CRC for
**Water Sensitive Cities**

# blueprint2013

**Stormwater Management in a Water Sensitive City**

To harness the potential of stormwater to overcome water shortages, reduce urban temperatures, and improve waterway health and the landscape of Australian cities.

An Australian Government Initiative

CRC AUSTRALIA

**blueprint2013**
*Stormwater Management in a Water Sensitive City*

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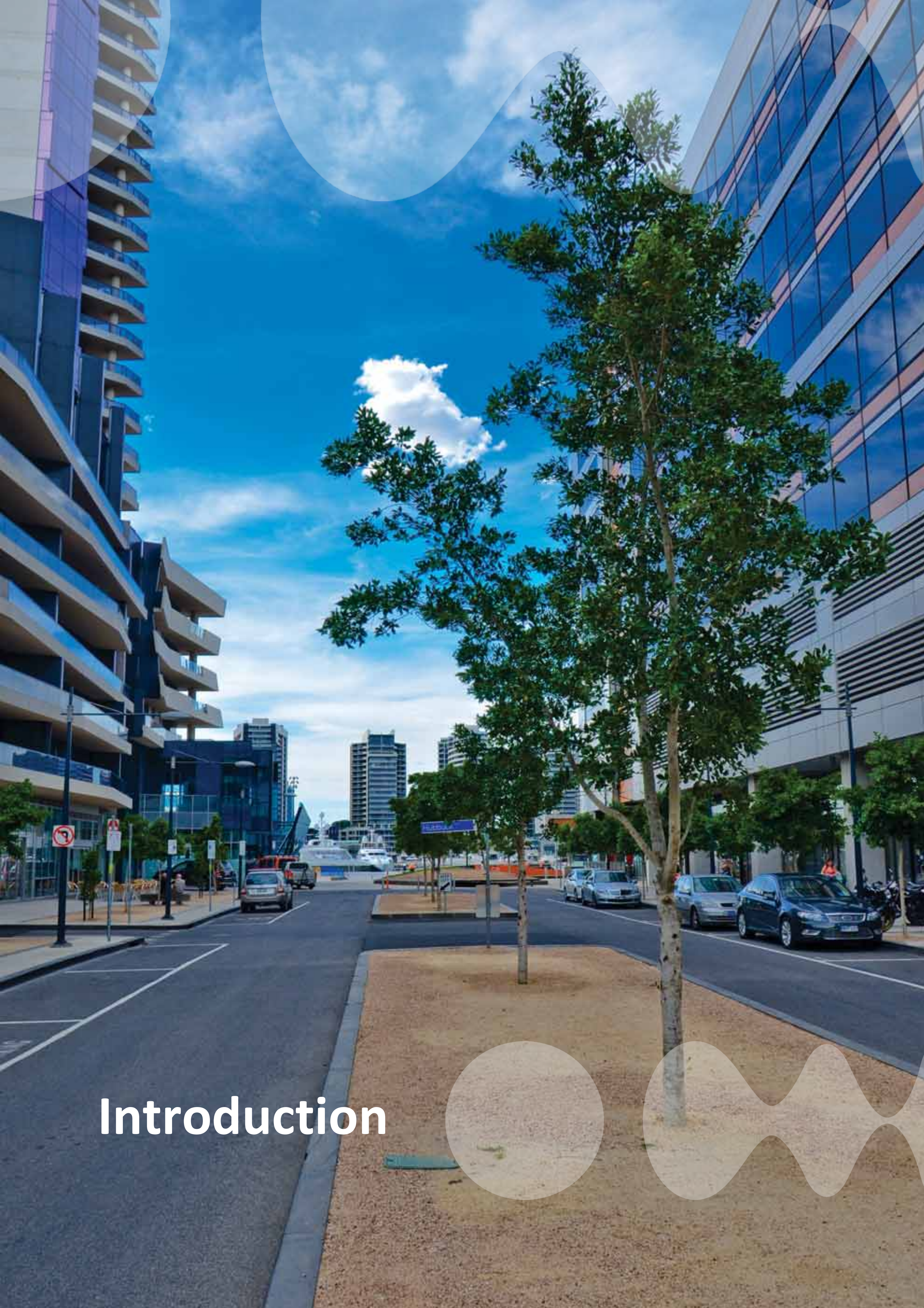


# Introduction

# Introduction

Urban environments have become a critical focal point for Ecologically Sustainable Development (ESD) practices, with the world's urban population now having surpassed the population living in rural environments. In Australia, approximately 63% of the population now live in large cities and towns and this will increase to 80% by mid-century.

Sustainability has emerged in recent years as a progression from previous environmental protection endeavours. The pursuit of sustainable urban environments involves development that neither depletes natural resources nor degrades the health and amenity of land and water environments.

Building resilience to the impacts of climate change, and in particular ensuring secure water supplies, the safe conveyance of flood waters and the ecological protection of water environments, is an emerging challenge as growing urban communities seek to minimise their impact on already stressed water resources.

Designing liveable cities and towns is now an emerging focus in many city planning initiatives. These initiatives are influences by the urban water system through the availability of water to support green infrastructure and associated ecosystem services for the built and natural environment.

The purpose of this blueprint is to foster discussion and innovation in harnessing the potential of stormwater to overcome water shortages, reduce urban temperatures, and improve waterway health and the landscape of Australian cities in their transformation into Water Sensitive Cities.

This report is the third version of an evolving document that articulates how, through a holistic approach to the management of urban stormwater, we can transition Australian cities to Water Sensitive Cities. Our reference to cities includes all urban environments and the approaches and philosophical context of water sensitive cities are equally applicable to regional towns and cities throughout Australia and overseas.

It should be noted that other parts of the urban water network such as water supply catchments, sewage management, demand management etc., are also important in progressing the objectives for a water sensitive cities but these are not covered by the research efforts underpinning this document.

***blueprint2013*** builds on the previous versions released in January 2011 and March 2012, and on subsequent and ongoing discussions and workshops with industry partners of the CRC for Water Sensitive Cities throughout 2012.

This document now also includes insights and recommendations emanating from research across multiple disciplines undertaken by the Cities as Water Supply Catchments research team in 2012. The blueprint outlines approaches to urban stormwater management that can be adopted today to support the transition of our urban areas to Water Sensitive Cities and Towns.

*This blueprint articulates how, through a holistic approach to the management of urban stormwater, we can transition our urban areas to Water Sensitive Cities and Towns.*


# Urban Water Policies for Cities of the Future

# Urban Water Policies for Cities of the Future

Cities are extremely complex socio-physical systems that are constantly evolving. Harmony of the built, social and natural environments within a city is the result of complex interactions between the quality of the natural and built environments, the social and institutional capital, and the natural resources that support a city. In 2008 the Victorian Government summarised these as the liveability of a city - *making a location a place where people want to live* and recognised that this was not the domain of a few agencies but *encapsulates the Government's entire portfolio responsibilities.*

Water is an essential element of place making, both in maintaining and enhancing the environmental values of surrounding waterways and in the amenity and cultural connection of the place. A Water Sensitive City combines physical infrastructure - water sensitive urban design and integrated urban water management - with social systems - governance and engagement - to create a city in which the connections that people have with their water infrastructure and services enhances their value and quality of life.

Our cities are shaped by policies, programs and practices at all levels of government (local, state, national). While setting the pathways to the future, policy is itself dynamic – responding to new knowledge and understanding, reflecting changing preferences and priorities and, in some cases, pushing boundaries that stimulate innovation.

Nationally, the Australian Government's Our Cities, Our Future - A National Urban Policy for a productive, sustainable and liveable future (2011)[1] and the Productivity Commission's (2011)[2] Australia's Urban Water Sector report help to set the scene for a future of Water Sensitive Cities and identify key reforms to enable effective transition. The State of Australian Cities report (2012)[3] provides an evaluation of progress in implementing the National Urban Policy and some insight to the changes occurring to our cities. Relevant conclusions of this report include that:

- Our cities continue to place high biodiversity pressures on urban waterways and estuarine environments, many of which contain sites of international heritage significance.
- Proper management of natural systems and 'green infrastructure' can make major contributions to the sustainability and liveability of our cities.
- Local, state and territory governments are moving to better manage natural and urban systems and are addressing challenges such as urban heat islands, cleaning waterways and more sustainable buildings.
- Liveability need not come at the expense of sustainability. The wealth of cities strongly correlates to environmental performance, especially given that their capacity to invest in urban infrastructure and drive environmental initiatives.

*Effective management of natural systems and 'green infrastructure' can make major contributions to the sustainability and liveability of our cities.*

[1] Department of Infrastructure and Transport (2011) *Our Cities, Our Future- A national urban policy for a productive, sustainable and liveable future,* Department of Infrastructure and Transport, Canberra. Available online at: infrastructure.gov.au/infrastructure/mcu/urbanpolicy/index.aspx

[2] Productivity Commission (2011), Australia's Urban Water Sector, Report No. 55, Final Inquiry Report, Canberra. Available online at: pc.gov.au/projects/inquiry/urban-water

[3] Department of Infrastructure and Transport (2012). *The State of Australian Cities 2012*. Department of Infrastructure and Transport, Major Cities Unit, Canberra. Available online at: infrastructure.gov.au/infrastructure/mcu/soac/index.aspx

Strategic policies, at the capital city scale, are providing the directions for sustainable and water-smart cities, for example :

- Brisbane City Council's *WaterSmart Strategy* (2010)[4]
- Victoria's Living Melbourne, Living Victoria Roadmap (2011)[4]
- South Australia's *Water for Good* (2010)4 and the *Thirty year plan for Greater Adelaide* (2010)[4]
- New South Wales' *Metropolitan Plan for Sydney 2036* (2010)[4]

Planning and policy processes continue to develop and progress towards strategies and on-ground work that deliver new urban forms that support the transition to Water Sensitive Cities. For example, the *Norman Creek Draft Masterplan* (2012)[4] represents a key step towards delivering Brisbane's *WaterSmart Strategy*. Development of a new *Melbourne Metropolitan Planning Strategy* (May 2013) provides an opportunity for embedding the ambitions of the *Living Melbourne, Living Victoria Roadmap* firmly into the city's future development. Sydney's *Draft Metropolitan Strategy for 2030* (2013)[4] articulates a vision for 'a strong global city, a liveable local city' and explicitly links land use planning with the states infrastructure plans. The need for strong and relevant knowledge continues to grow to ensure sound decision-making and to ensure a continuum of evidence-based policy across the spectrum and scales of policy to deliver Water Sensitive Cities.

There are growing qualitative and quantitative evidence that green infrastructure deliver a net positive economic benefits to urban communities, leading to a recent statement issued by the White House Council on Environmental Quality[4] (United States of America) advocating green infrastructure, acknowledging the cost-effectiveness and water quality benefits of green infrastructure, as well as additional benefits, such as increases in property values.

*There are growing qualitative and quantitative evidence that green infrastructure deliver a net positive economic benefits to urban communities.*

[4] Brisbane City Council (2010) *WaterSmart Strategy,* Brisbane City Council, Brisbane. Available online at: brisbane.qld.gov.au/environment-waste/water/watersmart-strategy/index.htm

[5] Living Victoria Ministerial Advisory Council (2011) *Living Melbourne, Living Victoria Roadmap*, Victorian Government - Department of Sustainability and Environment, Melbourne. Available online at: water.vic.gov.au/programs/living-victoria2/living-victoria-roadmap

[6] Office for Water Security (2010). Water for Good, Plan to ensure our water future to 2050. South Australian Government, Office for Water Security, Adelaide. ISBN 978-1-921528-34-7. Available online at: environment.sa.gov.au/files/d6fa26ca-72e0-404e-900c-a1d400fe3fd8/water-for-good-full-plan.pdf

[7] Department of Planning and Local Government (2010). Thirty year plan for Greater Adelaide, A volume of the South Australian Planning Strategy. South Australian Government, Department of Planning and Local Government, Adelaide. ISBN 978-0-7590-0114-5. Available online at: dplg.sa.gov.au/plan4adelaide/index.cfm

[8] NSW Department of Planning (2010). *Metropolitan Plan for Sydney 2036.* NSW Government, NSW Department of Planning, Sydney. ISBN 978–0–7313–3478–0. Available online at: gcc.nsw.gov.au/media/Pdf/MetroPlan2036_Overview Document.pdf

[9] Brisbane City Council (2010) *WaterSmart Strategy,* Brisbane City Council, Brisbane. Available at:

[10] NSW Government (2013). Draft Metropolitan Strategy for 2030. NSW Government. ISBN 978-0-7313-3570-1. Available online at: strategies.planning.nsw.gov.au/Metropolitan StrategyforSydney/Aboutthestrategy.aspx

[11] White House Council on Environmental Quality (2013), Building the Future: Innovative Water Infrastructure whitehouse.gov/blog/2013/01/18/building-future-innovative-water-infrastructure

# Vision for a Water Sensitive City

# Vision for a Water Sensitive City

The concept of the Water Sensitive City is progressively being refined both within Australia and internationally. The recent policy developments in Australia across Federal, State and Local governments serve to reinforce the need to continue to improve the knowledge and understanding of the many factors that influence the transition towards Water Sensitive Cities.

This blueprint for stormwater management in a Water Sensitive City is structured around the three principles (pillars) adapted from Wong and Brown (2009)[12]:

- Cities as Water Supply Catchments: meaning access to a range of different water sources at a diversity of supply scales;
- Cities Providing Ecosystem Services: meaning the built environment supplements and supports the functions of the natural environment; and
- Cities Comprising Water Sensitive Communities: meaning socio-political capital for sustainability exists and citizens' decision-making and behaviour are water sensitive.

The three pillars simply categorise initiatives into three themes: (1) water resources; (2) ecosystem services for the built and natural environments; and, (3) social and institutional capital.

Following a series of practitioner envisioning workshops in Brisbane and Melbourne, Binney *et al.* (2010)[13] presented a vision for Cities of the Future comprising twelve principles arranged under four themes as shown in **Figure 1**. These principles may also be grouped according to the three pillars of Wong and Brown (2009)[12]. Furthermore, many of these principles would apply to the way we manage urban stormwater, an important component of the total urban water cycle.

Attributes of a Water Sensitive City are compared against current urban water management paradigms in Table 1, which provides a basis for considering the transformations required to achieve a vision for a Water Sensitive City. These issues are covered in more detail in Pillar 3 of this blueprint.

*The vision and concepts of the Water Sensitive City are emerging directly in city-shaping policies.*

[12] Wong, T.H.F. and Brown, R.R. (2009) The Water Sensitive City: Principles for Practice, *Water Science and Technology*, 60(3):673-682.

[13] Binney, P., Donald, A., Elmer, V., Ewert, J., Phillis, O., Skinner, R. and Young, R. (2010) IWA Cities of the Future Program, Spatial Planning and Institutional Reform, Conclusions from the World Water Congress, Montreal, September 2010.

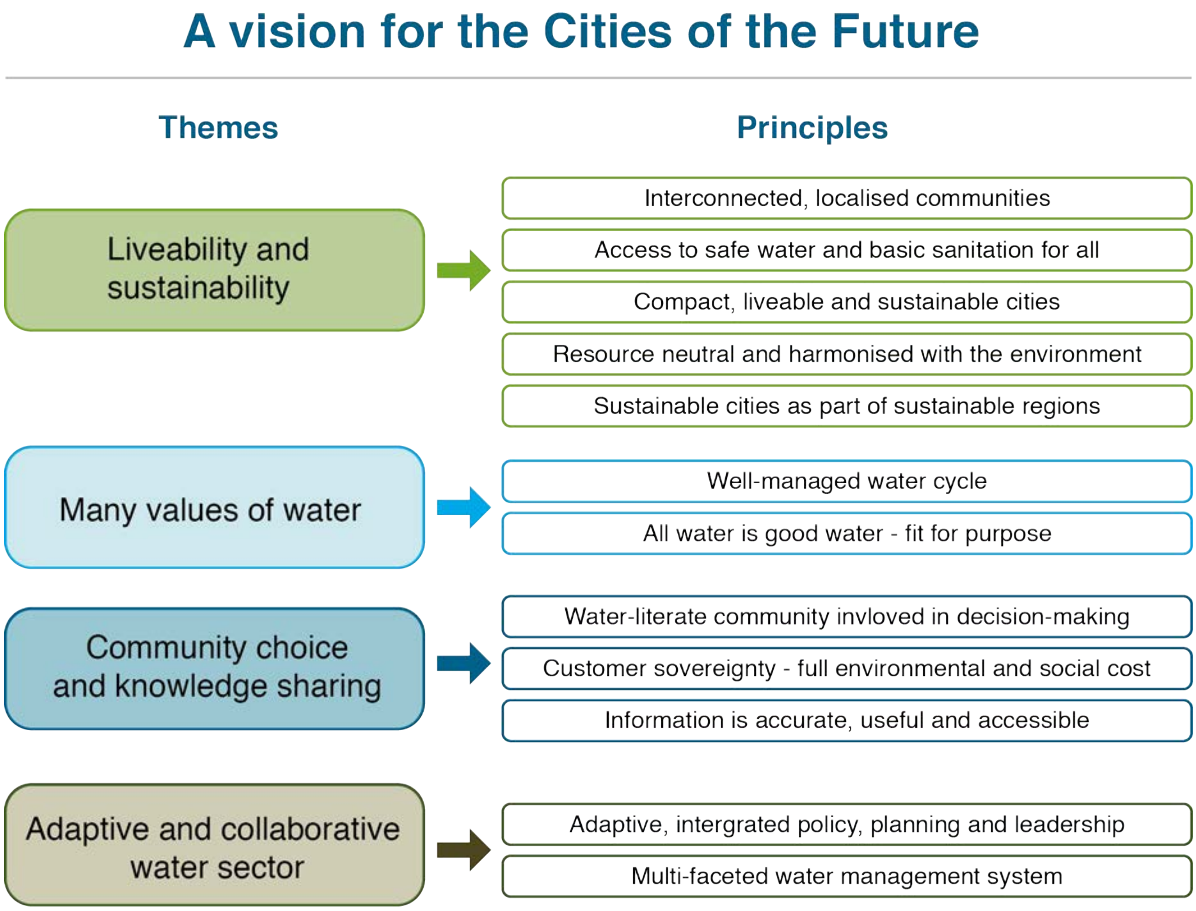



**Figure 1**. Principles for a City of the Future (adapted from Binney *et al*., 2010[13])

Participants at the 2012 World Water Congress in Busan, South Korea reached consensus on a number of critical challenges in achieving the Cities of the Future principles outlined in **Figure 1**. Howe, Skinner and Ewert (2012)[14] reported on these critical challenges, which include:

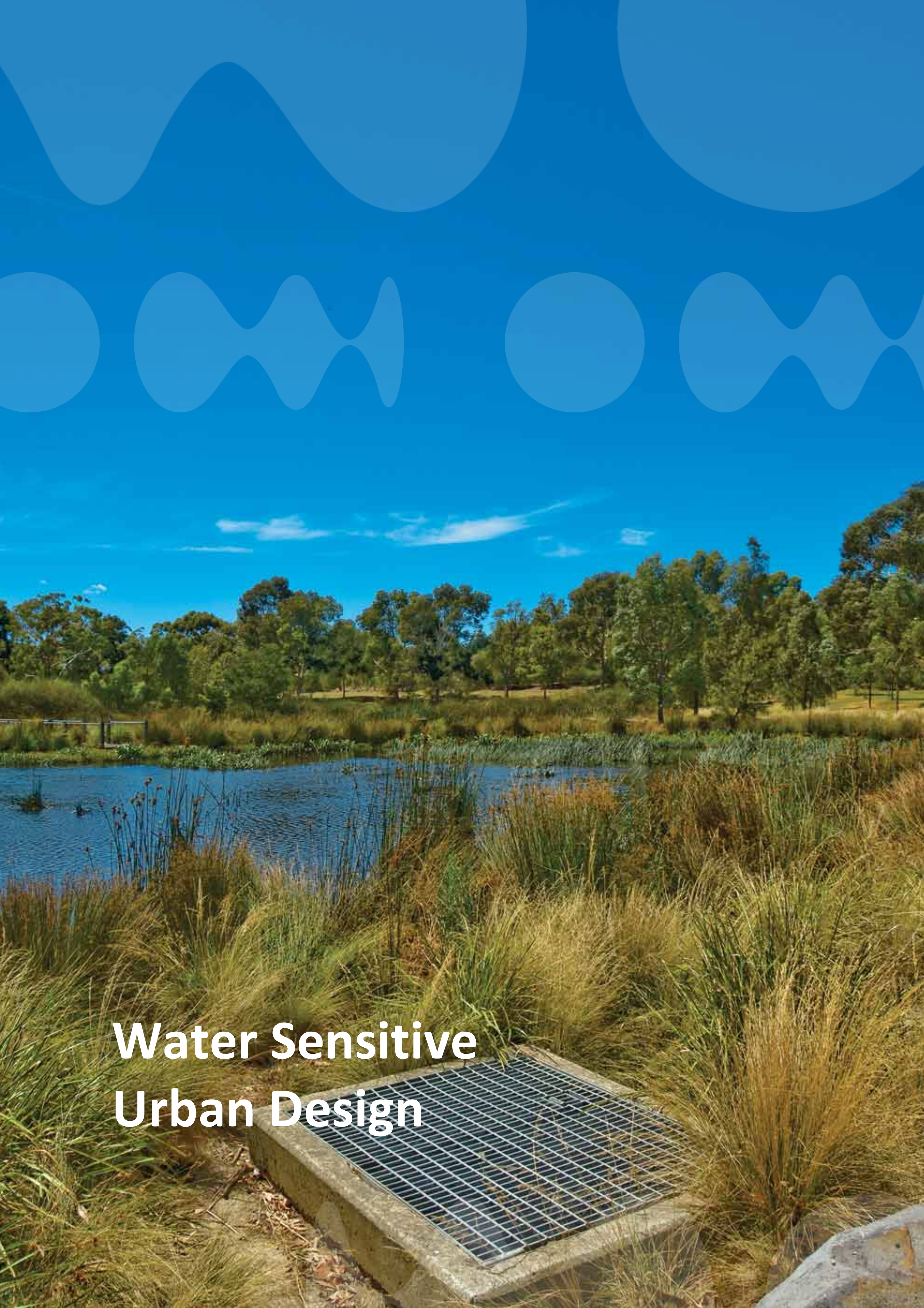
- engaging governments, industry, community and cross-sectoral stakeholders early and consistently in the planning of cities – to develop broad ownership of outcomes and commitments to implementation;
- embedding water thinking in all phases of urban planning and operations to achieve more liveable and connected cities;
- optimising and integrating water systems (central / decentralized and structural / non-structural options) to increase the resilience of cities;
- stewarding all resources (material and energy) and optimizing their use within the total water cycle;
- ensuring the ecological health of cities is protected or enhanced;
- providing citizens with accurate and useful information to enable them to participate fully in planning processes and make informed individual choices on water system behaviour;
- developing appropriate planning and investment decision tools – broadening the traditional economic, social and environmental evaluation approaches;
- building the capacity of professionals to embrace multi-disciplinary planning and systems analyses.
- managing risk to maximize innovation – tolerance of failure as a learning opportunity and commitment to continuous improvement and knowledge transfer; and
- transitioning cultures, governance processes and institutional arrangements to meet these new approaches.

[14] Howe C., Skinner, R. and Ewert J. (2012). Implementing the City of the Future: tackling the key issues. *Water21* (**14**.6), December 2012 pp12-14.

**Table 1**. Water Sensitive City attributes compared to our current urban water management paradigms. (Keath and Brown, 2009[15])

| 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, food production, 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) designed to secure a higher level of resilience to future uncertainties in climate, water services requirements while enhancing the liveability of urban environments. |
| Expertise | Narrow technical and economic focused 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 instruments |

[15] Keath, N. and Brown, R. (2009) Extreme Events: Being Prepared for the Pitfalls with Progressing Sustainable Urban Water Management, *Water Science and Technology*, **59**(7):1271-1280.



# Water Sensitive Urban Design

# Water Sensitive Urban Design

Water Sensitive Urban Design (WSUD) is a contemporary approach to the planning and design of urban environments that is 'sensitive' to the issues of water sustainability, resilience and environmental protection. WSUD has evolved from its early association with stormwater management to focus on integrating the urban water cycle (including potable water, wastewater and stormwater) into built and natural urban landscape to provide multiple benefits to society. It is linked to Ecologically Sustainable Development (ESD) and Integrated Water Cycle Management (IWCM), with a focus on sustainable management of urban water resources and environmental protection.

The definitions of WSUD amongst practitioners are often varied, reflecting wide coverage of the applications of the WSUD framework. The Australian governmental agreement of the National Water Initiative (COAG, 2004[16]) defines WSUD as "the integration of urban planning with the management, protection and conservation of the urban water cycle that ensures that urban water management is sensitive to natural hydrological and ecological processes".

In their submission to the IWA/IAHR Joint Committee on Urban Drainage, Wong and Ashley (2006)[17] state that the term WSUD "….comprises two parts – 'Water Sensitive' and 'Urban Design'. Urban Design is a well-recognised field associated with the planning and architectural design of urban environments, covering issues that have traditionally appeared outside of the water field but nevertheless interact or have implications to environmental effects on land and water.

A 'water sensitive' approach to planning and design defines a new paradigm in integrated water cycle management that brings together the social and physical sciences, and involves the various engineering and environmental science disciplines associated with the provision of water services including the protection of aquatic environments in urban areas. WSUD incorporates integrated water cycle management; however, the converse is not necessarily the case.

WSUD aims to ensure that water is given due prominence within the urban design processes. Community values and aspirations of urban places necessarily govern urban design decisions and therefore water management practices.

*Water Sensitive Urban Design integrates the social and physical sciences and brings 'sensitivity to water' into urban design. It defines a planning and design approach that supports the transition to Water Sensitive Cities.*

[16] Council of Australian Governments (COAG) (2004) Intergovernmental Agreement on a National Water Initiative. Commonwealth of Australia and the Governments of New South Wales, Victoria, Queensland, South Australia, the Australian Capital Territory and the Northern Territory, signed 25 June 2004. Available at: http://www.coag.gov.au/meetings/250604/iga_national_water_initiative.pdf.

[17] Wong, T.H.F and Ashley, R. (2006) International Working Group on Water Sensitive Urban Design, Submission to the IWA/IAHR Joint Committee on Urban Drainage, March 2006.

# Urban Stormwater Management in a Water Sensitive City

Urban stormwater is defined as storm runoff from the urban environment and consists predominantly runoff of impervious areas (e.g. roads, roofs, footpaths, car parks, etc.) during rainfall events. Storm runoff from pervious areas (e.g. gardens, lawns, vegetated open spaces, etc.) also contributes to stormwater flow during high intensity rainfall events.

Stormwater infrastructure in urban environments has traditionally been built to convey urban stormwater rapidly to receiving waters (e.g. waterways, bays and estuaries, groundwater, sea and oceans). Those infrastructure built on shallow groundwater systems also conveys groundwater flows during periods of rising groundwater table that are either associated with extended periods of wet weather conditions, or seasonal groundwater level fluctuation.

Urban stormwater conveys pollutants derived from urban activities. Symptomatic of the effect of stormwater pollution is the deterioration of water quality in the receiving water environment. Poor water quality in urban waterway is prevalent in many towns and cities throughout the world.

The most obvious effect of urbanisation on catchment hydrology is the increase in the magnitude of flow events in urban streams and the consequent impact on flooding, stream erosion, and public safety.

Stormwater management has traditionally focused on stormwater drainage, with the principal (and often only) objective of conveying stormwater runoff away safely and economically to receiving waters. Traditional approaches involve increasing the hydraulic capacity of urban waterways through a combination of channelisation and partial, or complete, concrete lining. These traditional approaches only serve to efficiently convey the pollutants flushed from urban areas to the receiving waterways, particularly the cities iconic rivers and bays.

