Towards Assessment Criteria for Water Sensitive Cities

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The Urban Water Security Research Alliance (UWSRA) is a $50 million partnership over five years between the Queensland Government, CSIRO's Water for a Healthy Country Flagship, Griffith University and The University of Queensland. The Alliance has been formed to address South East Queensland's emerging urban water issues with a focus on water security and recycling. The program will bring new research capacity to South East Queensland tailored to tackling existing and anticipated future issues to inform the implementation of the Water Strategy.

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FOREWORD

Water is fundamental to our quality of life, to economic growth and to the environment. With its booming economy and growing population, Australia's South East Queensland (SEQ) region faces increasing pressure on its water resources. These pressures are compounded by the impact of climate variability and accelerating climate change.

The Urban Water Security Research Alliance, through targeted, multidisciplinary research initiatives, has been formed to address the region's emerging urban water issues.

As the largest regionally focused urban water research program in Australia, the Alliance is focused on water security and recycling, but will align research where appropriate with other water research programs such as those of other SEQ water agencies, CSIRO's Water for a Healthy Country National Research Flagship, Water Quality Research Australia, eWater CRC and the Water Services Association of Australia (WSAA).

The Alliance is a partnership between the Queensland Government, CSIRO's Water for a Healthy Country National Research Flagship, The University of Queensland and Griffith University. It brings new research capacity to SEQ, tailored to tackling existing and anticipated future risks, assumptions and uncertainties facing water supply strategy. It is a $50 million partnership over five years.

Alliance research is examining fundamental issues necessary to deliver the region's water needs, including:

- ensuring the reliability and safety of recycled water systems.
- advising on infrastructure and technology for the recycling of wastewater and stormwater.
- building scientific knowledge into the management of health and safety risks in the water supply system.
- increasing community confidence in the future of water supply.

This report is part of a series summarising the output from the Urban Water Security Research Alliance. All reports and additional information about the Alliance can be found at http://www.urbanwateralliance.org.au/about.html.

Chris Davis
Chair, Urban Water Security Research Alliance

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EXECUTIVE SUMMARY

This report describes the outcomes from a wide ranging review of the scientific literature and current industry views and activities relating to sustainable urban water systems. The intent of this review is to not only summarise the current state of scientific literature and industry initiatives relating to this topic, but also to identify any particular directions which this debate is taking and the implications for the development of future water systems. Because of the large amount of literature written on this subject, the report is divided into two parts. Much of the detail of the literature review is contained in an appendix written by Greg Laves from Griffith University. The main part of the report builds on this literature review and describes the construction and use of analytical frameworks and associated sets of indicators proposed to assess sustainability. It also looks at Australian experience in implementing some of these methodologies and goes on to consider the principles and actions proposed as part of the Cities of the Future initiative.

The review clearly identifies the many complex factors involved in assessing sustainability and the challenges which this finding sets for the water industry. Despite these difficulties, the water industry has made significant efforts to incorporate sustainability principles into system planning, but has often reached a situation where pragmatic decisions have to be made under a degree of uncertainty. As a consequence of these difficulties, the water industry has used a variety of approaches to avoid so-called "paralysis by analysis". For example, one approach is to focus analytical effort on the areas with the biggest potential for improving sustainability such as net water usage, carbon footprint and nutrient discharges.

This debate has been widened to include the concept of sustainable Cities of the Future in which it is recognised that water systems are only one part of the total urban system and that opportunities exist to optimise water system planning within this wider context. While significant work has been done to identify sets of principles and actions required to implement this approach, difficulties in successfully integrating all of the issues surrounding sustainability will continue to frustrate.

This report suggests that a research gap in achieving more sustainable cities relates directly to the use and availability of physical resources. It is argued that, by obtaining a clear scientific understanding of the factors impacting on the availability and efficient use of physical resources, common ground will be found from which all parties involved in urban planning (including those in the social and organisational realms) can move forward.

The concept of 'urban metabolism' has been put forward as one way of pursuing this goal. However, this report also concludes that quantifying an urban metabolism model will only provide answers directly related to resource use efficiency and that other tools will still be required to answer questions related to factors such as cost, resilience and risk.

The report concludes with some recommendations for future work, which will not only explore the potential use of 'urban metabolism' models, but also assess their integration with other analytical tools relating to system resilience, risk and cost.

1. INTRODUCTION AND SCOPE

1.1. Background

Urbanisation and population growth are world-wide phenomena which are gathering momentum in the 21st century. Predictions from the United Nations indicate that, by 2030, not only will the world's population have increased by about 50% over current levels, but the proportion living in cities will have increased to about 60%. Even in Australia, with its relatively low population, it is anticipated that the major urban centres will grow substantially. For example, in South East Queensland, one of Australia's fastest growing metropolitan regions, the population is expected to grow from 2.4 million to 4.4 million from 2006 to 2031.

This growth will place increasing pressures on the need for human services in urban areas, in particular: water, food and energy. At the same time, it is likely that climate change and resource depletion will challenge the ability of cities to provide such resources in an affordable manner. Concern about these issues has led to the concept of Cities of the Future and the question of what will be required of these cities to make them not only habitable but also pleasant and healthy places to live. The concept of sustainability underlies many of these considerations and a considerable literature exists around defining this term in relation to cities.

While water is only one component of a liveable city, it is being increasingly recognised that it plays a central role in facilitating many of the sustainability characteristics required for the proposed Cities of the Future. In particular, water is crucially involved in the following services:

- secure, safe and resilient water supply;
- safe and effective waste disposal;
- flood prevention and stormwater management;
- ecologically diverse and healthy waterways;
- green and attractive open spaces which encourage outdoor activity;
- summer cooling and reduction of the heat island effect;
- aesthetically pleasing environments and gardens;
- urban agriculture/food production; and
- energy generation.

The Australian water industry has now recognised that, if all of these services are to be delivered in a sustainable manner, then a new strategy will be required in which all urban infrastructure and services are planned and delivered through a partnership involving urban planners and developers, the water sector and other service providers such as energy companies. It is only through such collaboration that real synergies can be obtained and the most sustainable city designs identified and implemented. Consequently, the urban water industry requires a paradigm shift away from the manner in which water services have traditionally been provided.

The scale of the challenge facing such a paradigm shift becomes clear when all of the factors impinging on water system design and operation are identified. For example, questions which need to be considered are:

- System scale – household, communal or city wide?
- People – what do people really want?
- Human health – how can it be best protected?
- Economics – how to price services to ensure affordability while maintaining financial viability of service provider?
- System resilience and risk – how to maintain healthy waterways and ecosystems?
- The underpinning science – how good is it?

1.2. Purpose

The longer-term vision for the project is to develop broadly applicable, transparent, soundly-based, defensible, balanced (qualitative and quantitative), easily understood, principle-based indicators and measures of "water sensitive cities" in the context of contributing to sustainable cities. Due to the fact that there are a number of related initiatives currently under way, the purpose of this initial phase of the project is to scan the national and international environment (literature and industry activity) and bring together the current state of literature discussion on this topic, with a view to identifying key principles which underlie sustainable urban water system design. Investigation and analysis of these principles will then be undertaken with the intent of identifying the potential for a generic analytical framework to guide particular actions which ensure sustainability in all future water systems. Such an outcome will maximise the long term efficiency and effectiveness of the very large financial investments which are and will be made in urban water infrastructure. The framework may also be a useful tool in communicating the essence of sustainable urban water systems to communities as well as serve as a vehicle to identify gaps for further research. Existing research activities, both of the Alliance and others, can be mapped onto the framework and gaps identified, providing the basis for motivating further research.

1.3. Relevance

The desired outcome is to develop a framework which is informative for the community and politicians on where we are, how we are improving and how we compare to other places, in terms of water sustainability:

- a framework for how we might assess urban water sustainability;
- to act as a catalyst for change – to become more sustainable;
- providing liveable cities indicators – water smart cities indicators;
- a framework to provide a basis for indicating where key researchers could link in and add value, maintaining responsibility for updating and improving measures; and
- for international benchmarking.

1.4. Key Research Questions

- What is the current state of literature discussion on the sustainability of urban water systems?
- Are there any key principles which can be identified that underpin sustainability?
- Can an analytical framework be identified which can facilitate the application of such principles to the design of urban water systems?
- What would the framework comprise?
- Can this framework be used as an aid to engage the community in discussion of sustainable water systems?

1.5. Research Deliverable

This report is the key deliverable of this project, clearly drawing together the current literature and industry debate about the precise nature of alternative water system designs which makes them sustainable in any true sense. The report also attempts to draw out of this literature a set of key principles which underpin such design and can form the basis for an analytical framework to analyse both existing and proposed schemes. The report describes and discusses possible analytical frameworks for evaluating the sustainability of alternative system designs. As required, the report also includes suggestions for the use of the framework in facilitating community discussion. A strategy for industry and community engagement to achieve widespread understanding of the basis and use of the analytical framework will also be discussed.

1.6. Report Structure

This report attempts to summarise the results of a wide ranging literature review relating to the development and use of tools for analysis of the sustainability of urban water systems and seeks to identify possible future initiatives to progress activity in this area. It is broadly structured into three parts. The first part is a review of the scientific literature on urban water systems and sustainability. The second part provides an overview of industry practice and views of implementing sustainable urban water systems and, finally, the report suggests some research options for progressing the transition to more water smart cities in response to industry-identified gaps.

- **Urban Water Systems and Sustainability – the theory (Sections 2-3) -** This part of the report includes a wide ranging discussion of the many issues which must be addressed when seeking to identify what determines the relative sustainability of one water system compared to another. In particular, it attempts to summarise the current state of **scientific literature** debate on this topic and identify any particular directions which this debate is taking. The report contains an appendix written by Greg Laves from Griffith University which provides much of the detail of this literature review. The main part of the report builds on this literature review and describes the construction and use of both frameworks and associated sets of indicators proposed to assess sustainability.
- **Creating Sustainable Urban Water Systems in practice (Section 4)** – This part of the report summarises current activity within the Australian water industry and includes comments on experience gained during practical application of some of these methodologies. The recognition by the water **industry** of the need to create a common platform for action among the various parties responsible for urban planning and the identification of the concept of **Cities of the Future** has taken the debate on sustainable urban water systems to a new level. This section also summarises the current debate within the international water community on identifying the key principles and actions which are required to effectively incorporate urban water system planning into the concept of Cities of the Future. The discussion highlights the identification of specific actions required to implement key principles across a wide range of issues. The need for a common framework to facilitate collaboration and communication across the various institutional and planning agencies involved is discussed.
- The final part **(Sections 5-6)** of the report discusses the potential of **urban metabolism** as the basis for developing an appropriate framework to bridge the knowledge and communication gaps that currently exist between water utilities, government planning agencies and the community. **Conclusions** and questions for the future are drawn from the preceding discussion and suggestions made for further research activities required to clarify the optimal way forward.

2. WATER AND SUSTAINABILITY – WHAT ARE THE GENERAL ISSUES?

2.1. Sustainability and Sustainable Development

Because of the wide range of literature discussion on the concept of sustainability and sustainable development, a literature review of these concepts as applied to sustainable urban water management (SUWM) has been included as Appendix 1 of this report. This review was written by Greg Laves from Griffith University. It provides a good background and source material relevant to the discussions outlined in this report.

As outlined by Laves (Appendix 1) and further discussed by Appleton (2006), the concepts of sustainability and sustainable development (Figure 1), grew out of the environmental crises of the 1960s and 70s and were a practical realisation of the inherent tensions between economic growth, social wellbeing and the health of ecological systems. Although the number of definitions of sustainable development now numbers in the hundreds, the most widely accepted definition remains that originally put forward by the Brundtland Report in 1987, namely "development that meets the needs of the present without compromising the needs of future generations to meet their own needs".

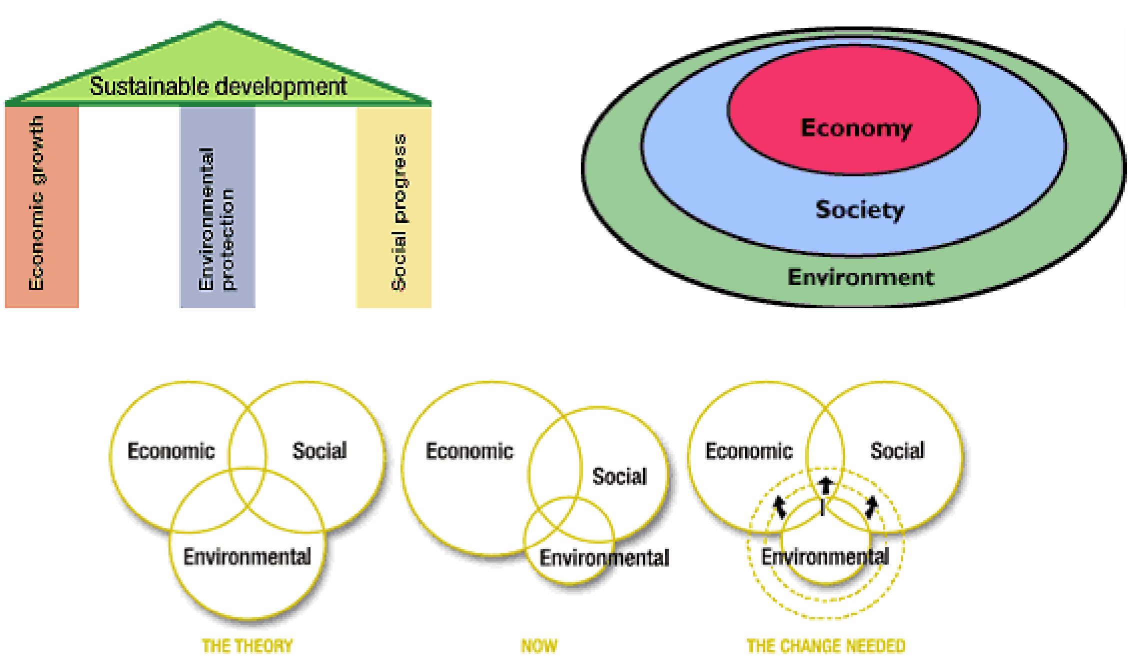


Figure 1: Three views of sustainable development: a) The three pillars; b) Constrained development; and c) The integrated view - from left to right, the theory, the reality and the change needed to better balance the model *(Source: Laves, 2010 (Appendix 1)).*

The most notable feature of this definition is its clear focus on human needs and intergenerational equity, with the environment being relegated to the role of a reliable service provider. This focus clearly places human values above those of the environment and has drawn the ire of those who promote what has been termed a 'strong' interpretation of sustainability. This 'strong' interpretation refuses to discriminate between human and ecological values and clearly illustrates the importance of people's ethical and moral structures.

Laves (2010) concludes from his review of the literature concerning sustainability and sustainable development, that:

- sustainability is a flexible concept that can be applied in a range of contexts:
  - this flexibility, on the one hand, can be a barrier to achieving consensus regarding the goals but, on the other hand, has been responsible for its widespread acceptance;
  - while this flexibility permits actors in particular sectors to proceed with their particular vision of sustainability, the solutions generated in any one sector may not contribute to sustainable development as a whole.
- sustainable development characteristics, in any context, are:
  - multi-decadal - requiring a long term perspective to be meaningful, generally encompassing several decades;
  - multi-scalar - achieving sustainability at one scale, e.g. local scale, does not necessarily translate into sustainability at another scale;
  - multi-sectoral - comprising multiple domains inextricably linked, needing to be viewed holistically - a single focus on sustainability in any one domain simply allows effects in other domains to be unaccounted for; and
  - multi-stakeholder - complex, subjective, involving many stakeholders applying selective interpretations, surrounded by uncertainties.
- the sustainable development process is iterative and much can be learnt from the successes and failures of others.

It is recognised that the concept of sustainability at least provides a forum for debating the incorporation of economic, social and environmental issues in decision making on major development issues. It is also recognised that sustainable development is a journey rather than a destination and that better decisions will result as experience in application of the concept accumulates. This optimistic scenario is questioned by some (Harrison, 2000) who see sustainable development as a 'Holy Grail' which does not exist, as it is essentially impossible to meet all values, ideals and hopes simultaneously for everybody.

2.2. Sustainable Urban Water Management

Gabe *et al.* (2007) cite integrated urban water management (IUWM) as an example of a response by urban water managers to societal and statutory demands for multiple-bottom-line outcomes. He points out that IUWM 'recognises that actions to improve urban water systems can include a broader range of social, economic and other environmental outcomes beyond improving water quality and managing quantity'. Changes in water management practices can contribute significantly towards sustainable cities by, for example: improving human health; supporting urban biodiversity; reducing greenhouse gas emissions; increasing amenity; sustaining environmental values; counteracting the effects of urban heat islands; and augmenting city liveability in general (Laves, Appendix 1).

The mainstreaming of sustainability principles has led to an emergence of innovative and integrative sustainable urban water management (SUWM) practices and an increasingly clearer vision of water sensitive cities (Laves, Appendix 1). While significant progress has been made with implementing SUWM in some cities (Mitchell *et al.,* 2007; Brown *et al.*, 2009), the transition has been hampered by: continued investment in traditional water infrastructure (Wong and Brown, 2009); socio-institutional issues including institutional inertia (Brown and Farrelly, 2009); a lack of a benchmarking tools for informing the development of long-term policy for SUWM; and a lack of vision regarding the attributes of a sustainable water city (Brown *et al.*, 2009).

Further to the seminal work of Brown *et al.* (2009) which proposed an 'urban water transitional framework' for guiding the transition to more water sensitive cities (Figure 2), the Centre for Water Sensitive Cities is playing a leading role in building Australia's capacity to advance sustainable urban water practices through research, engagement and policy support (Centre for Water Sensitive Cities, 2010). The Centre has attempted to describe the attributes of a Water Sensitive City in relation to the attributes of a more "traditional" city in terms of system boundary, management approach, expertise, service delivery, role of the public and risk (Centre for Water Sensitive Cities, 2010).

