and behavioural (what they do). One single technocratic decision, such as one arrived at by following the WSAA Framework, is not so important for ensuring transition towards sustainability, compared to a cumulation of small decisions and changing patterns of 'normal practice'.

There are critical points when innovations are proposed for introduction. Innovations are vulnerable to veto from outside the 'expert collective', and at these points, the decision process is critical: how people with a capacity to make the proposal stall, or go forward, relate to the process of considering it. The critical point about assessment methods is not whether they convince the experts, but whether the use of it forms part of a broad mobilisation of understanding and practices among both users and providers, as opposed to a short cut to a 'decision'.

The decision tools outlined in the WSAA Framework both inform and support changing beliefs and practices as they interact. This document includes a strong emphasis on engaging stakeholders throughout the decision-making process and technical details on how to use the available tools to inform such a decision. These broad principles of participation described here are supported with further explanation of their application through each of the phases.

The WSAA Framework allows that there are a number of different consultation processes that may be appropriate for any given project (see Table 1). Citizen and/or stakeholder participation for sustainability is a new and developing field (Kasemir et al., 2003) with limited history in water management in Australia (Robinson, 2002).

The planning process outlined in the WSAA Framework is based on the use of a steering committee (also known as advisory committee, working group, etc.), as this is already widely used and understood. Additional methods for informing and consulting a wider community may be necessary. These may include public information displays, websites, newsletters, fact sheets and telephone information lines.

The WSAA Framework proposes that a steering committee should be established for the duration of all six planning and evaluation stages, and that its size and scope of players is project specific. A consistent approach to involving stakeholders should maximise their sense of ownership and buy-in, and thus result in a shared feeling of trust and responsibility for implementation the selected system. Ideally the steering committee will take on ownership of the entire planning and decision-making process, consummating with a credible and acceptable decision (or recommendation to make to the decision-making body).

The size of the committee, degree of formality, the frequency and duration of meetings will vary by project. It is better (though not as important in minor projects) to have an independent chairperson. The chairperson should not have any personal interest in any one particular outcome, and could be a respected community leader or a private consultant.

The chairperson should aim to bring the committee to consensus through deliberation rather than bring closure early through voting, which may foster greater antagonism and discontent. Voting should be used only when consensus cannot be reached otherwise. Consensus does not necessarily mean everyone has to achieve a 'win' outcome, but it means the parties are able to live with the concessions necessary to achieve a workable solution.

Depending on the nature of the project, the WSAA Framework suggests the committee may consist of a few to up to 20 members, comprising representatives of all key stakeholder groups. The chairperson should preside over the selection process to ensure that no groups are over or under-represented on the committee.

3.2 Gold Coast Waterfuture Project

The GCWF project was characterised by intensive stakeholder participation. Special aspects were:

- Professional facilitation: The Advisory Committee that was chaired by an independent chair. The chair considered it his job to achieve an outcome in time without directing it and while deflecting any outside pressure. In the discussion he had to adjudicate the debate and ensure scientific rigour. During the project the chair did not do any project work for Gold Coast Water. He was not paid for his role as a facilitator.
- Constituents of the Advisory Committee: The Advisory Committee consisted of environmental groups, resident groups, youth representatives, industry groups, state government agencies, councillors and council officers. The Advisory Committee existed over the duration of the entire project. There were ~15 participants at any one time attending the Advisory Committee meetings, 22 participants were on the list. Establishing the Advisory Committee was a challenge. Some participants arrived with their own agendas.
- Terms of reference: at the beginning a paper was prepared by the Advisory Committee which dealt with the rules of the Committee's collaborative work. This document was passed by the Gold Coast City Council. These were considered fixed for the length of the project, but were able to be interpreted as new issues arose.
- Participation of stakeholders: the chairman encouraged active stakeholder participation. He made sure that everyone was heard. The debate was as important as the results. Some participants who did not cooperate 'in a constructive way' were replaced after a while.
- Iterations: Participants were encouraged to criticise the outcome(s) of each stage, such as the objectives, in order to ensure that all participants support the decision made. The process was very dynamic as a lot unforeseen information came up during the project. Consequently, there was usually one iteration within each stage to incorporate the changes.
- Communication with the public: The Advisory Committee agreed to act as a group, not as individuals. In other words, individual stakeholders were not allowed to present positions that dissented from the position the Advisory Committee had agreed upon to the press or other external people, such as the councillor (i.e. 'cabinet solidarity').
- Time requirements: four meetings were needed upfront in this project to achieve a similar knowledge base amongst the participants. That was frustrating for those who were familiar with the topic. Meetings were held on a monthly basis over the entire duration of the project. All participants had to review several documents which had been prepared by the Project Team or other external consultants. Hence, there was a lot of time pressure on all participants. A longer project duration would have been less stressful.
- Ensuring efficient work progress: The Project Team and other external consultants prepared discussion documents (draft papers) for stakeholder meetings, such as Terms of References, minimum requirements, strategies, recommendations etc. These documents were discussed at the meetings. Decisions were passed on that basis.
- Decision making: 50% of the votes were needed to pass a decision (quorum).
- Governmental representatives: Governmental representatives, i.e. elected and appointed state and local government officers were not allowed to vote. This had the effect of ensuring Advisory Committee decisions represented a local community position, rather than allowing party-political agendas to have a significant role in deciding the outcomes.

3 Stakeholder participation
Continued

3.3 Comparison of approaches and general findings

- The GCWF project is characterised by an intensive, interactive stakeholder engagement process throughout the entire duration of the project. The procedure taken in this project is very similar to the suggestions made in the WSAA Sustainability Framework. Key features are:
- The independent chair should not have any personal interest in any one particular outcome. The chair plays a crucial role in such a complex project. He or she has to be able to deal with and talk to different stakeholder groups within the Advisory Committee as well as outside. The chair has to look after the process and ensure that everybody is heard. It is the chair's job to make sure that there is an outcome, but to avoid having an influence on the direction of the outcome. By doing so, the chair achieves thorough agreement on the process, but not necessarily on the outcomes.
- Permanent Advisory Committee: There was a permanent Advisory Committee over the entire duration of the project. This enhanced confidence in the entire process. This approach seems to generate high continuity for stakeholders.
- Participation can be time and money intensive for a large scale strategy, but it ensures community ownership. It is vital for having ownership of the process, the outcome and the implementation later on. Timing might become problematic when many stakeholders are involved. Smaller strategies might not need the same level of participation as required in the GCWF project.
- Iterative procedure: Both the WSAA Sustainability Framework and the GCWF-project highlight the importance of an iterative procedure, i.e. having the chance to challenge assumptions and decisions that were made in earlier stages.
- Control of the process: Stakeholder engagement will make it more difficult to predict the outcomes and the timing of the planning process; the latter be varied by participants. On the other hand, stakeholder engagement may avoid delays associated with adverse community reaction during the more cost-intensive construction phase.

4 Methodological issues / analytical approach

4.1 Water Service Association Australia Sustainability Framework

A quick synopsis of the six phases in the proposed WSAA framework is given in Section 2 on page 106. Many methodological choices are made in phases 3 Selection of criteria, 5 Perform detailed options assessment and 6 Recommend preferred option:

- Phase 3 Selecting sustainability criteria: The selection of criteria to be used for screening options (Phase 4) and for assessing the performance of prioritised options in detail (Phase 5). The selection of criteria is critical, it should cover the five primary criteria (economic, human health, environment, technical and social) and it needs to encapsulate the various context-specific objectives identified in Phase 1 Framing the problem and objectives. However the number and types of secondary criteria depend very much on the actual project planned.
- Phase 5 Perform detailed options assessment: Performing an assessment of the options should provide reasonably accurate quantitative and/or qualitative comparisons of each option shortlisted in Phase 4 based on criteria chosen in Phase 3. If participation has been adequately undertaken in previous phases, relevant experts should be tasked by the stakeholders to undertake the detailed assessment and bring back data for the final option recommendation (Phase 6). It is during Phase 5 that various tools (such as Life Cycle Assessment, Life Cycle Costing, Microbial Risk Analysis, Chemical Risk Analysis etc.) are used to provide data on each of the agreed criteria that required quantification. The indicator results should be normalised in terms of selecting a reference point and weighted, or compared to aspiration goals set by the organisation or by the government. This will minimise any bias during the evaluation in Phase 6.
- Phase 6 Recommend preferred option: In Phase 6, the final recommendation is made for the preferred option(s). All of the previous information collected during Phases 1-5 are clearly presented to a more limited number of key stakeholders involved in Phase 6. In addition to the consolidated information provided on the five primary / secondary criteria from Phase 5, the stakeholders in Phase 6 should work through the data, possibly by way of a transparent multi-criteria decision aiding tool, such as the Simple Multi-Attribute Rating Method ("SMART") or the Strategic Advisor ("STRAD") approach. The goal here is not only to 'rediscover' the direct criteria ratings from Phase 5, but to understand the impacts caused by variations in rankings, uncertainty, and if necessary, weightings, so providing further insight for the final recommendation by covering each of the criteria and options.' The end result of this phase is either a set of criteria results or one aggregated score for each strategy by using multi-criteria decision aiding tool or rank order of options' (Lundie et al., 2005).

Lundie et al. (2005) highlight that all assumptions and value sets used need to be documented for each phase.

4 Methodological issues / analytical approach
Continued

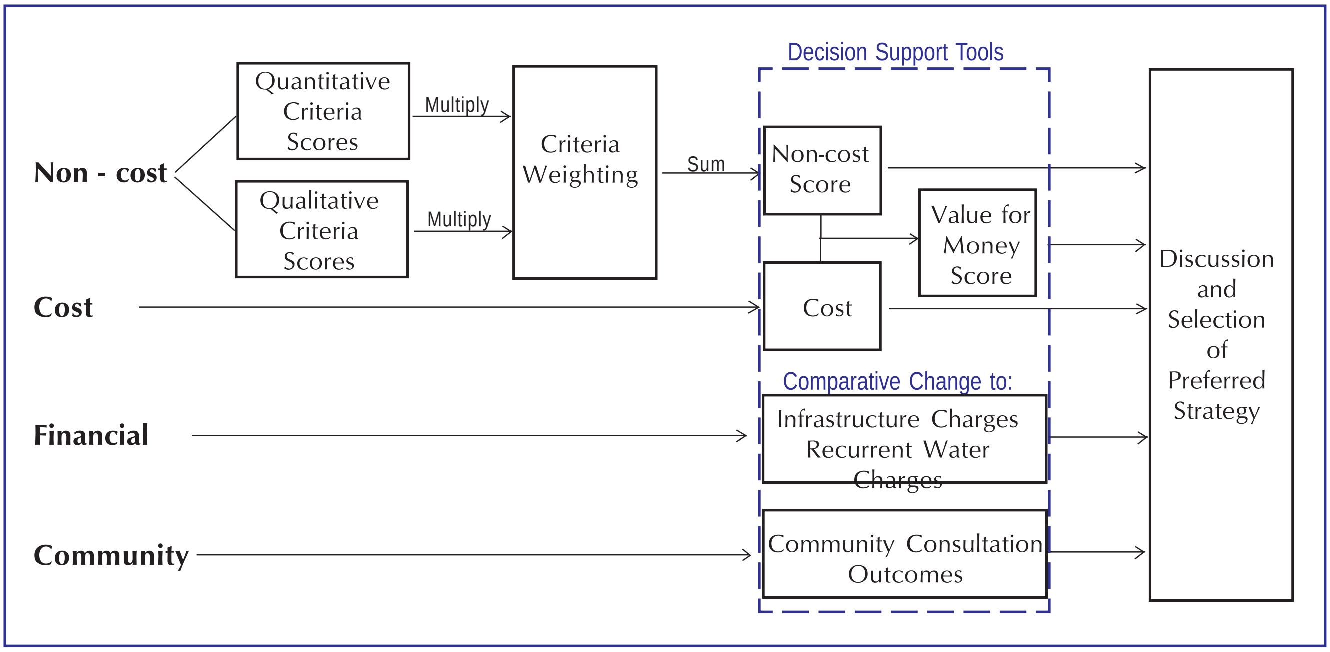
4.2 Gold Coast Waterfuture Project

Gold Coast Water followed a multistage decision making process that consisted of non-cost (environmental and social), cost, financial and community aspects (see Figure 3).