Drought conditions in many parts of Australia since the mid to late 1990’s have focused Australian governments on the emerging challenge of securing reliable water supplies for urban areas. In addition to major initiatives promoting water conservation and water efficiency, stormwater harvesting is gaining prominence as an alternative water source, supported by increased government funding for stormwater harvesting schemes.

Urban stormwater treatment and harvesting represents a significant opportunity to provide a major new water source for use by cities, while simultaneously helping to protect valuable waterways from excessive pollution and ecosystem degradation (PMSEIC, 2007[18]). The opportunities to realise this potential varies from cities to cities and are dependent on the seasonal variability of rainfall and corresponding demands for alternative water supply, and the availability of cost-effective storages.

The 2009 breaking of the millennium drought in many Australian cities has been marked by the occurrence of devastating floods, and extended periods of heat wave conditions and bush fires. These events remind us of the importance of adopting a holistic approach to urban stormwater management.

*Urban stormwater treatment and harvesting represents a significant opportunity to provide a major new water source for use by cities, while simultaneously helping to protect valuable waterways from excessive pollution and ecosystem degradation.*

[18] Prime Minister Science Engineering and Innovation Council Working Group (2007), Water for Our Cities: building resilience in a climate of uncertainty, a report of the PMSEIC Working Group, June 2007.

Stormwater provides an additional and abundant source of water to support the greening of cities, which in turn provides benefits in creating more liveable and resilient urban environments, including:-

- improved human thermal comfort to reduce heat related stress and mortality;
- decreased total stormwater runoff and improved flow regimes (more natural high-flows and low-flows) for urban waterways;
- sustaining a healthy waterway through maintaining ecological complexity and channel stability;
- productive vegetation and increased carbon sequestration;
- improved air quality through deposition; and
- improved amenity of the landscape.

As stormwater runoff is generated across distributed areas, distributed green infrastructure presents the best opportunity for delivering multiple benefit outcomes while managing stormwater impacts; end-of-pipe systems will have only local impacts.

In a Water Sensitive City, stormwater flow is conveyed through a network of green and blue corridors of open spaces and productive landscapes that also detain flood water for flood protection of downstream communities. This approach can often defer or eliminate the need for drainage infrastructure augmentation to accommodate increased catchment impervious area coverage attributed to urban consolidation.

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# Research Adoption and Implementation

# Research Adoption and Implementation

This section of the blueprint describes how research insights have been developed, adapted and implemented for precinct scale demonstration project. The influence of site context and evolving development considerations on the adoption and implementation of research outcomes are discussed.

The Places Victoria *Officer* development is a 340 ha greenfield site located approximately 50 kilometres south-east of central Melbourne. The development will ultimately incorporate homes for approximately 15,000 people and employment opportunities for approximately 5,000 people. Places Victoria established a vision for *Officer* as “a great place for people to live and work with a low environmental footprint” (VicUrban, 2009[19]). The vision was underpinned by objectives to:

- provide high quality open spaces to support higher density outer urban development;
- reduce potable water demand by up to 70%; and
- reduce carbon pollution by up to 50%.

The 30 hectare *Officer Town Centre* (**Figure 2**) is a precinct scale demonstration project of the CRC for Water Sensitive Cities. Innovative stormwater management has the potential to support the vision and aspirations for Officer and the transition to a Water Sensitive City.

Two key initiatives developed by the Cities as Water Supply Catchments Program as part of the *Officer* masterplanning and design process (2009 – 2012) were:

- improving the ecological health of Gum Scrub Creek by managing the quantity, frequency and quality of urban stormwater runoff through a combination of stormwater harvesting and riparian ‘sponges’; and
- identifying appropriate end uses for harvested stormwater (within the portfolio of available water sources) in a non supply-constrained local water environment.

Other initiatives (e.g. distributed green infrastructure for stormwater treatment and extreme temperature mitigation) were also investigated. With civil and landscape works along Gum Scrub Creek nearing completion, opportunities for reviewing and assessing the implemented initiatives (in particular the riparian ‘sponges’) are currently being considered.

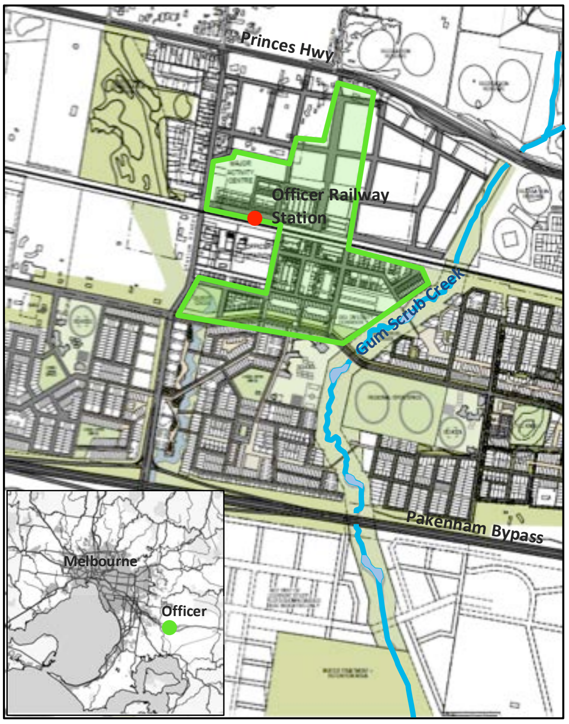



**Figure 2.** Places Victoria’s *Officer* Development Site. The *Officer Town Centre* precinct, centred on the Officer Railway Station is highlighted (Source: Places Victoria).

Construction of the Officer development commenced in early 2012. Bulk earthworks to recreate Gum Scrub Creek and its associated riparian corridor were completed in early 2013, with construction and establishment of waterway features including the riparian ‘sponges’ currently in progress. The contrast between the pre-urbanised waterway and the future 100m wide riparian corridor along Gum Scrub Creek (area with stripped topsoil) is shown in **Figure 3**. The re-creation of the waterway and associated riparian corridor provided an opportunity to deliver high standards of ecological protection and provision of ecosystem services without significant reduction in developable area.

[19] VicUrban (2009). VicUrban@Officer, A Vision for Australia’s Most Sustainable Urban Development. VicUrban, Melbourne.

**Figure 3.** Initial earthworks along Gum Scrub Creek (December 2012).

## Stormwater Management Innovations

Proposed urban stormwater management strategies and options for the Officer development were investigated by the Cities as Water Supply Catchments Program. The research program worked with Places Victoria and their project consultants to inform the development of the integrated water management strategy and provide input to the masterplanning and design process. The research program focussed on stormwater management innovation within the context of water demands, available water sources and environmental and economic considerations.

### Riparian 'Sponges'

An assessment of in-stream ecological responses to a range of urban development approaches (Walsh & Fletcher, 2010[20]) predicted that conventional urban development (meeting current environmental protection requirements) within the Gum Scrub Creek catchment would likely result in the loss of in-stream ecological values. It would also significantly reduce opportunities to improve the ecological values of the waterway. Project stakeholders identified that water quality, in-stream and riparian biodiversity, and the maintenance of flow regimes were important ecological values of Gum Scrub Creek that should be protected or restored. The maintenance of a flow regime approaching that of pre-development conditions could be attained through a combination of stormwater harvesting and infiltration. However, opportunity for extensive stormwater harvesting are limited in a mandated recycled water precinct such as Officer. The research program determined that conditions approaching the pre-development flow regime for the developed catchment could be achieved by incorporating riparian 'sponges' representing 5-6% of the contributing catchment. This assessment influenced a subsequent journal article (Walsh *et al.* 2012[21]) that presents urban stormwater runoff as a new class of environmental flow problem.

The riparian 'sponge' concept is a hydrologic intervention to manage the increased stormwater runoff (volume, pollutants and frequency) associated with urban development, primarily by retaining and evapotranspiring excess urban runoff. This provides the necessary conditions for the restoration or rehabilitation of the ecological health (and possibly the natural geomorphology) of an urban waterway.

Water quality objectives can often be met with stormwater treatment systems representing 1-2% of the contributing catchment area (e.g. biofiltration systems). However, a larger area is required to achieve the hydrologic objective of preserving the pre-development hydrology to a level that would protect/ enhance ecosystem health in the waterway.

The riparian 'sponge' concept aims to:

- emulate natural flow processes (with the vast majority of flows arriving in the creek through sub-surface means)
- emulate natural filtration processes (through the dense vegetation of the riparian 'sponge').

[20] Walsh. C.J. and Fletcher, T.D. (2010) Ecological scenarios for Gum Scrub Creek: informing water management plans in an urbanizing agricultural catchment, Cities as Water Supply Catchments Program (P4 Report), May 2010.

[21] Walsh. C.J., Fletcher, T.D. and Burns, M. (2012) Urban Stormwater Runoff: A New Class of Environmental Flow Problem. *PLOS One*, September 2012.

*The riparian 'sponge' concept is a hydrologic intervention to manage the increased stormwater runoff (volume, pollutants and frequency) associated with urban development, primarily by retaining and evapotranspiring excess urban runoff.*

The riparian 'sponge' would retain all low flows from the upstream urban catchment (nominally up to the 3 month average recurrence interval flow), with stormwater subsequently evapotranspiring from, or slowly filtering through, the riparian 'sponge' vegetation and media. Where in-situ soils allow, exfiltration of retained stormwater would also contribute a reduction in stormwater being released to the waterway (this would be minimal at Officer due to the clay in-situ soils and thus a larger sponge area is required). Stormwater pre-treatment (for example, through streetscape swales or sediment ponds) would protect the riparian 'sponges' from high urban sediment loads.

### Stormwater Harvesting and Use

The Officer development has ready access to mains potable water and is also located in a mandated dual supply (potable and recycled water) zone. As such, there is currently no shortage of water to meet projected demands. The use of recycled water reduces pollutant loads that may otherwise be discharged to regional receiving environments. Notwithstanding this, stormwater harvesting has the potential to provide an alternate water source to further enhance water security, particularly if they are treated to a standard suitable for uses where recycled water is inappropriate or less desirable. The research program considers that a hierarchy of fit-for-purpose water use could be implemented with water sourced from recycled water, mains potable water and stormwater. Harvested stormwater is considered a preferable water source to recycled water for the irrigation of open space adjacent to waterways where there is a risk of recycled water (with a higher nitrogen concentration) entering the waterway. The harvesting of stormwater will reduce the area riparian 'sponges' required to achieve hydrologic and ecological objectives.

Two possible stormwater harvesting strategies were investigated by the research program to determine how stormwater harvesting and use could contribute to the overall water supply strategy for Officer:

- stormwater harvesting to supply non-potable water demands within the development; and
- stormwater harvesting to supply potable and non-potable water demands within the development.

In both cases, stormwater forms part of an integrated portfolio of water sources together with recycled water and mains potable water. This integrated portfolio approach enables stormwater to enhance regional water security and environmental protection without the need to construct large storages to secure a high reliability of supply.

Spatial requirements for different ecological stormwater treatment systems (biofiltration and wetlands) were assessed. Likely micro-climate benefits of different spatial considerations were also considered. Potential water demands beyond the Officer development (for example, agricultural uses) and the potential opportunity of utilising a nearby reservoir for stormwater storage were also identified.

Conceptual scenario modelling showed that up to 30% (350 ML/yr) of the total water demand for the development (1,100 ML) could be met by harvested stormwater supplying non-potable demands. Stormwater treated to the required standards to supply potable and non-potable demands could potentially provide up to 70% (780 ML/yr) of the total water demand for the development.

An alternate proposition for a stormwater harvesting pilot project treating stormwater to a potable standard within the Officer town centre was also explored. If implemented, the pilot project could provide proof-of-concept for the contribution of green technology (biofiltration) as part of a decentralised potable water treatment system. It would also assist in facilitating the validation and verification of biofiltration as an approved water treatment process. While not currently supported by Victorian public health policy, the demonstration and monitoring of a water treatment system incorporating green infrastructure as part of the treatment train to treat stormwater to a potable standard (but not connected to the potable water network) could significantly progress the water industry's understanding of the risks, costs and benefits of stormwater as a potential potable water resource.

## Implementing Research Outcomes

### Riparian 'Sponge' Concept

The presence of the growling grass frog, listed as vulnerable under the national Environment Protection and Biodiversity Conservation (EPBC) Act 1999, led to the designation of a 100 m wide riparian corridor along Gum Scrub Creek. This enabled the 'sponges' to be located within the riparian corridor rather than developable land. The Water Sensitive City strategy nevertheless includes some stormwater treatment within the urban (developable) area to enable important environmental, social and economic benefits (for example, improved ecological connectivity, microclimate and amenity) to be realised.

The Melbourne Water Drainage Scheme for this area includes a retarding basin and wetland downstream of the Officer development. Together with sediment ponds located at stormwater pipe outlets to the waterway, they are sized to ensure compliance with best practice water quality objectives for the development. This approach does not include the contribution of riparian 'sponges' in meeting water quality and quantity objectives, thereby reducing risks of potential delays in the design and development approval process associated with approval of non-standard stormwater management systems. There is therefore a level of redundancy in the stormwater treatment train attributed to current institutional arrangements for approval of new WSUD elements. Field monitoring following construction will enable better quantification of the water quality improvements attributed to these systems, reducing the level of system redundancy required.

The relatively flat topography of the Officer site (particularly in the east-west direction) poses a common urban development challenge. Conventional stormwater drainage design seeks to optimise the trade-off between the volume of fill required to establish development platforms, the stormwater pipe sizes and longitudinal grades, and the depth of stormwater pipe outlets to the local waterway. At Officer, a conventional (piped) drainage system was adopted; however, an innovative waterway design incorporating elongated sediment ponds helped address the challenge presented by the flat topography. Collaborative and constructive engagement between the client, project consultants and researchers enabled a modified riparian 'sponge' configuration to be incorporated within the riparian corridor, as well as the demonstration of 'green fingers' to extend ecological functioning into the developable area. There is a corresponding loss of developable land but an increased distribution of ecological functions throughout the development.

The incorporation of adequate riparian 'sponge' area to achieve the hydrological objectives could only be achieved because of the available space within the riparian corridor.

### Stormwater Harvesting Concept

Stormwater harvesting in any substantial capacity was not recommended in the draft integrated water management strategy for the Officer development. The availability of mains potable and recycled water makes them obvious water supply choices, with the infrastructure required for stormwater harvesting representing an additional cost to the development. However the assessment of options based predominantly on lowest financial cost precluded serious consideration of stormwater harvesting and the potential non-monetary (environmental and social) benefits that could be realised. This project has highlighted the urgent need of expanding economic valuation methods for integrated water cycle planning to enable meaningful assessment of holistic solutions that incorporate non-market benefits.

Notwithstanding this, the continuing commitment of Places Victoria to the aspirations of the Officer development and the aims of the research program enabled continued investigation of stormwater harvesting options. A pilot project within the Officer town centre to demonstrate 'proof of concept' for a treatment process incorporating green infrastructure (biofiltration) to take stormwater to potable standard has been investigated. A facilitated strategic options analysis process (developed by the Victorian Government Department of Treasury and Finance) has been undertaken for the pilot project. While the pilot project has not been implemented to date, the strategic options analysis proved to be valuable process for engaging with key project stakeholders to consider and develop a robust business case for water sensitive city initiatives seeking to deliver multiple benefits.

*An integrated portfolio approach enables stormwater to enhance water security and environmental protection without the need to construct large storages to secure a high reliability of supply.*

## Observations

The Officer project has thus far demonstrated that high standards of ecological protection and provision of ecosystem services can be attained in greenfield developments without significant reduction in developable areas, even on very flat sites. This demonstration project highlights the strategic importance of spatial planning in facilitating the implementation of water sensitive cities innovations.

The innovative concept of riparian 'sponges' for hydrological control of the impact of catchment urbanisation on ecosystem health of natural waterways marries well with the Environment Protection and Biodiversity Conservation requirements for provision of riparian corridors.

In the same way that the vision and objectives for a site are developed and refined through the masterplanning and design process, strategies to implement research outcomes must also be refined and adapted to address the local physical and socio-political context of a particular site. However, the fundamental principles and scientific rigour underpinning the design must be maintained to ensure that 'proof of concept' can be achieved for the research initiatives being demonstrated.

The Officer demonstration project has delivered some, but not all research objectives identified at the beginning of the project. It was necessary to continually adapt the water sensitive city strategy for the development to accommodate the practicality and differing objectives of the many stakeholders involved. Research involvement in the masterplanning and design process for the Officer development has highlighted a number of potentially important factors for successful implementation of innovative urban stormwater management outcomes in urban development:

- the ongoing support and collaboration of all parties (client, consultants, researchers, key stakeholders) is critical as implementing innovation is complex;
- the risks and benefits of implementing research innovation must be clearly articulated and understood by all parties, with a shared responsibility to collectively respond to opportunities and address challenges;
- early collaboration between researchers and project consultants in masterplanning and design conversations is critical; and
- ongoing involvement of the researchers throughout the masterplanning and design process is required to ensure initiatives are refined and adapted to new opportunities and constraints as they arise.

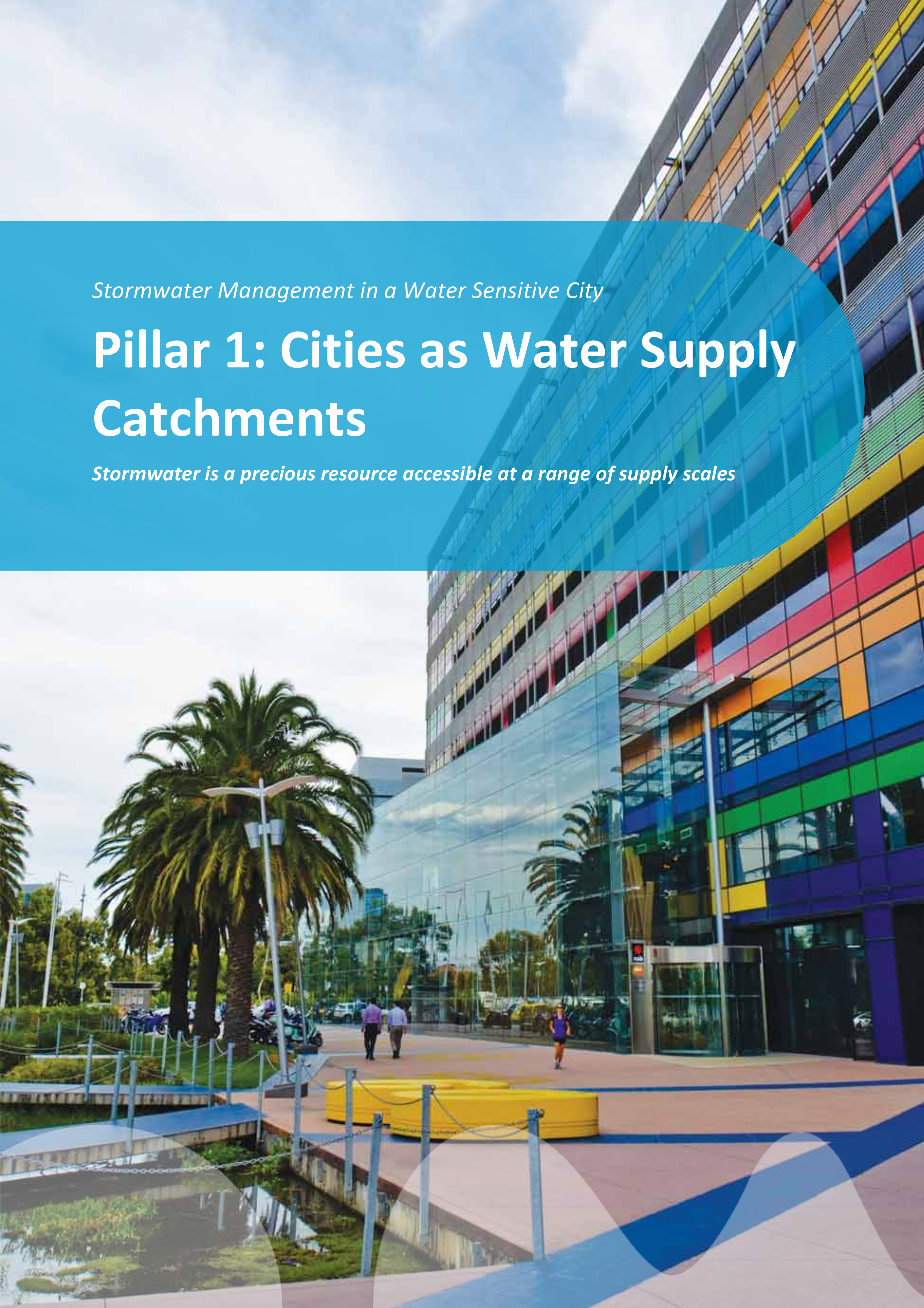
Ultimately, it is the shared vision, common objectives, and willingness of all stakeholders to collaborate that enables challenges to be overcome and aspirations for the implementation of innovative urban stormwater management outcomes to be realised.

*In the same way that the vision and objectives for a site are developed and refined through the masterplanning and design process, strategies to implement research outcomes must also be refined and adapted to address the local physical and socio-political context of a particular site.*

*Stormwater Management in a Water Sensitive City*

# Pillar 1: Cities as Water Supply Catchments

***Stormwater is a precious resource accessible at a range of supply scales***



# Pillar 1: Cities as Water Supply Catchments

***Stormwater is a precious resource accessible at a range of supply scales***

In the majority of Australian cities and towns, stormwater is now accepted as a valuable alternate water source. Systems that deliver water for both restricted and unrestricted irrigation of communal green spaces are particularly popular. However, there remain a number of barriers to the implementation of stormwater harvesting schemes involving a greater exposure of humans to treated stormwater. Of these, the most important are:

- our limited understanding of the microbial and chemical hazards present in urban stormwater;
- minimal knowledge of pathogen and chemical removal in low-energy and affordable stormwater treatment systems that are based on the proven concepts of WSUD; and
- non-existent validation procedures for these types of stormwater treatment systems.

## Guidelines for Managing Risks Associated with Stormwater Use

The Australian Guidelines for Water Recycling (AGWR) developed under the National Water Quality Management Strategy (NRMMC *et al.*, 2009a[22]) remain the most current guidelines for managing risks associated with stormwater use and provide the key guidance for stormwater quality and treatment. The AGWR, Managing Health and Environmental Risk - Phase 1 (AGWR-MHER; NRMMC *et al.*, 2006[23]) provides fundamental guidance of managing health risks and should be used in conjunction with the relevant AGWR, Phase 2 document. The most appropriate Phase 2 document for different stormwater harvesting schemes will vary. The most relevant document to be used will depend on the end use application and whether harvested stormwater will been stored in an aquifer prior to its use. Key considerations for the four documents that address water recycling are outlined in **Table 2** while key recommendations based on intended end use of stormwater are presented in

**Table 3**.

In addition to the research reported here, there are at present a number of initiatives and projects across Australia aiming to improve our understanding of the water quality hazards present in untreated stormwater, e.g. projects funded by the Urban Water Security Research Alliance[24] and Water Quality Research Australia. Given the vast body of knowledge that is being generated in this area the CRC for Water Sensitive Cities will critically review the information generated and issue updated guidelines, if deemed appropriate.

*There remain a number of barriers to the implementation of stormwater harvesting schemes involving a greater exposure of humans to treated stormwater.*

[22] NRMMC, EPHC and NHMRC (2009a). *Australian Guidelines for Water Recycling (Phase 2): Stormwater Harvesting and Reuse.* Natural Resource Management Ministerial Council, Environment Protection and Heritage Council, National Health and Medical Research Council, Canberra.

[23] NRMMC, EPHC and NHMRC (2006). *Australian Guidelines for Water Recycling: Managing Health and Environmental Risks (Phase 1)*. Natural Resource Management Ministerial Council, Environment Protection and Heritage Council, National Health and Medical Research Council, Canberra.

[24] Sidhu J., Gernjak W., Toze S. (eds.) (2013). Health Risk Assessment of Urban Stormwater. Urban Water Security Research Alliance Technical Report No. 102. ISSN 1836-5566 (available online).

**Table 2.** Key considerations for use of *Australian Guidelines for Water Recycling*

| Guidance document | Key considerations |
|---|---|
| Australian Guidelines for Water Recycling: (Phase 1) Managing Health and Environmental Risks[23] | • present the risk management framework including how to conduct Quantitative Microbial Risk Assessment (QMRA)<br>• outline requirements for validation of treatment systems and monitoring requirements. |
| Australian Guidelines for Water Recycling: (Phase 2) Augmentation of Drinking Water Supplies[25] | • consider chemical and pathogen risk but have been established based on reclaimed wastewater being the source water<br>• consider indirect potable reuse<br>• may not cover all hazards that could be present in stormwater as the range of pathogen and chemical hazards could be more variable in stormwater than wastewater |
| Australian Guidelines for Water Recycling: (Phase 2) Stormwater Harvesting and Reuse[22] | • are applicable to new small-medium stormwater harvesting systems involving non-potable end use scenarios<br>• do not provide health guideline values for chemicals as ingestion during non-potable end use scenarios is considered to be sporadic and of low volume<br>• characterise pathogen risk on the basis of data reflecting samples drawn from creeks and streams in urban catchments that receive stormwater. |
| Australian guidelines for water recycling: (Phase 2) Managed aquifer recharge[26] | • provides guidance on managing risks associated with water that has been stored in aquifers prior to reuse<br>• water source prior to recharge may be: stormwater; water recycled from wastewater treatment plants; water from streams and lakes; groundwater drawn from other aquifers or drawn remotely from the same aquifer; or water from drinking water distribution systems, including desalinated sea water. |

[25] NRMMC, EPHC and NHMRC (2008). *Australian Guidelines for Water Recycling (Phase 2): Augmentation of Drinking Water Supplies.* Natural Resource Management Ministerial Council, Environment Protection and Heritage Council, National Health and Medical Research Council, Canberra.

[26] NRMMC, EPHC and NHMRC (2009b). *Australian Guidelines for Water Recycling (Phase 2): Managed Aquifer Recharge*. Natural Resource Management Ministerial Council, Environment Protection and Heritage Council, National Health and Medical Research Council, Canberra.

**Table 3.** Key recommendations for guidance in stormwater reuse schemes based on end use

| End use | Recommendations |
|---|---|
| Potable use | - adopt AGWR-ADW (NRMMC *et al.*, 2008[25]) for chemical contaminants and pathogens; |
| Indoor non-potable use | - refer to State or Territory water safety and/or health act for Class A water to provide adequate pre-treatment to ensure efficient disinfection through filtration (Log reduction targets for pathogens recommended by AGWR-SHR (NRMMC *et al.*, 2009a[22] Table A3.6) – viruses: 2.4; protozoa: 1.9; bacteria: 2.4). When a state or territory does not have defined Class A water requirements consult health and environment agency for each individual jurisdiction. |
| Unrestricted and restricted irrigation | - refer to AGWR-SHR (NRMMC *et al.*, 2009a[22] |
| Fire fighting | - refer to AGWR-SHR; if likely sources of chemical contamination are identified during catchment survey refer to AGWR-ADW (NRMMC *et al.*, 2008)[25] |
| Recreational exposure | - refer to Australian Guidelines for Managing Risks in Recreational Waters (NHMRC, 2008[27]) |

[27] NHMRC (2008). *Guidelines for managing risks in recreational water*. National Health and Medical Research Council, Australian Government.