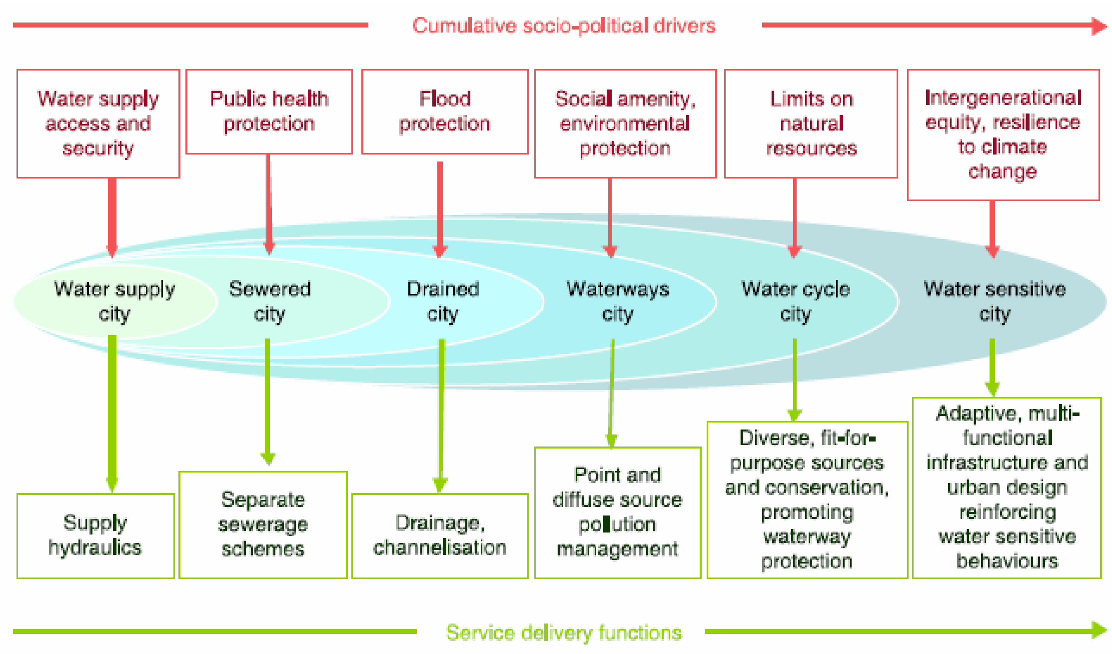


Figure 2: **Stages of Urban Water Management *(Source: Brown et al., 2009).***

The key point which emerge from this, and other, descriptions of Water Sensitive Cities given in the literature, is that not only can anyone not yet point to a clear example of such a city, but also the language used to describe it is still cast in generalised statements about the desirability of certain attributes, e.g. adaptive, multi-functional infrastructure, flexible institutional arrangements, engaged community and holistic thinking.

Clearly, clarification of these issues is critical to progress towards more sustainable urban water systems and providing direction for how to get there. The use of assessment criteria based on some form of analytical framework may provide some guidance on this journey and it is the intent of the rest of this report to explore that possibility.

3. ASSESSING THE SUSTAINABILITY OF URBAN WATER SYSTEMS

3.1. Sustainability Assessment Tools

Tools used to assess the sustainability of urban water systems usually revolve around the use of structured frameworks, which rely on the application of a range of metrics comprised of numerical indices and/or indicators. As described by Laves (Appendix 1), a framework to assess sustainability of any system is normally made up of three elements:

- setting of clear objectives or goals;
- identification of assessment criteria or metrics, usually comprising indices or indicators, which measure if the specified objectives have been met; and
- setting of measurable base data which feed into the evaluation of the indices or indictors.

Laves (Appendix 1) identifies typical framework approaches and their conceptual underpinnings. He also highlights a constant theme in the sustainability literature of the importance of involving people and communities in the assessment process. The real challenge identified by this discussion is the requirement to integrate inputs from a wide range of considerations into the assessment framework. It is in this light that the topic of metrics and the use of various indicators are introduced to the debate.

Laves (Appendix 1) summarises seven classes of framework approaches as described by Guio-Torres (2006):

- Dimensions of Sustainability approach considers the impacts of a range of strategies on various dimensions including at least social, economic and environment dimensions.
- Adjusted Economic Accounting approach attempts to allocate financial values to changes in social wellbeing and environmental goods and services. A typical indicator might be an adjusted GDP.
- Biophysical Accounting approach accounts for the total use (footprint) of natural resources consumed in the carrying out of particular activities.
- Resource and Material Flow Accounting approach typically examines 'cradle to grave' inputs and outputs associated over the lifetime of a particular activity. For example, life cycle analysis and urban metabolism.
- Pressure – State – Response approach and its variants (DPSIR and DPSEEA) consist of an analysis of cause and effect pathways to determine the negative impacts of particular activities.
- Guided by Objectives approach uses indicators and measurements to determine where the current activity stands against stated goals.
- System Analysis approach understands sustainability as the outcome of interaction between society and nature, recognises that societies and nature are constantly evolving hence sustainability goals are not static, with the core goal being the long-term viability of both nature and society.

A complementary inventory of the range of tools used for sustainability assessment is provided by Ness, Urbel-Piirsalu, Anderberg and Ollson (2007). Ness *et al.* (2007) point out that, in order to maintain a directed transition to sustainability, goals must be assessed and that these goals must relate to people, the economy and ecological systems. While the number of tools used for assessing sustainability has grown rapidly, experience in their use is only gradually accumulating and there is a clear need for the extension and integration of environmental and social assessment methodologies. They identify the purpose of sustainability assessment as the need "to provide decision makers with an evaluation of global to local integrated nature-society systems in short- and long-term perspectives, in order to assist them to determine which actions should or should not be taken in an attempt to make society (more) sustainable."

The key issues highlighted by this definition are:

- the physical scale over which the assessment is to be made and where boundaries to the system are defined;
- the time scale over which the assessment needs to be made and whether it is retrospective or forward looking in time; and
- what Ness *et al.* (2007) call nature-society interactions, which include a host of issues relating to environmental impact and community acceptance and understanding.

The statement clearly identifies the issues of physical scale, time frame and nature-society interactions as being essential components of any set of useful metrics. It also concurs with the four fundamental characteristics of sustainable development outlined by Laves (Appendix 1): time frame to ensure intergenerational equity; varying levels of physical scale; multiple domains including the economic, social and environmental; and numerous perspectives reflecting the complexity of the situation. The questions which consequently arise are the degree to which the present set of assessment tools fulfils these broader objectives and their ability to successfully integrate nature-society interactions over varying physical and time scales.

The aim of the inventory of assessment tools provided by Ness *et al.* (2007) is to provide a general understanding of existing approaches and to evaluate to which degree they are able to integrate these different dimensions of sustainability. They categorise these tools into three broad "umbrella" areas:

- directly measurable indicators and indices;
- product or service related assessment tools with the focus on material and/or energy flows from a life cycle perspective; and
- integrated assessment tools which focus on policy change or project implementation.

They also include an overarching category of **monetary valuation** used when non-market values are needed in the other three categories (Ness *et al.*, 2007).

3.2. Directly Measurable Indicators and Indices

Indicators are usually simple, quantitative measures of particular economic, social and/or environmental states in a defined region. They can be either integrated or non-integrated in the sense that they can combine nature-society interactions in one indicator. When they are aggregated in some manner, the resulting measure is called an index. Examples include Environmental Pressure Indicators, Input-Output Energy Analysis and Ecological Footprint. When such indicators are continuously measured or calculated, they can provide a tracking of long-term sustainability trends from a retrospective point of view (Ness *et al.*, 2007).

Environmental Pressure Indicators were developed by the Statistical Office of the European Community and consist of a compilation of 60 indicators put forward under the Fifth Environmental Program. The intention of these indicators, which can range from volume of waste landfill to tourism intensity, is to permit a direct environmental comparison between different EU member countries. They are non-integrated in that economic and social considerations are not considered and are purely retrospective, giving no indication of the impact of potential policy changes (Ness *et al.*, 2007).

More insight is potentially derived from carrying out analysis of material and energy flows in a region, as the analysis of such flows allows for the identification and understanding of inefficiencies within the system. In this vein, Material Flow Analysis, Substance Flow Analysis and Energy Analysis provide the ability to not only map the flows of physical resources and energy through a region, but also understand the fate of particular substances and the effectiveness of resource utilisation (Ness *et al.*, 2007). They can also be directly related to the emerging concept of urban metabolism (Kennedy *et al.*, 2007) as a unifying model for analysing all resource flows through a region. Again, such indicators are non-integrated and retrospective, although a properly constructed urban metabolism model does offer the prospect of modelling the impact of potential policy and/or behavioural changes.

The Ecological Footprint (Wackernagel and Rees, 1996) is a well established tool which establishes a link between the average resource consumption of a given region or population and the land area necessary to provide those resources and assimilate the wastes arising from their consumption. While it has been widely used at the national level, it can also be applied to the urban or regional level. However, in recent times, the use of Ecological Footprint as an accurate assessment of sustainability has been challenged (Fiala, 2008). Among other criticisms, it has been claimed that the Ecological Footprint cannot take into account improvements to the efficiency of intensive production and thus comparisons to biocapacity can be erroneous. It also places most emphasis on environmental sustainability and has little capacity to accommodate economic or social consequences.

3.3. Product Related Assessment Tools

Product related tools focus on the steps involved in the production and consumption of particular goods and services. As a consequence, they do not relate to any particular region but evaluate the global impact of resource use and environmental impact through the chain of production and life cycle of a product or service. While such tools are largely focused on environmental aspects, they do provide a measure of the impact of human production and consumption. For example, life cycle costing tools attempt to integrate environmental and economic concerns. They are mainly comprised of life cycle assessment and life cycle costing methodologies, as well as product material and energy flow analyses (Ness *et al.*, 2007). Life Cycle Assessment (LCA) has now been widely used for many years to evaluate the environmental impacts of a product or service throughout its entire life cycle. Guidelines and principles for the application of LCA have been established by the International Standards Organisation, although many have further developed the interpretation of these guidelines. Life Cycle Costing (LCC) is an economic approach that sums up the total costs of a product, process or activity discounted over its lifetime. While it is generally not associated with environmental costs, a number of variations, such as Life Cycle Cost Assessment and Full Cost Environmental Accounting, do attempt to include environmental costs. In such situations, monetary valuation techniques such as Contingent Valuation, Hedonic Pricing and Avoided Cost can be applied to produce a direct economic valuation for an environmental service (Ness *et al.*, 2007).

In a similar manner to the analysis for regions or urban areas, material, substance and energy flow analysis techniques can be applied directly to the provision of a product or service. Such an analysis must be performed throughout all the life cycle stages in order to fully identify where all of the inflows and outflows of substances and energy occur. It can clearly identify the sources of environmental impact and thus point to actions which can significantly reduce the environmental burden (Ness *et al.*, 2007).

3.4. Integrated Assessment Tools

Integrated assessment tools are designed to directly take into account nature-society interactions, while also considering the long term consequences of any system design. As a result, they are usually used for supporting decisions related to a proposed project or change in policy in a particular region. Tools such as Multi-Criteria Decision Analysis, Risk Analysis, Vulnerability Analysis and Conceptual Modelling techniques are often used in this regard (Ness *et al.*, 2007).

Conceptual modelling techniques are based on the qualitative analysis of causal relationships and often make use of stocks and flow diagrams, flow charts or causal loop diagrams (CLDs) (Ness *et al.*, 2007). Such diagrams essentially map all of the factors which can potentially impact any system design on to one diagram and then illustrate all of the possible causative connections via connecting arrows. No attempt is made to quantify any of these linkages, except to indicate whether they have a positive or negative impact. Conceptual modelling can be used for visualising and detecting where improvements to sustainability can be made in any system and, as argued by Guest *et al.* (2010), can be a very useful tool for ensuring key stakeholder engagement in any new system design. Guest's discussion and description of the use of CLDs clearly illustrates the complex interactions involved and identifies one avenue for decision makers to gain an understanding of stakeholder preferences through a transparent and participatory planning process.

Both Ness *et al.* and Guest *et al.* highlight the use of Multi-Criteria Decision Analysis (MCDA) to provide sustainability assessments in situations where there are competing social, environmental and economic criteria. By incorporating both quantitative and qualitative criteria into the analysis, the approach attempts to clearly identify the trade-offs involved in decision making. The advantages perceived by adopting MCDA techniques are:

- the approach provides a structured way of approaching the decision under analysis;
- it can account for multiple and conflicting criteria;
- properly conducted, it can add transparency to the decision making process; and
- it can help decision makers learn about their own and others' values and judgements.

As such, MCDA can be usefully applied in conjunction with the application of CLDs as described above. However, even with the assistance of CLDs, weighting of the various criteria is one of the most challenging aspects of applying MCDA. Experience has demonstrated that people's preferences can be highly variable and elastic, in which preference tradeoffs can change according to the perceived balance of rewards. Such considerations introduce a high degree of uncertainty into decision making. Even when stakeholder preferences have been established through a participatory planning process, experience indicates that cognitive biases may arise during the participation process itself, leading to skewed weightings of criteria. It has also been recognised that there exists a level of uncertainty from human input that may be irreducible because of the inherent variability of socio-political systems.

After assessing a number of methods reported in the literature which can be adapted for the assessment of sustainability, Maheepala, Speers, Booker, and Mitchell (2003) concluded that MCA is emerging as the most refined and favourable approach for the assessment of sustainability. Based on MCA, they devised a framework for assessing the sustainability of urban water systems comprising ten components. The proposed framework can bring together social, economic and environmental aspects of decision making into a single platform, and that platform can provide valuable insight into understanding the effectiveness of various management initiatives in terms of their ability to contribute to providing sustainable water systems in urban areas (Maheepala *et al.*, 2007).

Other tools which are used to assist nature-society deliberations include risk and uncertainty analysis, vulnerability analysis and cost benefit analysis (Ness *et al.*, 2007). Such tools are necessary not only for informing key decision makers about important risks and uncertainty related to a particular project, but are also vital for informed communication and discussion with key stakeholders. As pointed out by Ness *et al.* (2007), there are two types of uncertainties, firstly the stochastic uncertainty related to natural variability in any system (e.g., future rainfall) and, secondly, the uncertainty related to a lack of data and fundamental knowledge of the system. Such considerations are also related to vulnerability analysis which attempts to determine how sensitive and resilient any design is to changing circumstances. Such an analysis is particularly relevant to water systems subject to climate change.

Cost Benefit analysis is a long established tool for weighing the costs of a project against the expected benefits. For sustainability analysis, it has been used as an effective tool for comparing the values of social costs and benefits related to particular projects, e.g. energy production and transport systems. The difficulties associated with placing a monetary value on these benefits is the major problem with this approach (Ness *et al.*, 2007).

3.5. Monetary Valuation

Also referred to as shadow pricing or non-market valuation, this group comprises tools that are not sustainability assessment techniques themselves, but can be used to provide monetary value inputs to assessment techniques such as Cost Benefit analysis, Genuine Saving and Life Cycle Cost Assessment (Ness *et al.*, 2007). A range of different methods are used to assign values. The Contingent Valuation method uses surveys to estimate people's willingness-to-pay for nature's goods and services. Hedonic pricing, focusing mainly on property valuation, uses positive factors such as proximity to parks and beaches and negative factors such as proximity to factories and airports, to influence property values. Other methods such as Factor Income, Avoided Costs and Replacement Costs are also available (Pearce *et al.*, 1994).

3.6. Sustainability Assessment Tools – Some Conclusions

The above discussion clearly illustrates the wide range of tools currently available to assess the sustainability of urban water systems. Considering the difficulty and complexity associated with considering spatial and temporal aspects, as well as a broad variety of nature-society interactions, it is no surprise to find that most tools consider only a subset of these issues. Many tools have a strong focus on environmental parameters and consequently largely disregard the social and/or economic aspects. Life Cycle Costing is perhaps one exception to this rule (Ness *et al.*, 2007).

Another key shortcoming relates to the availability and reliability of data which the tools require. Certainly those tools, such as ecological footprint, which rely on retrospective data can provide a picture of current conditions, but are clearly flawed as forecasting tools because of the many subjective judgements made about how future systems will function. This issue can make it difficult for decision makers to place great credibility on their predictions. However, the availability of accurate and reliable data is a major challenge for most assessment tools. Again, one exception is Life Cycle Assessment where attempts have been made to develop generally reliable data sets.

Given this diversity of approach and paucity of reliable data, it is not surprising when decision makers and tool practitioners choose to use a set of tools which tend to reflect their political viewpoint and broader interpretation of sustainability. The sustainability literature includes both weak and strong interpretations of the concept. The weak interpretation usually assumes that manufactured capital can be substituted for natural capital, while the strong interpretation denies this and insists that natural capital must be preserved. Clearly, these differing interpretations can have major consequences for decision making processes (Ness *et al.*, 2007).

There is thus a need for a more widely agreed set of tools which standardise the assessment process and give more transparent results (Ness *et al.*, 2007). However, because the concept of sustainability has so many facets and so many parameters which must be considered simultaneously, achieving widespread agreement on a standardised set of assessment tools appears a very difficult task.

4. THE SUSTAINABILITY OF URBAN WATER SYSTEMS – WHAT INDUSTRY IS DOING

4.1. Formalised Approaches to Promoting Sustainability

The Australian urban water industry has been made very aware of the need to pursue the concept of sustainability because it has been at the forefront of managing the impact of climate change. Significant changes to rainfall and runoff across the continent have forced water authorities to confront the need to maintain urban water supplies, while at the same time coping with the impact of rising energy consumption and prices. The long life-time of the assets it manages and the increasing impact of community perspectives has added to these pressures. The industry has been very proactive in managing these issues and has developed a coordinated process to address these emerging challenges.

In January 2009, the Water Services Association of Australia (WSAA, 2009) published a position paper on a 'Vision for a sustainable urban water future'. This paper addressed the issues facing the Australian urban water industry and focussed on five key areas:

- integrated water management;
- sustainability pricing;
- climate change and carbon pricing;
- regulation; and
- industry structure and competition reforms.

This paper confirmed the industry's acceptance of a relatively strong definition of sustainability, in that it accepted that all forms of capital, including human, financial, manufactured and natural, should be enhanced and not degraded. It defined sustainability in the context of the Australian urban water industry as:

> *"Understanding the long term interdependence between natural and financial capital with the objective of protecting and enhancing environmental capital so as to ensure maximum long term economic value to the community".*

Such a definition clearly articulates the nexus between economic value and environmental protection and is clearly optimistic that this nexus can be successfully negotiated. It stands as a clear challenge to the industry to employ innovation in design and operation of its water systems to deliver on this promise.

While this paper made many particular recommendations, a number of them relate directly to the regulatory and statutory regimes controlling the operation of the industry and the need to align these with initiatives aimed at improving the overall sustainability of the industry. An example is the efficient use of recycled water. A particular need was also identified for "the Federal Government to clarify uncertainties and ambiguities relating to the urban water industry's participation in the Carbon Pollution Reduction Scheme".

Perhaps the most significant initiative undertaken by the urban water industry to address sustainability issues was the development of a sustainability framework and methodology by WSAA for evaluating the overall sustainability of urban water systems (Lundie *et al.*, 2008) (Figure 3). Laves (Appendix 1) provides a brief overview of this framework. The framework provides a well structured process to the identification and analysis of different options for providing urban water services. It attempts to cover the scale from small changes in plant design to complete new systems. Phases three and four of the framework are at the core of this process and involve the selection of sustainability criteria and their use in screening the wide range of options identified. In phase six, options which survive this screening process are subject to a much more detailed options assessment, again using a wide range of sustainability assessment tools.