The decision making process employed in the GCWF project was complex. It is worthwhile to highlight several features:

- Criteria development: The Project Team prepared a draft list of environmental, social and economic criteria. Only those criteria which would differ for the strategies under study were carried forward. These criteria were differentiated into quantitative and qualitative criteria. The Advisory Committee adapted the suggestion of the Project Team and agreed on a final set of 13 criteria:
    - o 5 quantitative criteria, i.e. 2 environmental criteria (area to be permanently cleared and minimisation of greenhouse gas emissions), 2 social criteria (security of water sources and provision of water that is 'fit for purpose') and 1 economic criterion (whole of life costs for all water services). Costs: The costs were calculated on whole of life costs for all water services basis. The Net Present Value was estimated by including capital costs, renewal costs, operational and maintenance costs; and
    - o 8 qualitative criteria, i.e. 3 environmental criteria (short term impacts of construction activities, importance and value of ecosystems lost and long term impacts on the environment), 4 social criteria (probability of restrictions being applied, ability to accommodate change, Impact on local communities and likelihood of community acceptance of the strategy). Exposure to significant risks has been qualitatively been addressed; this is a separate decision support tool itself.
- Criteria selection: The selection of the criteria was done before details of different strategies were revealed. This prevents 'tactical evaluation' of criteria in order to influence the selection process of the preferred strategy.
- Generating quantitative criteria scores: 3 methods were discussed for converting quantitative results into scores, i.e. min-max, distance to target and range method. The min-max method spreads out the results even if the comparing strategies are very similar (see page 41 of Lundie et al., 2005). For the distance to target method, aspirational targets are needed for each criterion. In the case of the range method a realistically best and worst option needs to be identified which requires additional effort. However, the scoring is more realistic than for the min-max method. In this project the latter method was chosen

Figure 3: Decision making process in the GCWF project



by the Advisory Committee. At the end, each non-cost criterion was normalised to a score from 1 to 5.

- Generating qualitative criteria scores: For calculating the non-cost score qualitative information needs to be converted into quantitative figures in order to multiply them with their respective weight.

  The Project Team provided information on all qualitative criteria, such as strategy descriptions, issues to be considered, community engagement report, strategic risk assessment report etc. Additionally, the Advisory Committee members were encouraged to use further information in order to get a rigorous understanding of each criterion. The members had the opportunity to present the view on any criterion to the group. Then each criterion was given a score from 1 to 5 by each of the Advisory Committee members; 9 members participated in this exercise. The members of the Advisory Committee had 3 weeks time for the assessment. There was no iteration for the qualitative assessment.

- Criteria weighting: The Project Team sent voting members a proforma. 100% were giving to each member. Everyone had to allocate the percentage points to the criteria according to the preference perceived by each member. The members tended to vote moderately.

  Based on the individuals' weightings, the median and average weight were calculated for all criteria[3]. The results were sent back to the members for reconsidering their respective voting ('Delphi'-type approach). A sensitivity analysis of the weighting was carried out in order to analyse whether the preference order of strategies was sensible compared to the weighting.

- Non-cost score: This score was calculated by multiplying the normalised scores of quantitative and qualitative criteria with their respective weights. These products are summed up to one aggregated score for each strategy.

- Value for money score was calculated by dividing the non-cost score by the cost score. These results provided a clear rank order of strategies. However, the strategies we not selected based on this rank order. Industry groups and residents intervened as best the strategy according to the value for money score was less adaptable later on and it was likely to require large infrastructure for recycling water at the beginning. This would have caused high costs at the beginning. Instead the third option according to the value for money score was modified and finally selected.

