Beyond Triple Bottom Line – Sustainable Cities RD&D at CSIRO

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Abstract: This paper presents the goals, underlying principles and framework, and the research, development and demonstration/delivery (RD&D) activities of the Sustainable Cities research theme at CSIRO, emphasising its focus on inter-disciplinary and integrated approaches to address urban sustainability issues. Performance goal setting and assessment with a *n*-bottom line (*n*BL) framework and following the performance approach in the planning, design and management of urban developments are introduced. CSIRO's RD&D activities in Sustainable Cities are organised around three streams – (1) high performance built environments, (2) integrated urban design and development and (3) transitioning to sustainable and healthier cities. Selected projects are listed to demonstrate the scope and diversity of theme topics. Practical application of the *n*-bottom line (*n*BL) sustainability concept and the performance approach is demonstrated through an urban water project in New Zealand.

Introduction

The livability and sustainability of Australian communities is one of the key focuses of research investment and activities in CSIRO. The CSIRO Flagship on Water for a Healthy Country has a major research theme focused on Urban Water. The Division of Sustainable Ecosystems hosts the research themes on sustainable cities and sustainable regional development. Research and development (R&D) projects in these themes could – and do usually – draw from a wide range of skills and expertise across science capability groups in the organisation to form inter-disciplinary teams. Recently, closer and more intentional engagement with stakeholders through an 'action learning' program called Sustainable Communities Initiative (SCI) has also commenced to apply and test R&D concepts, knowledge and tools to actual community projects – in partnership with communities, businesses, governments and non-governmental organisations (NGOs) – and to enable participants to collectively learn how to take action on addressing local sustainability challenges and opportunities. This extends traditional R&D effort to demonstration and/or delivery, or RD&D.

This paper aims to present the goals, framework and a snapshot of RD&D activities of the Sustainable Cities theme at CSIRO. The historically fragmented CSIRO research related to urban issues is now being re-organised and focused into this theme. The overall challenge is not only huge but complex. Thus, collaboration, integration and innovation – the core principles of SCI – are required particularly in addressing the pressing sustainability issues in Australian cities. This paper is presented to the wider research community with the same goals/principles in mind and to potentially attract collaboration where common interests complement or align.

Performance Approach and the *n*BL Sustainability Framework

Cities comprise of many parts and processes that interact in complex ways, sometimes with unexpected outcomes. Interdependencies between built and infrastructure assets (i.e. physical capital), people (social capital), the environment (natural capital) and economic capital within cities (Fig. 1a) affect the overall quality of life of people and will often have local and/or even regional impacts. Thus, the ability to identify a set of integrated sustainability performance goals that cut across these high level domain topics is an ideal first step towards a more holistic approach to address any particular urban sustainability issue. Any number of solution options (technology, policy, regulation, etc) or combination of options can then be assessed against this set of integrated sustainability performance goals.

This concept is known as the 'performance approach', and in simplest terms is about describing the target or required performance (the '*end*'), rather than the solution (the '*means*') (CIB 1982). Applications and examples of this approach in architecture, engineering and construction (AEC) have been discussed in Foliente (2000); the Building Code of Australia has adopted this concept in 1994 and since then has been evolving its provisions towards requirements that are more and more described in performance terms. The concept has also been applied in planning and designing individual 'green' building projects and subdivision development, and proposed as an important pathway to achieving the AEC industry's future vision for itself (Foliente et al. 2005; Foliente 2006). Harvard University researchers have discussed the performance concept's application in developing regulatory policy in health, safety, and environmental protection (Coglianese et al. 2002; Coglianese et al. 2003).

As Foliente and Coglianese et al. have noted in their publications, the concept's application can scale from an individual project to urban, state and national issues, and that innovative solutions are *always* encouraged (or allowed to be developed) where they are applied.