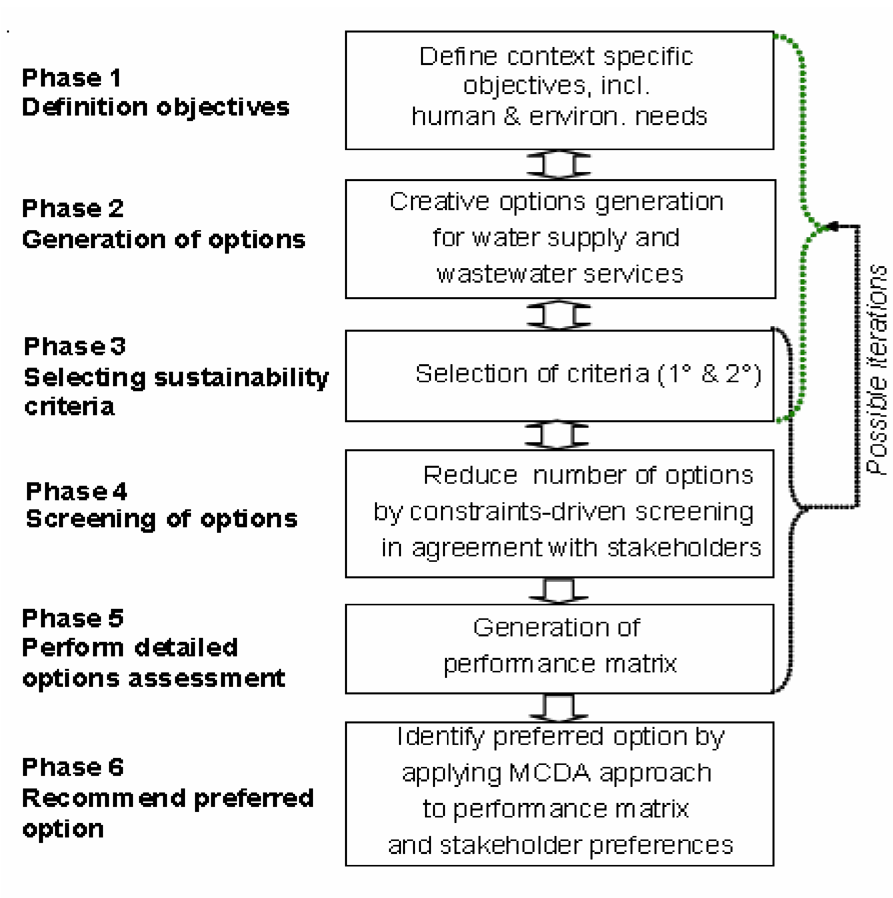


Figure 3: Schematic representation of the WSAA Sustainability Framework of Urban Water Systems *(Source: Lundie et al., 2008).*

The WSAA Sustainability Framework thus leaves the choice of assessment tools to the group undertaking the particular study, but clearly does indicate the use of a broad range of tools to include all of the considerations referred to in the literature discussion. A strong commitment to stakeholder engagement pervades the framework, although some words of caution are included. The need for a transparent approach to the application of multi-criteria decision analysis (MCDA) is emphasised, while the need for more deliberative approaches to community engagement, such as citizens' juries, is recommended. The latter is seen as necessary from experience with public meetings which appear to 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 similar sustainability assessment framework was proposed by Kenway, Howe and Maheepala (2007) with a strong case put forward for Triple Bottom Line reporting of sustainable water utility performance. A number of existing conceptual approaches to assessing sustainability are compared and contrasted including The Natural Step, Industrial Ecology, Natural Capitalism and Ecological Design Principles (Kenway *et al.*, 2007). An evaluation of a range of tools for quantifying sustainable assessment criteria, including financial, life-cycle, embodied energy, ecological footprint and multi-criteria assessment, is also provided (Kenway *et al.*, 2007).

Since the development of the WSAA Sustainability Framework, there has been further development of processes to enhance integrated urban water management. The Water Research Foundation and CSIRO produced a manual which describes a generic process (or a framework) to guide towns and cities to transition to an urban water management practice that is truly integrated. In the manual, the statement is made that "If our urban water management is to become sustainable we must adopt an integrated approach that considers all aspects of the water cycle and all of its impacts." (Maheepala, Blackmore, Diaper, Moglia, Sharma, and Kenway, 2010). The Integrated Urban Water Management (IUWM) planning process described in the manual (Figure 4) has three phases: setting the strategic direction; producing a shortlist of portfolios of urban water servicing options; and analysing and comparing options and selecting the preferred portfolio for final implementation. The importance of stakeholder involvement is stressed throughout the process. Case studies were used to test the alignment of the IUWM planning process with current practice.

The Healthy Waterways Partnership, Water by Design, has produced a Total Water Cycle Management (TWCM) Planning Guideline for South East Queensland Draft, 2010, which describes a TWCM Plan as a way of delivering sustainable water cycle management outcomes. A process for producing a TWCM Plan is recommended, comprising the following components: development a strategy; undertaking detailed planning (where necessary); preparing an implementation plan; publishing, monitoring and reviewing the plan; and obtaining certification and endorsement throughout the process (Healthy Waterways Partnership, 2010).

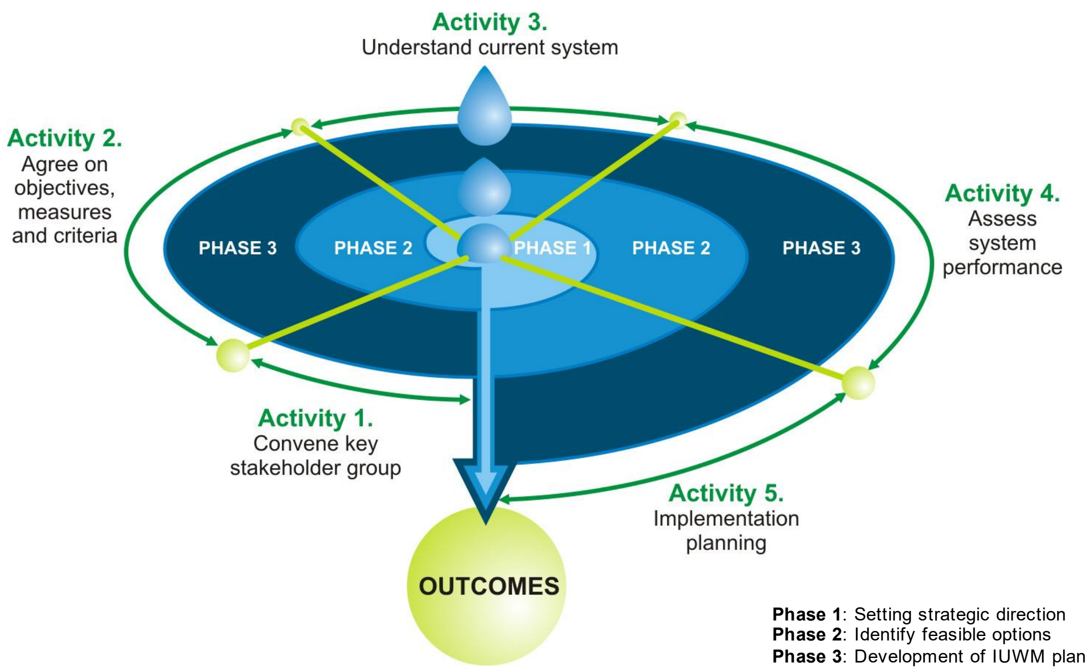


Figure 4: IUWM Planning Process ***(Source: Maheepala et al. (2010).***

The State of Queensland's Department of Environment and Resource Management (DERM) has produced a handbook "Towards a Water Sensitive Future" to assist urban water managers to undertake a more holistic or "water sensitive" approach to tackling urban water challenges where water supply and environmental water management is integrated in the urban context (State of Queensland, DERM, 2010). The handbook provides a five-step roadmap for developing water sensitive solutions. These steps guide the user through a logical process of understanding the issues, exploring the possibilities, choosing the path that best suits each situation, gaining approval or endorsement to proceed and implementing the project. Each step is supplemented by key ingredients necessary for success as learnt from actual on the ground experience together with case studies which illustrate what has been achieved by others (State of Queensland, DERM, 2010).

All these process-oriented frameworks provide the urban water industry with informed and well structured approaches to the process of improving sustainability in the water sector. The true test of their value will be industry experience in applying them. With this experience, these process frameworks will evolve over time, particularly as our understanding of sustainability also evolves.

4.2. Industry Experience in Implementing Sustainable Urban Water Systems

So what has been the industry's experience in adopting sustainability principles in the design and operation of new water systems? This experience has been described as a journey towards a water sensitive future with the outcome being the construction of so-called 'Water Sensitive Cities'. This term, and its associated 'Cities of the Future', will be discussed further in the next section of this report with a focus on extracting the key principles which underlie their development.

In the remainder of this section, an attempt will be made to summarise industry experience to date in applying sustainability assessments to new system designs. The comments made in this section are largely based on meetings held with various water industry representatives from Queensland and Victoria and draw on some draft discussion documents currently in circulation.

Professionals working within the urban water industry are well aware of the challenges currently facing the industry, a fact confirmed by the wide ranging debates held at both public and private fora. These debates have confirmed the plethora of issues which must all be addressed simultaneously if future water system designs are to be successfully implemented. The issues discussed cover the following areas:

- system scale – defining the system boundaries is important for clarifying optimum approaches;
- the people factor – determining what people value, their sense of social justice and ability to pay; and recognising that different priorities for different communities all play a role in achieving acceptance of new system designs - without this acceptance the project is doomed;
- human health protection – a fundamental requirement for any new system but one which has many dimensions, including system reliability and safety, good water quality, green connected urban spaces, cooling and mitigation of the heat island effect, aesthetics of public gardens and psychological health;
- economics – ability and willingness to pay for new services is critical, but considerations of social equity, including cost sharing, and accounting for offsets are also important;
- system resilience – it is vital that any new system designs are resilient to both operational and climate induced risks and the reliability and effectiveness of maintenance requirements are properly accounted for;
- institutional structures and planning – the importance for all planners to work off the same page is now recognised and hence there is a need for a commonly agreed analytical and decision making framework. For example, there is a need for urban planning regulations in SEQ to be able to recognise the local context, while incorporating important elements of water sensitive urban design into urban planning;
- environment – issues such as greenhouse gas emissions, aquatic health of waterways and water extraction and return levels all need to be included in the metric for a sustainable urban water system; and
- underpinning science – it is now generally agreed that good science, informed by accurate data, is vital to informed analysis and decision making.

The industry is also constantly debating just what a water sensitive city means. In essence, it is seen as a journey moving from a past where water supply, sewerage and drainage services were seen as separate entities to a future where water is managed in an integrated fashion across all elements of the urban water cycle. The words which characterise this development include adaptive, multi-functional infrastructure, flexible institutional arrangements and engaged communities. While this description is largely focussed on the urban water cycle, it is now being expanded to include a broader integration of water into urban planning and development (see later section on Planning Principles for Cities of the Future).

It is seen as a shift away from a traditional reliance on rainfall and large storage reservoirs as the sole source of supply, to a more diverse range of supply sources which provide more resilience and security against future water stresses induced by population growth and climate change. Another major shift recognises the values associated with healthy aquatic ecosystems and green open spaces, which act as a carbon sink while providing natural cooling to the urban environment. The third major shift confirms the importance of community involvement in defining and solving urban water issues. This collaboration is supported by facilitating appropriate institutional arrangements and increasing the capacity of skilled personnel to advance sustainable water management.

Perhaps the best illustrations of these changes are the widespread development of integrated water management strategies and the design and construction of innovative water systems in new urban developments. Examples include:

- development of the Pimpama-Coomera Waterfuture Master Plan in SEQ, in which all stakeholders including the community played a critical role in developing an integrated plan;
- production of an integrated Water Management Strategy for the south-east of Melbourne by South East Water. Developed in collaboration with a wide range of stakeholders, this strategy will address how South East Water and its partners manage the different water resources of the region. It will explore a wide range of options for water supply and environmental flows, while also investigating the potential for improvements in energy efficiency and small scale energy generation;
- construction and operation of the Silva Park Estate at Payne Road, The Gap, Brisbane, which pioneered both the development approval challenges of innovative water sensitive housing estates, while also gathering vital data on the operating performance of the system; and
- design of a new urban infill development at Doncaster Hill in Melbourne. The project involved collaboration between water authorities, local councils, government planning agencies and urban developers and considered use of rainwater harvesting, treatment and use. Projected benefits include significant reductions in imported water, greenhouse gas emissions and nutrient discharges. It demonstrates that the water industry is in transition to a new operating paradigm.

There are many other examples similar to those given above which illustrate the willingness of the urban water industry to embrace change. The challenge which now faces the industry is to successfully capture all of the learning and knowledge which operation of these new systems can provide. In particular, the benefits need to be measured and compared against those predicted in the original design. So far, only a limited number of projects, including the Payne Road development referred to above, and the eco-development at Currumbin have had sufficient monitoring to provide reliable answers to these questions. Until such comparisons can be made, based on real world operating data, questions will remain as to the true sustainability of these new system designs.

What all these new developments are providing is experience in the application of the WSAA sustainability framework or similar frameworks and the sustainability assessment tools embedded within. So, what is this experience telling us at the moment? Interviews with a number of water industry professionals produced the following points:

- Some water authorities are using an approach based on the ecological footprint and are finding that water represents only a small component of a new development’s footprint. Setting the right system boundary plays a major role in these considerations. These results are consistent with other work undertaken by CSIRO on the water/energy nexus. Consequently, some authorities now use more than one model in assessing sustainability and have found that their results are very context specific. The best decision for any one community can involve many factors and hence many questions while dealing with uncertainty.
- These considerations often result in more emphasis being placed on applying a series of ‘filtering questions’ to any new proposal before going in to any analysis based on triple bottom line (TBL) or multi-criteria decision analysis (MCDA) considerations, i.e. a stronger emphasis on Phase 4 of the WSAA sustainability framework.
- Experience in applying such tools as TBL and/or MCDA is that there is a lot of psychology involved and therefore it is very difficult to get a truly independent answer – the process is very people dependent and this can skew the results significantly.

- One response to this difficulty is to apply a so-called ‘analytical hierarchical process’ in which pair-by-pair comparisons are carried out over about 15 parameters. Options that pass this high level filtering process are then assessed for aspects like total community cost, risk (both technical and health) and resilience under changing operating environments. A sensitivity analysis is then applied to these considerations.
- While the industry has learnt by going through this process a number of times, it has recognised that there is a significant danger of being ‘paralysed by complexity’ and that pragmatic decisions need to be made under a considerable degree of uncertainty.
- As a consequence, there is a need to focus on the factors with the big potential impacts. For example, an ‘actuarial approach’ could examine the impact of three big items such as net water usage, carbon footprint and nutrient discharges. These big ticket items may well account for 80% of the picture and there is little to be gained by spending a lot of time and money on the remaining 20%. This approach is analogous to the insurance industry which can get reasonably accurate estimates of life expectancy from three critical parameters such as body/mass index, blood pressure and cholesterol levels.
- The notion of leverage can also influence these considerations, simply by asking and answering the question “what can we do that will REALLY make a difference”? In other words, identify the key point of leverage in a project and focus attention on it.
- A potential barrier to some projects is that the lowest overall community cost may not equate with the lowest direct cost to the water authority. Explaining this fact to the water price regulator can be a major challenge, unless the narrow economic focus of most price regulators is changed by government edict.

4.3. Water-Related Planning Principles for Cities of the Future

Efforts to define the exact nature of a water sensitive city have involved a range of initiatives within the Australian water industry. These efforts have broadened to include the concepts of Sustainable Cities and Cities of the Future (IWA, 2009), which recognise that urban water systems are an integral part of city services and need to be planned in a coordinated manner with other services such as transport, housing and employment. Laves (Appendix 1) provides a good summary of literature related to the identification and development of key principles seen as necessary to the design of such cities. The most recent effort in this area is the work of the IWA Cities of the Future Program undertaken by the Spatial Planning and Institutional Reform Working Group. They provide a list of eleven key principles and also discuss a list of actions which will be required to implement these principles in any particular case.

Another important input to discussion on this topic comes from the Centre for Water Sensitive Cities based at Monash University. Laves (Appendix 1) again provides a good summary of some of the work emanating from this group. The primary point which emerges from these discussions is that, whatever underlying principles are identified, the economy, people and the environment remain as the central components. A balanced tension will always exist between these factors, which are basically defined by people’s perceptions, understandings, aspirations and values.

The work of the Monash group describes a transitional process in moving towards water sensitive cities in which emphasis is placed on achieving multiple uses for water, the adoption of adaptive, integrated management approaches, the recognition of multi-stakeholder learning and the adoption of diverse, flexible solutions at multiple scales. They promote concepts such as:

- Cities as Water Supply Catchments in which the import of potable water and the export of wastewater are minimised;
- Water resources are used in an optimal manner within the city; and
- Water resources within the city boundary provide ecosystem services and community citizens are water sensitive and informed about water issues.

The principles enunciated by the IWA Cities of the Future program are largely in line with these concepts. In particular, they include among others concepts such as:

- Sustainable cities will combine a compact footprint with sustainability and liveability;
- Cities will be resource neutral or generative and part of prosperous, diverse and sustainable regions; and
- They will be served by a well-managed water cycle and recognise the concept of "fit for purpose" use.

A full reading of these concepts raises the question of whether they are real principles or simply an extended wish list of desirable attributes or states and does not clarify just how they may be implemented. For example, desiring a city to be prosperous and resource neutral does not provide any practical guidance as to how to achieve this goal. One can also question the universal applicability of the concept of minimising water import and wastewater export from a city. While examples can be shown where this concept has value, it is equally easy to show contrary situations. In some circumstances cities can and should be made to justify water imports on both environmental and economic grounds.

What these considerations illustrate is that it is not so much the concepts or principles of Cities of the Future which have value, but the actions identified to achieve these desirable attributes. In this vein, the IWA Cities of the Future Program does go on to consider a range of actions required to successfully implement the principles. Some examples of the actions identified include:

- clarify the vision, definition and measures of a sustainable city;
- establish a comprehensive evaluation framework to assess planning and water management options based on full lifecycle sustainability assessment;
- clarify roles and responsibilities for planning between the various levels of Government and the private sector;
- build resilience by diversifying water sources; and
- develop city wide resource budgets based on the principle of "urban metabolism".

While these proposed actions are clearly important in moving the concept of a sustainable city forward, they still do not provide detailed guidance on just how to implement them. Despite the plethora of frameworks and metrics which have been proposed to assist in this task, it is obvious that there is still not widespread understanding and agreement on a process for identifying the optimum way forward. As is clear from previous discussion, this situation can be ascribed to both the complexity of the many issues involved and the lack of reliable data on the many possible alternative designs. So what is a good way forward from this restricting nexus?

5. POSSIBLE AVENUES FOR PROGRESSING CONCEPTS FOR SUSTAINABLE CITIES OF THE FUTURE

5.1. Focus on Resource Flows

The multiple concepts and principles identified in the discussion above clearly indicate the complexity and variety of issues that need to be addressed before satisfactory progress towards a sustainable city of the future can be fully envisaged. As outlined earlier, the widely accepted Brundtland definition of sustainable development focuses attention on the use and availability of physical resources required to meet society's needs now and into the future. It can be argued that a basic requirement for achieving sustainability is the continued supply of critical resources such as water, energy, food and materials in sufficient quantities to allow society to function amicably and people to live safe, healthy and fulfilled lives.