4.3 Comparison of approaches and general findings

The GCWF methodology is largely consistent with the methodology proposed in the WSAA framework. Quantitative and qualitative environmental, social and economic criteria are normalised and used for selecting the preferred strategy.

However, there is an important difference between the approaches:

- The WSAA framework recommends identical consideration be given to economic, environmental and social aspects: economic, environmental and social criteria need to be normalised and aggregated using a common process before the results are used for selecting the preferred strategy. This means explicitly giving each factor, including any cost score, a weight.
- In the GCWF project a different approach is taken. Environmental and social criteria are normalised, weighted and then aggregated into single index for each strategy, i.e. the "non-cost" score. The whole-life-cycle costs are quantified separately and not normalised. Both costs and non-cost scores are then used for calculating the value for money score which is an impact score per billion dollars.

The separate handling of costs treats economic aspects

[3] Median = the middle value in a sample set. Examining the median as well as the mean (or average) of weights allowed the members to know whether any were strongly effected by an unusually strong preference from one member, or strategic voting/ biasing on the basis of a single issue.

4 Methodological issues / analytical approach
Continued

of decisions differently to the environmental and social aspects – at least formally. This separate handling of the financial data, and its use as a denominator in the value for money score, effectively forces a person reading the score to simultaneously consider cost and the aggregated non-cost score. Additionally, by normalising the non-cost scores and not normalising the cost score, the latter's variability relative to the non-cost score may be reduced. Valuably, this method was chosen consciously by the Advisory Committee and reflects their preferences for analysis. People who were not party to all the Committee's discussions on this at the time, and subsequent readers of the documentation, might not have access to all the Committee's deliberations and so not fully understand their reasons for using this method. With hindsight, the approach suggested in the WSAA project would be preferable from the point of view of delivering greater methodological transparency and consistency between this planning project and other strategic planning processes in other water service providers.

Further findings are:

- Greenhouse gas emissions: With the benefit of hindsight regarding recent national directions in climate change policy, it would have been prudent for the GCWF process to determine the impact of carbon emissions on the financial bottom-line. This could then have been carried through into the value for money scores as a rapid scenario check or iteration of the Advisory Committee's calculations. In this case the greenhouse component of the non-cost score would have to be deleted to avoid double-counting. The WSAA Framework says that emissions to air should be included in the calculation of life cycle costs if discharge fees apply. This now seems likely to occur in some form or other.
- Tangibility of terminology: This aspect of the project was a challenge for the Project Team as they had to use terminology / words which are fully understood by the Advisory Committee members. The Project Team may have had an influence on the scoring of the qualitative criteria (and with that on the overall non-cost score) depending on the quality of the description of social and environmental impacts.
- Application of 'sophisticated' tools: In the GCWF project a comprehensive set of criteria are analysed. However, the analysis is limited to specific aspects only, such as greenhouse gas emissions. Sophisticated tools, such as Life Cycle Assessment, are not applied because they were considered to be too labour intensive and costly. However, such tools would generate much broader view on the strategies under study; criteria, such as primary energy demand, human and various types of eco-toxicity etc., could be easily quantified. The results of a more diverse set of criteria may have helped to differentiate more clearly the strategies.
- System boundary: The analysis highlighted the importance of 'fair' system boundaries for all strategies. However, the larger the system boundaries are the more similar the costs tend to be.
- Relevance of indicator results: It is difficult for people to understand the meaning of indicator results, e.g. how do 400,000 t of CO^2-equivalents released to atmosphere impact on climate change and how does that impact on people's life? Therefore, it is important to make these results more understandable for them. The Project Team tried to overcome this problem by introducing figures that are meaningful to everyone, e.g. greenhouse gas emissions were expressed on a per capita per annum basis. This could be compared with other activities, such as emissions caused by driving a car. Greenhouse emissions in particular could also be monetised using an indicative price of carbon to use units to which people can relate.
- Similarity of results: The non-costs scores for the different strategies were not that much apart. Reasons for this are at least twofold:
- 1) application of the range method for quantitative criteria compressed the resulting score as a strategy rarely gets the worst possible score within a range, and
- 2) non-costs scores for qualitative criteria could have been further dispersed by using a 1 to 10 scoring system rather than a 1 to 5 system as the participants tended to give scores in a very narrow range for all options.
- At the same time, costs were very similar for all strategies, ranging from 5.7 – 6.1 billion dollars (~8% between the most and the least costly strategy).