In developing a practical framework to guide goal-setting in planning, design, construction and operation and management of built infrastructure, Foliente et al. (2005) presented what started as a 4-bottom line assessment framework: with the conventional triple-bottom line (environmental, economic and social) considerations combined with the physical/functional (or technical) requirements (Fig. 1b, x-axis). The latter is a prime object in the planning, design, construction and operation and management of built infrastructure (i.e. whole-of-life, or time dimension in Fig. 1b). And these considerations need to be considered (albeit with different levels of detail and importance) from the scale of materials and products to cities and regions (Fig. 1b, y-axis). The framework can extend to any number (*n*) of set(s) of 'performance attributes', as demonstrated in an example later in the paper; thus, the term '*n*BL framework'. A performance goal or objective can be described or expressed in every cell in this three-dimensional matrix, starting with high level descriptions (Level 1 in Fig. 1c) and potentially clarified through lower-level detailed descriptions of performance requirements (Level *x*, Fig. 1c).

The *n*BL framework in Fig. 1b encourages stakeholders – with different backgrounds, interests, disciplines and experience, among others – to focus on sustainability goals, thus allowing a holistic approach in defining and achieving them.

In our common goal of transitioning our cities to a more sustainable future, different stakeholders and "actors" will have different roles and contributions. From a research organisation's perspective, we are interested in addressing the basic question: "*where can RD&D contribute most in facilitating this transition*?"

This paper describes the current strategy and organisation of activities in CSIRO's Sustainable Cities Theme. A companion paper (Foliente et al. 2007) explores urban sustainability transition pathways based on the concept of 'tipping point'. Since our cities are already in a state of overshoot, we need to be very efficient (i.e. shortest path and best use of limited time and resources) and effective (i.e. sustained change