It is clear from much of the literature described in this report that social and organisational barriers to achieving sustainability rest largely on a confused understanding of just how **resources** are used in society and how organisational structures impinge on the efficiency of this use. Effective planning for efficient resource use can only be achieved when a clear understanding of these issues is achieved by all involved, and that this understanding then forms a common platform for discussion, agreement and action.

5.2. Mapping Resource Flows

From the wide array of sustainability assessment tools broadly considered in section 3, those that relate more specifically to resource use and flows include ecological footprint, input-output analysis and urban metabolism. Each of these methods has variously been applied and adapted, sometimes in conjunction with another, for a range of contexts and purposes.

Lenzen (2009) has used multi-region input-output analysis to identify the magnitude of virtual water flows in the state of Victoria, extending the method beyond simple accounting procedures to enumerate flows of energy and resources. Input-output analysis has been used to allocate impacts to consumption categories including the full supply chain. The approach accounts for intermediate and inter-industrial trade. It also can distinguish imports, domestic consumption and exports (Lenzen and Murray, 2001). In a similar manner, the opportunity exists to use input-output analysis in conjunction with other approaches such as urban metabolism to enhance the understanding of resource flows in and between regions. For example, input-output analysis could be modified to incorporate water and energy data to enable understanding of the water-energy-carbon links through the industrial and commercial sectors of the economy.

Urban metabolism is discussed in more detail below, but attempts have also been made both to extend the concept, for example by including a liveability aspect (Newman, 2007; Maheepala et al., 2003), and also to simplify it by applying only a part, or subset of urban metabolism in the form of a water mass balance analysis (Kenway, Gregory and McMahon, 2011).

The ecological footprint approach is least suitable for water sector applications. Both Fiala (2008) and Sahely *et al.* (2003) have pointed out that the ecological footprint has some conceptual shortcomings and does little to characterise the nature of flows through a city or identify areas of particular concern. Further, the ecological footprint does not characterise upstream or downstream impacts (such as altered environmental flows or biodiversity impacts) which are critical to the water sector.

5.3. Formulating Indicators

Drawing from the outputs of these resource flow analyses, from a single method application, in combination or in an extended form, it would be possible to generate a series of commonly understood, theoretically sound (and comparable across time and space), resource use and flow indicators. Such indicators could be used to monitor the progress of urban areas against a set of goals or desired outcomes relating to increasing resource efficiency through reducing inflows and outflows and increasing recycling.

Table 1 provides an example of possible measures of resource use efficiency which could be extracted from an analysis of resource use and flows and reformulated into a set of outcome-based indicators. Kenway *et al.* (2011) have already produced a set of indicators to characterise urban water on the basis of a mass balance analysis. Cities draw on the environment for resources and rely on the environment to accept waste. If we had perfect technology and water could be reused indefinitely at low energy, then water consumption would be a far less important issue.

In addition, the challenge would be to formulate some integrated indicators which relate across the different resources such as energy use per unit of water consumption. A further challenge would be to develop some indicators which would relate resource use and efficiency to socio-economic factors emanating from the application of some of the proposed "extended" analytical frameworks. In formulating, interpreting or comparing resource efficiency or metabolic indicators, context and purpose are important, suggesting that the concept has to be applied more specifically. A lower metabolic rate for water, for example, may not necessarily be the desired outcome for a city where water is abundant and its use is not creating significant impact (Kenway *et al.*, 2011).

Table 1. Possible resource use efficiency indictors to monitor the achievement of a set of desired outcomes based on results from analytical frameworks.

Resource	Outcome Sought from its Use	Overall Measure of Use Efficiency
Water	Water supply and wastewater disposal	Water consumption per head
Energy	Heating, Cooling, Lighting, Transport	Energy consumption per head
Nutrients	Healthy diet	Food consumption per head
Materials	Housing, clothing, vehicles, roads, transport	Water and energy intensity of each service/product

5.4. Urban Metabolism – a Concept for Understanding the Efficiency of Resource Use

While urban metabolism is not the only approach available for analysing resource flow in urban areas, it offers a number of advantages which make it a useful starting point in developing an analytical framework for understanding and promoting the role of water in achieving more sustainable cities. Some of these advantages are interrelated and do not necessarily apply exclusively to the urban metabolism approach, but urban metabolism certainly exhibits all these benefits as discussed in the following sub-sections.

The concept of urban metabolism was first promoted by Abel Wolman (Wolman, 1965), but it is only in the last decade that its use in urban planning has been seriously debated in the literature. Kennedy *et al.* (2007) review the development of the concept in the intervening period and show how the metabolism of cities can be analysed in terms of four fundamental resource flows or cycles, namely, those of water, energy, materials and nutrients. Barles (2010) also provides a review of the contribution of urban metabolism studies to sustainable urban development. Essentially, these studies map the flows of water, energy, materials and nutrients into an urban environment and then consider the degradation and/or transformation of these substances into waste products which then either accumulate or are transported out of the urban boundary. The analysis is based on mass and energy balances, but with the laws of thermodynamics being utilised to quantify efficiencies of transformation and the degradation of energy, e.g. high quality electrical energy is degraded to low quality heat energy. The aim is to explore ways of increasing resource efficiency through reducing inputs and outputs and increasing recycling (Figure 5).

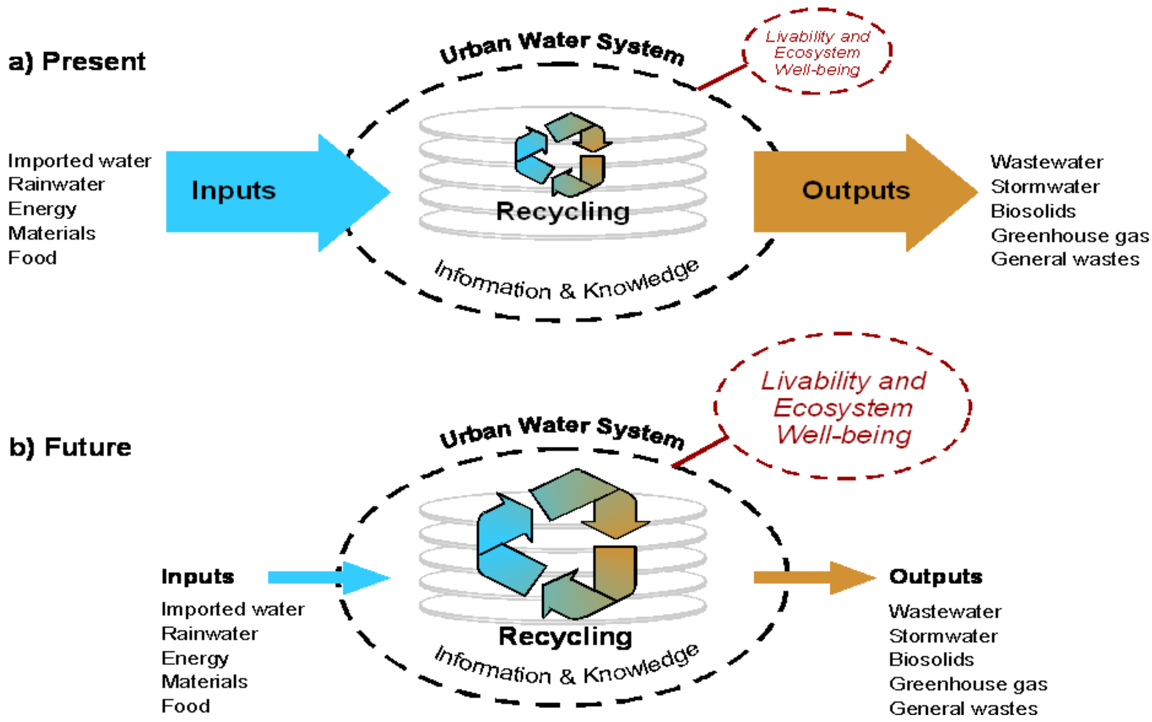


Figure 5: Metabolism of the "urban water system" and a sustainable future direction *(Source: Pamminger and Kenway, 2008).*

5.4.1. Water is Key

Wolman's original paper on urban metabolism (Wolman, 1965) identified that, in pure mass flow terms, water is by far the largest component of urban metabolism. It makes sense that if one is studying the role of water in achieving more sustainable cities, urban metabolism offers a viable approach.

5.4.2. Resource Flow Dynamics

The primary reason for advocating an urban metabolism-based analytical framework in this report is that it considers the physical and chemical processes which underpin the resource flows throughout the city rather than simply "accounting" for them as inflows and outflows. Understanding the dynamic processes which result in particular inflows and outflows allows for a far better identification of specific resource-use efficiency problem areas and the formulation of intervention strategies to increase resource efficiency. In comparison, for example, the ecological footprint approach does little to characterise the nature of flows through a city or identify areas of particular concern (Fiala, 2008; Sahely *et al.,* 2003).

Resource-use efficiency issues have become increasingly more important to address in water provision as financial costs of transporting large volumes of water over large distances have become prohibitive, and impacts on greenhouse gas emissions and energy use have been increasingly recognised. In the 1960s, when Wolman first proposed the concept of urban metabolism, the challenge of sourcing sufficient quantities of water for urban supply, even in very dry areas such as the south western United States, was overcome simply by building long distance water transportation systems involving pumps, pipes and channels. This solution largely ignored the significant cost and energy consumption involved. However, in the 21st century with growing concern over climate change and rising energy prices, limitations to this purely engineering approach have been recognised. Extended drought in many parts of the world has also highlighted the limitations to the conventional import/export philosophy for urban water supplies. The response to these pressures has been to consider all sources of water, including wastewater, as possibilities for urban supply. The rise in water recycling volumes has been a direct response to this change in philosophy.

Because urban metabolism considers the underlying chemical and physical processes to flows, it is able to accommodate these changing philosophies to water supply and consumption, providing guidance on which mix of water sources provides the required secure volumes of water with the desired quality at the least energy and infrastructure cost. As pointed out by Kennedy *et al.* (2007), it is important to take account of the potential for water accumulation or loss within the urban boundaries. These considerations go beyond the traditional concerns related to stormwater flows and flooding. Excessive capturing of water within the urban boundary can lead to impacts on the level and quality of groundwater, as well as minimum environmental flows required for the ecological health of local waterways. An urban metabolism model provides a mechanism for incorporating such considerations within urban planning.

5.4.3. Captures Flows Beyond the Urban Boundary

Kennedy *et al.* (2007) utilise the concept of urban metabolism to illustrate that urban areas draw considerable resources from surrounding areas and even internationally. For example, 81% of London's food consumption is imported from outside the United Kingdom. The city is compared to a plant which stretches its roots out further and further until its resource needs are met. For many cases, the equivalent areas of ecosystems for sustaining cities are often several orders of magnitude greater than the areas of the cities themselves. The ecological footprint approach also captures these flows beyond the urban boundary.

5.4.4. Virtual Water Flows

The scale of virtual water flows into an urban area through the import of food, energy and materials is not widely understood by urban planners, let alone the general community and politicians. As pointed out by Kenway *et al.* (2007), such flows can be an order of magnitude larger than the direct import of water and it makes little sense to focus all efforts on the direct water imports, while ignoring the possibility of reducing the virtual water flows. An urban metabolism model provides a mechanism for incorporating such considerations within urban planning.

5.4.5. Energy Consumption

When it comes to energy consumption, an urban metabolism model can capture a number of issues not normally considered by urban water planners. Firstly, there is increasing recognition of the importance of the so-called 'heat island effect' (Oke, 1995). Most mid- to hi-latitude cities now exhibit high urban air temperatures relative to their rural surroundings, particularly during the evening. While much of the heat island effect can be ascribed to the built form distorting the natural energy balance, there is also an effect from the direct use of energy within the city, most of which is eventually turned into heat. A positive feedback loop exists here, as higher temperatures in summertime result in increased use of air-conditioning and associated energy consumption. The use of water in maintaining green open spaces can play a critical role in ameliorating such effects through both evaporative cooling and changes to the built form.

The strong links between water and energy have been highlighted by a number of recent studies (Kenway *et al.*, 2006; Kenway *et al.*, 2009). These studies have highlighted the fact that while the direct use of energy in the provision of urban water services represents only a few percent of household energy consumption, the energy associated with the use of that water can be much greater. In fact, it is possible to offset all of the energy associated with even energy intensive water sources such as desalination, simply by improving the efficiency of domestic hot water production.

5.4.6. Nutrient Flows

Another important link which can be captured by an urban metabolism model is that between the urban water cycle and key nutrients such as nitrogen and phosphorus. A number of studies (Baker *et* *al.*, 2001; Faerge *et al.*, 2001) have revealed the extent to which natural nutrient flows have been altered by human dominated ecosystems. In particular, imports of nitrogen and phosphorus in food into the urban area are no longer returned to the agricultural fields from which that food was produced. Most of these nutrients end up in wastewater where treatment technologies are required to prevent their discharge from causing environmental damage to receiving waters. Energy and material consumption is required for this treatment process, thus adding further to the total energy and material consumption of the urban area.

While the most effective strategies for handling these nutrients will have to be tailored to individual urban ecosystems, the creation of such strategies will require an understanding of nutrient flows which can only be achieved within an urban metabolism study.

5.4.7. Extendable

There have already been a number of attempts made, in theory and practice, to extend the urban metabolism concept for wider application. Until recently, the human and ecological processes occurring in urban areas have generally been studied as separate phenomena. This approach precludes gaining an understanding of how human-dominated ecosystems emerge from interactions between socio-economic and ecological processes, both locally and over larger spatial scales. An extended metabolism model has been proposed and applied by Newman (1999) in assessing the sustainability of a number of cities. The inclusion of liveability factors, in addition to resource efficiency factors, is advocated to enable the identification of how a simultaneous increase in liveability benefits alongside a reduction of resource inputs and waste outputs, as the goal of sustainability in cities, might be achieved (Newman, 1999). The extended metabolism model has been used as a basis for deriving a set of principles to guide Integrated Urban Water Management (Maheepala *et al.*, 2003; Burn *et al.*, 2011).

In an attempt to more fully capture the interactions and feedbacks in human-dominated ecosystems, Alberti *et al.* (2003) have elegantly postulated and applied (Alberti, 2005) an integrated model of human and ecological processes to understand the forces driving urban development patterns, resulting patterns of natural and developed land, impacts on social and biophysical processes, resulting environmental and social changes and effects and feedback on human and biophysical drivers. In a recent report to the European Environmental Agency, Minx *et al.* (2011) present an extended concept of urban metabolism as part of developing a pragmatic approach to assessing urban metabolism in Europe. Three major extensions are recommended in going beyond a purely metabolic assessment: 1) linking the urban metabolism to environmental pressures and aspects of environmental quality at multiple spatial scales from local to global (with implications for concepts of carrying capacity and resilience); 2) linking urban metabolism to urban drivers, patterns (physical structure of the city) and lifestyles to enable an assessment of causes; and 3) linking urban metabolism to aspects of quality of life to understand consequences.

5.4.8. Divisible

It is recognised that the concept of urban metabolism can be difficult and complex to implement with issues of availability of appropriate data and analytical techniques. It is possible to apply only selected parts of the urban metabolism model to understand particular aspects. Techniques such as mass and energy flow analysis are a simplified subset of urban metabolism and provide a basic example of what the approach can offer. Consequently, the approach suggested in the conclusions to this report is to begin with such simple subsets of urban metabolism and build the simplest model which is capable of providing the required insights into resource use efficiency. Such models can then be used as the basis for demonstrating the value of the concept to politicians, planners and the general public.

5.4.9. Pragmatic

In recognition of the complexity and data-hungriness in applying the urban metabolism concept, a number of important contributions have been made, alongside proposals to extend the urban metabolism concept: 1) the necessity of being pragmatic in relation to data availability; 2) the importance of analysis at a disaggregated spatial scale; 3) ways in which downscaling techniques can be used to disaggregate higher level input-output stocks and flows data to smaller scale spatial units; and 4) the necessity of incorporating links and relationships from and to the specific geographic area of interest and between different scales so as to be able to explore questions related to the localisation and globalisation of resource flows (Alberti, 2003; Minx *et al.*, 2011). It has been demonstrated that it is still possible to achieve valuable outcomes from the application of the urban metabolism concept using pragmatic methods to acquire data, including downscaling techniques.

5.5. Urban Metabolism and Pathways to Sustainable Cities of the Future

The above discussion highlights the importance of the need for urban planners and policy makers to better understand the urban metabolism of their cities. In essence, this paper argues a primary approach to achieving sustainability is to maximise the efficiency and effectiveness with which key resources are utilised. It needs to be recognised that the laws of thermodynamics are the primary constraint facing the use of resources and all that can be done is to minimise their use for maximum gain. In other words, resource efficiency is a key component of sustainability. Consequently, it is vital that urban planners understand just how efficiently water, energy, nutrients and materials are being used in an urban environment and what avenues exist for improving this efficiency.

Developing and studying urban metabolism provides a means to achieving this understanding. Further analysis can then clearly identify where the potential for big gains in resource use efficiency lie and thus where to focus effort. Once these areas are identified, it will be much easier to mobilise the organisational, institutional and social structures to achieve them. The common understanding achieved through use of an urban metabolism model should facilitate this process, as all parties will be working from an agreed platform of knowledge and understanding.

It is enlightening to consider just how the use of an urban metabolism model could facilitate many of the actions identified in the IWA Cities of the Future Program (COTF). These actions were seen as critical to ensuring that the eleven principles identified in the Program could be advanced in a constructive manner. In Table 2, eight of these actions have been selected to illustrate the potential use of an urban metabolism model.

Table 2. Role of Urban Metabolism in Facilitating Key COTF Actions.

IWA COTF Action	Potential Use of an Urban Metabolism Model
Clarify the vision, definitions and measures of a sustainable city.	Identify and quantify important interactions between the various resource use demands of a city.
Establish a comprehensive evaluation framework to assess planning options based on full life cycle sustainability assessment. Include in this a common understanding of carbon neutrality and prepare guidelines for planners.	Provide a deeper and more comprehensive understanding of the various factors contributing to sustainability and carbon neutrality.
Develop resource accounts of the city's assets, resources, open spaces and biodiversity based on the principles of "urban metabolism'. To enable this, develop the tools and mechanisms to collate the necessary data.	Provide a scientifically credible basis for constructing resource accounts which give some insight into cause and effect processes.
Clarify the definitions and principles of integrated water management.	Help identify and understand what resource efficiency gains can be made through integrated water management.
Establish a comprehensive evaluation framework to assess water management options.	Provide a scientifically sound basis for applying an evaluation framework.
Adopt integrated urban and water planning processes to provide sustainable outcomes for cities and rural areas.	Facilitate the clarification of underlying principles and what can be done to implement them – see above.
Develop a resource and utilities atlas to communicate to customers.	Achieve a common understanding of critical resource issues which will facilitate clear communication to the public and politicians.
Build the capacity of the community, industry and government to make informed choices that deliver integrated water management.	As above.