## Human Health Hazards in Stormwater

Stormwater contains pollutants, some of which are harmful to humans. Pathogen and micropollutant concentrations in stormwater are not well understood, with even less information available about their corresponding causal links (e.g. rainfall patterns, catchment characteristics such as land use, soil types, etc.).

When designing stormwater harvesting systems with the aim of providing safe water for specific end-uses, we recommend the use of a generic risk assessment procedure (AGWR-SHR; NRMMC *et al.*, 2009a[22]; AGWR-MHER; NRMMC *et al.*, 2006[23]). This procedure has five main steps: Identify issues; identify hazards; assessment of exposure; assess dose-response; and finally characterize risk. The aim of the process is to gather knowledge to decide on the required level of treatment for a given end-use and associated exposure scenario.

In stormwater harvesting schemes, it is generally recommended that stormwater is collected before it mixes with other sources. However, this might not always be feasible; for example, highly permeable soils and high groundwater tables on the Swan Coastal Plain in Western Australia cause interactions between stormwater and groundwater to happen very rapidly.

In practice stormwater can be sourced in two different ways:

- from artificial stormwater conveyance systems (including constructed natural drains) before interaction with other water sources or receiving water environments;
- from artificial or natural waterways that predominantly receive stormwater (e.g. creeks, streams).

Distinguishing between the hazards likely to be present in these two scenarios is relevant when considering health risks associated with stormwater harvesting, as the water quality may vary between the two.

Harvesting stormwater from artificial stormwater conveyance systems is often the preferred case from a stream ecology perspective (refer Pillar 2). Harvesting stormwater from artificial or natural waterways may benefit waterway health downstream of the extraction point but will not ameliorate the upstream hydrological impacts of urbanisation or improve the upstream waterway. Nevertheless, in many built-up urban catchments, stormwater harvesting from urban waterways represents a practical means of securing a higher supply reliability on the basis of a larger catchment yield associated with a larger urban catchment.

#### Pathogens

Pathogens are currently believed to present the most severe acute human health risk for most stormwater applications. Pathogens and human faecal source tracking markers detected in stormwater drains and receiving waters in urban Australian catchments are presented in **Figure 4** and **Figure 5**. This data is representative of hazards detected only (i.e. qualitative data, not quantitative) and should be used with caution until full risk assessments can be conducted.

Nevertheless, our data confirms that some degree of sewage ingress into stormwater systems seems to be more prevalent than previously thought as evidenced by the simultaneous detection in stormwater of different biological markers specific to humans (e.g. polyomavirus, human adenovirus, bacteroides HF183) and a number of chemical pollutants abundantly present in untreated sewage (acesulfame-K, an artificial sweetener, caffeine, paracetamol and salicyclic acid, an aspirin metabolite[24]).

However, pathogens in stormwater are highly variable; their presence and concentrations vary not only by site, but also between different stormwater events. The data collected to date is still insufficient to adequately understand pathogen variability, thereby requiring conservative estimates of pathogen concentrations to be adopted for risk assessments. This means stormwater harvesting systems will generally need to provide a high level of treatment for pathogens until this variability is better understood, as it is essential that the appropriate risk assessment procedures are followed to ensure stormwater harvesting is safe.

The information provided here indicates that pathogens which infect via ingestion (the current focus in most guidelines) may be present in stormwater. However, existing operational stormwater harvesting schemes in Australia involve non-potable use scenarios (such as spray irrigation, car washing, etc.), where exposure through alternative routes such as inhalation and dermal contact are in principle feasible. One of our research aims is to verify if the inclusion of these alternative exposure routes in the risk assessment process is necessary.

*We have shown the frequent presence of pathogens in stormwater. In the absence of good understanding of their concentrations, conservative estimates should be adopted for risk assessments.*

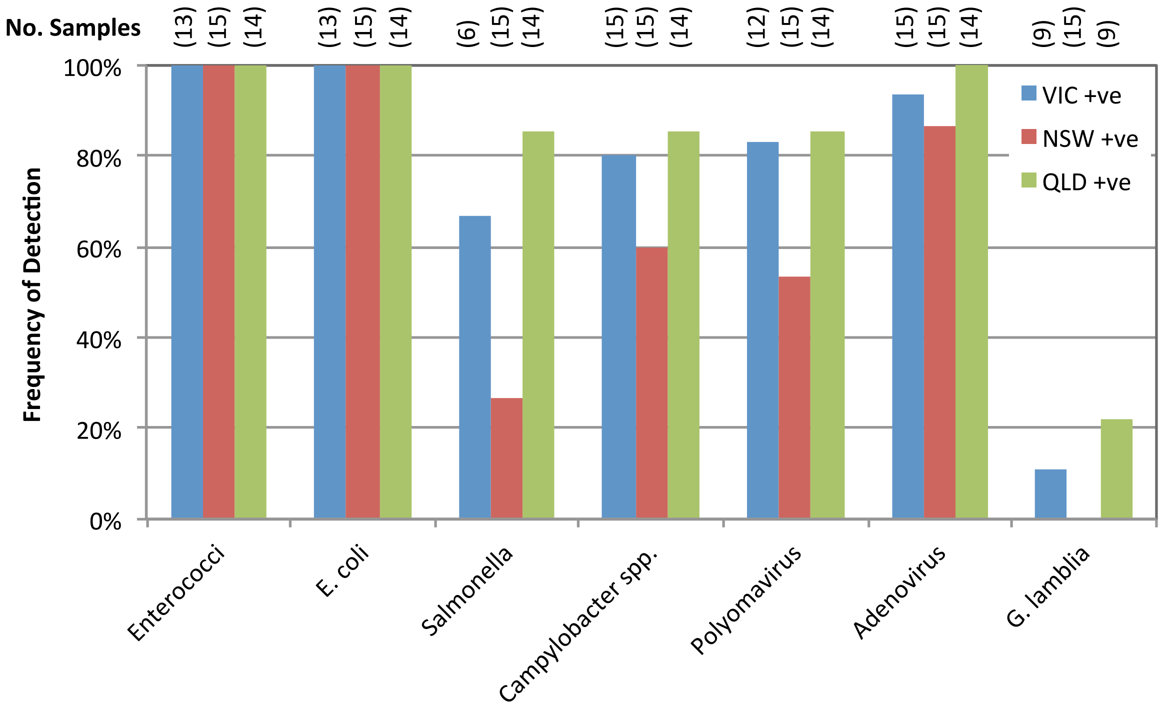



**Figure 4.** Positive detections of pathogens and indicator microorganisms in stormwater samples from seven urban catchments across Australia, 2011-2012. Sampling sites per state: Queensland (2), New South Wales (3)[24], Victoria (2)[24]. The number of samples tested is shown in brackets on top of each bar.

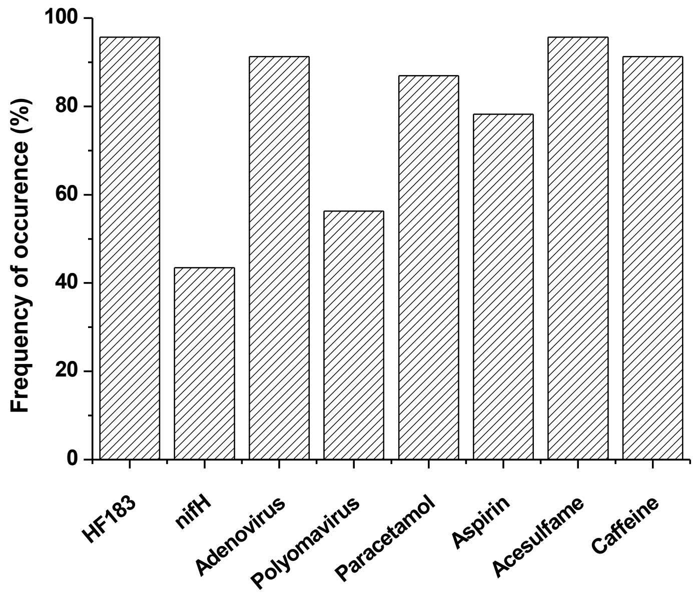



**Figure 5.** Frequency of occurrence of microbial source tracking and chemical source tracking markers in stormwater samples (n=23) collected from six catchments across Australia[24].

### Chemicals

Chemical hazards in stormwater potentially pose a human health risk where high and/or long-term exposure of individuals is possible, such as in potable reuse applications. Chemicals are not extensively covered in the Australian Guidelines for Water Recycling: (Phase 2) Stormwater Harvesting and Reuse[22] because these guidelines specifically focus on low exposure end-uses, such as drip irrigation. They are, however, often relevant to the ecological health of receiving waters[23].

A literature review (Lampard *et al.*, 2010[28]) showed that exceedances of the AGWR-ADW guideline values (NRMMC *et al.*, 2008[25]) in untreated stormwater predominantly occurred for a range of heavy metals and occasionally for a few other inorganic substances such as sulphate. Only a few regulated organic pollutants were occasionally detected in concentrations exceeding the AGWR-ADW guideline values such as dichloromethane, naphthalene, benzo(a)pyrene or pentachlorophenol.

We monitored event mean concentrations of untreated stormwater for individual storm events in eight different catchments with a range of diverse characteristics and land uses located in Queensland, New South Wales and Victoria (see **Figure 6**). To date around fifty samples have been collected and analysed. The data from these samples confirms the findings of our literature review. Some level of treatment will usually be required to remove PAH and metals. These contaminants are well understood and appropriate treatment using state-of-the-art WSUD systems will safely reduce these contaminants to below AGWR-ADW or ADWG guidelines values.

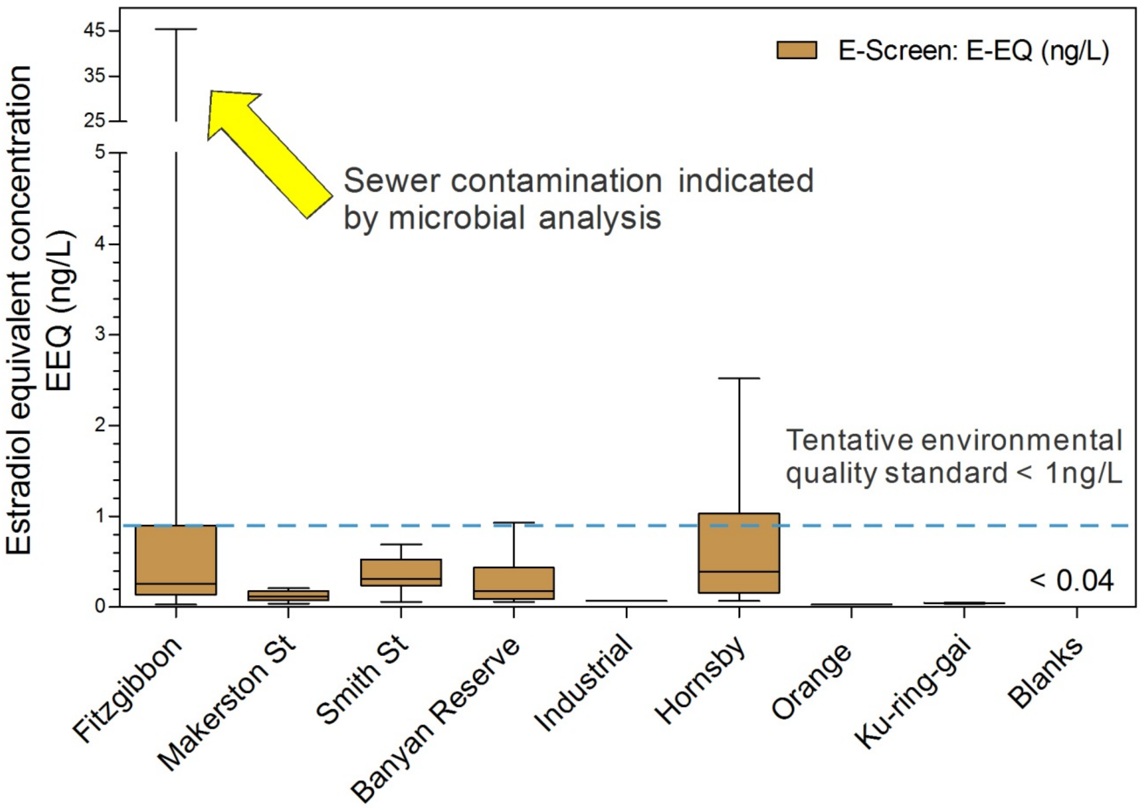



**Figure 6.** Estrogenicity of stormwater samples collected between 2011 and 2012 across Australia.

[28] Lampard J., Chapman H., Escher B., Ort C. and Gernjak W. (2010). Project 5: Risk and Health. Literature Review. Cities as Water Supply Catchments Program. Unpublished.

Around twenty different herbicides were measured and none was found above the recommended guideline values in AGWR-ADW (NRMMC *et al.*, 2008[25]). The herbicides found most frequently (>50% of samples) at concentrations above quantifiable limits were 2,4-D, diuron, MCPA, simazine and triclopyr. MCPA was the compound that was measured most closely to its respective guideline value (max. value measured 0.39 µg/L, guideline value 2 µg/L). Concentrations of both MCPA and diuron were shown to be highest in the densely urbanised catchments of Smith Street and Makerston Street (see **Figure 7**). However at Hornsby, which is also highly urbanized, very low concentrations have been measured. Therefore, while individual catchments seemed to be distinctively different from each other, a generally valid simple trend cannot be discerned at this stage. In-vitro bioassays confirmed unknown substances with strong herbicidal effects were not present. In conclusion, herbicides do not seem to present an important human health risk for stormwater, even for potable use. However, depending on the intended use, it may be necessary to consider the ecological impact of herbicides.

*The highest concentrations of MCPA and diuron were measured in highly urbanized catchments; however other highly urbanized catchments were associated with very low concentrations of these chemicals. Therefore, while individual catchments seemed to be distinctively different from each other, a generally valid simple trend cannot be discerned at this stage.*

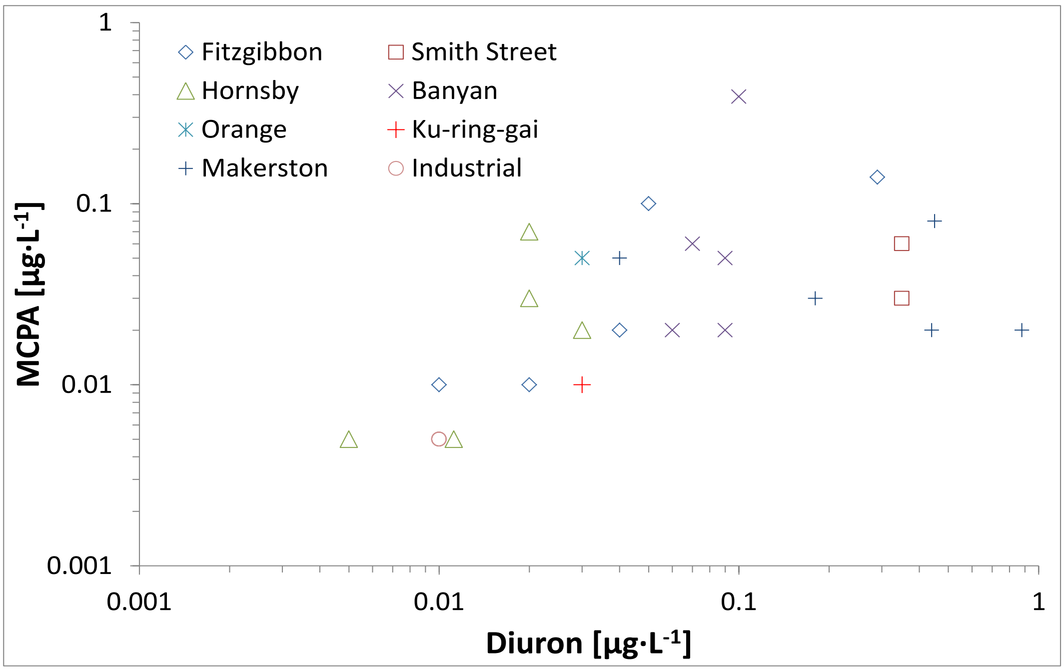



**Figure 7.** Concentrations of diuron and MCPA in different catchments (Sidhu *et al.*, 2013[24]).

Around sixty pharmaceuticals and personal care products were monitored. Concentrations of most compounds were below quantifiable limits and only caffeine was above a recommend guideline value is stated in AGWR-ADW (guideline value 0.35 µg/L, median 0.3 µg/L, maximum 5.2 µg/L). All other compounds were always a factor 30 or greater below their respective guideline value. As for herbicides, it can therefore be concluded that in general there seems to be little human health concern caused by pharmaceuticals and personal care products in stormwater.

The abundant list of pollutants listed in the AGWR-ADW is tailored to water quality hazards likely to be encountered in sewage-derived water sources. Consequently, a high number of miscellaneous organic compounds not explicitly addressed in current regulation have been reported in stormwater, adding to concerns voiced about 'unknown unknowns'.

We employ a battery of in vitro bioanalytical tools that utilise effects-based methods complementary to chemical analysis. They provide information on all micropollutants bioactive towards the monitored effect such as baseline toxicity, genotoxicity or estrogenicity. A major advantage of bioanalytical tools is the ability to detect the toxicity of mixtures of known and unknown compounds, while chemical analysis can only quantify the concentration of known targeted chemicals irrespective of toxicity. For example, the estrogenicity bioassay identified high estrogenic response in two sampling events, which may indicate the occurrence of large sewer overflow events. The results also confirmed that the observed bioanalytical equivalent concentrations were below the proposed environmental quality standard of 1ng/L[29] in the absence of sewer overflows.

*Concentrations of most pharmaceuticals and personal care products were below quantifiable limits. In general there seems to be little human health concern caused by these compounds in stormwater.*

[29] Jobling, S., Williams, R., Johnson, A., Taylor, A., Gross-Sorokin, M., Nolan, M., Tyler, C.R., van Aerle, R., Santos, E. and Brighty, G. (2006). Predicted exposures to steroid estrogens in UK rivers correlate with widespread sexual disruption in wild fish populations. *Environmental Health Perspectives*, **114**: 32-39.

## Treatment Technologies for Mitigating Risks

Stormwater harvesting systems should be designed to safely collect, treat, and store stormwater. The necessary elements of a stormwater treatment train depend on the intended end-uses (see **Table 4**). Current practice in relation to stormwater treatment is:

- If water is used for restricted or drip irrigation, no additional treatment/disinfection is needed.
- For all other uses disinfection is needed and for high level exposure uses, WSUD treatment technologies should be substituted with traditional drinking water technologies.

This reflects the limitations imposed by current guidelines, based on our understanding of the risks associated with pathogens and toxicants, and the current level of technological development of WSUD systems. However, WSUD technologies play a crucial role in stormwater pre-treatment by reducing the quantity and variability of pollutants and pathogens prior to additional treatment and/or storage. This pre-treatment can greatly improve the efficiency and effectiveness of traditional treatment technologies.

Our research efforts continue to focus on advancing stormwater biofilters (**Figure 8**) and associated filter technologies as they show the greatest potential for delivering reliable and safe water for outdoor irrigation without need for further treatment or disinfection (dark blue shaded area in **Table 4**).

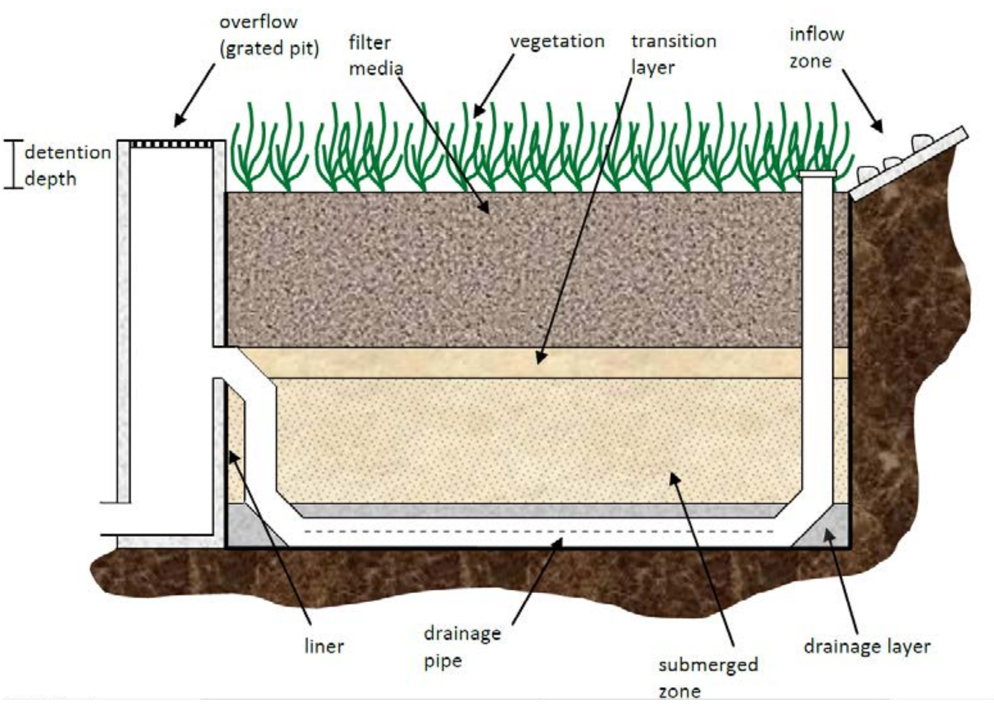



**Figure 8.** Biofilter design with submerged zone as recommended by FAWB (2009)[30]

[30] FAWB (2009). Adoption Guidelines for Stormwater Biofiltration Systems, Facility for Advancing Water Biofiltration, Monash University, June 2009. Available online at: monash.edu.au/fawb/publications/

**Table 4.** Stormwater treatment technologies achieving specific end-use water quality requirements - this should only be used as a broad recommendation, while a detailed site specific risk assessment should be carried out and appropriate treatment train selected. The different end uses refer to the options specified by NRMMC *et al.* (2009a[22]). The conservative uses of stormwater treated with WSUD technologies reflect those imposed by current guidelines.

| End use as per current Australian guidelines | | | Municipal use with restricted access (RAa) and drip irrigation (RAb) | Municipal use with unrestricted access (UA) | Dual reticulation with indoor and outdoor use (NP) | Drinking water[v] |
|---|---|---|---|---|---|---|
| Pre-Storage | Pre-treatment | Screens | | | | |
| | | GPTs | | | | |
| | Preliminary Treatment | Oil and sediment separators | | | | |
| | | Swales[i] | | | | |
| | | Tanks[ii] | | | | |
| | | Sediment basins | | | | |
| | | Ponds and lakes[ii] | | | | |
| | Secondary Treatment | Infiltration systems[i] | | | | |
| | | Wetlands[ii] | | | | |
| | | Biofilters[iii] | | | | |
| | | Stormwater filters | | | | |
| Post-Storage[iv] | Advanced Treatment[iii] | Sand filters | | | | |
| | | Aquifers[ii] | | | | |
| | | Suitable drinking water technologies (e.g. microfiltration, reverse osmosis, and advanced oxidation) | | | | |

i. Could also be used for collection

ii. Could also be used for storage

iii. Alternative/ additional drinking water technologies should be adopted where specific issues are present (e.g. colour, metals, odour, etc.)

iv. While aquifers are storages, they can also provide advanced treatment to stored water.

v Stormwater should be currently only be used for indirect potable use, as far more research is needed prior to direct potable use

Water quality level achieved when disinfection is employed (e.g. chlorination)

Currently requires disinfection but this requirement may be removed in the near future with the advancement of WSUD technologies.

## Current Stormwater Biofilters

### Pathogen Removal

A number of biofilter designs (all in accordance to guidelines developed by the Facility for Advancing Water Biofiltration (FAWB), 2009[30]) have been tested in laboratory conditions for removal of stormwater microorganisms, focusing primarily on pathogen indicators. This research has been published[31,32,33,34] with key findings summarised below.

- For a variety of system configurations (soil and plant media, presence or absence of saturated zone) and operation conditions (different inflow levels, drying/wetting regimes, etc.) the median removal rates of the tested pathogen indicators for bacteria, protozoa, and viruses (i.e. *E. coli, C. perfringens spores,* and *F-RNA coliphages)* were mainly above 1 log. However, there was a large variability in system performance across the different system configuration and operational conditions tested.
- Vegetation type can significantly influence pathogen removal, with shrub species (i.e. *Leptospermum continentale* and *Melaleuca incana)* showing the best performance (**Figure 9**). Preliminary data suggest that survival of *E. coli* is lower in vegetated filter media than in non-vegetated filter media, with *Leptospermum continentale* associated with the lowest survival rate of *E. coli* (it is hypothesized that this plant may exude anti-microbial compounds). These shrub species are also found to be very effective in removal of nutrients[30,35].
- The most important removal mechanisms for *E. coli* other than vegetation are adsorption by soil media during events, and competition and/or predation within soil media between events – it was found that *E. coli* will grow in sterilised filter media, while its level rapidly decreases in in-situ media.
- The presence of a submerged zone increases the overall removal of pathogens, as well as removal of nutrients. It is now well established that submerged zone water is generally of higher quality (for the majority of tested pollutants) than water treated during an event, since water detained in this zone is afforded additional treatment during the intervening dry periods[35].

*Biofiltration systems built in accordance with current best practice should be able to achieve around 1 log reduction of main pathogen indicators.*

[31] Li YL, A Deletic, L Alcazar, K Bratieres, TD. Fletcher, D.T. McCarthy, (2012). Biofilters for removal of microorganisms from urban stormwater, *Ecological Engineering* 49 137– 145.

[32] Chandrasena, G.I., Deletic A., Ellerton J., McCarthy D.T., (2012) Evaluating Escherichia coli removal performance in stormwater biofilters: a laboratory-scale study, *Water Science and Technology* 66(5) 1132-1137.

[33] Chandrasena G.I, A Deletic, DT McCarthy (in press). Evaluating Escherichia coli removal performance in stormwater biofilters: A preliminary modelling approach, *Water Science and Technology.*

[34] Pham T, Payne EG, Fletcher T D, Cook PL, Deletic A, Hatt, B. E. (2012). The influence of vegetation in stormwater biofilters on infiltration and nitrogen removal: preliminary findings. *7th International Conference on WSUD*, Melbourne, Australia.

[35] Payne E, T Pham, PLM Cook, TD Fletcher, BE Hatt, A Deletic (in press). Biofilter design for effective nitrogen removal from stormwater – influence of plant species, inflow hydrology and use of a saturated zone, NOVATECH 2013, Lyon, France, 2013.

Data on removal of pathogens and the indicators collected at a number of field biofilters (designed as per FAWB guidelines) confirm some of these laboratory findings[36]. **Figure 9** indicates that current best practice stormwater biofilters are consistently achieving well over 1 log reduction of key pathogen indicators under typical conditions (this can drop slightly below 1 log in highly challenging conditions; e.g. Monash car park tests where rather extreme operational conditions were adopted).

The more fundamental question of how well pathogen indicators represent removal of actual pathogens in field conditions remains. Research to date has established that the removal of *Campylobacter*, a pathogenic bacteria, was somewhat lower than the removal of the pathogen indicator *E. coli* (**Figure 9**). The removal of *F-RNA coliphage*, which is a commonly used indicator for viruses, showed around 3 log reductions in all laboratory and field tests. However, these findings are yet to be correlated with actual viruses since *Adenoviruses* and *Enteroviruses* were barely detected in both the inflow and outflow samples from our field studies.