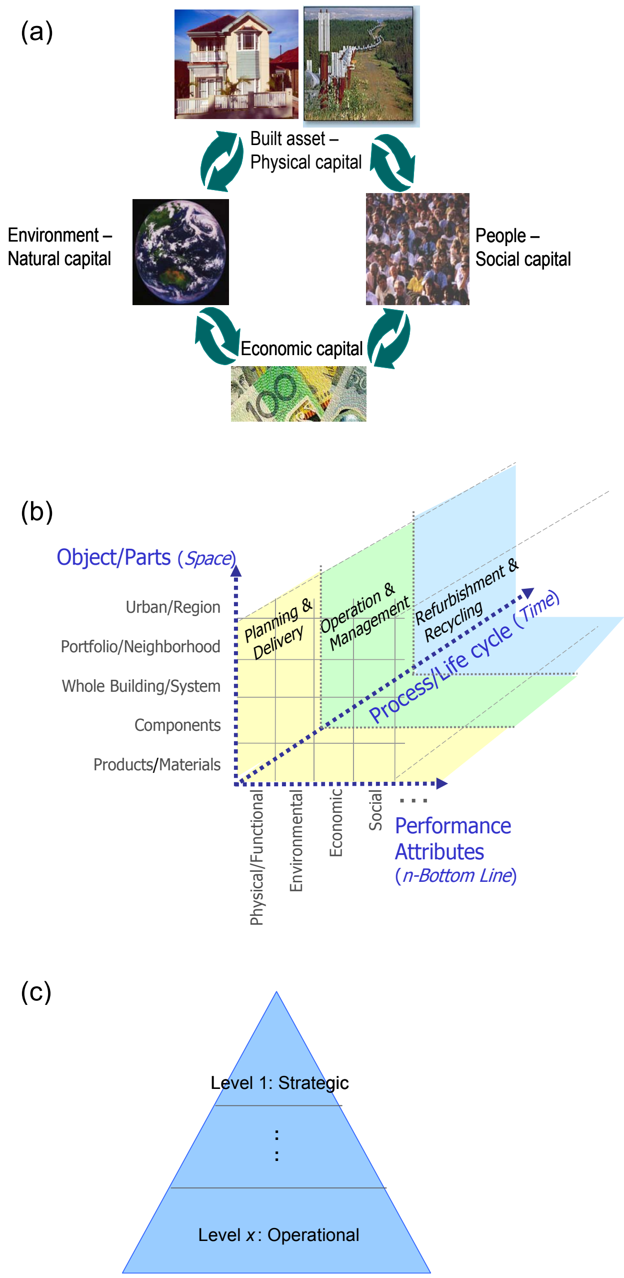

Figure 1. Integrated sustainability framework: (a) the four-bottom line primary domains of interest, (b) extension to *n*-number of bottom lines *(nBL)*, across life cycles and geographic scale, and (c) different levels of description of goals and/or performance targets.

over time). The companion paper argues that a tipping point approach that has the capacity to facilitate rapid rates of transformation is required.

'Sustainable Cities' Research Theme

Overview

The primary goal of the CSIRO Sustainable Cities Theme is the revitalisation of Australia's cities through new planning and design technologies and integrated urban infrastructure and management solutions that, when adopted, will significantly contribute to reduction in urban resource use per person.

The underpinning urban science development will be in bringing a more integrated appreciation of the interactions between economic, social and ecological ways of thinking about buildings and infrastructure, cities and urban sustainability.

Sustainable Cities Theme provides a focal point for bringing relevant capability/knowledge and specialist methods, tools and technologies from CSIRO Flagships (Water for a Healthy Country; Energy Transformed; Climate Adaptation) and Divisions (Sustainable Ecosystems; Land and Water; Energy Technology; Marine and Atmospehric Research; Materials Science and Engineering; ICT Centre) together into an integrated urban design and development framework. By working with industry, communities, government and other urban researchers and design professionals, Sustainable Cities intends to work across jurisdictional boundaries and integrate differing disciplinarian viewpoints in order to generate knowledge for improved policy and practice that informs urban managers and developers in the transformation of cities towards urban sustainability.

Organising Framework

To frame CSIRO's potential RD&D contributions and map its current and planned activities, the diagram shown in Fig. 2 is presented and briefly explained below (note that list-item referencing follows the letters in Fig. 2):

A. The basic question that begs an answer is "what does a sustainable city look like?" As reviewed and discussed in the companion paper (Foliente et al. 2007), there are a number of options to address this. Our proposed starting point is the *Melbourne Principles for Sustainable Cities*, comprising of 10 principles developed in an international charrette hosted by the Victorian Environmental Protection Agency (EPA), with the United Nations Environment Programme (UNEP) International Expert Group on "Building Urban Ecosystem" in 2002. The *Melbourne Principles* were adopted at the Local Government Session of the Earth Summit 2002 in Johannesburg, as part of the local communiqué known as "Local Agenda 21" or the "Johannesburg Call". The *Melbourne Principles* were intended to guide thinking and provide a strategic framework for action; the framers have noted and accepted that a tremendous amount of work is needed to build on these principles and to make them practically useful for stakeholders and "actors" or decision makers. The ultimate goal is to transition our existing cities (or develop new ones) – see F-block in the diagram below – into ones that more closely meet the ideals of the *Melbourne Principles*.