Table 2 illustrates that analysing urban water systems through an urban metabolism model can be an important aid in implementing many of the actions identified in the IWA COTF Program. In particular, by identifying and quantifying important interactions between the various resource use demands of a city, it provides a deeper and more comprehensive understanding of the various factors contributing to sustainability and carbon neutrality. Also, by providing a scientifically sound basis for constructing resource use accounts, it provides the necessary insight required to clearly identify where the maximum gains in resource use efficiency can be made. This sound scientific basis can underpin any particular evaluation framework and provide the common understanding of critical resource use issues necessary for clear communication with the general public and politicians.

However, it is also important to recognise that quantifying an urban metabolism will not assist in implementing all of the actions identified in the IWA COTF Program and will not provide the immediate guidance required about specific developments or infrastructure investments. As outlined in an earlier section, there are many factors to be considered in making such decisions, while urban metabolism tends to focus attention on only one aspect – resource use efficiency. Factors on which urban metabolism is largely silent include:

- whole of life or community cost;
- system resilience and vulnerability to climate induced or operational incidents;
- human health risk; and
- optimum system scale.

While Novotny *et al.* (2010) argue that an urban metabolism approach can be applied at any scale, only a detailed engineering analysis can provide answers on questions such as what is the optimum scale at which to apply water recycling and other resource recovery loops. Consequently, urban metabolism is a tool which needs to be used in conjunction with a suite of other evaluation methodologies described in earlier sections of this report. However, urban metabolism can provide the overarching framework which provides the information base for all other techniques which examine the many other criteria involved in a final system design.

As Kenway and Pamminger (2008) have cogently argued, "A fundamental challenge for the engineering of future cities and their water systems is to reduce metabolic throughput while improving liveability and overall ecosystem well-being". Urban metabolism provides a process where our cities and their water systems can be monitored and benchmarked for their 'metabolic efficiency'. The use of such metrics could drive system designs to configurations better suited and tailored to their local environment.

6. CONCLUSIONS AND FUTURE INITIATIVES

6.1. Concluding Remarks

This report has attempted to summarise the literature discussion on the concept of sustainability of urban water systems and the application of a range of frameworks and associated metrics to guide decisions on their design. This discussion has clearly illustrated the varied approaches to defining sustainability and highlighted the fact that it provides a forum for debating the incorporation of economic, social and environmental issues into decision making.

The processes required to facilitate this decision making include the application of a structured framework involving the setting of clear objectives and goals and the adoption and use of a set of indices or indicators to measure if the specified objectives have been met. The report identifies and describes the wide range of frameworks and indicators which have been proposed for these purposes and illustrates the many factors involved in using any particular set. Despite these complexities, the Australian water industry has developed and applied its own framework and sets of indicators for making decisions about new or alternative water system designs.

Experience within the Australian water industry in applying this framework has demonstrated the many factors which need to be accounted for and the complexities and potential pitfalls which may be encountered along the way. Because of the pressing need to make decisions under uncertainty, pragmatism has had to be applied and a variety of approaches adopted to prevent so called 'paralysis by analysis.'

While recognising the challenges involved in improving the sustainability of urban water systems, the Australian water industry has also taken the initiative to widen the debate on sustainability to include the concepts of Sustainable Cities of the Future. The vision being promoted is that water systems are only one part of the total urban system and true sustainability can only be achieved by incorporating urban water system design into planning considerations for the overall city. While significant work has been undertaken to identify the basic principles which will underpin such an approach and the actions required to implement them, more work needs to be done to clarify and understand the scientific basis of this approach. Without this clarification and understanding, it is unlikely that the social and organisational requirements needed to successfully implement system design changes can be brought into line with the technical and economic constraints.

In this report, it is argued that, by obtaining a clear understanding of the factors impacting on the availability and efficient use of physical resources, common ground will be found from which all parties involved in urban planning (including those in the social and organisational realms) can move forward. There are a number of existing analytical frameworks available to use as a starting point, of which urban metabolism seems to be the most beneficial. It is likely, however, that the appropriate guiding analytical framework will need to be some combined, extended, but simplified version incorporating, but not limited to, the urban metabolism concept. It is proposed that the framework will need to extend beyond pure resource use efficiency and include aspects relating to cost, resilience and risk.

As a consequence of these considerations, it is recommended that future work on the sustainability of urban water systems focus on three areas, namely:

- The development of urban metabolism models covering a range of system complexity and scale;
- Work which will allow the integration of the output of urban metabolism models with tools used for assessment of system resilience, risk and cost; and
- Approaches to the clear communication of the outputs of urban metabolism-based models to urban planners, politicians and the general public, including the development of discrete and integrated indicators.

6.2. Some Thoughts on Future Work

While urban metabolism models have been produced for a number of cities around the world (Kennedy *et al.*, 2007), their construction can become quite complex and require large quantities of data across a range of economic activities. Incorporating water/energy and water/nutrient interactions as described above will only add to the complexity of this task. Consequently, the construction of such models should be looked upon as a learning exercise, in which early work focuses on the construction of simplified models which are capable of being further developed.

The design of these simplified models would be based on an analysis which identifies:

(1) where the potential for big gains in resource use efficiency lie, and would thus reduce the extent of the model to only those factors which significantly increase resource efficiency; and

(2) what the drivers are, such as population change, climate change, economic growth, influencing the most significant resource efficiency factors and which would need to be tracked over time to enable the longitudinal monitoring of resource efficiency improvements.

It will be important to identify at an early stage the exact nature of the outcomes sought from such models and how this information will be incorporated into decision making activities. Clarifying the nature and level of detail of information required will largely define the level of sophistication required of the urban metabolism model. This activity will be important for ensuring that the outcomes are also compatible with the use of other tools associated with estimation of system resilience, risk and cost.

Perhaps the area where most thought will be required is how to use the outputs of an urban metabolism-based model to enhance communication and understanding with a wider audience that will include urban planners, public institutions responsible for pricing, health and the environment, politicians and the general public. In fact, it is possible that two levels of information output will be required; one at a more detailed level for urban and water system planners and a second at a more integrated level to explain major outcomes to politicians and the general public. These outputs could be in the form of a range of resource efficiency indicators, derived from selected simplified urban metabolism modelling outputs. These indicators could be measured over time to provide a monitoring and feedback service to track improvements in resource use efficiency.

In considering such activity, it is good to remain aware of another recommendation of the IWA COTF report which is to "learn by doing"! Many of the issues and actions discussed in this report will only achieve positive outcomes if an attitude of continuous learning and improvement underpins all future work. This recommendation applies not only to the gathering of critical information from new water system designs but also to the analytical and planning processes described above.

APPENDIX 1: LITERATURE REVIEW

Sustainability Frameworks for Assessing Sustainable Urban Water Management Policies and Practices

Greg Laves, 2010

Introduction

This literature review was commissioned by Sharon Biermann and Tony Priestly of the Urban Water Security Research Alliance. It aims to:

1. Provide an overview of issues and practices associated with aligning the urban water sector with the broader sustainable development context;
2. Discuss issues associated with developing sustainability frameworks for the progression towards developing water sensitive cities (WSCs); and
3. Summarise key points from documents and articles that provide collective insights relevant to assessing sustainable urban water management (SUWM) policies and practices.

This paper will firstly review the broader concepts of sustainability and sustainable development including their definitions and characteristics. Secondly it will examine the need for the application of sustainability principles to cities and their role in the transition to water sensitive cities. Finally, it will provide an overview of sustainability assessment frameworks, its underpinning principles and the development of appropriate indicators for assessing sustainable water management policies and actions.

1. Sustainability and Sustainable Development

Defining Sustainability and Sustainable Development

Sustainability, in its literal sense, refers to the capacity for a particular state to endure or to be maintained (Ott 2003). Sustainability as an ecological construct originally developed during the latter half of the 20th century and was chiefly associated with an emerging ecological stance that the harvest of resources (water, agriculture, fisheries, forestry, etc.), needs to be maintained within recoverable limits (Kajikawa 2008). In the water sector this concept was referred to as 'safe yield' (Alley and Leake 2004). Sustainability underwent a subtle paradigm shift during the eighties, leading to the more paradoxical concept of sustainable development (SD).

The key difference between these concepts is twofold. Firstly, sustainability describes a desirable state that is maintained over a period of time, whereas SD implies a *process* through which sustainability can be achieved (McLaren 1996). Secondly, sustainability has an environmental focus by virtue of its ecological origins, while SD is driven from a social and economic imperative for achieving growth within the limitations of environmental resources and services.

The Brundtland Report (WCED, 1987) provided the first widely accepted definition of SD, stating that SD is "*development that meets the needs of the present without compromising the needs of future generations to meet their own needs".* While this definition has been criticised for its vagueness and lack of operational parameters (Kemp and Marten 2007; Kajikawa 2008), it is still commonly employed in contemporary literature. (See **Appendix A** for a selection of sustainability related definitions).

While simple in concept, attempts to gain consensus for a definition of SD have proved elusive, and resist quantification for reasons ranging from data inadequacy to hidden value systems and problematic assumptions (Kim 2008). Regardless of this difficulty, SD has become a social and political aspiration which, as an outcome of 1992 the Rio Earth Summit, saw the mainstreaming of SD policies and legislation by many countries to meet their obligations under Agenda 21.

The number of extant definitions regarding SD is estimated to be in the hundreds (Kemp & Martens 2007), which provides a significant barrier to achieving any consensus regarding the goals of SD. Adams (2006) summarises this dilemma when he states "*In implying everything, sustainable development arguably ends up meaning nothing*". In this regard, sustainability and sustainable development must be viewed as ideological constructs that embraces a range of underlying principles from which governments, corporations, planners, economists and environmentalist pick and choose to create their own flavours of SD.

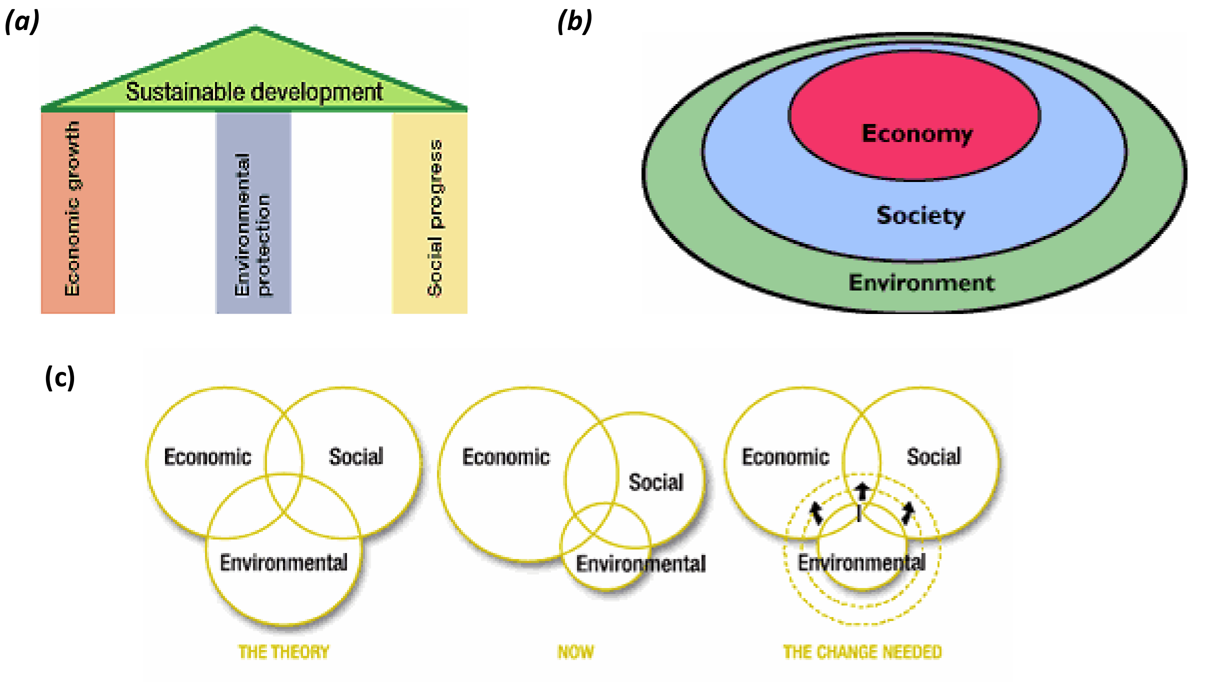
This flexibility of concept is considered by many analysts as a key reason for its widespread acceptance (Kajikawa 2008; Kemp and Martens 2007; Adams 2006), in that it allows a broader embracement of its ideals by those that would otherwise be excluded under a more precise definition (Robinson 2004). In this manner SD is released from the confines of an official doctrine, enabling it to become integrated in the social fabric

(Meadowcroft 1999). It also allows the dimensions of SD to expand, providing a fuller understanding of the costs and benefits associated with human activities (Kajikawa 2008).

While this flexibility permits actors in particular sectors to proceed with their particular vision of sustainability, Kemp and Martens (2007) point out that that the solutions generated in any single sector may not contribute to a broader sustainability for the whole of society. For example, desalination plants may provide a more sustainable outcome for the water sector, but its high energy requirements have negative consequences for a more sustainable energy sector. The broader implication of this observation is that achieving true sustainability in the water sector also requires sustainability in upstream and downstream sectors that overlap with the water sector. This principle of integrated sustainability at the city scale is a basic principle of WCSs and is addressed in **Section 2**.

Characteristics of Sustainable Development

Sustainable development engages the tension between economic growth and social well being on one hand, and the protection of the environment and the services it provides on the other (Kajikawa 2008; Kim 2008). This relationship has been expressed through a number of theoretical viewpoints including: 'the three pillars of sustainability' where social, economic and environmental issues are independently managed to support SD; 'the integrated view' which recognises that the three pillars are overlapping and integrated components of a single socio-ecological system; and 'the constrained view' (Ott 2003), which emphasises that social and economic aspirations are bound by the limitations of natural resources and the environmental capacity to absorb the stresses of human activities (Hay and Mimura 2006). These viewpoints are shown schematically in **Figure 1**.



The integrated view of sustainable development, from left to right, the theory, the reality and the change needed to better balance the model

Figure 1: ***Three views of sustainable development: (a) The three pillars; (b) Constrained development; and (c) The integrated view.***

An analysis of multidisciplinary definitions and interpretations of SD was undertaken by Martens (2006). Four common and fundamental characteristics of SD were identified by Martens from the literature. These were: intergenerational equity; varying levels of scale; multiple domains; and numerous perspectives. These are described below.

1. SD is an intergenerational phenomenon thereby requiring a minimum timeframe of at least 25 to 50 years to be meaningful. While planning in the urban water sector generally encompasses several decades, Lundin and Morrison (2002) recommend a longer perspective of 50 to 100 years when considering SD in the urban water sector ;
2. SD has multiple scales and can be operationalised at local, regional, national or even international scales. However, achieving sustainability at one scale does not necessarily transfer sustainability to another. For example applying sustainable practices in developed nations often involves shunting unsustainable practices to developing nations, thus negating a contribution to overall global sustainability.
3. SD embodies multiple domains. Most interpretations involve at least the economic, social and environmental, but may also include other domains such as the cultural, political or institutional (Sundberg et al. 2004). All domains are inextricably linked and need to be viewed holistically. A single focus on sustainability in any one domain simply allows effects in other domains to grow unchecked (Waheed 2009). In practice, however, economic needs tend to be prioritised.
4. SD is a complex concept which: lacks structural integrity and clear goals; is subjective, involving multiple stakeholders who apply selective interpretations of SD to their area of interest; and is inevitably surrounded by uncertainties.

The Issue of Trade offs

Inherent in the concept of SD is the paradox of resolving conflicting interests between economic and social needs on one hand and the needs of the environment on the other. Implicit in the models of sustainability is an acknowledgement that the growth of one domain will occur at the expense of another. A system that prohibits such tradeoffs is referred to as having "strong sustainability". In reality, most systems have "weak sustainability" as governments, businesses and societies trade off environmental resources for economic growth and improvements in life style (Gibson 2006). Weak sustainability is viewed by many as legitimate as long as one generation passes on to the next generation resources that equate to non-declining capital stock (Alley and Leake 2004). In the water sector, this may be achieved through the introduction of supply side and demand side technologies and behaviours.

2. Sustainable Cities

For the first time, the proportion of the world's population living in urban areas is greater than those living in rural areas (Brown et al. 2009). The ongoing trend of rapid population growth in cities has recently focussed a great deal of attention on how such growth can be realised within the sustainable development framework.

Identifying the principles for sustainable cities began indirectly with the Hanover Principles of 1992 which were developed for an international architectural design competition. Since then, the concept of sustainable cities has been driven by aspirational ideals, as well as the growing awareness of the reality for their need. There are a wide range of principle sets that underpin the concept of sustainable cities, but several themes tend to reoccur. These include:

- Avoid burdening future generations through employing long term and multi-staged visions;
- Cities are complex systems involving numerous domains and need to be viewed holistically;
- The impacts of cities must also be considered at other spatial and temporal scales;
- The integration of sectors is crucial to the planning process;
- Developing sustainable cities is an innovative and iterative process involving both success and failure;
- A healthy natural environment has intrinsic values which are critical for a cities existence; and
- Participatory engagement of the community and its institutions is essential.

A comparison of four sets of principles for sustainable cities including the water focused 'IWA Cities for the Future' is provided in **Table 1**.