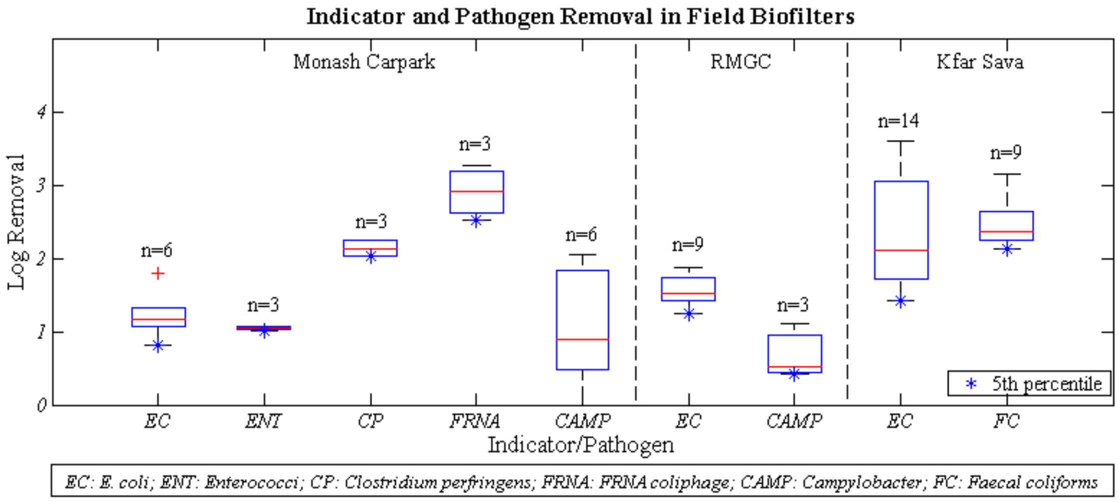



**Figure 9**. Removal of selected pathogen indicators and reference pathogens by three biofilters, designed according to FAWB, 2009 guidelines[30]: (1) Monash Carpark biofilter, a 10 $m^2$ system which was spiked with semi-synthetic stormwater that contained sewage (the results are from validation monitoring tests for highly challenged operational conditions), (2) Royal Melbourne Golf Club (RMGC) biofilter, a 450 $m^2$ system that treats stormwater from an old residential catchment for irrigation (after additional disinfection) of a golf course in Melbourne, and (3) Kfar Sava biofilter, a 85 $m^2$ system that treats very polluted stormwater from a city located near Tel Aviv, Israel, for aquifer recharge.

[36] Chandrasena G I, Filip S, Zhang K., Osborne CA, Deletic A, McCarthy DT (2012). Pathogen and indicator microorganism removal in field scale stormwater biofilters. 7th International Conference on WSUD, Melbourne, Australia.

### Chemical Removal

Investigation of the removal efficiency of micropollutants by biofilters [37,38,39] led to the following observations of the capacity of biofilter in chemical removal:

- *Heavy metals* – removal of heavy metals is excellent, with almost all metals (with the exception of aluminium) in the outflows being below AGWR-ADW (NRMMC *et al.*, 2008[25]) guideline values, despite inflow concentrations being relatively high and generally above these guideline values.
- *Pesticides and herbicides* – while biofilters initially have good capacity for removal of pesticides and herbicides, chemical such as triazines (including simazine, atrazine and prometryn, usually used as herbicides) may accumulate in the filter media with a high possibility of them breaking-through after a short operational timeframe. However, challenge tests using inflow concentrations well above AGWR-ADW targets showed that outflow concentrations of glyphosate, the most commonly used pesticide in Australian cities, was always below AGWR-ADW(NRMMC *et al.*, 2008[25]) values. In all cases media with higher level of organics performed better due to its higher adsorption capacity.
- *Miscellaneous Organic Chemicals* (MOCs) – Polycyclic aromatic hydrocarbon (PAHs), Total Petroleum Hydrocarbons (TPHs), and phthalates were not detected in the outflows, indicating excellent removal of these chemicals by biofilters. Phenols were detected in one outflow test associated with highly challenging conditions (out of 6 different tests), while Pentachlorophenols (PCPs) were detectible, but only during extremely challenging conditions where inflow concentrations were much higher than AGWR-ADW (NRMMC *et al.*, 2008[25]) guideline values.

### Novel Filtration Media for Pathogen Removal

The development of new cost-effective filtration materials for the inactivation of pathogens in stormwater is one of our research objectives. It is anticipated that the materials will be incorporated in the next generation of biofilters and filters to further improve the quality of treated stormwater for non-potable uses. The focus so far has been on modification of filtration media (with materials such as zeolites and Granular Activated Carbon – GAC) using antimicrobial agents (such as quaternary ammonium compounds and heavy metal compounds). Preliminary findings[40,41,42] suggests that we may be able to deliver such novel media in the near future. In summary:

- Zeolites coated with copper ions (Cu2+ or CuO) are the most promising materials for *E.Coli* removal during and in-between events.
- Calcination of the copper coated zeolites at high temperatures ensures low leaching of Cu (concentrations in the treated water is well below appropriate guideline levels set for long-term irrigation), while the media continues to provide a high level of removal (during dry periods) of accumulated E. coli in the filter.

We are currently working on incorporating these novel material in the next generation of biofilters to (at least) deliver safe treated stormwater for unrestricted irrigation without any post-treatment / disinfection (see Table 1).

*Biofiltration systems built in accordance to current best practice are very effective in removing heavy metals and hydrocarbons, while less effective for pesticides.*

[37] Zhang K.F., Filip S., Chandrasena K.K.G.I., McCarthy D.T., Daly E., Pham T., Kolotelo P. and Deletic A. (2012). Micro-pollutant removal in stormwater biofilters: a preliminary understanding from 3 challenge tests. *7th International Conference on WSUD Proceedings*. Melbourne, Australia.

[38] Feng W, Hatt B.E., McCarthy D.T., Fletcher T.D., and Deletic A. (2012) Biofilters for stormwater harvesting: understanding the treatment performance of key metals that pose a risk for water use. *Environmental Science and Technology*, 46, 5100–5108.

[39] Zinger Y and A Deletic (2011). Kfar-Sava Biofilter: The first milestone towards creating water sensitive cities in Israel, report of Monash Water for Liveability.

[40] Li Y.L., McCarthy D.T. and Deletic A. (2011). Treatment of pathogens in stormwater by antimicrobial-modified filter media. *12th International Conference on Urban Drainage Proceedings*, Porto Alegre, Brazil, Sept 2011.

[41] i Y.L., McCarthy D.T. and Deletic A. (2012). Removal and inactivation of E. coli from water using copper modified natural zeolite. *7th International Conference on WSUD Proceedings*, Melbourne, 2012.

[42] Guest, R.M., Schang, C., Deletic, A., McCarthy, D.T. (in press). Development of Novel Activated Carbon Filter Media for Pathogen Removal from Stormwater, *Water Science and Technology*, **66**.7, 1582-1589.

## Stormwater Collection and Storage

Stormwater collection can be done using traditional gutter-pipe-channel systems or linear WSUD systems, such as swales and biofilters. Collection and storage systems should be designed sized

Stormwater treatment and use systems that utilise aquifer storage are usually the most cost effective, and should therefore be explored as a first preference when site conditions are favourable. In the case of shallow aquifers, treatment systems should generally be unlined to promote infiltration to the aquifer following sufficient treatment to ensure appropriate water quality and protection of the receiving environment. However, potential risks to nearby buildings and other structures need to be considered.

Schemes involving other storage options (e.g. underground or aboveground tanks, ponds, lakes, etc.) should be generally designed to meet a moderate volumetric reliability to limit storage costs. For example, if the mean annual runoff volume is well in excess of the water demand at a site, it is generally optimal for stormwater harvesting schemes to meet between 50% to 80% of total water demand[43]. The optimal volumetric reliability for sites where the mean annual runoff volume is also a limiting factor would be much lower. Increasing the storage size to achieve a high volumetric reliability is typically associated with a greatly diminished cost-benefit ratio.

Local rainfall variability and proposed demand regime (i.e. seasonal or non-seasonal) are the most important factors in determining the storage size required for efficient stormwater harvesting. In determining the optimal storage volume for a stormwater harvesting scheme, a detailed storage behaviour modelling analysis using a 10 year time series is recommended. If possible, low resolution rainfall data (e.g. 6 minutes) should be used[44]).

## Validation Framework for Passive Stormwater Treatment Systems

As defined in the draft guidance for validation of treatment processes for wastewater recycling for non-potable uses (DHV, 2010[45]), treatment validation is the process of ensuring that (i) a treatment system can produce water of the required quality under a defined range of operating conditions, and (ii) it can be monitored in real time to provide assurance that the water quality objectives are being continuously met. There are currently no guidelines for validation of stormwater harvesting systems, including validation of passive stormwater treatment systems. Therefore, these systems are usually not recognised as treatment barriers by water recycling regulators. National Validation Guidelines are proposed to be developed by the Australian Centre for Water Recycling (Qld), but it is unlikely that the guidelines will cover stormwater harvesting or any passive stormwater treatment systems.

*Local rainfall variability and proposed demand regime are the most important factors in determining the storage size required for efficient stormwater harvesting.*

[43] Mitchell VG, Hatt B, Deletic A, Fletcher TD, McCarty D, Magyar (2006). Technical Guidance on the Development of Integrated Stormwater Treatment and Reuse Systems, ISWR Technical report 06/01.

[44] McCarthy DT, Deletic A, Fletcher TD (2008). Urban stormwater harvesting – sensitivity of a storage behaviour model, *Environmental Modelling and Software*, **23**(6), 782-793.

[45] Department of Health Victoria (DHV) (2010). Draft guidelines for validating treatment processes for pathogen reduction - supporting Class A water recycling schemes in Victoria (draft for consultation).

To bridge this gap, we are developing a (world-first) framework for validation of passive stormwater treatment systems. **Figure 9** outlines the proposed framework which will be further developed and fully tested. The framework has three main steps:

- *Pre-Validation* is about determining target pollutants and pathogens, their required reduction levels, and identifying key treatment mechanisms that should be present in a well functioning system. Challenging operation conditions also need to be determined for these pollutants/pathogens. This may include maximum loading rates, inflow pollutant / pathogen levels, challenging hydrological regimes (e.g. designed treatment volume and challenging length of dry periods in-between two events – we are proposing that this is done by modelling the inflows and outflows of the system using MUSIC or similar software tools).
- *Validation Monitoring* is about testing the system performance under challenging operational conditions, thereby providing evidence that the systems can cope in extreme situations. Both hydraulic and treatment performance must be validated, and this ideally should be done in-situ (i.e. use change tests similar to work done by Zhang et al, 2012[10] for biofilters). However it is recognised that this is not feasible for large WSUD systems (such as large scale wetlands or biofilters), so we are working on the development of validation methods that may use both lab and in-situ measurements as well as modelling (so far this has only been done for biofilters and chemicals).
- *Operational Monitoring* is about measuring inflow and outflow levels of indicators or targeted pollutants or pathogens during their normal operations to ensure that it is delivering the necessary level of treatment. How this could be done in a cost effective way is yet to be determined (e.g. what are reliable surrogates for on-line monitoring, how many discreet samples should be collected and analysed, etc.).

Monitoring of chemicals, and in particular pathogens, in stormwater systems is typically very difficult and expensive. Therefore, the key challenge associated with development of the proposed framework is how to make the procedures simple, robust and inexpensive.

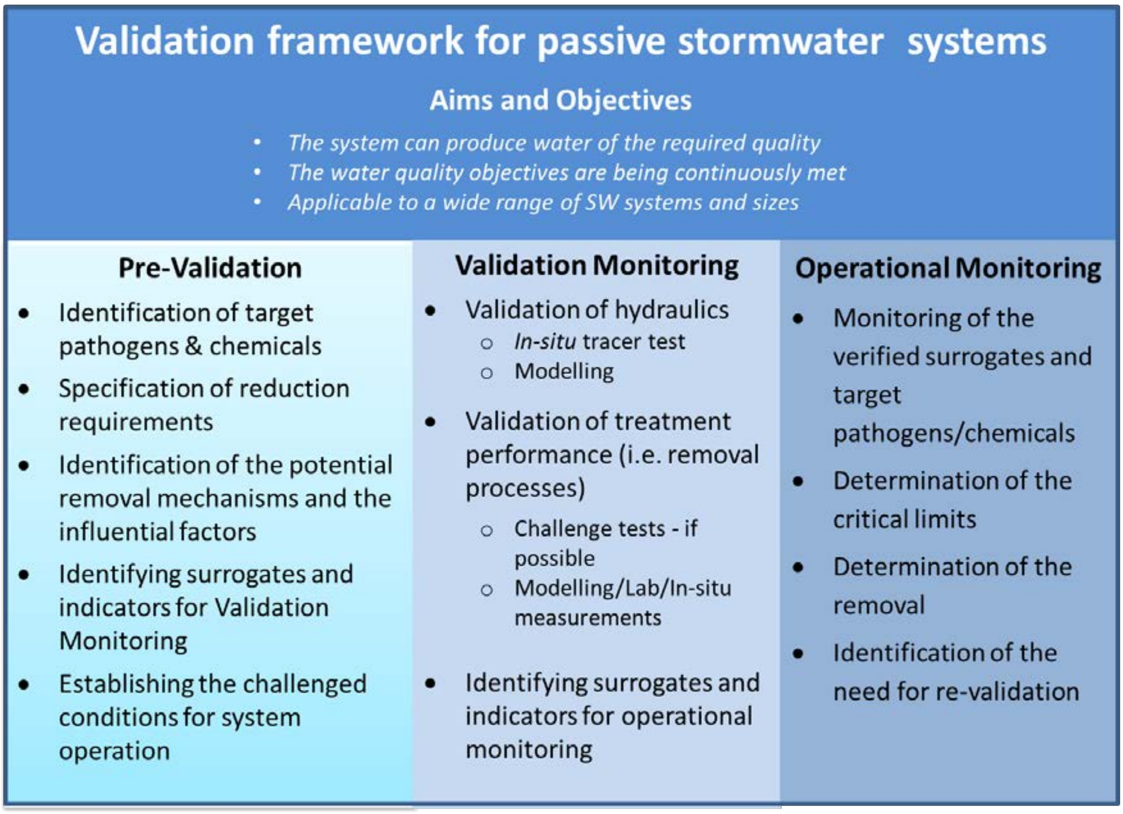



**Figure 10.** Proposed validation framework for passive stormwater harvesting system that needs more development and testing (currently we are working on validation for chemicals only)

## Design of Stormwater Harvesting Measures in Changing Climates

Assessing the performance of stormwater harvesting schemes under future climate change scenarios can be undertaken using any number of suitable modelling packages available for simulating the processes of stormwater generation, collection, treatment and storage. These simulations must be informed by plausible climate change scenarios at the city scale, and equally importantly, estimates of their uncertainties, as the latter will inform the resilience levels required in the design decisions. The derivation of such scenarios and uncertainty estimates must rely on state-of-the-art climate science combined with the needs of the user community.

Providing the data to support the design of stormwater harvesting schemes under climate change provides a significant challenge. Simulation of treatment trains and storage sizes must be undertaken using rainfall data series of at least ten years, at spatial scales of order one kilometre and with a small time step determined in relation to catchment size and treatment systems (e.g. 6 minute time steps for typical urban developments). Larger time steps (e.g. monthly and daily) and larger spatial domains (e.g. tens to hundreds of kilometres) are too coarse and should not be used, and yet, they are the typical output of standard climate change scenarios.

Historical time series of rainfall and evaporation are often used to design stormwater harvesting schemes, but they are unlikely to capture the anticipated changes to the climate of the major Australian cities over the next decades.

Intergovernmental Panel on Climate Change (IPCC) reports have clearly highlighted through the comparison of climatic predictions of a number of global climate change models that, with the exception of global mean temperature, predictions of future trends in climatic conditions including rainfall remain highly uncertain. In practice, methods have been proposed to adjust historical time series of rainfall and evapotranspiration to reflect future climate change trends, and these data have been used to assess the performance of stormwater harvesting schemes under potential future climate conditions. These procedures often draw on published data on predicted changes in climatic parameters from government reports and websites. However, these attempts to adjust historical time series of seasonal and event rainfall (and evapotranspiration) do not adequately reflect the uncertainties of future climate predictions.

*With the exception of global mean temperature, predictions of future trends in climatic conditions including rainfall remain highly uncertain. Attempts to adjust historical time series of seasonal and event rainfall (and evapotranspiration) do not adequately reflect the uncertainties of future climate predictions.*

Designing resilient stormwater harvesting schemes needs to focus on ensuring that they are adaptive to a wide range of possible rainfall and water demand scenarios. It is therefore necessary that several rainfall and evapotranspiration time series be generated and used with a suitable modelling package to simulate the processes of stormwater generation, collection, treatment and storage, and water demands (particularly for open space irrigation), in order to test the resilience of proposed schemes to future climate scenarios. The climate time series used must encapsulate all possible scenarios and provide a quantitative assessment of their likelihood as well as allowing for the estimation of uncertainty. They must also meet the high spatial and temporal resolution requirements of the user community.

At present, there is no generally agreed suitable method for incorporating information on future climate change scenarios to generate high resolution stochastic time series of rainfall to assess the performance of stormwater harvesting schemes under future climatic scenarios. Climate change scenarios are first and foremost based on sophisticated global climate models applied to a range of emission scenarios under the auspices of the international community. Uncertainties in the projected climate change using these tools arise from uncertainties in the emission scenarios themselves as well as uncertainties in the global model formulation. Both must be taken into account when assessing future stormwater harvesting schemes.

Global climate models provide information on spatial and temporal scales that are much too coarse for use in stormwater harvesting assessment. As a consequence, downscaling techniques must be employed to achieve the required spatial and temporal resolution. Several possible techniques for downscaling are currently available. Dynamical downscaling is a physically consistent way to construct rainfall projections at high resolution. However, it is computationally too expensive to estimate uncertainties because the calculations are simply too large to be applied to sufficiently many global models and emission scenarios. As a consequence, established methods for dynamical downscaling are unable to provide robust estimates of rainfall uncertainty. These problems may be overcome to some degree by combining the dynamical techniques with the use of high-resolution stochastic space-time models of rainfall derived from current observations. Only the combination of these various approaches will ensure that quantitative estimates of the uncertainties in the relevant variables will be available to the user community. The effect of the uncertainties can then be estimated by propagating the climate scenarios through hydrological models used to support the design of stormwater harvesting systems.

*Some of the limitations of current techniques for downscaling rainfall and evapotranspiration predictions under climate change scenario to scales of 1km and several minutes can be overcome by combining dynamical techniques with the use of high-resolution stochastic space-time models of rainfall derived from current observations.*

**Figure 11** shows a prototype system to develop quantitative estimates of the relevant variables under climate change including their uncertainties, which is currently being developed through the CRC for Water Sensitive Cities. Inputs to the system are the results of global model simulations for various emission scenarios carried out in support of the IPCC. These will provide estimates of the global circulation under climate change at a spatial scale of approximately 100 km and temporal scale of a few hours to a day. In a first step the strengths of the dynamical downscaling approach will be exploited by applying a dynamical model to each of the global model simulations. This will provide the regional circulation around a city of interest as well as the area mean rainfall around that city at scales of tens of kilometres and hours. To further downscale this information to scales of one kilometre and several minutes requires the use of statistical techniques (step 2 and 3). Here the system makes use of the well-known fact that the regional circulation drives the local rainfall distribution around a city - in short it is the local weather situation that determines the rainfall distribution in space and time. A stochastic model of the space-time distribution of rainfall whose parameters are chosen based on the circulation and mean area rainfall provided by the dynamical model will then provide estimates of rainfall at the scales as required to design and assess stormwater harvesting systems (one kilometre and several minutes). As the model contains a stochastic component, it will be applied several times to provide a large ensemble of possible output scenarios. As is evident from **Figure 11**, the proposed climate scenario system not only fulfils the spatial and temporal resolution requirements, but also includes quantitative estimates of all sources of uncertainties in the process, ranging from emission scenario uncertainty to global model uncertainty to parameter uncertainty in the stochastic model. It is therefore the most suitable system to date for application in the design and assessment of stormwater harvesting schemes.

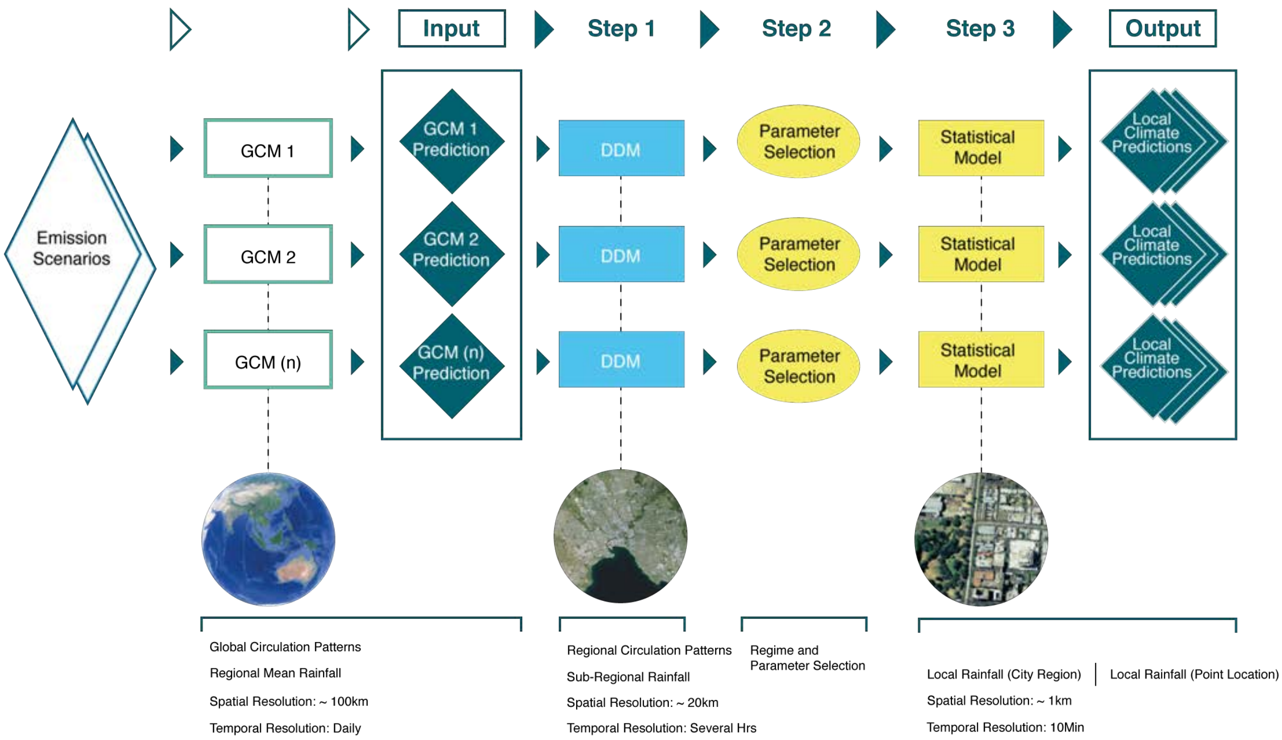



**Figure 11.** Schematic of a climate projection system for stormwater harvesting assessments (GCM: Global Climate Model; DDM: Dynamical Downscaling Model).

*Stormwater Management in a Water Sensitive City*

# Pillar 2: Cities Providing Ecosystem Services

***The built environment supplements and supports the functions of the natural environment and society***

# Pillar 2: Cities Providing Ecosystem Services

***The built environment supplements and supports the functions of the natural environment and society***

The process of urbanisation (including land-use change, building densification, removal of vegetation and population growth), along with climate change and variability has substantially altered the ability of the natural environment to provide ecosystem services, which support the wellbeing of people. Human benefits provided by terrestrial and aquatic (natural and modified) ecosystems include:

- maintenance of water quality through retention, filtration and transformation of pollutants through natural processes
- reduced urban heating and improved human thermal comfort through evapotranspiration
- improved flow regimes (more natural high-flows and low-flows) for urban waterways by attenuating stormwater runoff and reducing peak flows
- healthy ecological condition and reduced risks to infrastructure through waterway channel complexity and appropriate levels of stability
- productive vegetation that can provide increased carbon sequestration, shade to reduce heat loading on people and support biodiversity
- improved air quality through pollution removal by vegetation, and
- improved amenity of the urban landscape, particularly the stream and riparian zone.

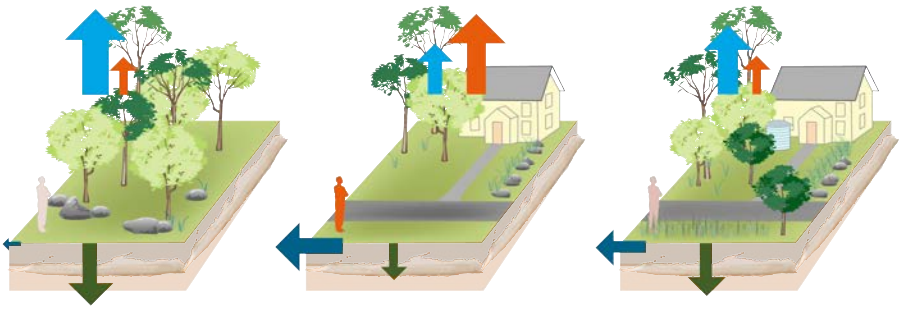
Stormwater harvesting provides an additional and abundant source of water that can be used to retain water in the landscape, to irrigate urban areas to sustain vegetation and improve urban microclimates, and to provide multiple benefits including the ecosystem services mentioned above. Overall stormwater harvesting and associated green infrastructure create more liveable, healthy and resilient urban environments.

The hydrologic cycle – the movement of water between the atmosphere, the terrestrial biosphere and running water environments – provides a natural framework for understanding the effects of urbanisation and the potential for stormwater harvesting to modulate against those effects (Figure 12).

Many impacts of urbanisation on ecosystems relate to changes in the ways in which rainfall is intercepted and cycles back into the atmosphere or moves into surface water or groundwater systems. Urbanisation removes vegetation and introduces impervious surfaces, reducing the amount of water that is infiltrated to maintain soil moisture and evapotranspired back into the atmosphere. Evapotranspiration is an important mechanism through which radiant energy is dissipated and the reduction in this function associated with urbanisation contributes to making cities hotter. Urbanisation also reduces the amount of water available to recharge groundwater aquifers or be conveyed slowly via sub-surface pathways back into streams.

Sealed surfaces and conventional storm drainage systems direct water quickly into stream channels, rather than more slowly via groundwater and percolation through vegetation. This results in a significant alteration to the supporting hydrology of the natural waterways and its ecosystem, often expressed in higher flow rates and rapidly changing flow conditions. These modified flow regimes contribute to degraded water quality, altered channel form, ultimately resulting in reduced biodiversity and delivery of ecosystem services by receiving waters.

*Changes in the movement of water through the landscape and into the atmosphere underlie many of the impacts of urbanisation, and can be restored through stormwater harvesting to support ecosystem services.*



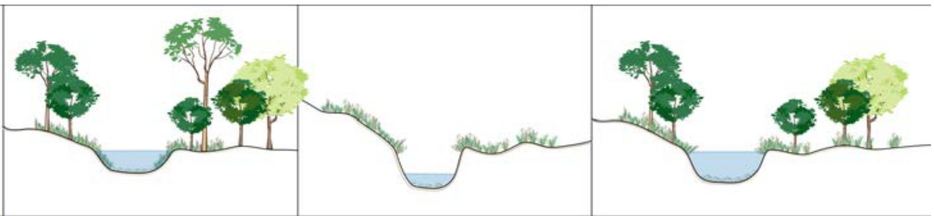

| | Natural | Urbanised | Harvesting & WSUD |
|---|---|---|---|
| **Stream channel form and biodiversity** |  | | |
| **Groundwater recharge** | High | Low | Moderate |
| **Evapotranspiration** | High | Low | Moderate |
| **Atmospheric heating and heat storage in buildings** | Natural | Hotter | Closer to natural |
| **Human thermal comfort** | Neutral | Hot | Slightly warm |
| **Surface runoff** | Low and infrequent | High and frequent | Infrequent and moderate |
| **Stream hydrology** | Natural | 'Peaky' | Moderated (both high flows and low flows) |
| **Riparian vegetation** | Intact | Degraded | Restored |
| **Channel form** | Natural | Severely degraded | Potential for recovery |

**Figure 12.** A synthesis of our understandings of urban impacts on the landscape, atmosphere and hydrology and the benefits of stormwater harvesting and WSUD.