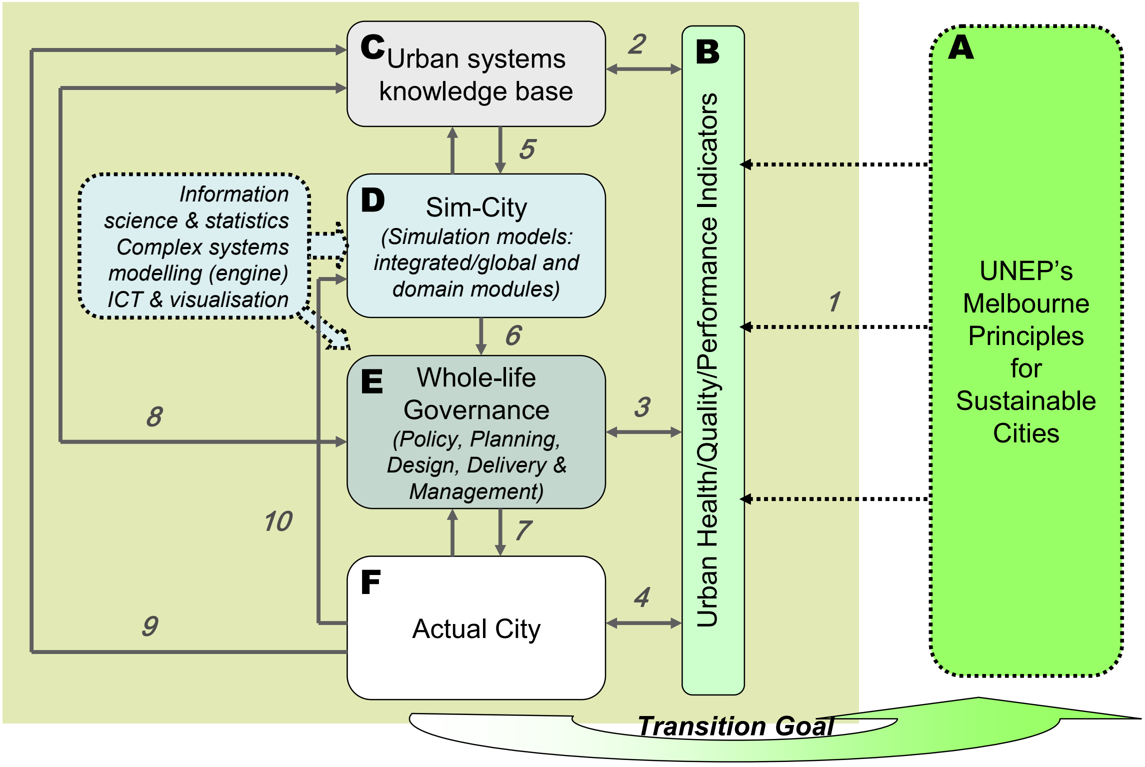

Figure 2. Organising framework of CSIRO RD&D activities in Sustainable Cities

B. The first and most obvious R&D opportunity is the development or establishment of a set of high level indicators of urban health or quality or performance, which directly map into the *Melbourne Principles* (or vice versa, i.e., flow 1 in Figure 2). This small set of high-level (or Level-1) indicators should be supported by lower level indicators all the way to a level that can be easily targeted and estimated (e.g. in planning or design), and/or practically estimated, measured and monitored (e.g. in management phase); Fig 1c. This effort requires international collaboration and support (e.g., via UNEP and, preferably eventually, ISO) and will draw from existing knowledge (state-of-the-art) and practice (flows 2, 3 and 4 in the diagram). An indicator is the objective element in, or one side of, a health/quality/performance "criteria"; the other element or the "target value" should reflect the socio-economic-political-economic values of a city/region, their laws and national agenda/priorities, and their global commitments. Technical issues and challenges in establishing performance criteria have been discussed elsewhere (Foliente 2000; Foliente et al. 1998, 2005).

C. The urban systems knowledge base consists of existing and evolving knowledge in all disciplines directly relevant to urban systems, including planning and architecture, transport, engineering, social sciences, health sciences, environmental sciences, management and administration, economics and business, etc, and their inter- and multi-disciplinary relationships.