Table 1: Principles for Sustainable Cities

Hannover Principles (1992)	**Melbourne Principles (2002)**	**Sustainable Cities PLUS Principles (2007)**	**IWA Cities for the Future Principles (2010)**
1. Insist on the rights of humans and the environment to coexist. **2.** Recognise the interaction of design with the environment at every scale. **3.** Respect relationships between spirit and matter. Consider the social and spiritual aspects of all aspects of human settlement. **4.** Accept responsibility for the effect of design decisions on the wellbeing of humans and the environment.. **5.** Create safe objects that have long-term value. Do not burden future generations as a result of poor design. **6.** Eliminate waste and consider the entire life-cycle of designed objects. **7.** Make use of "natural energy flows" such as solar power and its derivatives. **8.** Be humble, and use nature as a model and mentor, not as an inconvenience to be controlled. **9.** Share knowledge, strive for continuous improvement, and encourage open communication among stakeholders. **10.** The Hannover Principles should be seen as a living document committed to the transformation and growth in the understanding of our interdependence with nature, so that they may adapt as our knowledge of the world evolves.	**1.** Provide a long-term vision for cities based on: sustainability; intergenerational, social, economic and political equity; and their individuality. **2.** Achieve long-term economic and social security. **3.** Recognise the intrinsic value of biodiversity and natural ecosystems, and protect and restore them. **4.** Enable communities to minimise their ecological footprint. **5.** Build on the characteristics of ecosystems in the development and nurturing of healthy and sustainable cities. **6.** Recognise and build on the distinctive characteristics of cities, including their human and cultural values, history and natural systems. **7.** Empower people and foster participation. **8.** Expand and enable cooperative networks to work towards a common, sustainable future. **9.** Promote sustainable production and consumption, through appropriate use of environmentally sound technologies and effective demand management. **10.** Enable continual improvement, based on accountability, transparency and good governance.	**1.** Adopt a long-term lens (100 years) to vision desirable futures and backcast to determine Strategic Actions (10 – 30 years) and Implementation Plans (5-10 years) The long term lens: • Considers trends • Anticipates unexpected events • Exceeds narrow interests • Aligns with the lifespan of infrastructure; • Inspires creativity and innovation. **2.** View the city as one complex system incorporating the four elements of sustainability - economic, environmental, social and cultural, with each other and with governance in a holistic approach to planning. **3.** Use an integrated and comprehensive approach that aligns and integrates the various sectors of cities such as energy, water, transport, health and waste. **4. A**daptive management and collective learning management systems operate in a mode of constant learning and experimentation. **5.** View cities within their larger ecosystem, bioregion, water and air catchments, as well its socio-political and economic relationships with neighbouring areas. **6.** Plan through Participatory Engagement of multi-sectoral and multi-stakeholder groups and the public and is supported by highly skilled multi-disciplinary teams.	**1.** Cities will continue to grow in population but will be increasingly liveable. A feature of cities will be more interconnected communities. **2.** Sustainable cities will combine a compact footprint with sustainability and liveability. **3.** Cities will be resource neutral or generative, combining infrastructure and building design which will harmonise with the broader environment. **4.** Sustainable cities will be part of prosperous, diverse and sustainable regions. **5.** Sustainable cities will be served by a well managed water cycle that – in addition to public health and water security – provides for healthy waterways, open spaces and a green city. **6.** Sustainable cities will recognise that all water is good water – based on the concept of 'fit-for purpose' use. **7.** Cities will be served by informed, engaged citizenry and multi scale governance that enables local community choice. **8.** Customer sovereignty with full environmental and social cost. **9.** Accurate and useful information, including smart metering. **10.** Sustainable cities will be served by adaptive and integrated approaches to urban development. **11.** Sustainable cities will be served by a multifaceted water management system.

From: McDonough 1992, UNEP 2002, Seymoar 2007 and IWA 2010

In Australia, the sustainability of cities is evaluated through the Sustainable Cities Index (Trigg 2010), which employs three groups of criteria consisting of:

1. **Environmental Performance Indicators** which assess air quality, ecological footprint, green buildings, water and biodiversity
2. **Quality of Life Indicators** which assess health, density, subjective wellbeing, transport and employment
3. **Resilience Indicators** which assess climate change, public participation, education, household repayments and food production

The final report expressed the difficulty experienced in determining what indicators were required and which metrics best suited them. While self critical, the report acknowledged that the process is in an emergent stage and makes recommendations for the improvement of each indicator for future evaluations. Selection criteria for sustainability indicators are discussed in **section 3**.

The Need for Sustainable Water Management in Cities

The Standing Committee on Environment and Heritage report on sustainable cities (Com. of Aust. 2005) states '*The management of water is one of the most critical issues faced by Australian cities today and into the future*'. It further recognises that '*all Australian cities are facing a growing water deficit as population growth drives demand and, most ominously, climate change causes a reduction in rainfall'.* In providing a vision for sustainable Australian cities Davis (Com. of Aust. 2005) identified several key issues including:

- Current indicators suggest that cities are developing in an undesirable fashion;
- Creating sustainable cities requires planning;
- 80% of Australians live in cities, making sustainable cities a primary goal of sustainable development;
- While Australian cities may have similar challenges, their responses to them will most likely be very different.

Pearson (2009) warns that we have entered an era where urban water is a scarce resource and that the traditional top down, quality and supply approach to water management fails to address the issues of the time. Water planning, he continues, requires *'sustainable planning and decision-making in a complex and uncertain environment'*. Mitchell (2007) describes the implementation of sustainability in the Australian water sector as a series of push and pulls. The push is '*exemplified in regulatory shifts, for example towards water conservation, or through the imposition of targets for water recycling, or through new planning instruments that require significant reductions in water demand from new homes, or more generally requiring adherence to 'ecologically sustainable development' principles in a utility's enabling legislation*'. The pull comes from the impact of changing societal expectations which influences utilities to address both its own competitive interests and the interests of wider society (Mitchell 2007).

Gabe (2007) cites integrated urban water management (IUWM) as an example of a response by urban water managers to societal and statutory demands for multiple-bottom-line outcomes. He points out that IUWM '*recognises that actions to improve urban water systems can include a broader range of social, economic and other environmental outcomes beyond improving water quality and managing quantity'.* Changes in water management practices can contribute significantly towards sustainable cities by, for example: improving human health; supporting urban biodiversity; reducing greenhouse gas emissions; increasing amenity; sustaining environmental values; counteracting the effects of urban heat islands; and augmenting city liveability in general.

Water Sensitive Cities: An example of a SUWM framework for a sustainable city

The mainstreaming of sustainability principles has led to an emergence of innovative and integrative sustainable urban water management (SUWM) practices and an increasingly clearer vision of water sensitive cities (WSCs). In meeting the challenges of the future, the WSAA (2005) highlighted the imperative of assessing alternative water sensitive systems '*so that the most sustainable outcome is achieved*'. While significant progress has been made with implementing SUWM in some cities (Mitchell et al. 2007; Brown et al 2009), the transition is hampered by: continued investment in traditional water infrastructure (Wong and Brown 2009); socio-institutional issues including institutional inertia (Brown and Farrelly 2009); a lack of a benchmarking tools for informing the development of long-term policy for SUWM; and a lack of vision regarding the attributes of a sustainable water city (Brown et al. 2009)

To assist the transition, Brown et al. (2009) has proposed an 'urban water transitional framework'. This framework describes six distinct, yet cumulative, conceptual stages of urban water management leading to WSCs (see **Figure 2**). Transitions between stages are driven by socio-political factors towards a more complex albeit more sustainable urban water future. The first three stages are well developed in most Australian urban centres while 'Waterways City' and 'Water Cycle Cities' are in various phases of development.

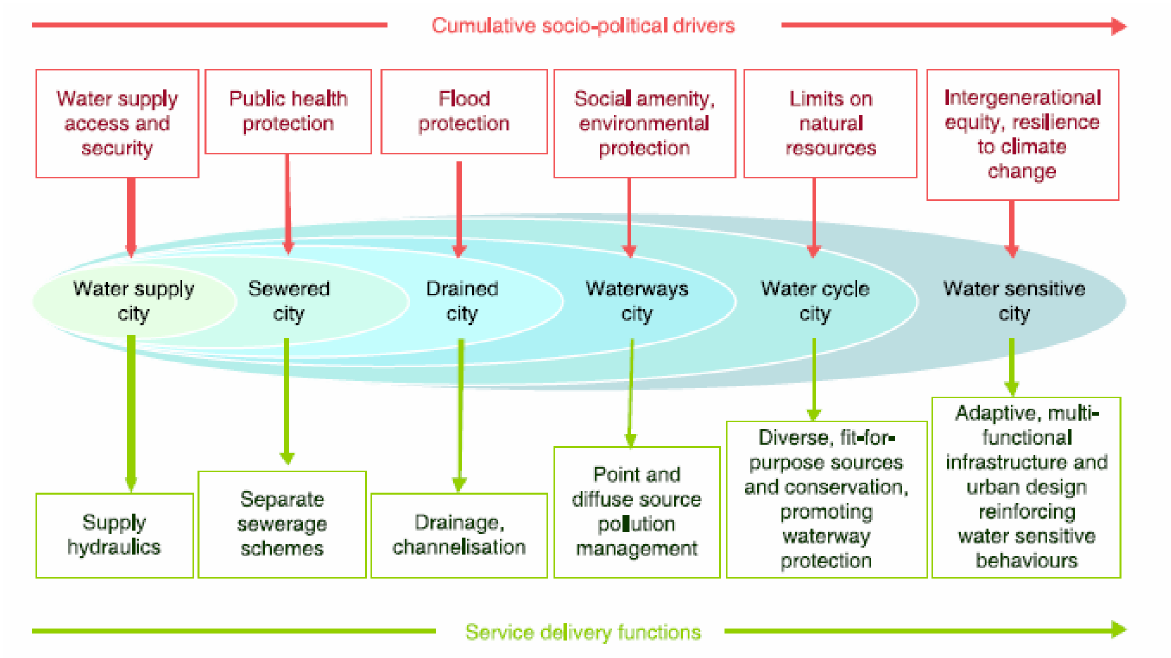


Figure 2: Stages of Urban Water Management (Source: Brown et al. 2009)

The final stage in Browns model, the 'Water Sensitive City', views water management in Water Sensitive Cities as '*an integrated component of environmental repair and protection, supply security, flood control, public health, amenity, liveability and economic sustainability, amongst others*'. Brown points out that there is no example of a Water Sensitive City anywhere in the world and that a major socio-technical overhaul of conventional urban water management approaches must be undertaken to achieve this state. Interestingly, Ison et al. (2009) in reporting on practitioners perceptions of WSCs, states that *'Although time scale estimates differ, there is a clear sense in which participants feel it is feasible to create water sensitive cities in Australia in the next 5-20 years*'.

The Centre for Water Sensitive Cities (2010) describes the conceptual basis of WSCs by stating that '*a philosophy of flexibility in supply and use to meet all users needs underpins the collection and movement of water, and the technologies to facilitate the physical movement of water are designs which manifest these ideals visually for all to acknowledge and appreciate"*. The centre sets down the following three principles as the foundation for their vision of a Water Sensitive City:

1. **Cities as Water Supply Catchments:** meaning access to water through a diversity of sources at a diversity of supply scales;
2. **Cities Providing Ecosystem Services:** meaning the built environment functions to supplement and support the function of the natural environment; and
3. **Cities Comprising Water Sensitive Communities:** meaning socio-political capital for sustainability exists and citizens' decision-making and behaviours are water sensitive

In discussing the design of WSCs, Wong (2010) also provides the following two underpinning principles.

1. Minimise the import of potable water into, and the export of wastewater out of, the boundaries of the city; and
2. Optimise the use of water resources within the city.

The differences between current water management characteristics and those of WSCs are listed in **Table 3,** while differences in catchment management are illustrated schematically in **Figure 3**.

Table 3: Comparison of the attributes of a Water Sensitive City with current urban water management

Attributes	**Traditional Regime**	**Water Sensitive Regime**
System Boundary	Water supply, sewerage and flood control for economic and population growth and public health protection	Multiple purposes for water considered over long-term timeframes including waterway health and other sectoral needs i.e. transport, recreation/amenity, micro-climate, energy etc.
Management Approach	Compartmentalisation and optimisation of single components of the water cycle	Adaptive, integrated, sustainable management of the total water cycle (including land-use)
Expertise	Narrow technical and economic focussed disciplines	Interdisciplinary, multi-stakeholder learning across social, technical, economic, design, ecological spheres etc
Service delivery	Centralised, linear and predominantly technologically and economically based	Diverse, flexible solutions at multiple scales via a suite of approaches (technical, social, economic, ecological etc)
Role of public	Water managed by government on behalf of communities	Co-management of water between government, business and communities
Risk	Risk regulated and controlled by government	Risk shared and diversified via private and public instrument

Source: Centre for Water Sensitive Cities, Monash University

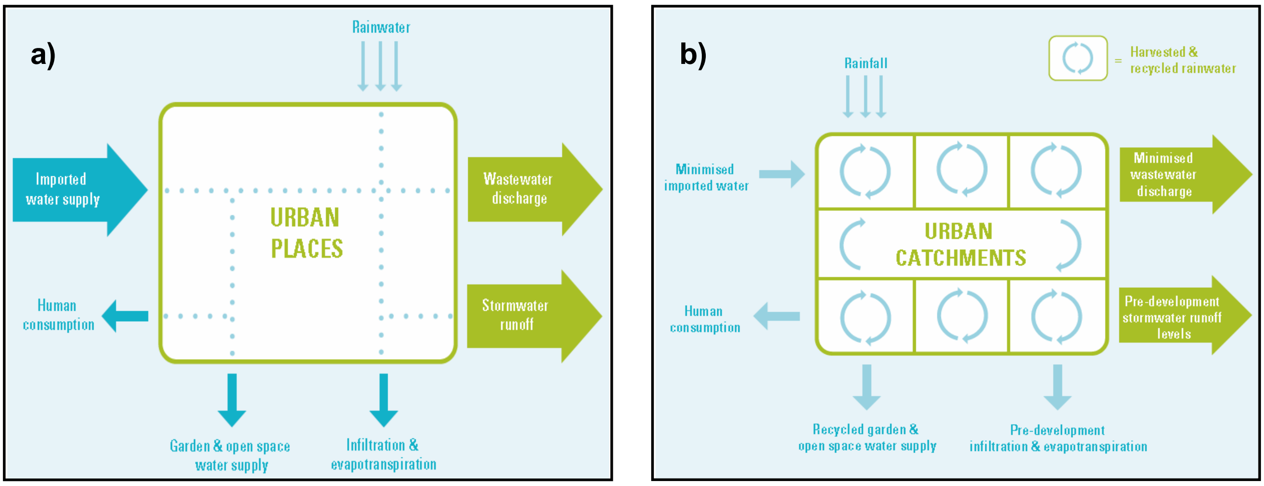


Figure 3: ***a) Linear model of catchment management associated with current UWM practices; and b) The closed loop model characteristic of WSCs (Source: Marrickville Council 2007)***

A major undertaking to assess practitioners' perceptions of WSCs was recently conducted by the International Water Centre. The report, 'Transitioning to Water Sensitive Cities' (Ison et al. 2009), summarised the findings of workshops held in 5 cities throughout Australia involving 529 practitioners operating within the Australian water sector. A précis of key results are given in **Table 4**.

Table 4 Key findings of 'Transitioning to Water Sensitive Cities' (Ison et al. 2009)

Issues & Concerns	Opportunities	Characteristics (3 themes)	Key Messages
• Lack of vision, goals and common understanding • Social and institutional perceptions, change and attitudes • Institutional capacity and governance • Funding, (true) cost, value.	• Advancing (De)centralised and green technology and infrastructure; water (re)sources and diversity of use; & replacing old & aging infrastructure • Developing knowledge, data, information and research and learning • Focusing regulation, policy and planning • Recognising social concerns, raising awareness, support and stakeholder involvement • Climate change, drought and (financial) crisis provide opportunities for change	• Cities as supply catchments – diversity of sources, flexible use and delivery options; embedding resilience and adaptivity as part of a holistic and integrated system. • Cities provide ecosystem services – space, green infrastructure, ambiance and atmosphere of the city, and waterways (including quality). • Sophisticated and water smart cities - community collaboration, acceptance and engagement, and the incorporation of true cost	• Realising the urgency • Leading, facilitating and sustaining a vision for Australia's cities • Designing in sustainability and focussing on the long-term; • Tackling issues holistically – enabling integration; • Rethinking institutional arrangements • Building community and industry support and • Recognising situational and contextual nature of innovation and change.

3. Sustainability Assessment Frameworks

ISO 24500 defines assessment as "*a process or result of this process, comparing a specified subject matter to relevant references*". Sustainable development assessment processes require the design, application and interpretation of quantitative or qualitative measures that can illustrate the effectiveness of policies and actions against the goals of sustainable development. Frameworks are usually multi-tiered which, according to Waheed (2009), include:

- Objectives or goals set by decision makers and the community;
- Assessment criteria including indices and indicators which provide the principles to establish that specified objectives have been met; and
- Performance data, variables and parameters which are the basic data that can be directly measured, observed or otherwise monitored.

As the concept and goals of SD differs from stakeholder to stakeholder, the approaches employed as assessment frameworks have their roots in a diverse range of disciplines. For example: Material Flow Analysis (MFA) comes from an engineering perspective; Pressure-State-Response (PSR) frameworks have a firm footing in the environmental sciences; Adjusted Economic Accounting provides an economic evaluation; while other approaches such as "dimensions of sustainability" are multidisciplinary in nature. According to Guio-Torres (2006), typical framework approaches can be grouped into seven broad categories. These are:

- **Dimensions of Sustainability.** This approach considers the total impacts of a range of strategies on various dimensions including at least the social, economic and environment. The Global Reporting Initiative is an example of this approach.
- **Adjusted Economic Accounting.** This approach attempts to allocate financial values to changes in social wellbeing and environmental goods and services. A typical indicator might be an adjusted GDP.
- **Biophysical Accounting.** This approach accounts for the total use (footprint) of natural resources consumed in the carrying out of particular activities.
- **Resource and Material Flow Accounting.** This approach typically examines 'cradle to grave' inputs and outputs associated over the lifetime of a particular activity. For example, life cycle analysis and city metabolism.
- **Pressure – State – Response.** This approach and its variants (DPSIR and DPSEEA) consist of an analysis of cause and effect pathways to determine the negative impacts of particular activities.
- **Guided by Objectives.** This general approach uses indicators and measurements to determine where the current activity stands against stated goals.
- **System Analysis.** Sustainability is understood as the outcome of interaction between society and nature. This approach recognises that societies and nature are constantly evolving hence sustainability goals are not static. The core goal here is the long-term viability of both nature and society.

Conceptual Components of Sustainability Frameworks

Jabareen (2004, 2006a & 2006b) undertook an extensive review of the multidisciplinary literature involving sustainable development and identified seven key concepts that underpin the current theoretical view of sustainability frameworks. These are:

The concept of ethical paradox of a theory that purports to reconcile the irreconcilable, i.e.:

1. Balancing the conflicting needs of society and the environment, where the well being of one can only be achieved at the expense of the other; and
2. The fallacy of perpetual sustainability in a world with finite resources (Kemp and Martens 2007).

The concept of natural capital stock which can be divided into three categories: non-renewable resources such as minerals; renewable but finite resources including water; and the capacity of natural systems to absorb pollutants (Roseland 2000). Hintenberger et al. (1997) highlighted the problems that can arise when societies consume natural capital rather than the income it produces. The management of natural capital was recognised by Kohn et al. (2001) as one of the key challenges associated with sustainability.

The concept of equity embodies the social conditions and aspirations of sustainability. The literature generally identifies two types of equity regarding sustainability being: intergenerational, involving the fairness in allocation of resources between current and future generations; and intragenerational allocation, between competing interests at the present time.

The concept of eco-form involves the design of the form of human habitat, so that it functions in more ecologically sustainable ways than at present.

The concept of integrative management is a corner stone of sustainable development which recognises that ecological and human systems are inextricably interwoven and that environmental integrity is a precursor for sustained human development.

The concept of utopianism embraces the goal of achieving a society where justice, equity and harmony with nature prevail.

The concept of political global agenda which cautions that sustainability transcends political boundaries and requires global cooperation for sustainable development to occur. In recent decades the international political agenda has evolved as one of the key drivers for the implementation of sustainable practices (Waheed et al 2009).