## Building on Previous Knowledge

A review of relevant studies undertaken previously and the results of research undertaken by the CRC for Water Sensitive Cities have led to the conclusions that are presented below.

There is now substantial research from around the world to show that as soon as urban streams receive stormwater runoff from impervious areas making up more than a few percent of the catchment, the stream ecosystem will be significantly degraded (Walsh *et al.* 2012, King *et al.* 2010, Vietz *et al.*, in-review (a)). There is also a growing body of literature demonstrating that increasing channel complexity and riparian vegetation cover has little or no effect on in-stream ecological structure and function if catchment-scale stressors remain limiting (Bernhardt and Palmer, 2011; Sudduth et al 2011; Violin et al 2011; Webb et al, in review). In undeveloped catchments and those with very low levels of stormwater input, the highest priority is thus to use planning controls to deliver the flow regime and water quality necessary to prevent the impacts of urbanisation.

Stormwater harvesting combined with filtration, infiltration and irrigation can reduce runoff volumes for the vast majority of storm events to close to pre-development levels whilst also helping to restore baseflows, return natural soil moisture levels to urban landscapes and maintain water quality. Capturing and storing rainwater and /or stormwater for subsequent passive irrigation reduces runoff volumes and increases the amount of time that it takes for water to reach stream channels, thereby reducing the peakiness of flows. Directing rainwater and / or stormwater into rain-gardens for passive irrigation can also support this outcome. In addition, stormwater treatment and harvesting systems can reduce stormwater pollutant loads and concentrations to levels appropriate for the protection of local receiving waters and downstream estuaries and bays.

Infiltration systems located throughout the catchment, including in the riparian zone, can help to restore ecosystem functions and can contribute to stream health and public amenity. A healthy riparian zone can also help maintain floodplain engagement, reduce channel incision and maintain geomorphic stability. Stormwater quality management measures such as roof gardens, bio-retention systems, constructed wetlands and ponds can provide stormwater detention (to varying degrees) and can therefore reduce drainage infrastructure requirements.

Climate change – in particular trends in climate extremes, accelerating urbanisation, the process of urban consolidation, and an ageing urban population all contribute to this vulnerability, particularly in relation to heat (Tapper, 2012)[46]. Restoring the natural urban water balance through passive irrigation or stormwater harvesting facilitates higher rates of evapotranspiration and natural cooling of the urban landscape that can often be a primary mechanism for minimising the exposure of urban residents to extreme heat and uncomfortable climates.

Work on heat and population morbidity/mortality (see for example Loughnan *et al.*, 2010a[47]; 2010b[48]), has shown that the health outcome is very sensitive to threshold temperatures, meaning that small reductions in temperature (even of 1-2 °C) can produce significant and positive health outcomes. Human thermal stress can be reduced by minimising exposure (urban planning, building design, green infrastructure) and targeting areas of vulnerability (schools, aged care centres, low socioeconomic areas).

Green infrastructure supported by stormwater can provide microclimate benefits by reducing excess urban heating (through shading, and cooling by evapotranspiration). Green infrastructure must be fit-for-place, meaning that local constraints and opportunities will inform appropriate solutions.

Urban heat mitigating design responses should place particular emphasis on the strategic implementation of WSUD technologies that includes sufficient irrigation, prioritisation in dense urban areas, distributed in space, integrated with the built environment and designed to maximise human thermal comfort benefits (i.e. cooling and shade).

Stormwater harvesting ultimately provides an additional and abundant source of water to support the greening of cities (Walsh *et al.*, 2012[49]). Green infrastructure provides benefits in creating more liveable and resilient urban environments. Water sensitive planning and design of urban stormwater systems can facilitate the creation of attractive public spaces that promote social engagement and cultural expression involving the water environment.

Distributed stormwater systems are most effective in protecting urban ecosystems because they help to retain pollutants within the catchment, restore base flows and provides cooling benefits, thereby achieving multiple objectives. Connecting distributed green spaces with green (vegetated) and blue (waterway) corridors also provides opportunities for the safe attenuation of flood waters through urban environments.

A suite of water sensitive urban design tools, including stormwater harvesting, allow us to reduce the impacts of urbanisation and these are discussed in more detail below.

[46] Tapper, N., (2012). Adapting Urban Environments to Climate Change: A Case Study of Melbourne, Australia. Chapter 11 in M. Robertson (ed.) *Schooling for Sustainable Development: A Focus on Australia, New Zealand and the Oceanic Region*, Schooling for sustainable Development 3, DOI 10.1007/978-94-007-2882-0_11, Springer Science+Business Media Dordrecht 2012

[47] Loughnan, M., Nicholls, N. and Tapper, N. (2010). "Mortality-temperature thresholds for ten major population centres in rural Victoria, Australia." *Journal of Health and Place,* 16, 6, 1287-1290.

[48] Loughnan, M., Nicholls, N. and Tapper, N. (2010). The effects of summer temperature, age and socioeconomic circumstance on acute myocardial infarction admissions in Melbourne, Australia. *International Journal of Health Geographics*, 9, 41. doi:10.1186/1476-072X-9-41.

[49] Walsh, C. J., Fletcher, T. D., and Burns, M. J. (2012). Urban stormwater runoff: a new class of environmental flow problem. *PLoS ONE*, **7**(**9**) e45814. doi:10.1371/journal.pone.0045814

## The Relative Importance of Stressors to Urban Aquatic Ecosystems

Hydrology is a primary driver of the geomorphology and water quality of waterways, and consequently their ecological condition (**Figure 13**). Streams with even a small amount of conventionally drained urbanised catchment are invariably physically and ecologically degraded, with lost biodiversity and ecological function, such as nutrient retention. Management activities aimed at addressing these symptoms in the channel, such as through restoring channel complexity, natural erosion rates or riparian vegetation condition, are likely to be overwhelmed by urban-stormwater-induced flow and water quality stressors unless catchment interventions address the flow regime *and* water quality. Addressing the causes of urban stream degradation has been shown to be more likely to achieve goals for geomorphic and ecological condition. In catchments with low levels of urbanisation, investment in stormwater harvesting and retention – sufficient to replicate important elements of the natural flow regime – should be a precursor to major expenditure on direct channel and riparian zone interventions (Burns *et al.*, 2012[50]). Doing so will enable subsequent local-scale works to be more successful.

In catchments with higher levels of urbanisation, dealing with catchment-scale stressors will require longer timeframes, and in-stream and riparian interventions in the meantime may be required for a variety of reasons. These should be accompanied by longer-term catchment efforts, including point source controls, aimed at reducing flow and water quality disturbance, so that the local-scale actions are not undermined by further damage.

Where possible, planning controls should be put in place to allow these longer-term catchment scale objectives to be achieved. In all cases this systemic management approach requires improved integration of stormwater and waterway management strategies.

*Hydrology is a primary driver of the geomorphology and water quality of waterways, and consequently their ecological condition.*

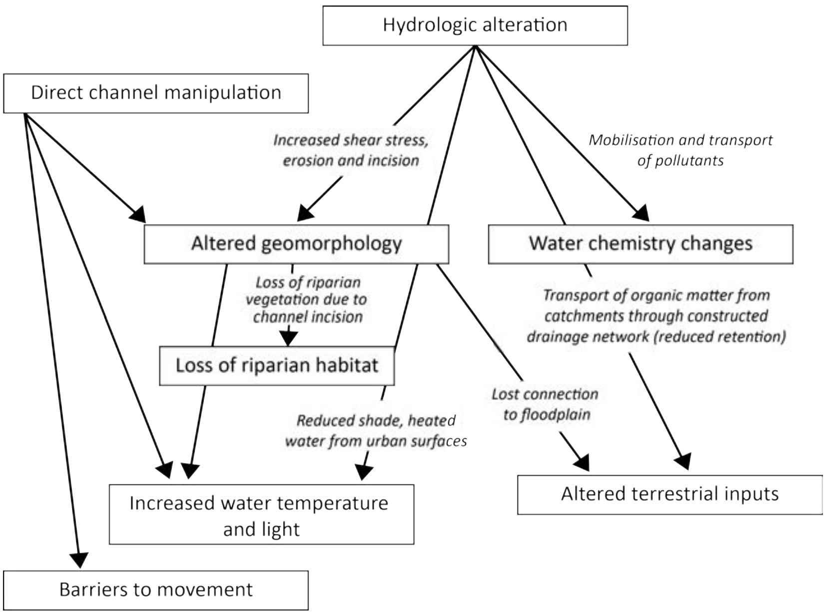



**Figure 13.** Key mechanisms driving degradation of receiving waters, showing the role of hydrology as a 'master variable' (Fletcher *et al.* 2012)[51].

[50] Burns M.J., Fletcher T.D., Walsh C.J., Ladson A.R. and Hatt B.E., (2012) Hydrologic shortcomings of conventional urban stormwater management and opportunities for reform. *Landscape and Urban Planning* **105,** 230–240

[51] Fletcher, T. D., Andrieu, H., and Hamel, P. (2012). Understanding, management and modelling of urban hydrology and its consequences for receiving waters; a state of the art. *Advances in Water Resources*.

## Using Distributed Stormwater Management to Deliver Suitable Flow Regimes and Water Quality

Stormwater is a 'new' class of environmental flow problem requiring that the excess runoff volume be reduced (Walsh *et al.* 2012[49]) so that the pre-development volume, rate and timing of flows to receiving waters are returned. At the same time, water quality suitable for the receiving waters must be maintained.

At the site scale, stormwater management objectives for stream protection have been developed based on four indicators (Walsh *et al.* 2010[52], Walsh *et al.* 2012[49]):

- *Overflow-frequency*: systems should be designed to overflow as infrequently as possibly, ideally only as frequently as storm events that are large enough to initiate widespread overland flow on hill slopes of similar undeveloped catchments;
- *Filtered-flow regime*: filtration systems should supply water to streams at no greater rate than the baseflow rates in similar undeveloped catchments (scaled to the area of the impervious surfaces being treated by the measure), and in a similar pattern over time;
- *Filtered-flow quality*: filtration systems should supply water to streams with contaminant concentrations suitable for a healthy stream ecosystem; and
- *Total volume reduction*: the above three objectives will only be achievable if total volume delivered to the stream is reduced by a large proportion through harvesting.

At the catchment or stream scale, hydrologic targets should be based on ecologically important components of the flow regime or flow-duration curves as outlined in **Table 5**.

Meeting target flow regimes and water quality is difficult if the excess volume of runoff resulting from urban development is not dealt with. Using the work of Zhang *et al.* (2001)[53], Walsh *et al.* (2012)[49] propose a target range for the amount of runoff that should be retained (through harvesting) and that which should be discharged to the stream, after being treated to a suitable water quality (**Figure 14**).

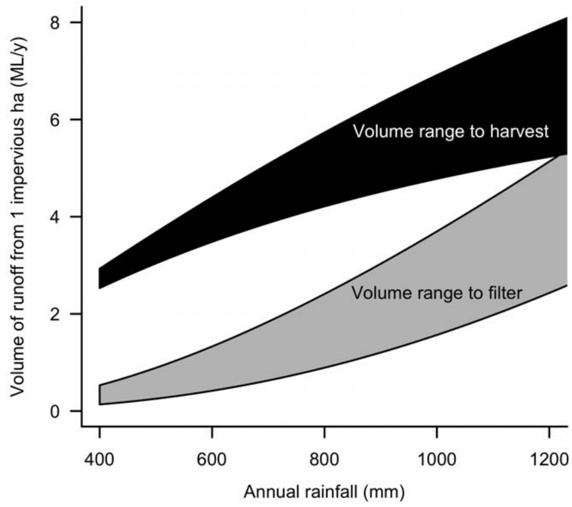



**Figure 14.** Target partition of stormwater runoff to be retained (through harvesting) and discharged to the stream (after appropriate treatment). The targets are based on the difference in runoff coefficient between a natural catchment (range shown in grey, derived from the work of Zhang *et al.* (2001)[53]) and an impervious catchment (range shown in black). The volume to be filtered can be infiltrated (and thus conveyed through groundwater) or treated through appropriate stormwater treatment systems (e.g. raingardens) and conveyed at a suitable flow rate consistent with catchment baseflow rates.

[52] Walsh, C.J., Fletcher, T.D., Hatt, B.E. and Burns, M. (2010). New generaton stormwater management objectves for stream protecton: stormwater as an environmental fow problem. In: *Stormwater Industry Association, Australian National Conference*. Stormwater Industry Association, Sydney, NSW, Australia.

[53] Zhang, L., Dawes, W. R., and Walker, G. R. (2001). Response of mean annual evapotranspiration to vegetation changes at catchment scale. *Water Resources Research*, **37**(3), 701–708.

*Stormwater is a 'new' class of environmental flow problem requiring that the excess runoff volume be reduced so that the pre-development volume, rate and timing of flows to receiving waters are returned.*

**Table 5.** Example of indicators applicable at the stream scale worthy of further investigation and testing. Indicators are listed from most significant to least (Sources: Burns unpublished; Hamel *et al.*, 2012[56]).

| Indicator | Reference | Description | Hydrologic Impacts Characterised |
|---|---|---|---|
| Flow pulse frequency | (Clausen & Biggs, 1997[54]) | The number of high flow pulses during a water year. A high flow is defined as a flow that is three times that of the median daily flow (flow exceeded 50% of the time) across multiple water years. | The frequency and magnitude of high flow events. To a lesser degree, the magnitude of more regular flows (since the indicator is conditioned on the median). |
| Time exceeding mean flow | (Konrad, 2000[55]) | The fraction of time during a water year that the daily average flow rate is greater than the annual mean flow rate of that year. | The magnitude of summer and winter baseflows. Also, the rate of streamflow change (rising and falling limb of the hydrograph). |
| Flow duration curves | (Clausen & Biggs, 1997[54], Hamel *et al*., 2012[56]) | Plot of flow rate against the proportion of time exceeded. | Provides an integrative measure of the flow regime and can give a more complete understanding of the impacts of a particular stormwater management scenario |
| Baseflow Index 1 | (Olden & Poff, 2003[57]) | The 7 day minimum flow during a water year, divided by the annual mean daily flow averaged across all available water years. | The magnitude of particularly summer baseflow. Also, the occurrence of any cease-to-flow periods. |

[54] Clausen B., and Biggs B.J.F. (1997). Relationships between benthic biota and hydrological indices in New Zealand streams. *Freshwater Biology*, **38**(2): 327-342.

[55] Konrad C.P. (2000) The frequency and extent of hydrologic disturbances in streams in the Puget Lowland, Washington. University of Washington.

[56] Hamel P., Fletcher T.D. and Daly E. (2012). Baseflow restoration in peri-urban catchments: what is known and what is needed? Journal of Hydrology (in review).

[57] Olden J.D. and Poff N.L. (2003). Redundancy and the choice of hydrologic indices for characterizing streamflow regimes. *River Research and Applications*, **19**(2): 101-121.

## Integration of Stormwater Harvesting with Stormwater Treatment and Retention

An integrated strategy of stormwater harvesting and other stormwater treatment and retention strategies such as infiltration or biofiltration (designed to release flow at rates compatible with the pre-development baseflow rate) can be effective in restoring pre-development hydrology and water quality. Carefully designed, such strategies can return most parts of the flow regime towards its natural levels (**Figure 15**). Burns *et al*. (2012)[50] showed that such a strategy applied to a given site (e.g. allotment, streetscape or precinct) can be effective in restoring dry weather flows, and reducing the frequency and magnitude of high flows following rain.

The integration of stormwater harvesting with other techniques is essential for two reasons:

- the water which is not harvested must be treated so that it is of a suitable quality to support healthy receiving waters.
- infiltration or equivalent are required to provide filtered flows of appropriate quality, timing and magnitude to protect receiving waters

Harvesting alone will almost always be inadequate to retain the excess runoff volumes from typical urban developments. The greater than natural frequency and magnitude of stormflows will lead to accelerated erosion and degradation.

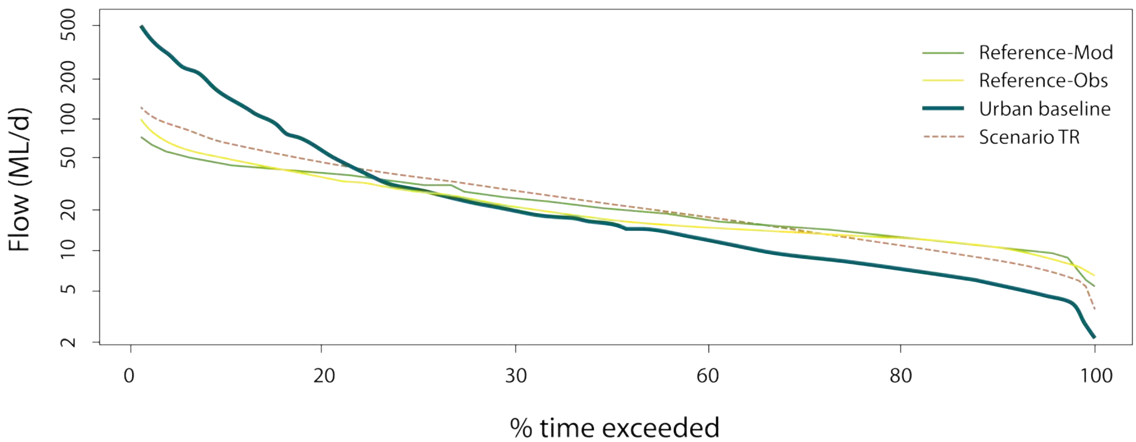



**Figure 15.** Influence of a combination of stormwater harvesting, infiltration and filtration systems on stream flow regimes. In this case, the reference flow duration curve (FDC) (observed data shown in yellow, modelled data shown in green) is substantially altered by the urbanisation of the catchment (urban baseline). A combination of stormwater harvesting and the use of raingardens (Scenario TR) produces a flow regime which is similar to the natural state, although a slight loss of baseflows is still evident. Figure taken from a modelling study by Hamel & Fletcher (2013)[58].

*Changes in the movement of water through the landscape and into the atmosphere underlie many of the impacts of urbanisation, and can be restored through stormwater harvesting to support ecosystem services.*

[58] Hamel, P and Fletcher, TD. (2013). The impact of stormwater source-control strategies on the (low) flow regime of urban catchments. *NOVATECH Conference Proceedings*, June 23-27, 2013, Lyon, France.

## Baseflow Restoration

Conveying impervious runoff through piped drainage systems directly to receiving waters reduces baseflows, as water is prevented from infiltrating to soils and is delivered to streams only during rainfall. Anthropogenic inputs into drainage systems such as ingress from leaking potable water or sewage infrastructure can, in some places, act to counter this effect.

In cities such as Perth, where discharge of urban runoff into groundwater is common because of highly permeable soils, increased baseflows are observed, pointing to the importance of stormwater harvesting in concert with infiltration systems to achieve appropriate volumes and patterns of filtered flows. In other cities where infiltration of stormwater is actively encouraged, the progressive rise in the local groundwater table has been observed. This can by attributed to the loss of evapotranspiration due to urbanisation. It is therefore important to understand the local context in setting hydrological objectives.

Where baseflows have been lost, infiltration and over-irrigation can be used. Passive irrigation in particular can be effective because it can be distributed over a wide area at low cost, increasing both evapotranspiration and infiltration. Combined with cost-effective, simple raingarden (vegetated) infiltration systems, such a distributed approach will maximise benefits to restoring catchment-scale hydrology and mitigating the urban heat island effect, by distributing moisture throughout urban soils. However, significant uncertainty remains regarding the scaling-up of local-scale infiltration to catchment-scale flow regimes (Hamel *et al*., 2012[56]).

## The Role of Riparian Zones

The relative influence of the riparian zone on stream ecological condition depends on the hydrologic impacts of urban stormwater runoff. Once stormwater is appropriately managed, riparian vegetation, along with channel form, become very important drivers of ecological condition. The ability of the riparian zone to mitigate stormwater impacts is lost if stormwater pipes pass through the riparian zone and discharge directly to the receiving water.

In combination with stormwater harvesting and retention in the catchment, riparian ‘sponges’ might be constructed to retain and filter stormwater within riparian zones, restoring both baseflows and denitrification in riparian soils (Klocker *et al*., 2009[59]). The riparian zone also provides space to ‘park’ floodwaters along the system, reducing the energy expended within the channel (Vietz *et al.*, 2012[60]). Not only does this reduce disturbance in the channel but provides opportunities to reduce the size of flood peaks in the lower reaches, where flood risks are generally greatest. Opportunities for floodplain engagement are best achieved in the upper and middle reaches where space is typically less constrained. Greenfield developments on small upland channels that incorporate floodplain engagement, rather than flow evacuation, will provide the greatest benefits to the entire river system.

Riparian zones also allow streams adjustment space. The ability of streams to adjust their planform through widening or channel migration reduces the instability inherent as streams adjust to the hydrologic stress imposed by urbanisation. The amount of riparian space required depends on the extent of stabilisation works (**Table 6**).

*Greenfield developments on small upland channels that incorporate floodplain engagement, rather than flow evacuation, will provide the greatest benefits to the entire river system.*

[59] Klocker C.A., Kaushal S.S., Groffman P.M., Mayer P.M. and Morgan R.P. (2009). Nitrogen uptake and denitrification in restored and unrestored urban streams in urban Maryland, USA. *Aquatic Sciences*, **71**: 411-424.

[60] Vietz, G., Stewardson, M., Walsh, C., and T. Fletcher, 2012. Another reason urban streams are stuffed: Geomorphic history, challenges and opportunities. *Proceedings of the 6th Australian Stream Management Conference*, Canberra, Australia, 6 to 8th February 2012.

## Managing the Physical Form of Channels

Increases in stream width and depth as a consequence of urbanisation are likely to be of less concern to stream ecology than reductions in channel complexity. Undercut banks, bars and benches are ubiquitous in healthy alluvial streams and contribute to channel complexity and consequently hydraulic diversity. Once harvesting and stormwater retention have been applied to limit hydrologic disturbance, restoration of such features is more feasible, even if the channel has been widened and incised as a result of past urban stormwater impacts.

Sediment delivery to streams, particularly coarse-grained sediments such as cobbles, gravels and sand, have been shown to 'buffer' the impact of excess stormwater runoff on the physical condition of streams (Vietz *et al.*, in-review[61]). For the same level of urbanisation, streams with bank or hillslope sediment sources are characterised by greater diversity e.g. bars, lower erosion rates, and greater bedload sediment depths. Once flow regimes are restored, sediment supply may become a limiting factor in the recovery of streams without bank or hillslope sediment sources. Headwater sources of sediment should be protected where possible given their role in the supply of coarse-grained sediment, and the difficulty in reintroducing coarse-grained sediment to streams.

The management of urban stream channels over the last two decades has seen a considerable shift in approaches from traditional 'symptomatic' approaches focused on hydraulic efficiency and channel control to those focused on working with geomorphic processes (**Table 6**). This shift is heading toward an approach we refer to as Natural Channel Mimicry (NCM) where stream management considers channel complexity, dynamism and floodplain interaction (Vietz *et al.*, in-prep.)[62]. This trend, however, is highly constrained by our ability to address the catchment-scale causes of stream degradation, namely stormwater runoff. In many cases more traditional approaches to urban stream management may be necessary until catchment-wide causes of degradation can be addressed.

**Table 6.** Urban stream management approaches and the trend toward increasing consideration of channel morphology (Vietz *et al.*, in-prep.)[62].

| | Increasing geomorphic and ecological consideration → | | | |
|---|---|---|---|---|
| | Traditional River Engineering (TRE) | Geomorphologically Referenced River Engineering (GRRE) | Natural Channel Design (NCD) and Deterministic Approaches | Natural Channel Mimicry (NCM) |
| Channel Complexity | **Low**<br>hard engineering to reduce roughness and increase stability | **Medium**<br>constructed features designed to resemble 'natural' stream with some 'hard' features designed for low resistance | **Medium**<br>some variable cross sectional features with a reliance on rock stabilisation | **High**<br>stream driven geomorphic features such as benches, bars and variable sediment sizes which increase flow resistance |
| Allowable Dynamism | None | **Low**<br>no stream adjustments, no mobile substrates, no erosion accepted | **Medium**<br>limited stream adjustment, limited mobile substrate sediments, erosion commonly addressed | **Medium to High**<br>stream adjusts dynamically within confined corridor, mobile substrates, acceptable rates of erosion |
| Riparian Space Required | Very low | **Low**<br>no lateral flow engagement or adjustment | **Medium**<br>minimal lateral flow engagement and minor channel adjustment | **Medium to High**<br>engagement with actual or 'internal' floodplain to alleviate channel energy, provide adjustment corridor |

[61] Vietz, G.J., Sammonds, M., Walsh, C.J., Fletcher, T.L., Rutherfurd, I.D., Stewardson, M.J. (in-review). Ecologically relevant geomorphic attributes of streams are severely impaired by even low levels of watershed effective imperviousness. Geomorphology.

[62] Vietz, G.J., Fletcher, T.F., Rutherfurd, I.D., Walsh, C.J. (in-prep.). Can urban stream channel restoration keep evolving? Watershed-scale impediments and opportunities toward a geomorphically-considerate approach. Landscape and Urban Planning.

## Dealing with Highly Degraded Urban Streams: Do What When?

In catchments that are already degraded, but with relatively small areas of connected impervious area (i.e. either small catchments, or larger catchments with little urbanization), the *cities as water supply catchments*' concept offers a framework to reduce stormwater inputs (in combination with other stormwater retention and treatment systems), while enhancing human amenity and water supply in the catchment. In these catchments restoration of key ecological values, functions and services is feasible within a relatively short timeframe (i.e. < 10 years).

In catchments with larger areas of connected impervious area, mitigating the impacts to the stream hydrology, water quality and geomorphology from stormwater will require longer term investment, involving:

- Planning controls to ensure that new development, in conjunction with renewal of building stock and infrastructure, meets flow and water quality targets such as those outlined in this report.
- Long-term investment in strategic and opportunistic retrofit with stormwater harvesting, retention, infiltration and treatment systems, particularly where infrastructure renewals are taking place.
- Synergistically building on opportunities such as increasing water demands from alternative sources and desires for flood attenuation.

I

Where possible, objectives to restore stream ecological values and functions through catchment-wide stormwater retention and harvesting should be pursued, recognising that these will be long-term. There is also the need to consider how to maximise the value to the community from streams and their riparian zones in the intervening period (which may be decades) before catchment-wide stormwater impacts can be mitigated sufficiently to see an ecological response to any instream works to improve habitat and channel diversity. In this situation, an approach that focuses on increasing amenity as well as restoring values in the riparian corridor (such as returning a diversity of plants and the provision of habitat for riparian fauna) is required.