D. Scenario (or simulation) models and tools – collectively referred to as "Sim-City" tool – are needed to communicate and represent in simple or easy-to-understand ways the outcomes of policies, decisions, introduction/adoption of technologies, physical development, social change, etc, on the health/quality/performance of a city. (*Note* that this internal labeling was simply for easy recall since many have heard of, or are already familiar with, a very popular computer game called *SimCity*™, the latest version of which – *SimCity Societies*™ – allows one to take into account Greenhouse Gas Emission and other relevant factors that impact cities). This is where urban systems knowledge intersects with the fields of information science and statistics, complexity science and mathematical modelling, ICT and visualization to better understand urban dynamics and metabolism (e.g. Batty 2005). Some tools may be primarily focused on a specific urban issue (e.g. subdivision development, urban transport model, etc) and may be stand-alone applications, while others may be treated as modules that fit or link to other tools forming a more integrated Sim-City toolkit. Decision-makers and users can investigate how a range of decision options compare with business as usual (BAU) or doing nothing, and seeing the likely implications and impacts of these options visually considering layers of output data in temporal and spatial dimensions (flow 6). These tools can also be used by those trying to better understand complex urban dynamics and extend urban systems knowledge (flow 5); see also Foliente et al. (2007) about modeling and analysis to understand tipping point conditions and find the key leverage points for urban sustainability transition. As the knowledge base, modeling capability/techniques and visualization technologies become more sophisticated and reliable, we get closer and closer to the realization of a "digital city" capable of simulating complex urban dynamics. Some of the discussions within CSIRO and with others around this topic be found at: www.complexsystems.net.au/wiki/Complex_Dynamics_of_Urban_Systems

E. Those charged with policy development and the planning, delivery and management of actual cities (strategic and operational levels) will benefit from the expanding urban systems knowledge base (flow 8, downstream) and use of scenario/simulation tools in decision-making, as explained above. In the former, direct contributions can be in new and innovative ideas of policy and governance. In turn, the real and practical experience and knowledge of the people involved in urban governance (at any stage, or in whole-of-life) will contribute in improving the knowledge base and in identifying gaps in knowledge (flow 8, upstream). They also help set the urban performance targets, and monitor or assess these over time (flow 3). The fields of information science, ICT and visualization can also have direct contributions (i.e., without modeling and simulation components) in re-engineering urban development and management processes (e.g. e-planning submissions and approval system), and in facilitating new participatory processes with stakeholders and communities.

F. The on-going "health/performance" of actual cities can be gathered/collected and monitored using key indicators in B (flow 4) and other criteria set in E (flow 7). These and "real-life" studies of actual cities will also contribute to the knowledge base (flow 9). Key parameters needed for Sim-City tools (specific or global models) can be obtained to validate and calibrate models (flow 10), and thus, improve scenario/simulation capabilities. The more automated this process of urban health monitoring and feedback reporting is, the more responsive authorities can be in managing our cities and the better our forecast scenarios will be (as the models can be updated with the most accurate input data). We have previously envisaged a "physical nervous system" for our cities based on smart sensor networks. A critical and very challenging factor in the health and performance of our cities is human behaviour, attitude and response (both at individual and group/community levels) to initiatives and drivers that impact urban sustainability. These are not easily and readily assessed. Finally, any major integrated program that aims to contribute to urban sustainability transition should be implemented with stakeholders in actual settings (as demonstration or action learning and action research projects) and monitored and assessed over time. This way, both endogenous and exogenous forces (including man-made and natural disasters, and climate change impacts) that influence urban change (Bai 2003) can be considered.

R&D Streams

The RD&D framework and topic areas presented above (esp. the parts with background shading) present a very broad scientific and RD&D scope. Thus, collaboration and

Three streams comprise the Sustainable Cities Theme:

Stream 1 – High Performance Built Environment

The purpose of Stream 1 is to facilitate performance based planning, delivery and management of sustainable built environment, across geographic scales and considering broad *n*BL performance requirements. Built form ranges from products/components to whole buildings, whole subdivisions and infrastructure networks (e.g. telecommunication, power/electricity, gas, water and wastes, transport); R&D includes physical performance assessment, modeling, analysis and optimisation of performance. Examples of specific projects include:

- *Your Building* web portal which was launched in September 2007 [with the CRC for Construction Innovation, the Australian Greenhouse Office (AGO) and the Australian Council for Sustainable Built Environment (ASBEC)];

- Development of key software tools (*AccuRate*, *Energy Express* and *LCADesign*) for energy/greenhouse and broader environmental assessment of buildings and infrastructure; and
- The Australian Life Cycle Inventory (AusLCI) database initiative [with the Australian Life Cycle Assessment Society (ALCAS), government agencies and industry].