These complex and often idealistic concepts makes the assessment of sustainable development a significant challenge. Nonetheless, Gibson (2006) identified eight 'safe assertions' that provide insights when developing sustainability assessments. These are:

1. *Sustainability considerations are comprehensive, including socio-economic as well as biophysical matters, and their interrelations and interdependency over the long term as well as the short term.*
2. *Precaution is needed because human and ecological effects must be addressed as factors in open, dynamic, multi-scalar systems, which are so complex that full description is impossible, prediction of changes uncertain, and surprise likely.*
3. *Minimization of negative effects is not enough; assessment requirements must encourage positive steps towards greater community and ecological sustainability, towards a future that is more vi-able, pleasant and secure.*
4. *Corrective actions must be woven together to serve multiple objectives and to seek positive feedback in complex systems.*
5. *Sustainability requires recognition both of inviolable limits and of endless opportunities for creative innovation.*
6. *Sustainability is not about balancing, which presumes a focus on compromises and trade-offs. Instead the aim is multiple reinforcing gains. Trade-offs are acceptable only as a last resort when all the other options have been found to be worse.*
7. *The notion and pursuit of sustainability are both universal and context-dependent. While a limited set of fundamental, broadly applicable requirements for progress towards sustainability may be identified, many key considerations will be location-specific, dependent on the particulars of local ecosystems, institutional capacities and public preferences.*
8. *In the pursuit of sustainability, the means and ends are intertwined and the process is open-ended. There is no end state to be achieved.*

The Importance of People and Communities in the Assessment Process

The degree of sustainable development is dependent on the extent to which the concept is embraced by institutions and the public. Pearson (2009) points out that '*sustainable water management is not about achieving an end point (or even measuring for this end point) but rather it is the **process** of influencing what people believe (the cognitive process) and what they do (the behavioural process)*' .

Becker (2004) asserts that public and stakeholder engagement is critical in every step of the SD process and refers to the Bellagio Principles (IISD 1997) as an appropriate framework for developing effective assessment frameworks. The Bellagio Principles (see **Figure 4**) involve a four stage iterative process, centred on public participation whereby: the assessments purpose, issues and goals are visualised; the framework and indicators are developed in the specific context of the situation; the results are presented with clarity to prompt community awareness and action; and finally actualisation of the results into performance or policy. In this manner the assessment leads to actions that through a series of small steps bring about long term societal change which, according to Colebatch (2005), lies at the core of SD.

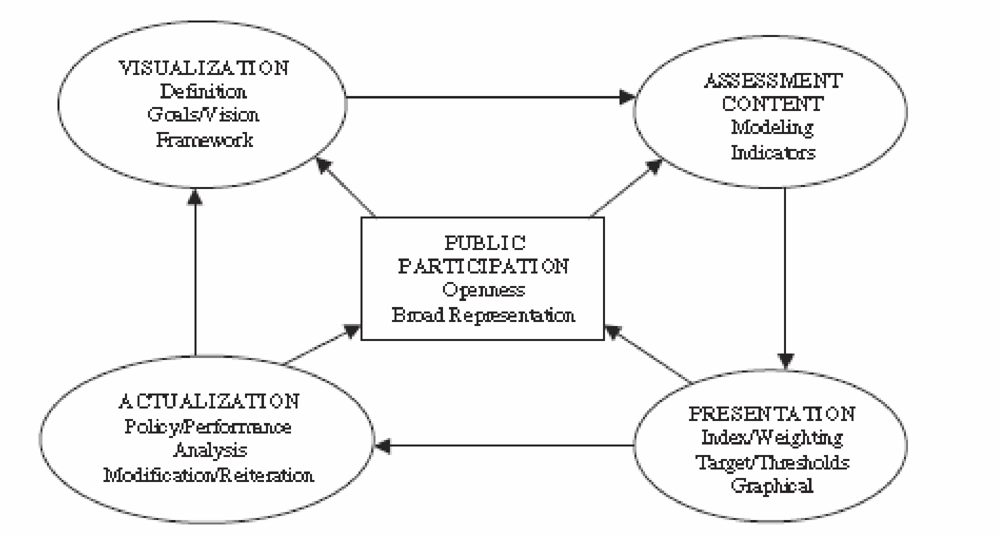


Figure 4: Conceptual model of the Bellagio Principles (Source: Becker 2004)

Ison et al. (2009) summarised the opinions of 529 participants at workshops on Water Sensitive Cities. They found that the significant constraints in moving towards water sensitive cities had a strong focus on personal attributes including the *'lack of commitment, will and support, lack of ability to influence decisions and policy and current mindsets and attitudes'.* They go on to say however that '*many of the constraints, with suitable shifts, also hold the key for enabling action'* and that *'these findings point towards the significance of social processes to enable deployment of technologies for creating water sensitive cities'.*

A key personality for driving the progression of SUWM is 'the champion' who Taylor (2009) defines as '*emergent leaders who have specific attributes and are adept at influencing others to adopt SUWM principles and practices*'. The lack of emergent international leadership at the 2009 Climate Change Convention in Copenhagen has further highlighted the need to seek alternate and innovative leadership pathways for building resilience in critical infrastructure (Biggs 2010). Biggs points out that innovation rarely comes from a top down approach, but is more likely to be driven by communities, businesses and local governments seeking-out solutions for local issues. Instead of awaiting guidance from Federal or State authorities, more local entities such as communities and cities are looking to the lessons provided by others pioneering the field of sustainable development.

Examples of Assessment Frameworks for Sustainable Cities

Urban land use policies and decisions regarding the development of urban infrastructure have significant and long-term impacts. However few cities have the capability to apply rigorous analysis and modelling to evaluate the sustainability consequences of their actions (Brits et al. 2007). Currently, there are a number of frameworks available for assessing sustainable development in cities but no single framework has emerged as a generic model. Seymoar (2004) indicates desirable frameworks for assessing the sustainability of cities should include the following four characteristics. They should: be holistic in their approach; have a multi-generational perspective; be applicable to a variety of scales; and have an adaptive management framework. A comparative overview between several widely used frameworks was prepared by Seymoar and is provided in **Appendix B**.

WSAA Sustainability Framework of Urban Water Systems

A sustainability framework for the urban water sector was developed for the WSSA (Lundie et al. 2008) after the Intergovernmental Agreement for a National Water Initiative identified the need to create WCSs. This framework for assessing new and alternative projects de-emphasises the traditional focus of economic and engineering considerations to also include those of the natural environment and social values. The framework (shown schematically in **Figure 5**) is an iterative process consisting of six phases which are summarised below.

Phase 1 Framing the problem and objectives. This phase focuses on problem framing and the objectives for its solution. Definition of the context-specific objectives includes affected stakeholders, selection of participants and the intended use of the results, as well as the driver(s) of the project.

Phase 2 Generation of preliminary options. Stakeholders develop numerous preliminary options which will be further investigated in Phase 4 and if 'kept', in Phases 5 and 6. These options consist of conventional as well as alternative options. Phases 1 & 2 will both draw out the values of stakeholders.

Phase 3 Selecting sustainability criteria. Criteria are selected 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; should cover all domains; and encapsulate the various context-specific objectives from Phase 1.

Phase 4 Screening of options. Pragmatism allows only a few options to be developed and assessed in detail (Phase 5). Phase 4 reduces the list of options to a number that can feasibly be assessed.

Phase 5 Perform detailed options assessment. Relevant experts are tasked by the stakeholders to undertake the detailed assessment using various tools (such as LCA, LCC, MRA, CRA etc.) to provide data on each of the agreed criteria. Results are normalised and compared to aspiration goals.

Phase 6 Recommend preferred option: Final recommendations are made for the preferred option(s). All of the previous information collected during Phases 1-5 is presented to key stakeholders. A transparent decision process is undertaken and a final selection is made.

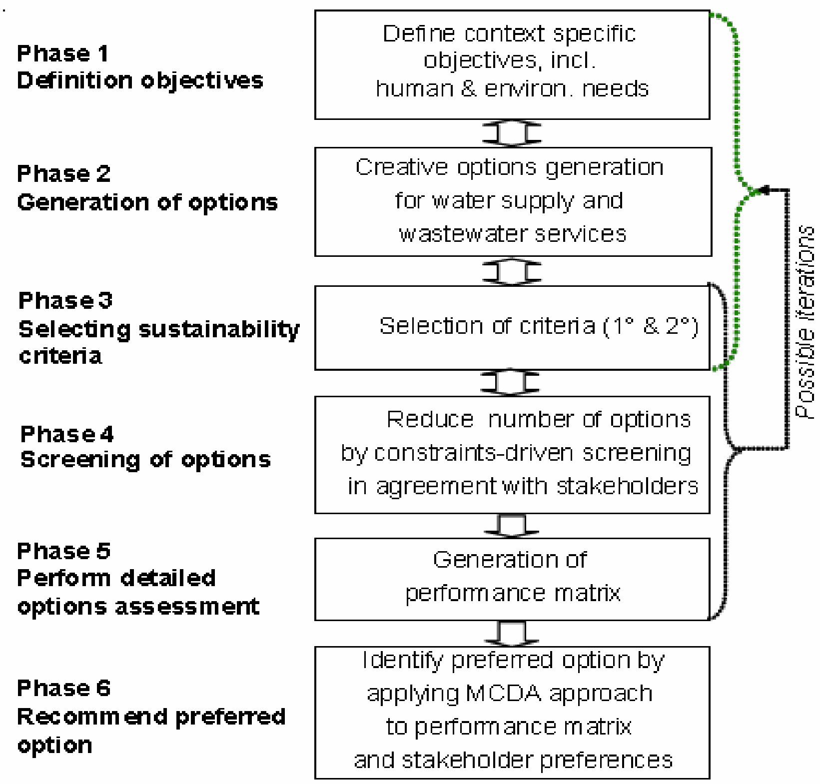


Figure 5: Schematic representation of the WSAA Sustainability Framework of Urban Water Systems

4. Metrics

Indicators

Lundin (2003) describes indicators as 'pieces of information, which summarize important properties, visualize phenomena of interest, quantify trends and communicate them to relevant target groups'. According to Innes and Booher (2000), indicators can be developed as either:

- **All-purpose indicators** involving dozens or hundreds of indicators to enable decision-makers to find relevant information for ***any*** issue;
- **Specific purpose indicators** to describe the condition of a particular issue such as dam storage levels; or
- **Aggregated values** for a particular state, such as the Healthy Waterways Report Card grades. However, Munda (2005) makes the point that the more comprehensive aggregate indicators are, the less able they are to inform decision makers of the underlying causes and thus influence policy.

Li (2008) also points out that, indicators operate at three levels.

1. **Individual indicators** represent a menu of separate indicators or statistics that can be seen as a first step in aggregating existing quantitative information.
2. **Thematic indicators** are individual indicators grouped around a specific area or theme. This approach requires identifying a core set of indicators that are linked or related in some way. These are generally presented individually rather than synthesised.
3. **Composite indicators** are formed when thematic indicators are compiled into a synthetic index and presented as a single composite measure.

Criteria for Indicators

Developing indicators can be a troublesome task. Liverman et al (1988) recommends that indicators be sensitive to change, have predictive ability, identify threshold values and have an integrative capacity. Other studies (Hellstrom 2000; Dhakal and Imura 2003; Alegre 2006) have specified that indicators should be: clearly defined; analytically sound; policy responsive; auditable; simple to understand; easily measured; open; and flexible. Li (2008) also recommends that indicators be cost effective. A summary of Li's indicator criteria is provided in **Appendix C**, while **Appendix D** reproduces an IWA summary of common mistakes made by organisations when undertaking performance indicator projects in the water sector.

Indicators provide a popular set of tools for assessing sustainability. Guio-Torres (2007) undertook an analysis of indicator sets used in the urban water sector (UWS) and, while finding many similarities, also found strong conceptual differences. This research raised five key questions regarding the formulation of UWS indicators.

1. **What is considered as "sustainability" of the UWS?**
   The concept of sustainability in the water sector is highly subjective and contestable. Therefore a clear operational definition is essential for any assessment project. Consideration should also be given to identifying achievable aspirations. According to James (1999) and Hiessel et al. (2001), true sustainability of water systems in large cities is implausible. In their opinion, the goal of the UWS should be the reduction of 'un-sustainability'.
2. **What is the system under analysis? Or, in other words, what is the UWS comprised of?**
   The type of boundaries used for an analysis of UWSs may vary depending on the stakeholders needs. Each set of boundaries has a limited focus which significantly affects the outcome of the final assessment and the course of action ultimately followed. Boundaries may be perceived as infrastructural units, water company boundaries, city or other administrative institutions responsible for more than just water, or the UWS as a whole. In terms of WSCs, sustainability parameters could be inclusive of impacts at the regional scale, or also include the impacts generated by supporting industries and consumers.
3. **Should the emphasis be on current water problems or on thinking about future viability?**
   When considering SD goals, the timeframe of the goals is a key factor. Not only do UWSs need to address current needs, but they also need to consider potential future opportunities and hurdles. Guio-Torres (2007) puts forward four issues that current UWS planning needs to be sensitive to. These are: technological change; urban design changes; distributional effects of water in economy, society and nature; and the evolution of sustainability problems.
4. **What does SI tell us about possible solutions that humankind could generate in the future?**
   SIs are traditionally focused on negative outcomes and, in some approaches, try to link impacts with societal behaviours. However the ability of SIs to suggest how UWSs may increase or reduce these impacts is generally missing.
5. **What is the target?**
   Stakeholder's needs and perspectives are diverse. Generally indicators are either chosen to reflect these needs by an expert group or through stakeholder participation. On determining targets, Guio-Torres refers to the following two observations.

   i. *While SIs chosen by an expert group may be scientifically sound, certain aspects will be included and others overlooked (Scheller 2000).*
   ii. *On the other hand, SIs chosen by engaging stakeholders may be more comprehensive but tend to emphasize feasibility and are prone to accept limitations in sustainability (Starkl and Brunner 2004).*

Simplifying Indicators for Sustainable Cities

Sustainability in cities is driven by community and institutional needs and conditions, as well as their own perception of what SD involves. Consequentially, indicator sets deemed suitable for measuring progress in meeting SD goals in one situation may not necessarily be appropriate to meet the requirements of another (Singh 2010). Cities are complex systems which could potentially require an extensive range of indicators to provide an inclusive insight into the state of the various dimensions concerned. However, this conflicts with some of the properties of indicators discussed above (simple, cost effective, easily communicated etc). McLaren (1996) put forward four underlying properties which, when included in the indicator design process, could minimise the number of indicators while still providing for effective support for decision-making. These are:

1. **Integrative indicators** illustrate linkages between various dimensions. For example, water consumption trends provide an insight into the economic, social and environmental dimensions, while the amount of water recycling can reflect community attitudes, changes in environmental contamination, costs of water provision and removal, as well as the capacity of water providers to be innovative.
2. **Forward-looking indicators** provide a measure of progress towards sustainability goals and are a prerequisite for addressing intergenerational equity. Trend indicators linking past and current conditions provide indirect information regarding the effectiveness of policies and actions to meeting goals or avoiding critical thresholds for variables such as water quality. Predictive indicators, such as those generated from modelling, can be combined with conditional indicators to produce 'if, then' indicators. For example, 'If water consumption is maintained at current levels for the projected population of 2050, then water extractions will exceed current capacity for supply'.
3. **Distributional indicators** provide the ability to assess the distribution of conditions within a particular urban setting or differences between population centres. Indicators based on totals or averages for a spatial entity are not necessarily representative of conditions in all cases (Singh 2010). Water consumption and waste management practices may vary considerably due to age, education, income, local environmental situations or even planning policies. Indicators may also attribute conditions locally when in fact the issue being measured is a result of non-local behaviours. Downstream pollution generated from upstream activities is a typical situation where this would occur.
4. **Multi-stakeholder input** in the indicator development process has been shown to provide influential, valid and reliable indicator sets (Moglia and Sharma 2009; IISD 1997; Innes and Booher 1990). This is mainly due to value-laden and context-sensitive nature of SD (McLaren 1996).

5. Conclusion

This review has described the characteristics and issues associated with sustainability and its role in the sustainable development of the urban water sector. As a result of this process several key points can be made regarding assessing sustainable urban water management policies and practices. These are:

1. Sustainability is a flexible concept that can be applied in a range of contexts;
2. Sustainable development, in any context, shares common characteristics involving long-term views, multiple scales, multiple domains and integrative practices;
3. The process of sustainable development is iterative and much can be learnt from the successes and failures of others;
4. There is a recognised need (and desire) for water sensitive cities;
5. The approaches available to assess SUWM are numerous;
6. The process of evaluating sustainability is potentially complex and requires clear objectives and parameters to be established as a first step;
7. Developing appropriate sustainability frameworks and functional indicators are essential for effectively assessing progress in achieving sustainability goals for SUWM; and
8. There is a clear consensus for a participatory approach when developing assessment frameworks.

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Appendix A: Selected Sustainability Related Definitions and Comments

Sustainability

Sustainability means that present and future persons have the same right to find, on the average, equal opportunities for realising their concepts of a good human life. *(Ott 2003)*

Sustainability is "not a state to be arrived at but a broad evaluative framework for understanding and justifying social practice". *(Lundie et al. 2005)*

Sustainability is the persistence of certain necessary and desired characteristics of people, their communities and organizations, and the surrounding ecosystem over a very long period of time (indefinitely). *(IISD 1997)*

Sustainability is about a cumulation of small decisions and changing patterns of 'normal practice' *(Colebatch, 2005).*

Sustainability is a principle of life about both sustaining a particular resilient state and adjusting to changing internal and external conditions. *(Kohn et al. 2001)*

Sustainable Development

Defining sustainable development is an exploration into a tangled conceptual jungle where watchful eyes lurk at every bend. *(O'Riorden 1985)*

Sustainable development is development that meets the needs of the present without compromising the needs of future generations to meet their own needs. *(The Brundtland Report WCED, 1987)*

Sustainable development is development that reaches or maintains a sustainable state. *(Ott 2003)*

Meeting fundamental human needs while preserving the life-support systems of planet Earth *(Kates 2008)*

Sustainable development aims to meet human needs while preserving the natural environment so that these needs can be met not only in the present but also indefinitely in the future. *(Waheed 2009)*

Ecological sustainable development is using, conserving and enhancing the community's resources so that ecological processes, on which life depends, are maintained, and the total quality of life, now and in the future, can be increased. *(National Strategy for Ecological Sustainable Development Australia, COAG 1992)*

Sustainability and SD are essentially ethical statements regarding desirable outcomes of social and economic policies and actions *(Adams 2006)*

Sustainable Cities

Sustainable cities are those cities, towns and urban areas that use their resources to meet current needs while ensuring that adequate resources are available for future generations. Sustainable cities seek community development that enhances the local environment and quality of life as well as developing a local economy that supports both thriving human and ecological systems. Sustainable cities are characterized by improved public health and a better quality of life for all the residents by limiting waste, preventing pollution, maximizing conservation, promoting efficiency, and developing healthy regional economic development and vibrant communities. Integrated planning and design are key elements of developing sustainable cities and communities. (*The Social Network for Sustainability 2008)*

Sustainable cities of the future: they will be vibrant urban regions which are economically productive, environmentally responsible, and socially inclusive. *(Commonwealth of Australia 2005)*

Sustainable Urban Development: Improving the quality of life in a city, including ecological, cultural, political, institutional, social and economic components without leaving a burden on the future generations. *(URBAN21 Conference Berlin, July 2000)*

Sustainable urban development is the ability to make development choices which respect the relationship between the three "E's"-economy, ecology, and equity. (*Mountain Association for Community Economic Development)*

Cities are where it is all happening. If we are going to succeed in sustainability it is going to live or die in the cities. *(Dr Harry Blutstein, Director of Integrating Sustainability in Commonwealth of Australia 2005)*

Sustainable Urban Water Systems

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)*

Sustainability in the context of the Australian urban water industry can be defined as: "Understanding the long term interdependence between natural and financial capital with the objective of protecting and enhancing environmental capital so as to ensure maximum long term economic value to the community.*" (WSAA 2009)*

Sustainable water systems are defined as "water systems that are managed to satisfy changing demands placed on them (both human and environmental) now and into the future, whilst maintaining ecological and environmental integrity of water systems" *(ASCE/UNESCO 1998)*

Sustainable use of water 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. (Gleick 2000)

For urban areas, our vision is water management where water and its constituents can be safely used, reused and returned to nature *(Malmqvist, 1999)*.