Not surprisingly, many community desires for the physical form and 'natural' character of streams, focused on amenity and interactions with nature, align with goals for geomorphologic and ecological functioning of streams (House and Sangster 1991)[63]. The CRC for Water Sensitive Cities project *Urban Waterway Remediation in Developed Catchments (Project B2.3)* will examine approaches to optimise the ecosystem services and public amenity of highly urbanised streams while enhancing or maintain existing waterway functions (e.g. flood protection, open space, etc.). Remediation of some highly urbanised waterways may focus on a desired condition or set of ecosystem services rather a pre-development template. However, strategies to enhance the biodiversity and amenity of highly urbanised waterways should be considered carefully to ensure that they do not limit future options to pursue ecological improvements once catchment-scale impacts have been mitigated.

[63] House and Sangster, 1991. Public perception of river-corridor management. *Water and Environment Journal*, **5**(3), 312-316.

## Urban Heat, Heat Reduction and Public Health

### Impacts of Urban Climate and Microclimate on Human Thermal Comfort and Health

A recently completed study in partnership with the National Climate Change Adaptation Research Facility (NCCARF) has identified threshold temperatures above which mortality and morbidity increases in all Australian capital cities (**Table 7**). Primarily the project developed a mapping tool to identify areas of high vulnerability during extreme heat events and predicted changes in the number of days exceeding threshold temperatures into the future for two time periods (2020-2040 and 2060-2080). As an example of the information on spatial vulnerability of capital city populations available in the report, **Figure 16** presents a comparison of heat vulnerability and emergency department presentations by postcode for Sydney. A clear association between extreme heat vulnerability and hospital emergency department presentations is evident. Urban warmth features strongly across all Australian cities, often associated with higher densities of vulnerable groups such as the elderly, the poor, or culturally and linguistically diverse communities. Of considerable concern (but not shown here) is that this study shows heat extremes and the number of days exceeding the critical heat-health thresholds are projected to increase in all Australian capital cities in the coming decades. Highlighting the areas most affected by extreme heat allows a targeted response and a focus for urban planning and policy.

*blueprint2013* readers may wish to access the report by Loughnan *et al.* (2013)[64] and the website mappingvulnerabilityindex.com that contains interactive heat vulnerability maps for information specific to their own city.

*Heat extremes and the number of days exceeding critical heat-health thresholds are projected to increase in all Australian capital cities in the coming decades.*

**Table 7.** Threshold temperature (maximum, minimum, mean and apparent temperature) derived from analyses of daily all cause mortality, daily emergency hospital admissions, daily ambulance callouts or emergency department presentations in Australian capital cities. Table shows number of days exceeding the temperature threshold over the record period. (Loughnan *et al.*, 2013)[64]

| City | Number of days of data | Tmax | % increase in median | Tmin | % increase in median | meanT | % increase in median | AT | % increase in median |
|---|---|---|---|---|---|---|---|---|---|
| **Brisbane** | | | | | | | | | |
| Morbidity | 2956 | 36 (55) | 2.5-12% | 26 (7) | 2.5% | 34 (2) | 9% | 40(25) | 4-11% |
| Mortality | 4007 | *36(58)* | *12%* | 25(11) | 5% | 31(6) | 15% | 40(9) | 8% |
| **Canberra** | | | | | | | | | |
| Morbidity | 2320 | 37 (33) | 5-10% | 20 (30) | 5% | 28 (28) | 5-8% | 38(11) | 8-10% |
| Mortality | 4007 | 33(179) | 5% | 20(43) | 2% | 28(16) | 2% | 41(4) | 5% |
| **Darwin** | | | | | | | | | |
| Morbidity | 1826 | 36 (4) | 5% | 28 (17) | 5% | 31 (19) | 7% | 35(5) | *5%* |
| Mortality | 4007 | 37(11) | 5% | 29(19) | 8% | 31(94) | 3% | 47(5) | *10-20%* |
| **Hobart** | | | | | | | | | |
| Morbidity | 2953 | NA | | 18 (28) | 5-20% | 27 (3) | 5% | 36(5) | *4-10%* |
| Mortality | 4007 | 35(13) | 11% | 20(5) | 2% | 28(5) | 6% | 37(6) | *5-20%* |
| **Melbourne** | | | | | | | | | |
| Morbidity | 3287 | 44 (5) | 3% | 26 (6) | 3% | 34 (6) | 3% | 42(10) | 2-3% |
| Mortality | 4007 | 39(23) | 2-65% | 26(9) | 5% | 28(112) | 3-13% | 36(68) | 4% |
| **Perth** | | | | | | | | | |
| Morbidity | 2007 | 43 (3) | 14% | 26 (4) | 4% | NA | | 43(8) | 2-5% |
| Mortality | 4007 | 44(3) | 30% | NA | | 32(20) | 3-10% | 45(3) | 10% |
| **Adelaide** | | | | | | | | | |
| Morbidity | 3045 | NA | | 31(4) | 5% | 39(1) | 24% | NA | |
| Mortality | 4007 | 42(21) | 2-8% | NA | | 34(2) | 8% | 43(16) | *2-10%* |
| **Sydney** | | | | | | | | | |
| Morbidity | 4162 | 41(3) | 5-38% | 25(5) | 4% | 31(5) | 2% | 41(3) | 5% |
| Mortality | 4007 | 38(3) | 2-18% | 25(3) | 5% | 30(12) | 5% | 37(27) | 2-24% |

[64] Loughnan, M., Tapper, N., Phan, T., Lynch, K. and McInnes, J. (2013). *A spatial vulnerability analysis of urban populations during extreme heat events in Australian capital cities*, National Climate Change Adaptation Research Facility, Gold Coast pp.128. ISBN:978-1-921609-73-2. nccarf.edu.au/publications/spatial-vulnerability-urban-extreme-heat-events

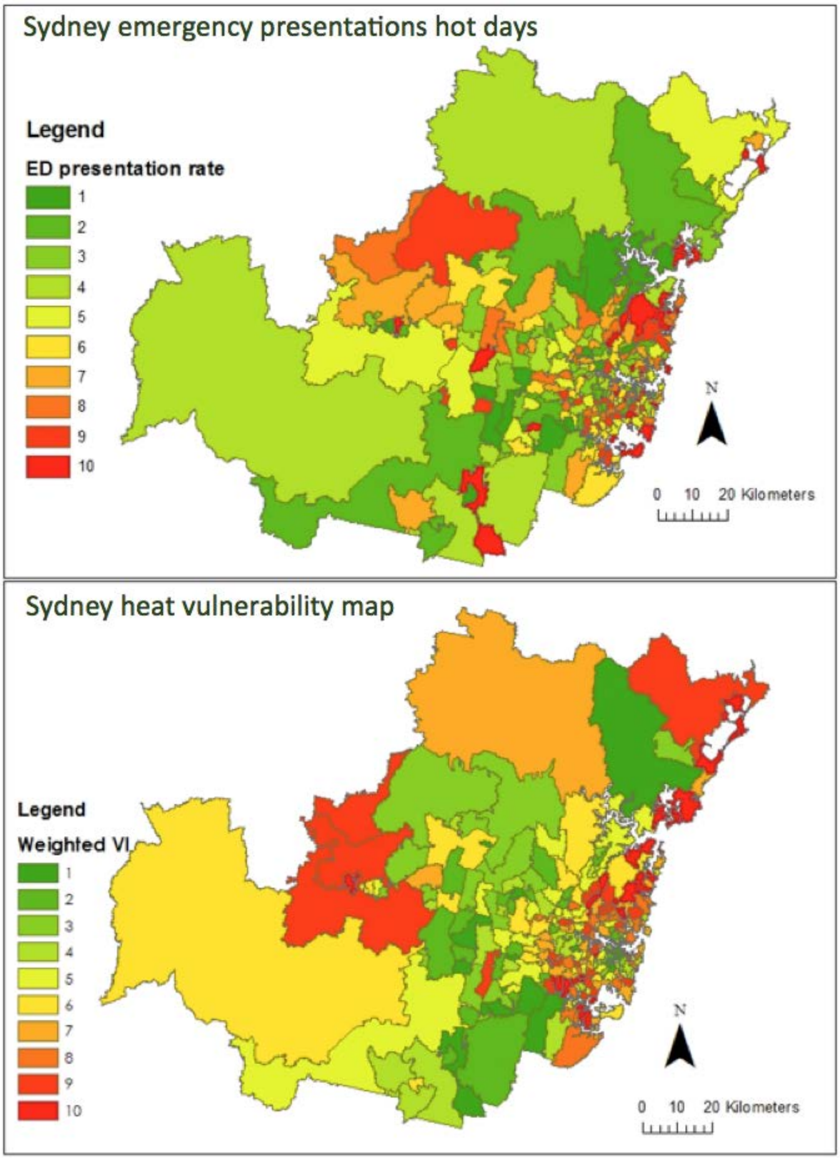



**Figure 16.** Spatial patterns of emergency department presentations on hot days (upper map) and heat vulnerability (lower map) for Sydney. See Loughnan *et al.* (2013)[64] for a detailed explanation of these data and for results for other Australian capital cities.

A significant element of urban liveability is thermally comfortable temperatures. Human Thermal Comfort (HTC) refers to 'that condition of mind which expresses satisfaction with the thermal environment'. Perceptions of HTC are affected by air temperature, radiant temperature, relative humidity, air velocity, activity and clothing. There is no global or absolute number that reflects HTC. This is not surprising since humans occupy every climate zone, therefore thermal comfort will be region specific.

Adaptive models have been developed to assess outdoor HTC and suggest that humans are more tolerant of temperature change than early laboratory studies indicated, and respond using physiological thermoregulation (unconscious response), behavioural adaptations (clothing, activity, location) and technological adaptations (windows, doors, blinds, fans, air-conditioning, and characteristics of a building such as materials, orientation, moveable shading, vegetation/green spaces) to maintain comfortable temperatures.

A key finding of our ongoing work[65] on identifying thermally comfortable temperatures ranges for Australian Cities is that the provision of shade and good ventilation is paramount in protecting humans from heat stress. HTC models indicated that persons in exposed environments in typical Australian summer conditions, whether resting or physically active, experience some level of heat stress. This can occur at lower ambient temperatures than may intuitively be expected.

Public education is an important factor in heat stress mitigation as is modifying urban environments, for example through use of climate sensitive and water sensitive urban design to reduce temperatures and minimise exposure. The reduction of mean radiant temperature (MRT) through provision of shade is particularly important, as shown in **Figure 17**.

Physiological Equivalent Temperature (PET) is a measure of the apparent rather than actual temperature for the human body. The provision of shade substantially reduces Physiological Equivalent Temperature by up to 20°C on occasion. This is enough to reduce extreme heat stress to moderate heat stress, or strong heat stress to comfortable. Clearly, intelligent use of building and tree shade in city environments can provide great benefits for Human Thermal Comfort.

*Perceptions of Human Thermal Comfort are affected by air temperature, radiant temperature, relative humidity, air velocity, activity and clothing.*

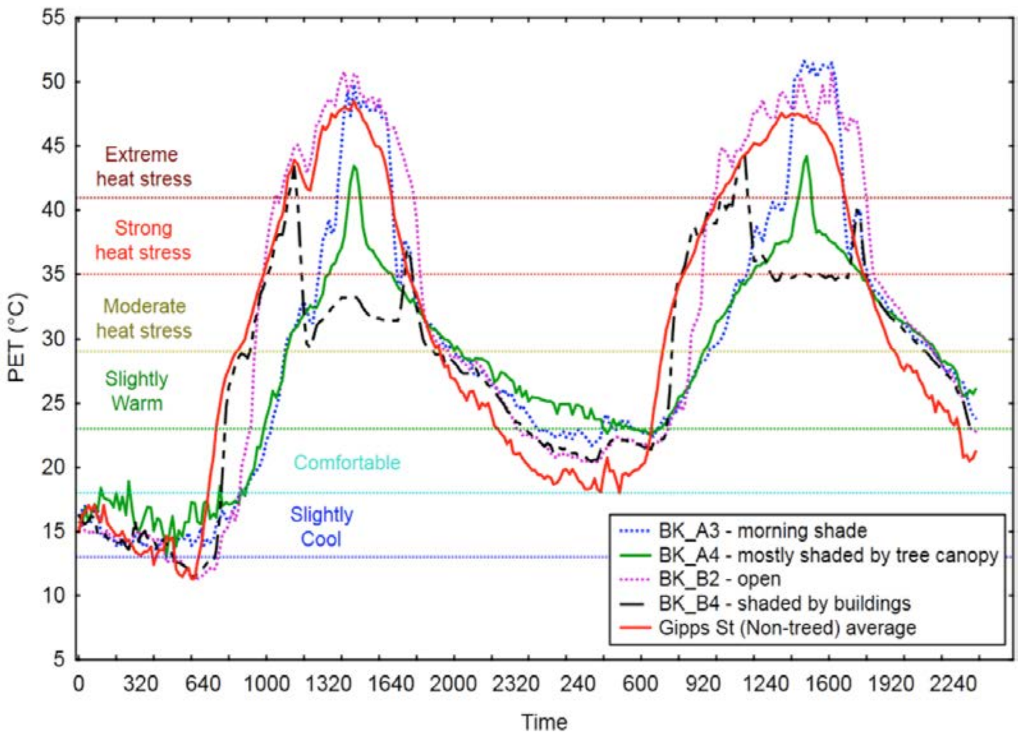



**Figure 17.** Influence of shade from trees and buildings on Physiological Equivalent Temperature (PET) in Bourke (BK) and Gipps Street, Melbourne, 24-25 February 2012. (Coutts *et al.*, 2013)[65]

[65] Coutts, A., Loughnan, M., Tapper, N., Beringer, J. Daly, E., White, E., Broadbent, A., Pettigrew, J., Harris, R., Gebert, L., Nice, K., Hamel, P, Fletcher, T and Kalla, M. (2013). Project B3.1: Green Cities and Microclimate Interim Report – Determining the micro-climatic influence of harvesting solutions and WSUD at the micro-scale, March, 2013.

### Understanding the Influence of Stormwater Harvesting and Green Infrastructure on Urban Climate

Research work continues at a range of scales, from micro-scale evaluation of individual WSUD processes and green infrastructure elements, to neighbourhood and city scale evaluation of the beneficial role of green infrastructure and irrigation in influencing surface and air temperature. Summaries of much of this work can be found in Coutts *et al.* (2013) but for *blueprint 2013* we concentrate on the neighbourhood and city scale advantages of green infrastructure and landscape irrigation, substantially based on remote sensing data captured at the suburb of Mawson Lakes in Adelaide in February 2011.

Mawson Lakes is a mixed urban neighbourhood that combines residential and commercial development of different styles and densities. It is characterised by a large system of wetlands and artificial lakes, as well as tracts of irrigated public open space. Recycled water is available to residents for irrigation. This high level of water available in the landscape is unique for Adelaide with surrounding neighbourhoods characterised by water-limited landscapes. Open water bodies and green and irrigated landscapes have the potential to locally cool the environment and to support oasis effects, where warm dry air is advected over moist surfaces, significantly enhancing evapotranspiration. This mechanism provides the potential for cooling adjacent urban landscapes.

We undertook an extensive microclimate study of Mawson Lakes In February 2011 that involved in-situ observations from 27 automatic weather stations (AWS) as well as remote sensing. Analyses of those data to understand the influence of land cover type on local temperature are nearing completion; some preliminary results are reported here with more details of the analyses provided in Coutts *et al.* (2013). **Figure 18** (a) shows land cover, vegetation cover, characteristic night land surface temperature (LST) and sky view factor (SVF) for Mawson Lakes. Statistical analysis was used to approximate the size of an idealised footprint for daytime and nocturnal cases (25 m radius circle). This footprint was used to characterise each of the static sites, and multiple regression analysis was conducted. During the day (**Figure 18** (b)), wind speed (−0.60 ◦C per 1 $ms^{-1}$), tree fraction (−0.38 ◦C per 0.25 tree fraction), SVF (−0.21 ◦C per 0.25 SVF), and water fraction (−0.35 ◦C per 0.25 water fraction) were associated with cooling; while pervious fraction (0.53 ◦C per 0.25 pervious surfaces), building fraction (0.45 ◦C per 0.25 building fraction), and concrete fraction (0.40 ◦C per 0.25 concrete fraction) have a heating effect. This illustrates the important role that ventilation, green infrastructure and water have in providing daytime cool refuges. Trees and water bodies (lakes and wetlands) have a significant cooling effect during the day. This cooling is apparent, independent of other influential factors, such as wind speed and SVF. At night (not shown), trees and water surfaces have no specific influence. As such, trees and water can provide daytime cooling, and do not cause any notable nocturnal heating effect.

*Trees and water bodies (lakes and wetlands) have a significant cooling effect during the day. This cooling is apparent, independent of other influential factors.*

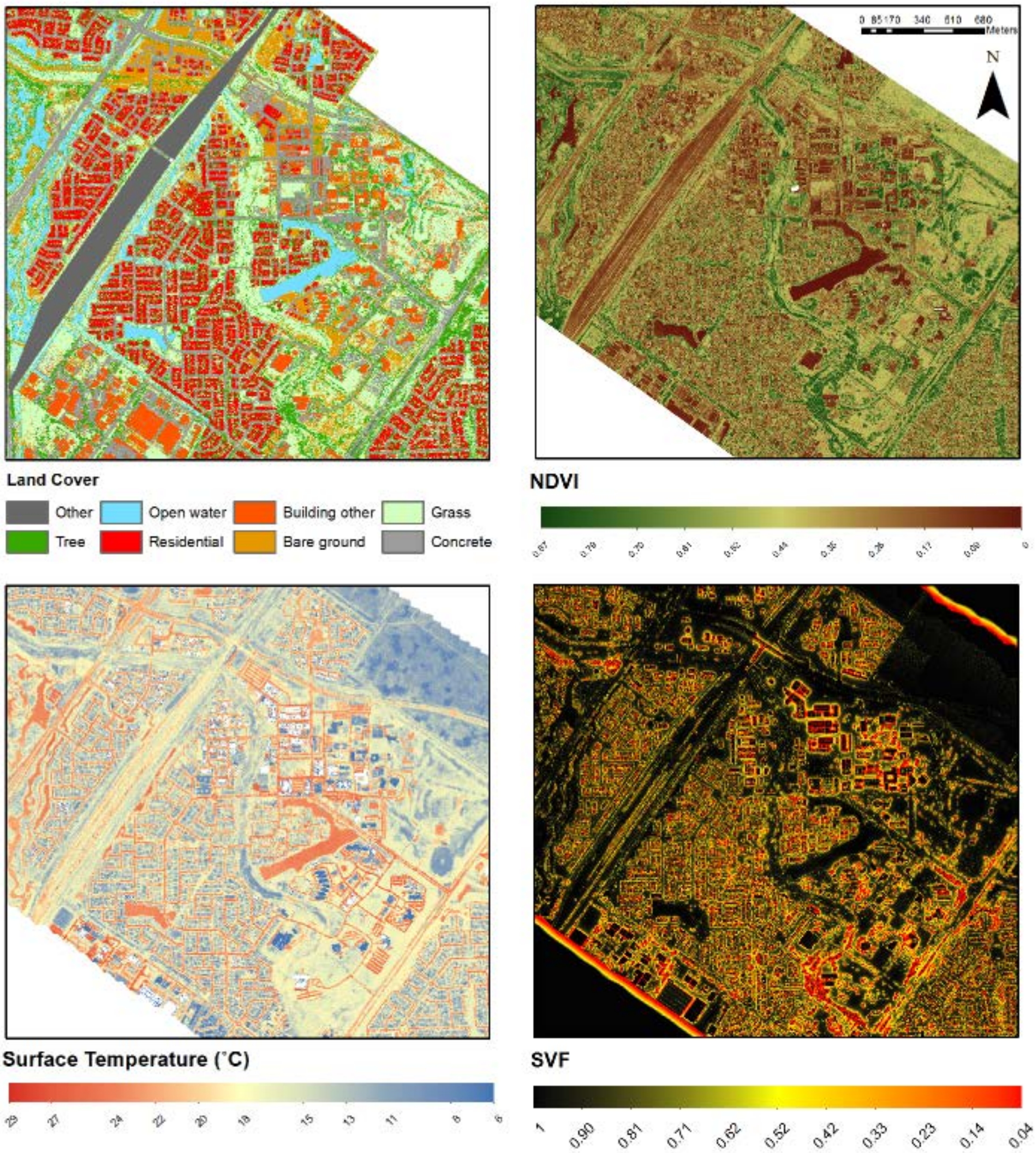



**Figure 18 (a).** Mawson Lakes remote sensing data showing land cover, vegetation cover as measured by Normalized Difference Vegetation Index (NDVI), night land surface temperature (LST), and sky view factor (SVF).

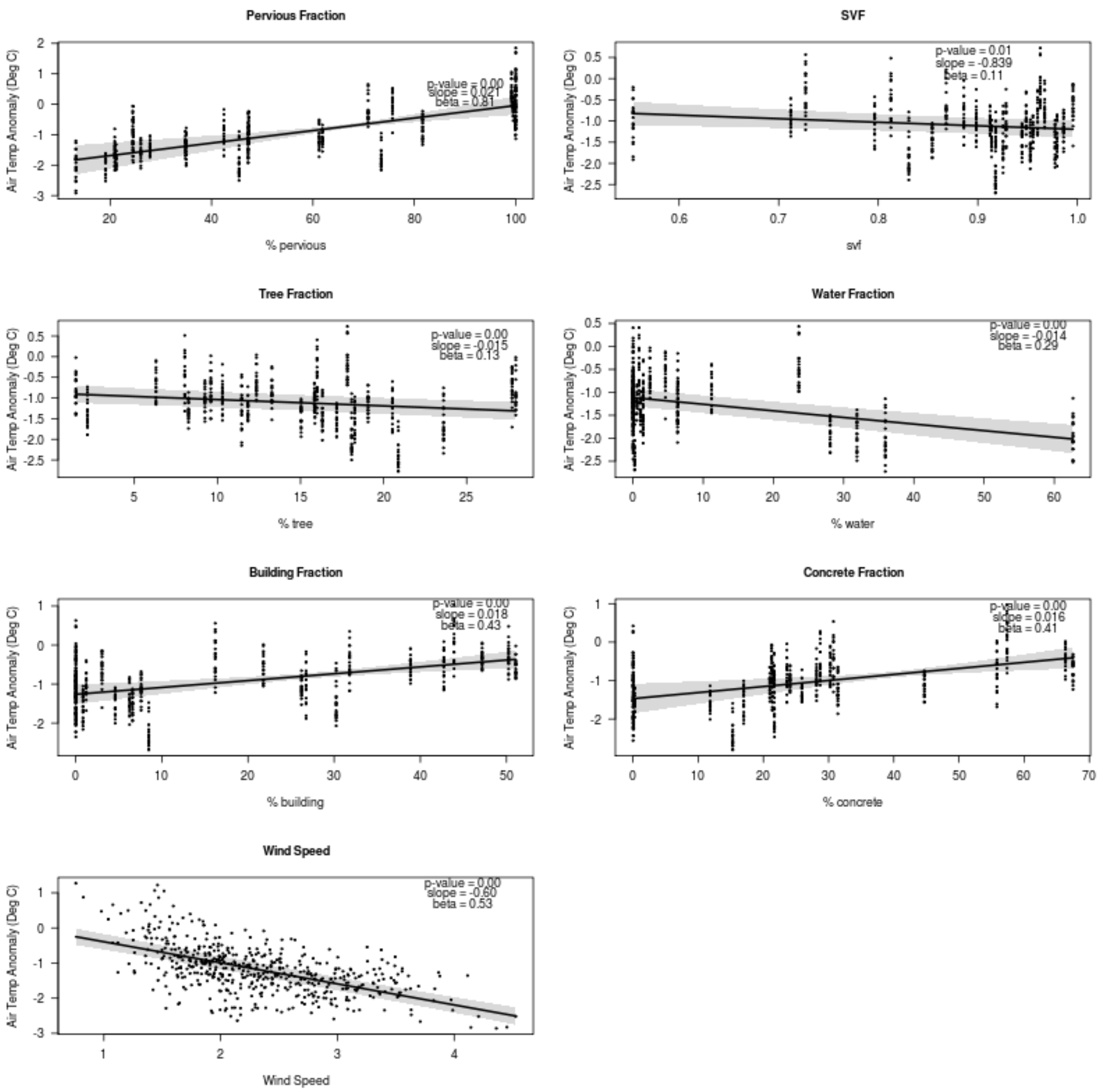



**Figure 18 (b).** Mawson Lakes remote sensing data showing multiple regression results for daytime average air temperature anomaly and (a) pervious fraction, (b) SVF, (c) tree fraction, (d) water fraction, (e) building fraction, (f) concrete fraction, and (g) wind speed. Point-wise 95% confidence bands for linear trend are included.

Some of these neighbourhood-scale relationships also appear to hold more widely at the city scale. In work part-funded by City West Water, Nury *et al.* (2013)[66] have used Landsat TM and MODIS satellite imagery, along with LiDAR data, to examine relationships amongst vegetation cover, built area index and land surface temperature for three discrete Local Government Areas (LGA) in Melbourne: the cities of Darebin, Melbourne and Monash. **Figure 19** shows the relationship between mean land surface temperature and the various land covers. These relationships have been derived from data obtained from a number of summer daytime satellite overpasses at a 30 m resolution. There is a remarkable degree of similarity in the relationships for each of the LGAs, broadly showing that for each 10% increase in tree cover, there is a reduction in land surface temperature of between 0.5°C and 1°C. These results are not directly comparable with those shown in **Figure 18** (b) (which relate to air temperature rather than land surface temperature), but do confirm the important role of green infrastructure in providing cooler urban environments.

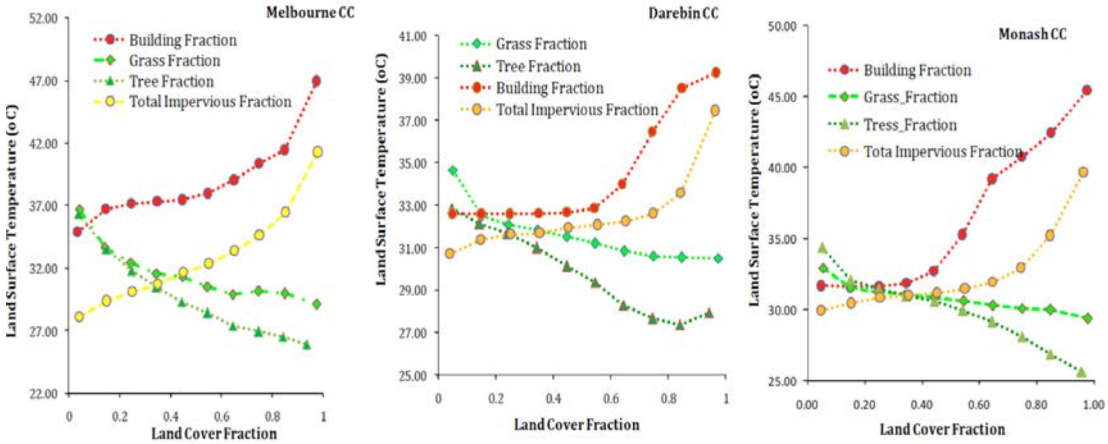



**Figure 19.** Relationships among summer daytime mean land surface temperature (LST) and various land cover fractions. Data are on a 30 m grid and temperatures are derived from a number of summer daytime satellite overpasses at approximately 11 am Eastern Summer Time.

*For each 10% increase in tree cover, there is a reduction in land surface temperature of between 0.5°C and 1°C.*

66 Nury, S., Coutts, A. Beringer, J. and Tapper, N. (2012) Spatial relation between urban vegetation and land surface temperature in Melbourne, Australia. 8th International Conference on Urban Climate, Dublin, Ireland.