Stream 2 – Integrated Urban Design and Development
The purpose of Stream 2 is to facilitate new ways of thinking and action through working in urban planning, design and development partnerships that create effective new urban communities, and renew existing urban communities, through a focus on design for better human health and wellbeing in cities. Examples of specific projects include:

- Development of the *Your Development* web portal with the AGO;
- Development of participatory approaches to planning, delivery and management of subdivisions, including the integration and application of a suite of integrated urban design and development tools that optimise yield in context of solar access, ventilation, water sensitive urban design, integrated water systems, biodiversity and ecosystem services and minimising bushfire risk; and
- Development of bushfire risk prediction models for houses and communities based on radiation and ember models, and contribution to the development of appropriate planning and building guidelines and standards.

Stream 3 – Transitioning to Sustainable and Healthier Cities
The purpose of Stream 3 is to facilitate efficient and effective pathways to more sustainable and healthier cities through improved knowledge networks and tools for policy-making, urban management, governance and scenario analyses that address major national urban challenges such as population and demographic changes, climate change, health threats and other natural and man-made hazards. Examples of specific projects include:

- Developing and advancing key concepts and theories to advance the understanding of transitioning processes, key drivers, and key leverages in Australian cities;
- Review and establishment of nationally and internationally accepted urban sustainability indicators and contributions to setting a national urban sustainability charter; and
- Techniques and scenarios developed for measuring the urban metabolism of Australian metropolitan areas/regions (e.g. using the Stocks and Flows model), and establishment of expert network and discussion platform for urban dynamics modelling.

Common Elements

All the streams share the following issues/topics:

- Need for *performance indicators and metrics* (and organised to link/contribute to the high-level urban indicators in block B) – this will scale multiple dimensions (space, time) and include key indicators of human health and well-being (Fig. 1b);
- Critical role and contribution of *informatics* (including data management frameworks and platforms/APIs) and *mathematical modeling capability* (applicable to multiple domains and applications) in understanding complex datasets, phenomena and communicating impacts/implications of decision options;
- Critical role of *data* (quantitative and qualitative, measured or estimated, etc) in developing, validating and calibrating or updating any computer models;
- Need to maintain strong relationship with, and aim to contribute to, *sustainability science*, as discussed by Clark (2007); and
- Need for *action learning and action research* or *demonstration projects* (extending traditional R&D into RD&D.

Case Study of *n*BL Sustainability Assessment – Papamoa Development in New Zealand

General

The key concepts discussed in this paper as being central to the work of CSIRO Sustainable Cities Theme – i.e., performance approach and holistic sustainability assessment using a *n*BL framework – are practically illustrated in the case study of a CSIRO Urban Water project in New Zealand. The basic procedure is outlined and briefly explained in this paper; details have been omitted but can be found in Maheepala et al. (2004). The concept and procedure are general enough to be applicable to other topics.

Project Background and Overview

The Papamoa development in New Zealand was a residential and commercial development of 750 hectares of rural land in Papamoa East, in the jurisdiction of the Tauranga City Council (TCC). The proposed development had to meet the following site-specific objectives:

- Lower the impact on the natural environment
- Must be socially acceptable
- Must be economically viable
- Minimise health risk to the community
- Must recognise Maori cultural values
- Must be specifically applicable to the study area

There is an increased interest for seeking alternatives to the traditional way of providing urban water services, particularly in areas where new developments are planned. The original project proposed and applied an assessment method that was a hybrid of life cycle, multi-criteria and indicator assessment methods and it is applicable at the planning and conceptual design stages of the water system of both green-field and infill development schemes. Briefly, it requires a set of sustainability assessment criteria and at least one measurable indicator for each criterion be defined, values of indicators to be estimated for a set of scenarios for which sustainability assessment is to be performed and ranking of scenarios using a multi-criteria assessment method. The *n*BL sustainability assessment framework was applied to Papamoa East development to determine a water servicing option that best meets the site-specific objectives. An application of each step of the framework is described below.