5 Conclusions

The comparison of the WSAA Sustainability Framework and the approach taken in the GCWF project shows a high degree of concordance between the two approaches and gives us confidence that the WSAA Framework works.

We have considered the overall procedure of the WSAA Framework and the GCWF project, reviewed the stakeholder consultation processes employed and analysed the methodological content of the two planning processes. While there are some differences of nomenclature, scoring methods and alternative ordering of structural elements, it is recognised that the WSAA Framework is a guideline document rather than a detailed operating procedure. The WSAA Framework proposes variations and iterations in planning processes based on the particulars of the particular project.

The GCWF project is a significant example of a successful planning project consistent with the WSAA Framework. GCW should be recognised as having undertaken a very comprehensive sustainability assessment process and having incorporated an advanced form of community engagement which leads the way in the Australian water industry. This engagement lead to a high degree of community support for GCW's plans.

The WSAA Sustainability Framework provides a practical procedure that allows the evaluation of the overall sustainability of urban water systems.

6 References

Gold Coast Water (2005a) Gold Coast Waterfuture – Ensuring our future is on tap. Your complete guide to the preferred Gold Coast Waterfuture Strategy 2006 – 2056, Gold Coast City Council

Gold Coast Water (2005b) Gold Coast Waterfuture Community Engagement Report. May 2005

Gold Coast Water (2005c) Water Supply Strategies Development and Assessment Revision 4, Draft. July 2005.

Kasemir, B., Jäger, J., Jaeger, C. C. and Gardner, M. T. (Eds.) (2003), Public Participation in Sustainability Science, Cambridge University Press, Cambridge.

Lundie, S., Ashbolt, N., Livingston, D., Lai, E., Kärrman, E., Blaikie, J. and Anderson, J. (2005) Sustainability Framework - Methodology for Evaluating the Overall Sustainability of Urban Water Systems. Sydney 2005

Lundie S., Peters G., Ashbolt N., Lai E., Livingston, D. (2006) A sustainability framework for the Australian water industry. Water, 33(7)83-88. ISSN 0310-0367, November 2006. Australian Water Association, Sydney.

Robinson, J. J. (2002), Environmental value transfer: an application for the South East Queensland waterways, Water Science and Technology, 45(11), 91-100.

Contact details:

CENTRE FOR WATER AND WASTE TECHNOLOGY
School of Civil and Environmental Engineering

THE UNIVERSITY OF NEW SOUTH WALES

School of Civil and Environmental Engineering
Centre for Water and Waste Technology
University of New South Wales
Building H22, Vallentine Annex
Botany Street, Gate 11
Kensington NSW 2033

Associate Professor Sven Lundie
Email: S.Lundie@unsw.edu.au

U.S. Environmental Protection Agency
26 W. Martin Luther King Dr.
Cincinnati, OH 45268
USA
Professor Nicholas Ashbolt
Email: ashbolt.nick@epa.gov

WATER SERVICES ASSOCIATION OF AUSTRALIA
http://www.wsaa.asn.au
email info@wsaa.asn.au

MELBOURNE OFFICE
Level 8
469 La Trobe Street
Melbourne
Victoria 3000

PO Box 13172
Law Courts Post Office
Melbourne
Vic 8010
Phone: 03 9606 0678.
Fax: 03 9606 0376
Email info@wsaa.asn.au

SYDNEY OFFICE
Level 11
91 York Street
Sydney
NSW 2000

PO Box A812
Sydney South
NSW 1235
Phone: 02 9290 3266
Fax: 02 9299 0298
Email: david.cox@wsaa.asn.au