In the Nury *et al.* (2013)[66] study it was not possible to determine if green infrastructure was or was not irrigated. However, it is interesting to consider whether or not citywide landscape irrigation has the potential to cool the environment at the city scale, especially during extreme heat. To investigate this particular question we have undertaken a further remote sensing study of the City of Dubbo (Pankhania *et al.*, 2013)[67] in the mid-West of New South Wales. Dubbo is a large rural city covering approximately 6 km x 8 km. Summers are warm to hot and dry and the city has considerable public and private gardens and green spaces that are typically supported by abundant irrigation with water derived from the Macquarie River. We obtained high resolution ASTER and Landsat TM satellite data for 15 extreme summer temperature days over the period 2000 – 2011, a period characterised by severe drought, and then (in 2010-2011) by flooding rains.

**Figure 20** shows NDVI and LST data for 13 January 2005, a day when air temperatures reached close to 40°C. The maps highlight an extremely dry and hot rural landscape except for some notable areas of irrigation (see the irrigated crop circles at the top and bottom of the image). Broadly, rural surface temperatures are ~ 50°C, while much of the urban landscape is 3-5°C cooler. This is despite the presence of the normal urban infrastructure of roads, buildings, car parks, etc. Clearly the provision of water to the green infrastructure in this urban landscape is having a remarkable cooling effect on land surface temperatures. These differences in surface temperature *will* translate to cooler air temperatures and we are currently working on developing appropriate transfer functions.

The thermal signature of Dubbo changed during the 12-year period of observation. During the middle of the drought, liberal use of irrigation water produced a daytime surface cooling, as shown in **Figure 20**. However, as the drought wore on, and irrigation use was restricted, the daytime thermal signature of Dubbo lessened and merged into the rural background. Then, during the last two years of plentiful rainfall when both rural and urban landscapes were naturally well watered, the city showed up as an area of relative daytime warmth, because of the warmer city surfaces associated with urban infrastructure.

*The provision of water to the green infrastructure in this urban landscape is having a remarkable cooling effect on land surface temperatures.*

[67] Pankhania, D., Tapper, N. and Coutts, A. and Beringer J. (in-prep.). Decadal Analysis of High Resolution Landsat TM and ASTER Thermal Imagery to Assess the Effects of Irrigated Green Space on Urban Temperature in Dubbo, New South Wales..

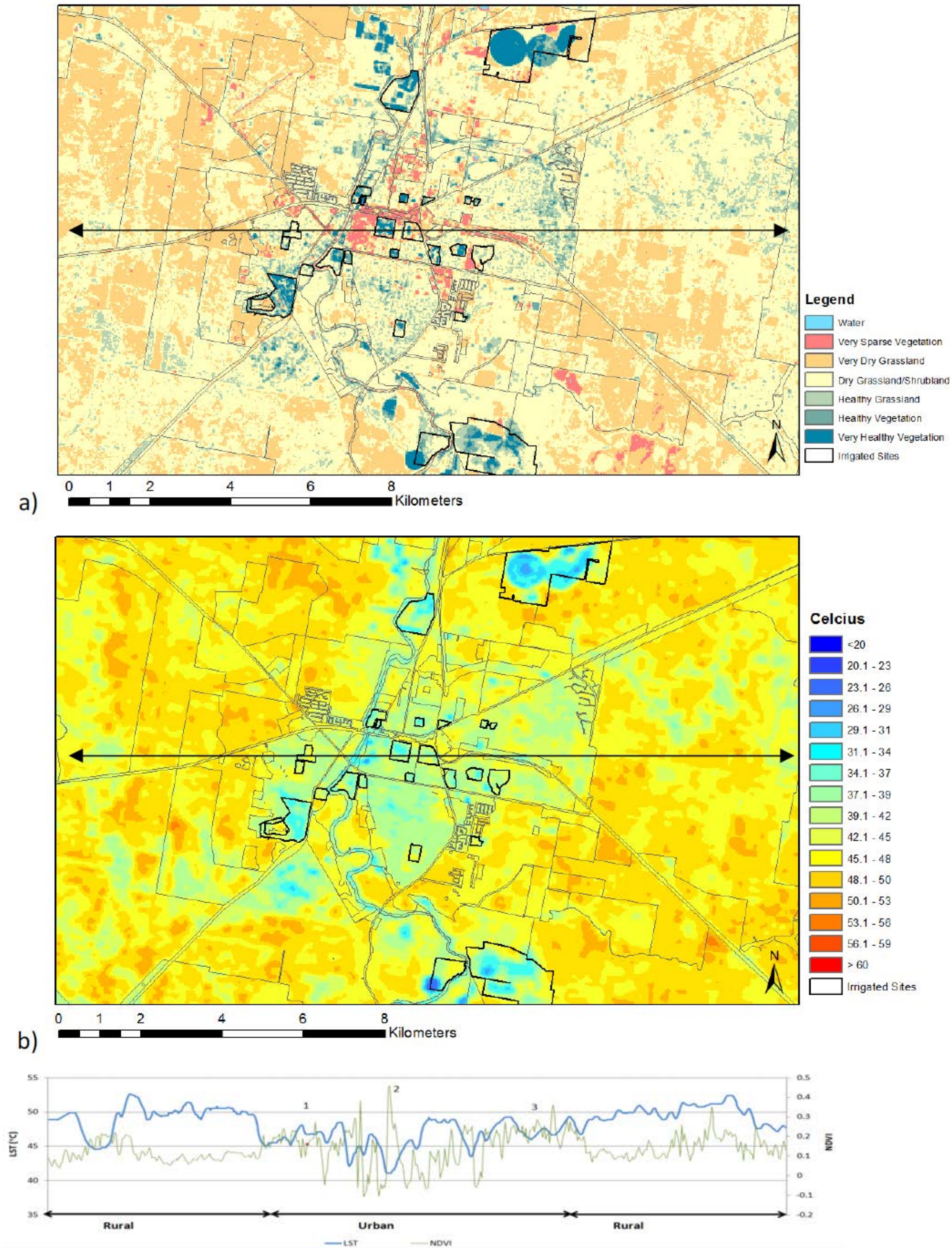



**Figure 20.** Landsat TM imagery data for Dubbo, Western New South Wales on 13 January, 2005 showing maps of (a) the vegetation greenness index (NDVI) converted to vegetation cover classes, and (b) the land surface temperature (LST) and a NDVI/LST transect along the line indicated. Dubbo occupies the middle of each image.

*Stormwater Management in a Water Sensitive City*

# Pillar 3: Cities Comprising Water Sensitive Communities

***Building socio-political capital for sustainability***

# Pillar 3: Cities Comprising Water Sensitive Communities

### *Building socio-political capital for sustainability*

Expediting a transition to water sensitive cities will require explicit policy attention towards: the economic value of stormwater infrastructure and reuse benefits; identifying decision-support frameworks for policy makers; and an understanding of current governance strategies.

Addressing the well-documented disconnection between new resource management policies and practice relies on smart policy design. With the aid of appropriate decision-support tools, policy makers have the capacity to help steer a transformation of the Australian urban water sector towards a water sensitive city.

The many pathways for adoption and potential mainstreaming of new resource management policies, practice and technology may be represented by the illustration in **Figure 21** (van de Brugge and Rotmans, 2007[68]).

The four potential pathways illustrated are influenced by a combination of factors including community receptivity to a changing paradigm, institutional inertia, poor implementation or legacy path-dependency. To avoid system breakdown or path-dependent (technological) lock-in, there are a number of mechanisms available for policy makers.

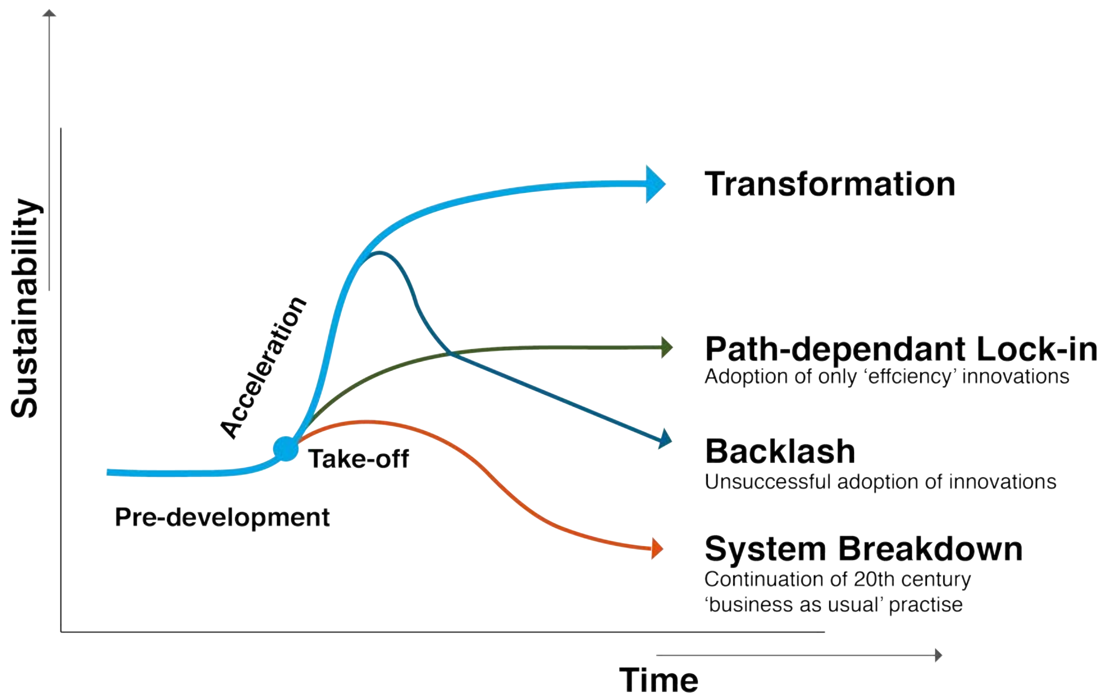



**Figure 21.** Technological-diffusion pathways (Source: van de Brugge and Rotmans, 2007)[68].

[68] van de Brugge R. and Rotmans J. (2007). Towards transitions management of European water resources. *Water Resources Management*, **21**: 249-267.

## Nine Key Enabling Factors for Fostering Technological Diffusion

The nine key enabling factors for fostering technological diffusion identified by Brown and Clarke (2007)[69] are essential ingredients for fostering system-wide transformation in urban water management. These factors are summarised in Table 8.

Policy makers can assess the relative strength of each factor at a project, organisational and regional scale to identify deficits and opportunities for designing incentives to seed the transition to a water sensitive city. A mix of technology/strategy (push) and demand (pull) initiatives should be adopted to support the development and interplay of a multi-sectoral network of issue leaders (champions) and enabling factors.

The location of the influence of these factors along the transformation pathway and in transition governance is now becoming clearer. Some of these factors have been associated with different phases of the transformation pathway as a new niche (e.g. stormwater harvesting) emerges within an existing regime (e.g. traditional drainage system), expands and stabilises to become accepted as mainstream practice. These different phases result from the dynamics of loosely networked champions from government, private, community and scientific communities.

These champions:

- lead the transition, motivated by a shared vision;
- develop a common narrative around the vision;
- adapt the narrative, depending on whether the current institutional context is supportive or not; and
- generate enabling conditions with a series of creating, disrupting or maintaining strategies.

*The nine key enabling factors are essential ingredients for fostering system-wide transformation in urban water management.*

**Table 8.** Nine key enabling factors for fostering technological diffusion (Adapted from Brown and Clarke, 2007)[69]

| | |
|---|---|
| **1. Socio-Political Capital**<br>Community, Media and Political | **6. Bridging Organisations**<br>Facilitates Science - Policy<br>Facilitates Capacity Building |
| **2. Champions**<br>Vision<br>Multi-sectoral Network | **7. Binding Targets**<br>Measurable System Target<br>Science, Policy and Development |
| **3. Accountability**<br>Coordinate Processes<br>Water Cycle<br>Land-use Planning | **8. Strategic Funding Points**<br>Dedicated External Funds |
| **4. Reliable and Trusted Science**<br>Academic Leadership<br>Technology Development | **9. Demonstration Projects**<br>Experimentation<br>Technology Development<br>Policy and Institutional Learning |
| **5. Market Receptivity**<br>Business Case for Change | |

[69] Brown R.R. and Clarke J.M. (2007). *Transition to water sensitive urban design: The story of Melbourne, Australia*, Report No. 07/1, Facility for Advancing Water Biofiltration, Monash University, June 2007, ISBN 987-0-9803428-0-2.

## Liveability and the Water Sensitive City

Notions of 'liveability' are emerging as common narratives for Water Sensitive Cities. While these seem appropriate at the conceptual level, they need to be characterised and defined to some extent to be useful for framing and shaping investment in and design of urban water systems. Review and analysis of liveability literature led Adamowicz (2011)[70] to connect liveability to the satisfaction of societal needs. Combining this approach to liveability with de Haan *et al's.* (2011)[71] societal urban water needs allows a framework that aligns water sensitive cities, societal urban water needs and liveability to be developed. Following de Haan, societal urban water needs can be framed by Alderfer's Existence, Relatedness and Growth Theory of human needs. **Table 9** presents typical examples of societal urban water needs in accordance with Alderfer's existence, relatedness and growth categories.

Existence needs are 'essential' urban water services, such as access to clean water, protection from flood hazards and supporting the economy of a city.

Relatedness needs correspond to the bio-physical attributes supported by sustainable and resilient urban water management. For example, water can support grassed playing surfaces that service some recreation needs of society. More broadly, urban vegetation, sustained by adequate water, contributes to a range of societal needs (particularly relatedness needs). Many existence and relatedness needs can be satisfied through ecosystem services provided and sustained by water in urban environments.

Growth needs are influenced by the way in which water systems are developed and delivered, in particular the associated governance arrangements and how communities are engaged with systems and processes.

**Figure 22** illustrates the alignment of societal urban water needs (as identified in **Table 9**) and urban water management activities mapped against the transitional city states developed by Brown *et al.* (2009)[72].

**Table 9.** Examples of societal urban water needs (Johnstone *et al.* 2012)[73] grouped according to the human needs categories of Alderfer's Existence, Relatedness and Growth Theory.

| Needs category | Types of needs | Examples of societal urban water needs |
|---|---|---|
| Existence | Physical and material needs | Drinking Water |
| | | Non-drinking Water |
| | | Public Health |
| | | Public Safety |
| | | Property Protection |
| | | Economic Activity |
| Relatedness | Social Interaction and Inter-personal Relationships | Recreation |
| | | Social Cohesion |
| | Societal-environmental Inter-relationships | Beauty |
| | | Comfort |
| | | Ecological Health |
| Growth | Societal Self-esteem and Self-actualisation | Identity |
| | | Purpose and Ambition |
| | | Control and Independence |
| | | Equity and Social Justice |
| | | Intergenerational Equity |

70 Adamowicz, R. C. (2011). The role of integrated water cycle management in creating the liveable city. Master of Environment and Sustainability – minor thesis, Monash University.

71 de Haan, F.J., Ferguson, B.C., Adamowicz, R.C., Johnstone, P., Brown, R.R. and Wong, T.H.F. (2012). The needs of society: a new understanding of transitions, sustainability and liveability. 3rd International Conference on Sustainability Transitions held August 29-31, 2012, Copenhagen.

72 Brown, R. R., Keath, N. and Wong, T. H. F. (2009). Urban water management in cities: historical, current and future regimes. *Water Science and Technology*, **59**(5), 847-855.

73 Johnstone P., Adamowicz R., de Haan F J., Ferguson B. and Wong T. (2012). Liveability and the Water Sensitive City. Monash Water for Liveability, Monash University, Melbourne, Australia.

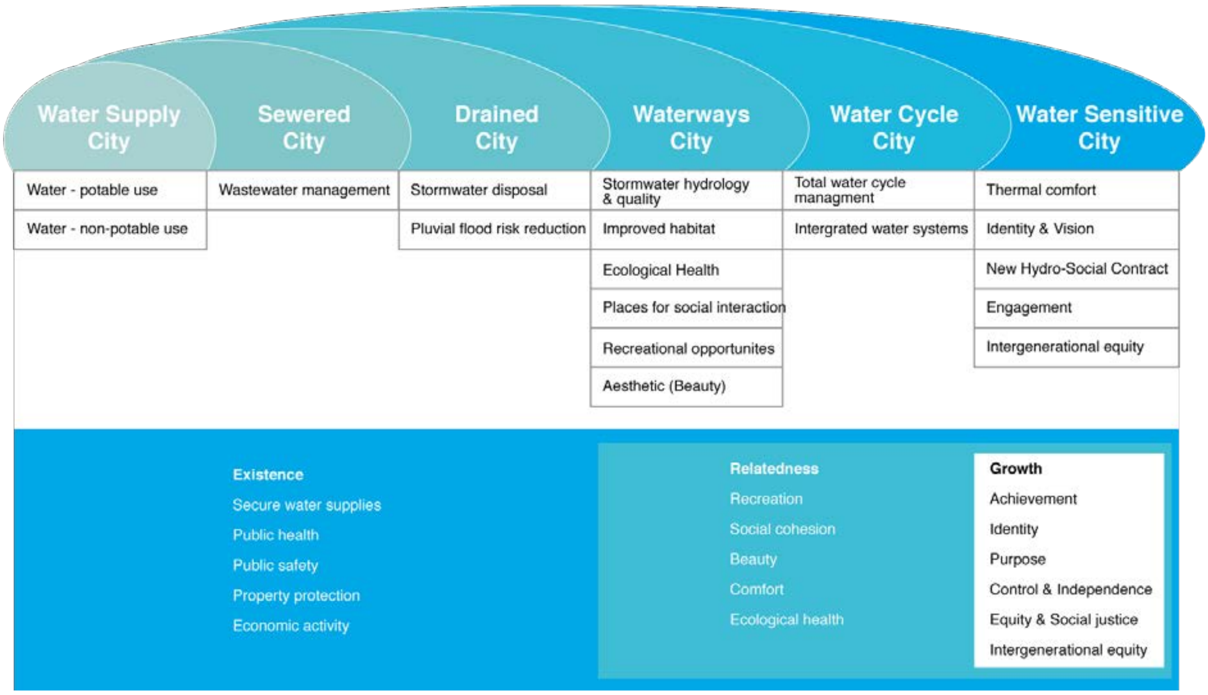



**Figure 22.** Illustration of the characteristic features of the transitional city states of Brown *et al.* (2009)[72] and societal urban water needs.

## Strategic Action for Transformative Change

Strategic action is important in fostering transformative change towards a shared future vision (Ferguson *et al.* 2012[74]; Frantzeskaki *et al.* 2012[75]) and should be guided and supported by:

- envisioning process to identify the preferred future;
- demonstration projects and learning platforms for innovation (including co-governance); and
- stakeholder reflexivity, especially in relation to perceived risks.

These factors are discussed in the following sections.

### Envisioning Process to Identify the Preferred Future

For transformative change in urban water management, a long-term visionary strategic planning process is required. A shared vision of the future is essential. This can be developed at workshops attended by representatives of organisations involved in the planning, design, management and use of the urban water system (Ferguson *et al.* 2012)[74]. Once a vision is established, guiding principles or themes can then be identified, to underpin the vision. These are then translated into a practical form as strategic objectives, which might involve both trade-offs and synergies. There might be multiple pathways to the future vision, each associated with short-term, medium-term and long-term strategies and actions (**Figure 23**). The vision can be enriched with narratives and illustrations of the overall vision itself (**Figure 24**) and of its underlying themes (**Figure 25**).

The workshop process must be structured, with a suggested timeframe of 18 months (Frantzeskaki *et al.* 2012: **Figure 26**)[75]. It provides participants with the opportunity to understand the challenges facing the current system, to develop a shared vision of the future, and to identify strategies and actions to realise the vision. Resilience of both the vision and the transition pathways to it is important.

[74] Ferguson, B., Frantzeskaki, N., Skinner, R., and Brown, R. (2012). *Melbourne's transition to a Water Sensitive City. Recommendations for strategic action*. Monash Water for Liveability, Monash University, Melbourne, Australia. ISBN 978-1-921912-13-9.

[75] Frantzeskaki, N., Ferguson, B., Skinner, R., and Brown, R. (2012). *Guidance manual. Key steps for implementing a strategic planning process for transformative change*. Dutch Research Institute for Transitions, Erasmus Unviersity Rotterdam, The Netherlands. Monash Water for Liveability, Monash University, Melbourne, Australia. ISBN 978-1-921912-14-6.

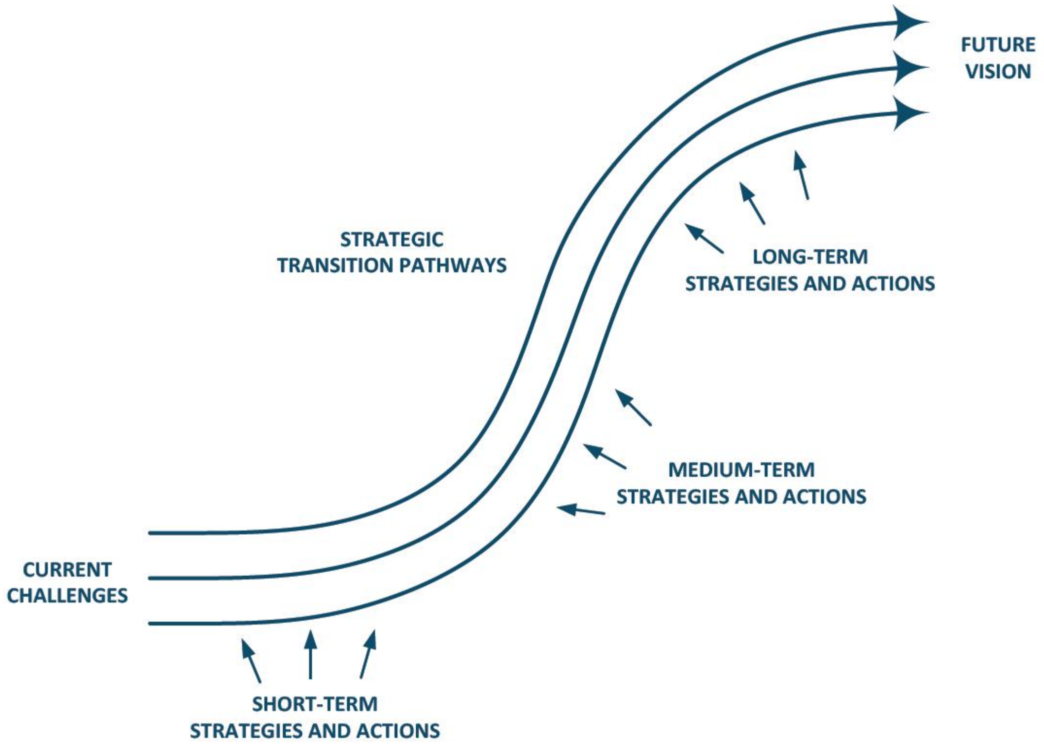



**Figure 23.** Outcomes of an envisioning exercise to develop a shared vision for a water sensitive city. Multiple pathways might be identified, each associated with short-term, medium-term and long-term strategies and actions (Source: Ferguson *et al.* (2012)[74].

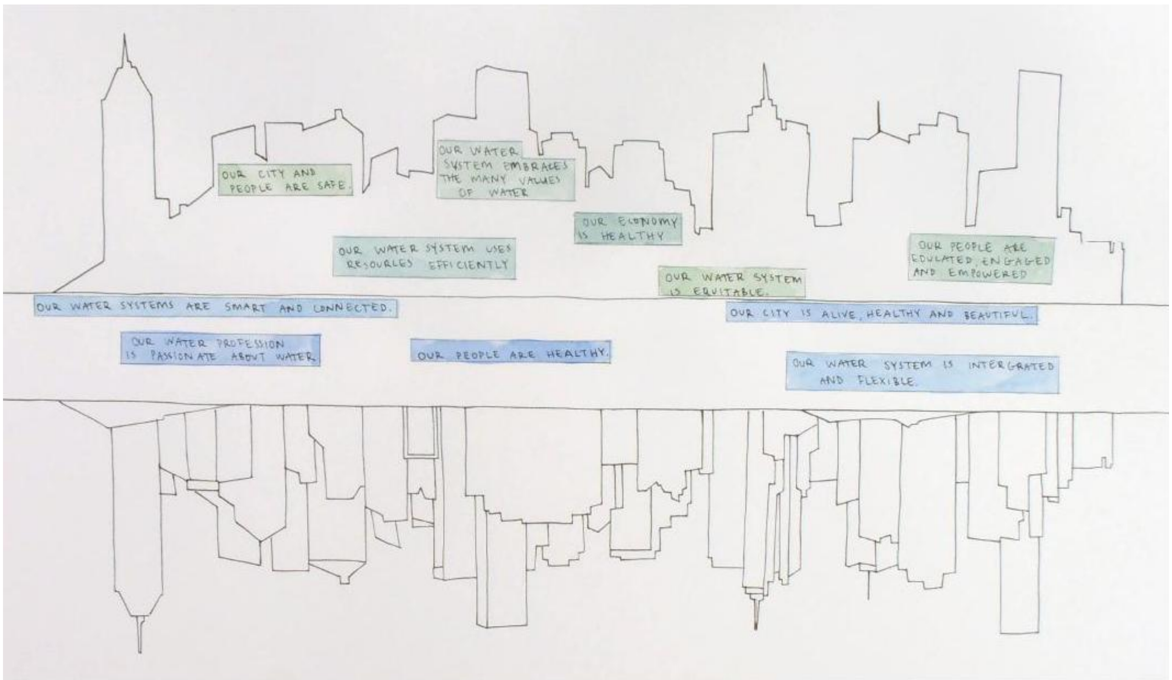



**Figure 24.** A shared vision recognizes that a community has shared desires and concerns (Ferguson *et al.*, 2012)[74]

**Figure 25.** Themes underpin the vision, with principles that elaborate the vision and guide strategies to achieve it (Source: Ferguson *et al.*, 2012)[74].