Analysis Procedure

Step 1: Define sustainability assessment criteria

Guidelines provided by Hellstrom et al. (2000) and the stakeholder input were used to define a set of assessment criteria in line with the site-specific objectives. The assessment criteria adopted for this study were:

1. Economic criteria – defines the desired state in terms of economic costs and benefits associated with urban water service provision
2. Social criteria - defines the desired state in terms of social needs and expectations which include health requirements and maintaining inter and intra generational social equity
3. Environmental criteria – defines the desired state in terms of enhancing ecosystem wellbeing and protecting hydrologic integrity of the urban water system
4. Health criteria – defines the desired state in terms of community health aspects.
5. Cultural criteria – defines the desired state in terms of cultural values, i.e. Customary Maori values in this study.
6. Technical criteria – defines the desired state in terms of technical feasibility, which takes into account technical and/or engineering factors that influence applicability of the option and any governance issues.

Thus, this was a case of six-bottom line (6BL) assessment.

Step 2: Define measurable indicators for each criterion

Indicators considered under each criterion and the objective or the purpose of each indicator are summarised in **Table 1**.

Table 1 Sub-assessment criteria used for the case study

Main Criterion	Sub-criteria or indicators (ID)	Objective of sub-criteria
Economic	Total infrastructure cost (EC1)	To maximise the economic viability of water service provision
Economic	Cost to customers (EC2)	To minimise the cost to individual customers
Social	Social acceptance (S1)	To maximise the social acceptability of water service provision
Environmental	Freshwater use (E1)	To minimise resource depletion
Environmental	Energy use (E2)	To minimise the use of fossil resources and related greenhouse gas emissions
Environmental	N discharge to receiving waters (E3)	To minimise contamination of water ways
Environmental	P discharge to receiving waters (E4)	To minimise contamination of water ways
Environmental	TSS discharge to receiving waters (E5)	To minimise contamination of water ways
Environmental	BOD discharge to receiving waters (E6)	To minimise contamination of water ways
Environmental	Wastewater generation (E7)	To minimise wastewater generation
Environmental	Stormwater generation (E8)	To mimic pre-development stormwater flows
Environmental	Recycling of nutrients (E9)	To maximise nutrient use locally thereby reducing the use of fossil resource and GHG emissions.
Environmental	Use of material for construction of infrastructure (E10)	To minimise material use
Environmental	N discharge to land (E11)	To minimise contamination of soil and land degradation.
Environmental	P discharge to land (E12)	To minimise contamination of soil and land degradation.
Environmental	TSS discharge to land (E13)	To minimise contamination of soil and land degradation.
Environmental	BOD discharge to land (E14)	To minimise contamination of soil and land degradation.
Health	Public Health water supply (H1)	To minimise health risk of water supply
Health	Public Health wastewater (H2)	To minimise health risk of wastewater provision
Cultural	Customary Maori values (C1)	To ensure customary Maori values are reflected appropriately, and do not damage heritage items in the course of provisioning water services and its operation.
Functional	Out-leakage (F1)	To minimise unaccounted water in water supply
Functional	In-leakage (F2)	To minimise wet-weather flow in sewers
Functional	Odour (F3)	To minimise air pollution
Functional	Flooding (F4)	To minimise frequency of flash flooding.
Functional	Landscape and regulation (F5)	To maximise the use of existing landscape features and the current regulatory frameworks.