Sustainable water management is not about achieving an end point (or even measuring for this end point) but rather it is the process of influencing what people believe (the cognitive process) and what they do (the behavioural process). *(Pearson et al. 2009)*

A Water Sensitive City is one where water's journey through the urban landscape is managed with regard for its rural origins, coastal destinations and spiritual significance. *(Centre for Water Sensitive Cities 2010)*

A water sensitive city is not desirable; it is critical and indeed inevitable. The only unknown is when.

(Ison et al. 2009)

Appendix B: Overview of Selected Sustainable Cities Frameworks (From Seymoar 2004)

The Sheltair Adaptive Management Framework & Tools for Long-term Urban Planning (as applied in CitiesPLUS)			
Guiding Ideas	**Conceptual Structure/Framework**	**Engagement and Institutional Base**	**Mechanisms and Tools**
1. Holistic A central part of the framework is to explore the components comprising the urban system and to explore synergies, conflicts and trade-offs through an integrated one-system approach. 2.**Multi-Generational** The framework incorporates multiple timeframes. It starts off with the long-term view (100-year timeframe) and explores the medium (20-30 year) strategies and their immediate actions required. **3. Scale** Applies to the local scale (regions, communities, neighbourhoods, even buildings). It explores opportunities within the realm of influence. **4. Adaptive** Adaptive Management Framework aligns the steps in the planning process, incorporates continuous monitoring and feedback. Policy becomes experiment and the plan adapts as the results are fed back.	• Long-term values & vision unfolding into short-term actions & implementation • Comprehensive, holistic approach that thinks of the pieces as well as the whole • Integration across systems, departments, professions • Alignment between levels for a transparent, accountable planning process • Monitoring performance and feeding back the results • Adapting as we learn	•Collaborative approach incorporating a range of sectors, multi-disciplinary professionals and stakeholders throughout • Consulting firm	• The Sheltair Adaptive Management Professional Development Workshop • Visioning and Goal setting Sessions • Scenario Planning using MetaFlow Diagrams • Best Practice Library • Integrated Planning and Design Charrettes • Target-setting Workshops using MetaScale • Local Action Plans

The Natural Step (TNS)

Guiding Principles	Conceptual Structure	Process of Engagement Institutional Base	Mechanisms and Tools
1. Holistic Framework for systems thinking; rooted in the idea of the Earth as a system **2. Multi- Generational** No specific timeframe; long-term view is implied (i.e. as long as it takes) **3. Scale** Applicable at all levels (e.g. region, community, organization, department, etc) **4. Adaptive** Backcasting from principles implies continuous adjustments and improvement;	Key concepts: • Funnel metaphor to create a shared mental model of current unsustainable trends and meaning of sustainability • Scientific consensus provides rigorous basis for understanding sustainability • Four System Conditions – define sustainability at the principle level (i.e. first-order principles	Shared language and mental model for sustainability; lends itself to participatory, multi-stakeholder processes • Planning approach is "Backcasting from principles;" can be used in conjunction with scenarios • ABCD implementation methodology **A**: Awareness **B**: Baseline Analysis based on the System Conditions **C**: Compelling Vision – Opportunities for Innovation **D**: Down to Action – Prioritizing and action planning • TNS is a not-for-profit Organization.	• Meant to add strategic direction and to be used in conjunction with other tools (e.g. Environmental Management Systems, Life Cycle Assessment, etc.) • Sustainability Analysis

LOCAL AGENDA/ACTION 21			
Guiding Principles	**Conceptual Structure**	**Process of Engagement** **Institutional Base**	**Mechanisms and Tools**
Founded on the elements of the Local Agenda 21 process **1. Holistic** Integrates economic, social and environmental development. **2. Multi-Generational** Has a long term perspective and long term goals. **3. Scale** Transfers the global perspective of "Agenda 21" to the local level. **4. Adaptive** Aims at the development of long term management structures which are sustainable. EMS systems can to incorporate adaptive approach	• The motto, movement and mandate to move from Local Agenda 21 to Local Action 21 i.e. from planning to implementation. • The goal is to take the outputs from the Local Agenda 21 process to support: • The planning, development and maintaining of sustainable cities. • Protection of Global Common Goods • Securing unwavering implementation through the use of principles, policies and sustainability management mechanisms.	Multi-stakeholder processes ICLEI is an international organization of over 500 local governments with 3 structures: **1. Movement of Cities** – planning for sustainability (Agenda 21) or implementation (Action 21). Uses campaigns (climate change and water) and a milestone performance model. **2.Membership Services**: Knowledge exchange Advocacy to national and international bodies. **3. Agency** to develop pilots, do research and develop mechanisms and tools.	**Agenda 21** • Local Authorities Self Assessment of Local Agenda (LASALA) • CapaCity – local action planning for employment **Action 21** • Triple Bottom Line EcoBudget • Sustainability Inventory • DESTINY - Decision Support System for local development based on ecoBUDGET methodology • Land-Use Management - Urbs Pandens • Local Integrated Resource Management. • Urban EMS Resource Training Kit

MetroQUEST Overview

Guiding Principles	Conceptual Structure	Process of Engagement Institutional Base	Mechanisms and Tools
1. **Holistic** – MetroQUEST is an integrated modelling system that integrates economic, social and environmental development 2. **Multi-Generational** – MetroQUEST allows users to explore 40-year future scenarios 3. **Scale** – MetroQUEST is adapted to the city and region using a library of local data and maps 4. **Adaptive**– MetroQUEST allows users to test various planning options in an iterative and adaptive process using its integrated simulation models	**Backcasting** – Helps users create, explore and test alternative visions for the future **Normative** – Engages users in discussion about desirable future scenarios **Holistic** – Represents a broad range of regional sustainability issues (triple bottom line) **Fun** – Recognizes that engagement is much easier and often more productive if it is enjoyable **Realistic** – MetroQUEST has benefited from over 10 years and $10M of development at UBC and many practical applications that give credibility to the modeling framework 'under the hood'.	**Participatory** – MetroQUEST is designed to facilitate stakeholder, public and decision maker participation in hands-on scenario exploration sessions. Designed for use in: 1. Council meetings – 2. Stakeholder workshops – 3. Public Meetings – Depending on goals the process can include: -Defining priorities -Setting targets -Creating scenarios/ exploring option -Evaluating results/seeing consequences -Iterating to improve -Comparing alternatives - Recording feedback - Selecting a preferred plan -Discussing implementation Envision is a private sector firm with close ties to UBC	MetroQUEST is primarily a Tool as opposed to a Process or a Conceptual Framework although it is grounded in a conceptual structure and has processes of engagement developed to guide its use. It can be thought of as **scenario exploration software** that can be adapted to any city or region – often called the real life version of Simcity. MetroQUEST runs on a Pentium PC and can be adapted for use over the Internet for widescale community engagement.

Integrated Community Planning and Design			
Guiding Principles	**Conceptual Structure**	**Process of Engagement Institutional Base**	**Mechanisms and Tools**
1.Holistic - when used with processes such as citiesPLUS or Smart Growth on the Ground goals can be broadly defined; strives for a comprehensive approach that addresses all components of urban system. **2. Multi- Generational -** can be used for short or long term planning, key attribute of Charrette process is to speed up implementation **3. Scale** applies at any scale from the parcel to the region **4. Adaptive** Incorporates use of guiding principles unbundled into goals, objectives, design targets, and in certain applications also incorporates monitoring and measurement.	Driven by public input across a broad range of stakeholder issues Uses existing policy as a starting point – one of key attributes is ability to show ramifications of full implementation of accepted policies Consensus model Integrative approach looks for synergies among issues Ideas are given three dimensional form to facilitate the leap from vision to implementation – uses design to assist in ensuring complete translation of principles into action	Partnership with other leading organizations to expand scope and sphere Network with interested community Research community issues and organize public events Public workshops to solicit input from stakeholder groups Design event to put ideas into form and resolve differences in stakeholder perspectives Concept plan (document translates guiding principles goals, objectives into design) Implementation of plan (working with regulators to establish and monitor alternative development standards)	The Sustainable Communities Program provides broad integrated planning and design services to communities and organizations. The Charrette-based design method is used as a tool to integrate issues and ideas and to translate principles into physical design through an adaptive management approach Three-dimensional feasibility analysis evaluates possible solutions Though not required, the charrette process is capable of including the use of a range of other tools – for example, scenario-building tools, benchmarking tools, and indicators approaches.

SMART GROWTH B.C.

Guiding Principles	Conceptual Structure	Process of Engagement Institutional Base	Mechanisms and Tools
Holistic Applies to whole communities. Addresses many facets of development and includes all stakeholders. **Multi-Generational** The approach supports development plans that span generations. **Scope** Applies specifically to the local scale where citizens can direct influence over development of their communities. **Adaptive** Continual community engagement allows for restructuring of plans and ideas through ongoing monitoring and communication. Development plans differ depending on community needs and geographic location.	Community engagement to produce development plans that address growth and sprawl issues. Provide citizens access to alternative policy solutions to development and sprawl issues. Provides a holistic framework within which smart growth advocates can engage effectively.	Community involvement in the municipal planning process. Multi – stakeholder approach through workshop series. Charrette design based on public input and inclusion of public feedback.	Education through the provision of substantive literature, studies and presentations Online toolkit Community Assistance Program Small Communities Workshop On the Ground Program Design Charrettes Alternative Development Strategies

Environmental Management Systems

CH2MHILL Responsible Solutions for a Sustainable Future®

Guiding Principles	Conceptual Structure	Process of Engagement Institutional Base	Mechanisms and Tools
1. Holistic Can apply to a specific entity within a community or the community as a whole **2. Multi-Generational** The policy statement can declare a "temporal" commitment. **3. Scope** Focuses primarily on that which the community has direct influence over in terms of assets and services within its own operations. **4. Adaptive** Commitment to continual improvement over time based on ongoing monitoring, measurement, audits and input from key stakeholders	Demming Model of Plan, Do, Check, Act	Requires input from key internal and external stakeholders Consultation with senior management and key stakeholders occur within the planning phase of the management system. Scalable for small and large teams within the municipality (as an entity). Engagement improved through the integration of The Natural Step planning processes in advance of management system roll out.	The Demming model and ISO 9000, 14001, and 18000 standards are mechanisms in their own right and include specifications on policy development, risk assessments, objective and target setting, implementation, checking and corrective action and review (ACT)

Cities as Sustainable Ecosystems

1. Holistic Cities as Sustainable Ecosystems can be seen as ethical, healthy and equitable, zero-waste, self-regulating, resilient, self-renewing, flexible, psychologically fulfilling and co-existing. **2. Multigenerational** Works toward a long-term vision. **3. Scale** The ecosystem approach may be applied at all levels of resource consumption in a city. **4. Adaptive** CASE is not prescriptive; it allows cities to develop sustainable solutions that are relevant to their particular circumstances	The goal is to elaborate upon the *Melbourne Principles* and provide theoretical and practical background designed to engage cities within an integrated sustainability framework.	Network with interested community; The Cities as Sustainable Ecosystems Program is part of the United Nations Environment Program's International Environmental Technology Centre.	**ESTIS** - provides a decentralized IT network for improved access and local control in EST related information transfer. **maESTro** – a free, searchable directory for environmentally sound technology (EST). **e-learning products:** 1. Sustainable Sanitation 2. Energy Savings in Cities 3. Rainwater Harvesting 4. Wastewater Reuse. 5. Water Demand Management.

Summary of Framework Approaches

	Sheltair Group	The Natural Step	Agenda/Action 21 (ICLEI)	MetroQUEST	Environmental Management Systems (CH2M Hill)	Sustainable Communities Program	Cities as Sustainable Ecosystems CASE	Smart Growth
Holistic Systems	Yes	Yes	Yes	Yes	Limited depends upon application	Limited – depends upon application	Yes	Yes, depends upon application
Multi-Generational	Yes	Yes	Yes	Yes (40 year)	Implied	No	Yes	Implied
Scale	Any	Any	Local/regional	City & Region	Any	Local/regional	Bioregion	Local/regional
Adaptive Management	Yes Well defined	Concept compatible	Concept compatible	Yes, realignments, monitoring	No	Yes – approach uses adaptive management pyramid	Yes	Concept compatible
Multi-party Engagement	Yes	Yes - depends upon client's application	Yes	Yes	depends upon client's application		Yes	Yes
Proprietary	Yes	TNS framework is in public domain	Concepts widely distributed, ICLEI tools proprietary	Yes	Widely distributed, ISO14001 proprietary to ISO, EMS UNEP	Charrette approach widely known, tools are proprietary	Widely distributed	Widely distributed
Training and consultation	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Distributed Network Infrastructure	No	Active in 10 countries, Network of 60 Swedish communities	Yes- 500 members worldwide	No	Yes –through UNEP/ IETC and CASE project	No	Yes – through UNEP/IETC	Yes – largely in the USA, beginning in Canada
Range and strengths of Tools	Adaptive Management Framework, plus various training programs and software tools Strong conceptual analysis	Training Programs, materials science based – strongest at awareness, principles, visioning and target setting phases	Training programs, principles, planning and implementing tools. Many self-assessment tools Widely tested Strongest during implementation	Integrated computer modelling tool, to test policy options and scenarios Highly engaging and educational Strongest at the visioning and options stage	Training programs, extensive manuals and check lists through UNEP/IETC Limited applications to long-term but compatible start Strongest at the implementation phase	Very strong on engagement and design process using Charrettes as tool Highly visual Strongest at the visioning, integration and implementation stages	Melbourne Principles accepted and their application is well thought out in IETC primer Relatively new in its application in practice	Very practical and engaging Strongest at the implementation phase Puts economic development in sustainability context
Institutional Base	Private Sector Firm	Not-for Profit	Not-for Profit	Private Sector Firm	Private Sector Firm	Academic Institution	UNEP Program	Government Sector Initiative

From Seymoar 2004

Appendix C: Key Criteria for Selecting Sustainability Indicator

1. Policy relevancy

The indicators will:

- directly or indirectly monitor key outcomes, policy or legislation
- measure progress towards goals;
- provide information to a level appropriate for decision-making; and
- guide policies and decision-making at all levels.

2. Analytical validity

The indicators are:

- accessible and measurable;
- clearly defined and reproducible;
- representative of the system being assessed;
- based on critical attributes of the system;
- developed within a consistent analytical framework; credible and robust;
- helpful in relating causes, effects and responses;
- responsive to environmental change;
- able to detect human-induced change from natural variations;
- allow trend analysis or provide a baseline for future trends;
- have predictive capabilities, a framework, process and criteria for finding an adequate set of indicators, and
- contain data collected using standard methodologies.

3. Systematic

- The indicators and their compositing methods must capture systems information, including system variables, system levels and component systems.
- They should provide comprehensive information on the systems shaping sustainability and should be defined in such a way that they provide essential and reliable information on the viability and behaviour of each part and of the total system in terms of state and rate of change.
- They must represent all important concerns, and an ad hoc collection of indicators is not adequate.
- The process of finding indicators must be participatory to ensure that the set encompasses visions and values of the community for which it is developed.

4. Simplicity and operability

The indicators must be:

- unambiguous, understandable and practical;
- clearly display the extent of the sustainability;
- appeal to the public and reflect the interests of different stakeholders; and
- contain as few indicators as possible, but no fewer than necessary.

5. Cost effectiveness

The indicators

- require a limited number of parameters to be established;
- use existing data and information wherever possible; and
- are simple to monitor.

From Li et al 2008

Appendix D: Lessons Learnt for Water Industry Indicators

H Alegre, H., E. Cabrera** 2006*

* Chair of the IWA Strategic Asset Management Specialist Group
** Chair of the IWA Benchmarking and performance indicators Specialist Group

In 20 years of performance assessment of water services, some lessons have been learnt. The following list includes some of the most typical misunderstandings that should be avoided when running a Performance Indicator (PI) project:

Lack of engagement of the organisation CEO. Performance Indicators systems are useless if data are not reliable or if results achieved are not used to support improvement measures within the organisation. Unless there is tangible support from the top management of the organization, projects are doomed to fail.

Incorrect selection procedure. The procedure recommended by IWA and in the ISO 24500 standards for the implementation of a PI system starts with the definition of objectives, followed by the establishment of assessment criteria and only then by the selection/definition of performance measures matching to these objectives and criteria. This is not usually the case, and the selection of indicators is in many cases inconsistent, unbalanced and not very useful.

Temptation of going from zero to a "PI heaven". When an organisation starts to select and implement performance indicators, there is typically the temptation that every aspect of the management should be covered. It is fundamental to assure that a balanced solution is found, and that the number of indicators is kept as small as possible, so the cost of data collection, validation, archiving and processing can be recovered.

Temptation to reinvent the wheel. Many organisations feel that they are unique and therefore will need to develop their own performance measures and establish their own systems. This is partially positive and understandable. However, it is important to take benefit of the existing PI systems like the IWA proposal, which have been tested and refined over the years. The use of existing PI systems recognised as international references has the obvious added advantage of allowing comparisons with other organisations adopting the same platform.

Misuse of concepts. Using the right words and the right tools for each problem is important. A direct measure is not an indicator (length of pipes) and something that can be changed by a management decision is not part of the context. These basic notions, often forgotten, are well documented and easily available in the IWA manual and in the ISO 24500 standards.

Only best results welcome. Utility leaders are human individuals and tend to easily accept good results (even without sufficient proof), while failing to adequately react on low performance. A common response is to invest a lot of effort trying to justify poor results instead of concentrating on the analysis of potential problems and countermeasures to improve. A fault-positive culture in the utility is crucial for accepting bad performance results as a chance for improvement.

High short-term expectations. Measuring the company or the sector performance will not provide automatically improved performance. Improvement measures often need some time to make an impact on the performance figures. Benchmarking is per definition a continuous process and its effectiveness cannot be evaluated after one period. Nevertheless, there are many examples for immediate positive response on starting performance measurements, presumably due to the fact that introducing performance thinking in a company automatically drives decisions towards higher efficiency.

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