Step 3: Identify the base case and/or generate options

Six alternative water service provision options (or scenarios) were considered and they are listed below:

- Scenario 1: The Status quo ('Base case')

- Scenario 2: Sustainability improvement model 1
- Scenario 3: Sustainability improvement model 2
- Scenario 4: The Maori model – (4a) On-site disposal of all greywater; (4b) Off site disposal of greywater via piped network to centralised wastewater treatment plant; and (4c) 50% of greywater disposed of on-site and 50% off site.

Step 4: Collect data and estimate values for indicators
A monitoring strategy of each indicator was developed. Values for some indicators were determined quantitatively through modelling of water and contaminant flow paths and costs. Qualitative assessment was carried out, for cases where sufficient data were not available. The estimated data values of the each indicator for all six scenarios were presented in Maheepala et al. (2004).

Steps 5 and 6: Decide on a MCA method and perform assessment
The PROMETHEE MCA method was used as the Multi-Criteria Analysis (MCA) method, which was available as a commercial software system. The PROMETHEE MCA method required subjective information such as weights of importance of each criterion and preference function for each criterion. After the analyses, Table 2 shows the ranking of scenarios from the best one to the worst one. The *phi* value associated with a particular scenario can be considered as the overall relative score of that scenario, and it is called *Phi score of a scenario* - the larger the *phi* value the better the scenario in terms of being more sustainable. Thus, the best scenario in terms of meeting the principles of sustainability is scenario 3.

Table 2. Ranking of scenarios

Scenario	3	2	1	4b	4a	4c
***phi* score**	0.27	0.20	0.17	-0.06	-0.15	-0.42

Step 7: Conduct sensitivity analysis
The sensitivity analysis of the final assessment ranking revealed that Maori cultural values, followed by economic and then social criteria, were the most sensitive to any change in weightings. i.e., changing their weighting would have the greatest impact on final rankings. Environmental criteria were the most robust. Doubling the weightings of Maori cultural values still ranked Scenario 3 first, but when doubling the weightings of either social or health criteria, Scenario 3 ranked third. When doubling the weightings of economic criteria Scenario 3 is ranked second.

Steps 8, 9 and 10: Finalisation of sustainability assessment outcomes
The outcomes of the assessment process were presented to stakeholders and the feedback received did not change the weighting scheme adopted because there was no strong justification as to one assessment criterion was more important than another. Therefore, it was concluded that conceptually, preferred urban water service provision options for Papamoa East are those described under Scenario 3, closely followed by Scenario 2.

This concludes the application of the sustainability assessment framework to Papamoa East. The next step is to carry out a detailed analysis for the preferred two scenarios and select a scenario based on that detailed assessment. Then an engineering design must be carried out for the preferred scenario before taking up any measures for implementation.

Concluding Notes

The primary goal of the CSIRO Sustainable Cities theme is the revitalisation of Australia's cities through new planning and design technologies and integrated urban infrastructure and management solutions that, when adopted, will significantly contribute to reduction in urban resource use per person. This paper has presented the underlying principles and framework, and the supporting research, development and demonstration/delivery (RD&D) activities at CSIRO to support this goal. The urban sustainability challenge requires an emphasis on inter-disciplinary and integrated approaches because of the inherent complexity in an urban system. Performance goal setting and assessment with a *n*-bottom line (*n*BL) framework and following the performance approach in the planning, design and management of urban developments were introduced. And a practical application of the *n*-bottom line (*n*BL) sustainability concept and the performance approach was demonstrated through an urban water project in Papamoa East, New Zealand.

By taking an action learning and action research approach, and by working with industry, communities, government and other urban researchers and design professionals, Sustainable Cities aims to develop new urban planning and design technologies that address the urgent need for new ways of thinking and action for integrated urban infrastructure and management solutions. The Sustainable Cities theme intends to work across jurisdictional boundaries and integrate differing disciplinarian viewpoints in order to generate knowledge for improved policy and practice that informs urban managers and developers in the transformation of cities towards urban sustainability.

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