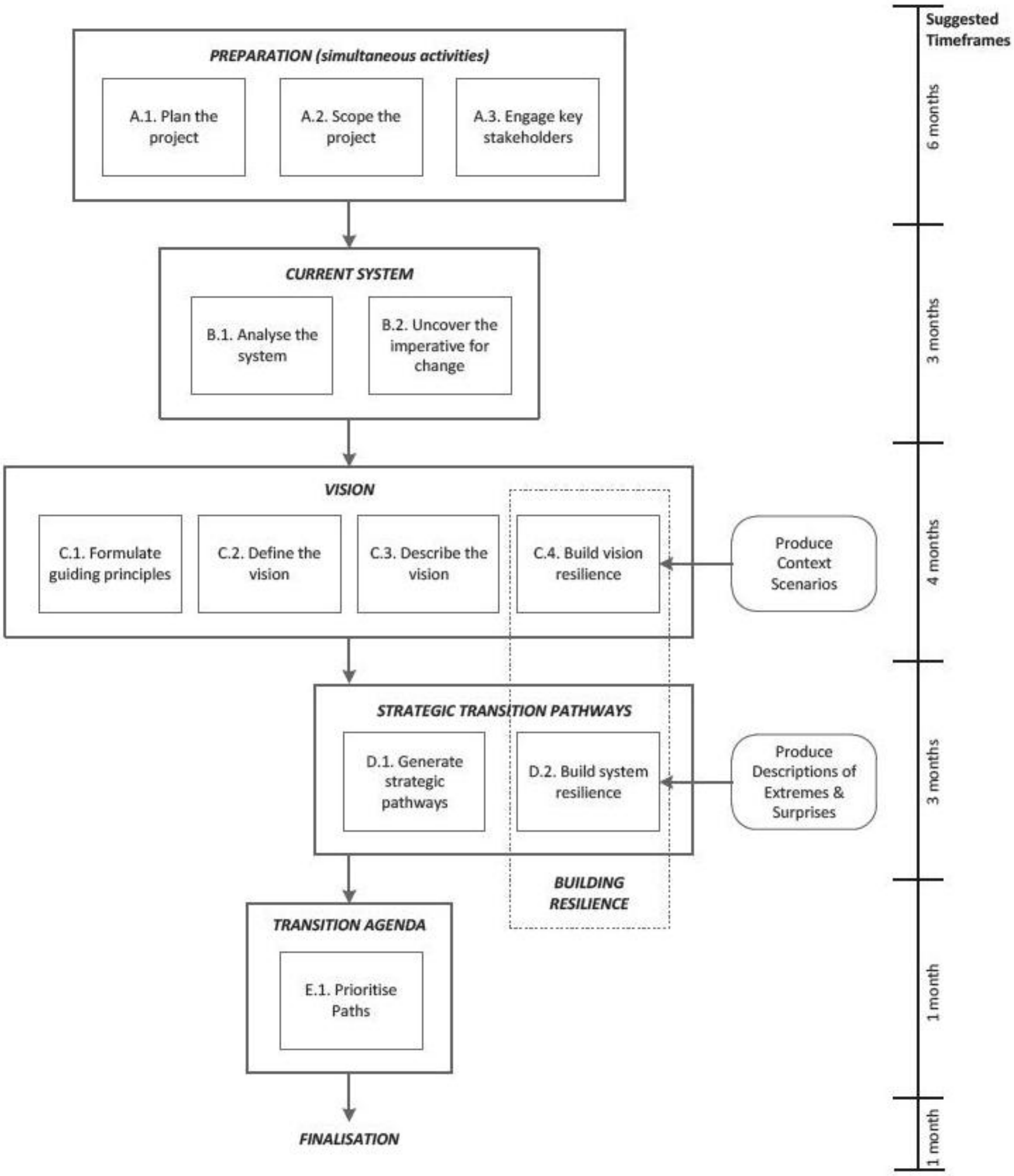



**Figure 26.** Methodology to develop a long-term vision requiring transformative change. This is a strategic planning process, with an explicit focus on the long term, which brings together science, policy and community stakeholders in a safe forum to develop strategies for change from the bottom up. It combines the process of identifying a shared vision ('what') with the development of strategies to achieve that vision ('how') (Source: Frantzeskaki *et al.*, 2012)[75].

### Demonstration Projects and Learning Platforms for Innovation - Toward a Mix of Centralised and Decentralised Systems

Demonstration and experimentation are important tools for testing and learning about the potential and impact, the applicability, benefits, and replicability of innovations across local conditions. These tools are critical as we transition toward a more networked urban water configuration comprising a range of water sources, technological systems, service delivery arrangements and end-user types (**Figure 27**).

The spatial, technological and institutional changes outlined in **Figure 27** highlight the complexities involved in designing appropriate 'mixes' and 'fit' between various infrastructure options and existing conditions. **Figure 28** outlines how certain dimensions of the variables of resource, technology and end-user are correlated to specific service delivery arrangements (see Yu *et al.*, 2011[77] for more information). It shows that the choice of service delivery arrangement moves towards greater centralisation (i.e. local water authority) when:

- risks in relation to public health and the natural, physical environment are high;
- the system is large and highly complex, and its operation is highly connected to, hence dependent on, larger infrastructure; and
- end-users are isolated, unwilling and have limited capacity to operate and maintain the system.

In contrast, systems may be owned and operated by communities or individual end-users when:

- risks in relation to public health and the natural, physical environment are low;
- the system is small, relatively easy to maintain, and can function independently; and
- end-users are actively involved and have the capacity to operate and maintain the system.

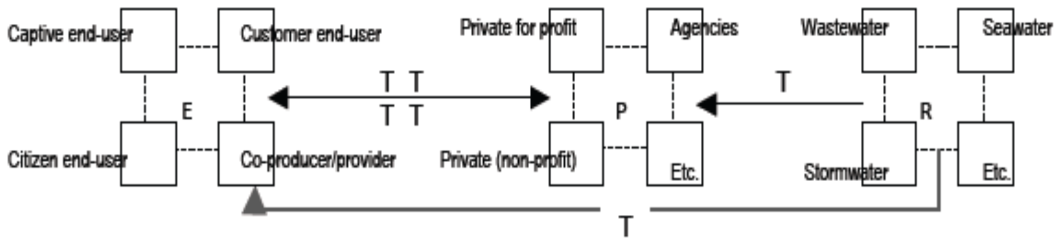



**Figure 27.** Emerging trends in water supply. E–end-user; T–technology; P–provider; R–resource (Adapted from van Vliet *et al.*, 2005)[76].

[76] van Vliet, B., Chappells, H., and Shove, E. (2005). Infrastructures of consumption: environmental innovation in the utility industries. London: Earthscan.

[77] Yu, C., Farrelly, M. and Brown, R. (2011). Governance arrangements for decentralized stormwater systems. Industry Report for the Centre for Water Sensitive Cities. Monash University, Melbourne, Australia. Available online at: [watersensitivecities.org.au/wp-content/uploads/Project6-SocietyInstitutions-Nov2011.pdf](watersensitivecities.org.au/wp-content/uploads/Project6-SocietyInstitutions-Nov2011.pdf)

**Figure 28** can be used to assess 'fit' between service delivery arrangements of existing technological innovations or to develop appropriate social and technological mixes for planned demonstration projects. However, the relationships are not absolute (e.g. very high public/environmental risk, etc., does not automatically mean that service delivery must be by a local water authority) as there are interdependencies (e.g. contrast, relevance) within and among the dimensions. Additionally, variables interact with, and are affected by, external processes and trends.

Now with the active participation of various stakeholders, including end-users, in the provision of urban water services, co-governance becomes imperative. Co-governance is the collaboration between private, government and public sectors (end-users, in particular) in various phases of the service cycle, from planning to delivery and evaluation. **Figure 29** presents a framework for designing (and experimenting with) co-governance processes to maximise their potential to:

- increase uptake and ownership of a process or innovation, and
- enhance service delivery and/or service quality.

The framework includes three design phases – decision analysis, end-user analysis and end-user engagement planning – as foundations of the three phases of the service cycle (i.e., planning, delivery and evaluation)[78].

The upper level, Designing Co-governance Processes and Service Delivery Arrangements, reveals *the making* of co-governance processes and service delivery arrangements for technological innovations. The figure shows that the *design team* may comprise many stakeholders (and/or roles) including project sponsors, managers, technical and social personnel as well as consultants. The involvement and/or influence of these people could vary from one design phase to another. For instance, technical specialists may be very useful in the decision analysis phase, which aims to identify the relevant decision-makers, the purpose of the decision and the rationale for end-user involvement. On the other hand, facilitators would be more useful in end-user analysis and/or engagement planning, where they outline co-governance processes and determine a potential service delivery arrangement based on understanding of end-user interests and motivations. Analyses and planning in this level become the basis for activities in the lower level, Co-governance Processes and Service Delivery Arrangements. In other words, the activities during the planning, delivery and evaluation phases and the service delivery arrangement are all outcomes of the analyses and planning in the upper level.

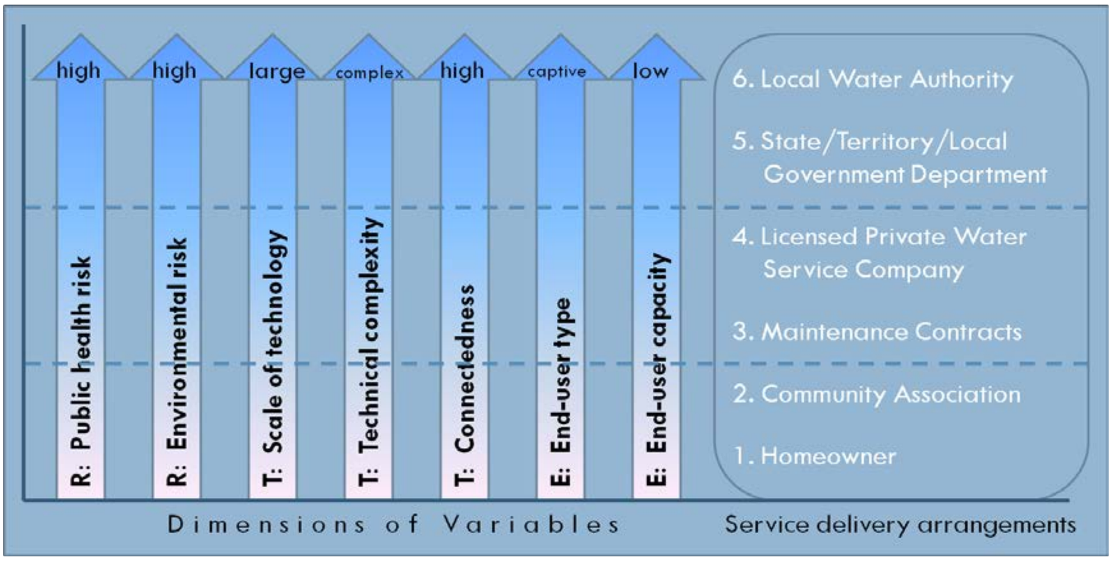



**Figure 28.** Relations between variables and service delivery arrangement. R–resource; T–technology; E–end-user (Adapted from USEPA. 2005)[79].

[78] See Yu et al. (2011)[77] for more information on the design phases and tasks. It must be noted that the design of co-governance processes and service delivery arrangements is complex and delicate. At the end of the analyses and engagement planning, the design team must produce 1) a co-governance plan, which outlines the rationale and sequence of activities (e.g. co-design), etc., and 2) a broad outline of the potential service delivery arrangement, which highlights the roles of stakeholders in various phases of the service cycle.

[79] USEPA (2005). *Handbook for managing onsite and clustered (decentralised) wastewater treatment systems*. Office of Water. US Environmental Protection Agency. December.

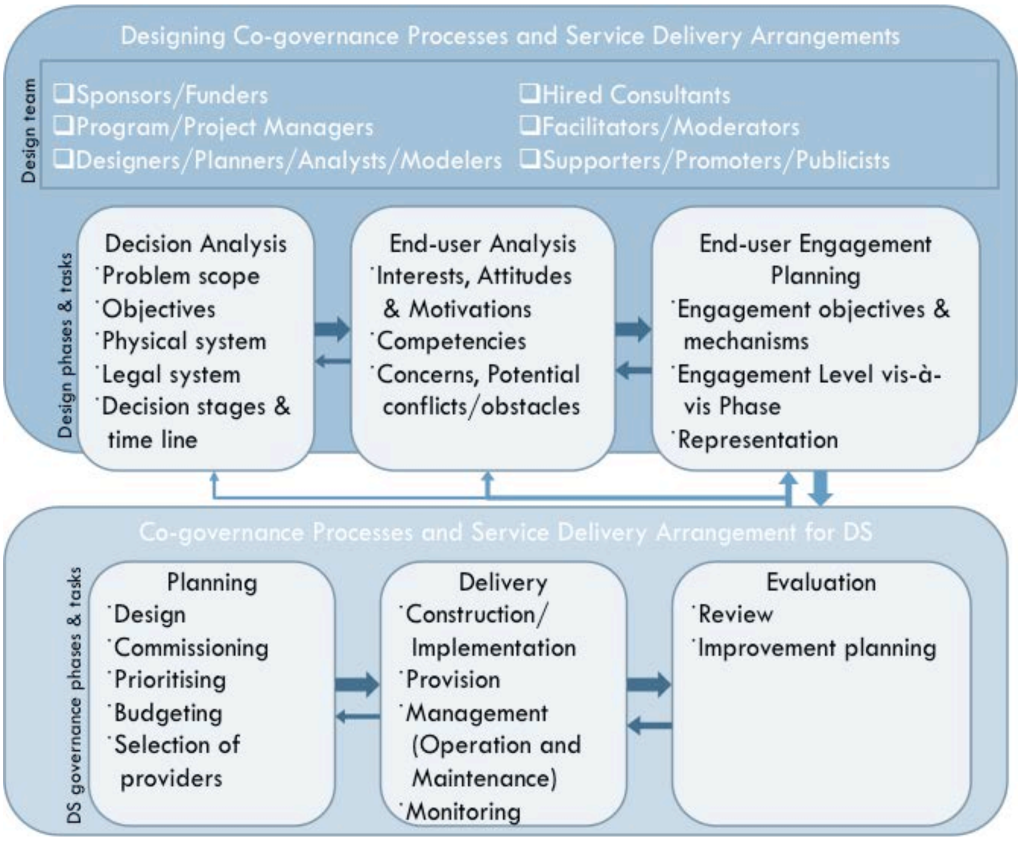



**Figure 29.** Framework for designing co-governance processes and service delivery arrangements for decentralized systems. Note: width of arrow corresponds to extent of influence (Adapted from Daniell *et al.*, 2010[80] and von Korff *et al.*, 2010[81]).

[80] Daniell, K. A., White, I., Ferrand, N., Ribarova, I. S., Coad, P., Rougier, J.E., Hare, M., Jones, N. A., Popova, A., Rollin, D., Perez, P., and Burn, S. (2010). Co-engineering participatory water management processes: theory and insights from Australian and Bulgarian interventions. *Ecology and Society,* **15**(4): 11. Accessed November 10, 2011 http://www.ecologyandsociety.org/vol15/iss4/art11/

[81] von Korff, Y., d'Aquino, P., Daniell, K. A. and Bijlsma, R. (2010). Designing participation processes for water management and beyond. *Ecology and Society,* **15**(3): 1. Accessed November 10, 2011 http://www.ecologyandsociety.org/vol15/iss3/art1/

### Stakeholder Reflexivity, Especially in Relation to Perceived Risks

Co-governance highlights the relevance of risk perceptions in sustainable urban water management. Stakeholders can be expected to perceive risks associated with alternative water systems (Slovic 1999)[82]. The public is likely to be most concerned about risk to public health (Kereman *et al.* 2011)[83]. In contrast, Australian urban water practitioners perceived higher cost-related risks associated with stormwater harvesting and water quality treatment systems than health-related risks (**Figure 30**: Dobbie and Brown 2012)[84].

However, practitioners did not perceive risks the same. Familiarity and sense of control are important influences on Australian water practitioners' risk perceptions (Dobbie and Brown, 2013)[85]. These perceptions can vary with the practitioners' discipline, area of activity within the water industry and the organization for which they work. Practitioners working with government or water utilities, compared with other practitioners, perceived higher risks associated with stormwater harvesting systems. Similarly, engineers and biologists perceived higher risk with these systems. More specifically, practitioners working in water supply and sewerage perceived higher public health, reputation loss and political risks associated with stormwater harvesting systems. In contrast, researchers consistently perceived less risk associated with various uses of treated stormwater involving very close personal contact. It would seem that these risk perceptions reflect familiarity and management control offered by the current centralised system of urban water supply, overseen by technocrats.

*Risk perceptions can vary with discipline, area of activity within the water industry and the organization for which they work.*

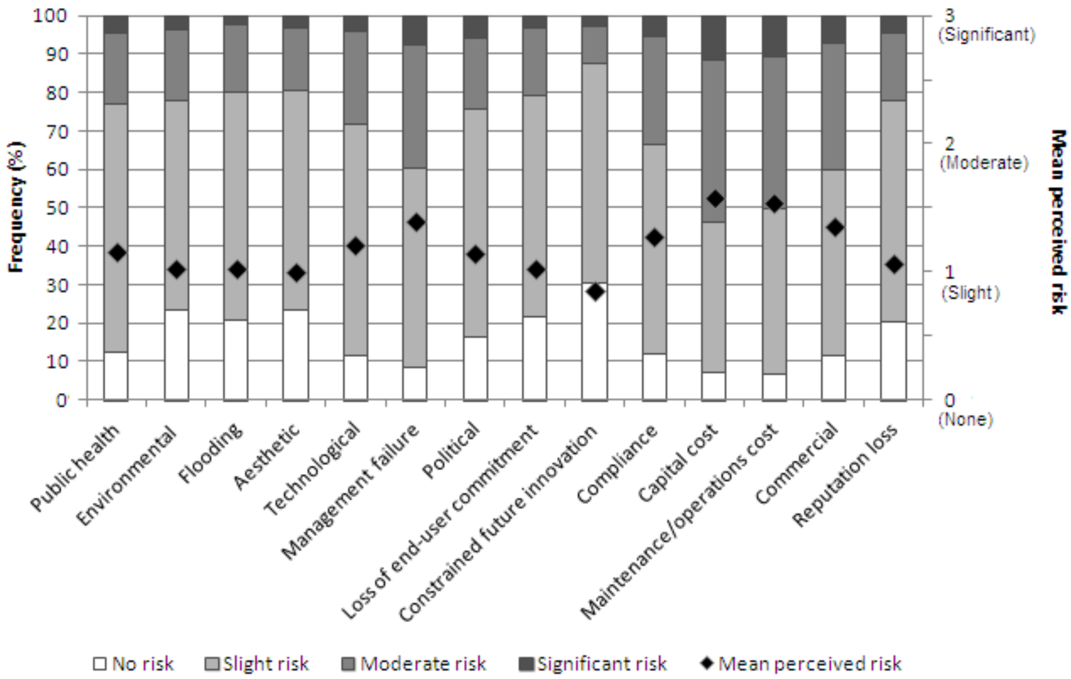



**Figure 30.** Australian urban water practitioners perceive a number of specific risks associated with stormwater harvesting systems as more than slight. However, they do not all agree, risk perception varying with familiarity (Source: Dobbie and Brown, 2012)[84].

[82] Slovic, P. (1999). Trust, emotion, sex, politics, and science: surveying the risk-assessment battlefield. *Risk Analysis,* **19,** 689-701.
[83] Keremane, G. B., Mckay, J. and Wu, Z. (2011). No stormwater in my tea cup: an internet survey of residents in three Australian cities. *Water (Melbourne),* **38,** 118-124.
[84] Dobbie, M. F. and Brown, R. R. (2012). Risk perceptions and receptivity of Australian urban water practitioners to stormwater harvesting and treatment systems. *Water Science and Technology: Water Supply*, **12**(6), 888-894.
[85] Dobbie, M. F., and Brown, R. R. (2013). Transition to a Water Cycle City: sociodemographic influences on Australian urban water practitioners' risk perceptions towards Alternative Water Systems. *Urban Water Journal*, DOI: 10.1080/1573062X.2013.794846. tandfonline.com/doi/abs/10.1080/1573062X.2013.794846?ai=cv53andui=3jpu1andaf=T

The importance of control in risk management is also suggested by the proportion of urban water practitioners trusting different stakeholder groups to manage risks associated with stormwater systems. Local government was trusted to manage risks associated with stormwater harvesting technologies and stormwater quality treatment systems by the greatest proportion of practitioners (69% and 73% respectively). Between 49% and 58% of practitioners trusted state government and water utilities to manage risks associated with these stormwater systems (Dobbie *et al.* 2013[86]; Dobbie *et al.* 2012[87]). Less than 20% of practitioners indicated trust in community groups, bodies corporate or homeowners to manage risks associated with stormwater systems.

These risk perceptions, preference for management control and lack of trust in community stakeholders to manage risk pose challenges for the broad-scale adoption of stormwater harvesting and water quality treatment systems and co-governance arrangements. Demonstration projects, including co-governance experiments, can facilitate transition to sustainable urban water management by offering a social learning platform for practitioners to recognise, acknowledge and reflect on these risk perceptions.

Social learning builds on technical and conceptual learning to drive change in professional and organisational cultures that might be disadvantaging the transition (Farrelly and Brown 2011[88]). It is a group process, in which individuals working at different scales within the system interact, communicate freely and exchange ideas. Farrelly and Brown (2011)[88] and Bos and Brown (2012)[89]) identified that social learning requires:

- a learning platform, such as a demonstration project or co-governance experiment;
- open and flexible networks;
- champions providing leadership;
- financial, temporal and creative space:
- favourable reputations of both champions and the experiment itself;
- relevant scientific research; and
- skilled facilitation.

Experimentation with new technologies and governance systems offers the opportunity of learning by doing. Once perceived risks are identified, they can be addressed and managed, thereby facilitating the transition.

*Trust, control and familiarity can influence practitioners' risk perceptions of alternative water systems.*

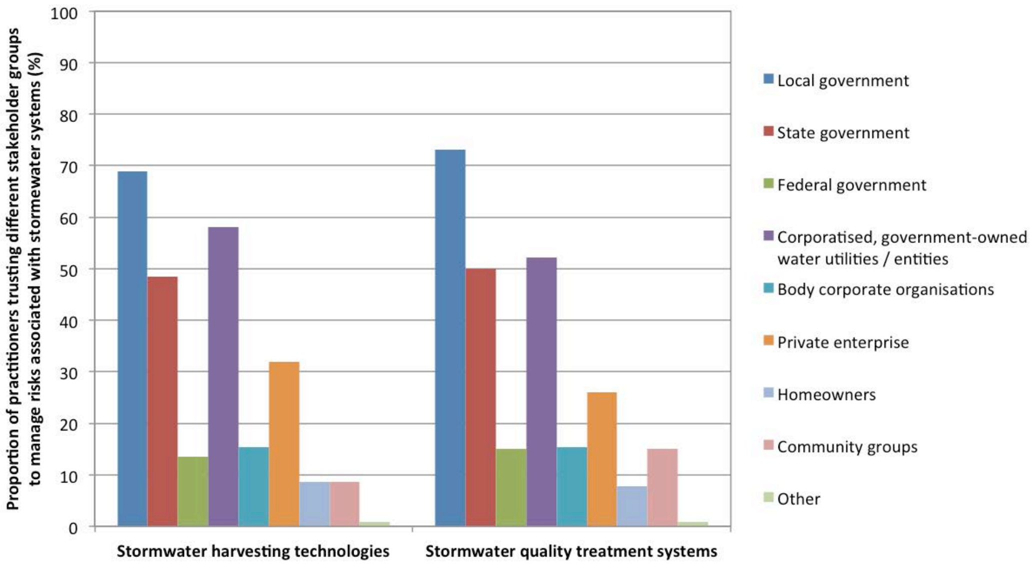



**Figure 31.** Proportion of Australian urban water practitioners trusting different stakeholder groups to manage risks associated with stormwater harvesting technologies and stormwater quality treatment systems (Dobbie *et al.* 2013[86]; Dobbie *et al.* 2012[87]).

[86] Dobbie, M. F., Brookes, K. L., and Brown, R. R. (2013). Transition to a water-cycle city: risk perceptions and receptivity of Australian urban water practitioners. *Urban Water Journal*.

[87] Dobbie, M. F., Brookes, K. L., and Brown, R. R. (2012). *Risk perceptions of Australian urban water practitioners towards alternative water systems, including stormwater harvesting and quality treatment systems*. Report for The Centre for Water Sensitive Cities, Monash University, April 2012. ISBN 978-1-921912-09-2.

[88] Farrelly, M. and Brown, R. (2011). Rethinking urban water management: experimentation as a way forward? *Global Environmental Change*, **21**(2), 721-732.

[89] Bos, J. J. and Brown, R. R. (2012). Governance experimentation and factors of success in socio-technical transitions in the urban water sector. *Technological Forecasting and Social Change*, **79**, 1340-1353.

## An Optimal Portfolio Approach for Managing Urban Water Supply Risk

Risk is not unique to stormwater harvesting. For example, conventional groundwater and surfacewater sources are rainfall-dependent and subject to supply risks that can lead to shortfalls in urban water supply. These supply risks will increase as rainfall becomes more variable and inflows into reservoirs decrease (due to changing rainfall pattern and high soil moisture deficit) as projected under climate change.

This situation has already resulted in a global surge in actual and planned investments to augment urban water supply and ensure future supply security (Rygaard et.al, 2011)[90]. Some have invested in desalination and recycling technologies, others have fostered stormwater harvesting initiatives. All of these investments alter the mix of total urban water supply and, as a result, the level of supply risk: investments in large capital-intensive desalinisation and recycling plants that are capable of producing water at any time may be seen as insurance against the declining supply from conventional sources. By contrast, decentralised stormwater harvesting initiatives represent a means to capitalise on the greater variation in precipitation patterns by harvesting and treating surface runoff from rainfall events when and where they occur.

Leroux and Martin (2012)[91] adapt Merton's (1969[92], 1971[93]) optimal portfolio model to the urban water sector to analyse the existing mix of water supply technologies and capacities for Melbourne, in light of its historic precipitation and inflow patterns as well as the different costs of water supply by source. The returns on investment are modelled as water flows per investment dollar and supply uncertainty from conventional reservoirs and decentralised stormwater harvesting initiatives are realistically represented by gamma distributions. Closed-form solutions are derived for urban water consumption and contributions to a given total annual water supply for each of three types of water supply assets: i) conventional surface and/or groundwater sources, ii) desalination and recycling technologies, iii) stormwater harvesting.

From the analysis of the current portfolio choice, inferences can be drawn about the level of risk aversion to supply shortages. Importantly, the framework can be used to inform the relationship between demand management and supply management as well as the optimal portfolio composition of water supply assets under past and future climate conditions, as illustrated in **Figure 32**.

This analytical tool, once calibrated, could be adapted for application elsewhere. The dynamic portfolio model could be used to address such questions as "given future supply and demand uncertainty, how much water can we afford to consume relative to storage levels (e.g. when should we introduce water restrictions)". With the analytical tool having a variable related to risk aversion, rapid numerical experiments could be undertaken with this tool to examine the relationship between infrastructure investment and community receptivity to the risk and severity of water restriction. Furthermore, ongoing development is directed at enhancing the capability of the tool to represent the significant rainfall gradients (such as that experienced within greater Melbourne) to test investment decisions on water supply portfolio.

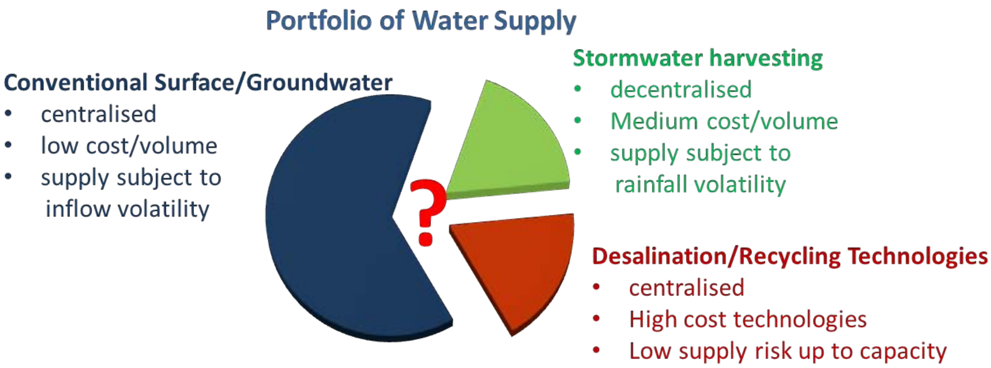



**Figure 32.** An optimal portfolio of urban water supply may balance supply risk against the cost of supply.

[90] Rygaard, M., Binning, P. J., and Albrechtsen, H.-J. (2011). Increasing urban water self-sufficiency: New era, new challenges. *Journal of Environmental Management* **92**, 185-194.

[91] Leroux, A. and Martin, V. (2012). An optimal portfolio of urban water supply assets. EAERE 19th Annual Conference, Prague.

[92] Merton, R. C. (1969). Lifetime portfolio selection under uncertainty: the continuous-time case. *Review of Economics and Statistics*, **51,** 247.

[93] Merton, R. C. (1971). Optimum consumption and portfolio rules in a continuous-time model. *Journal of Economic Theory*, **3**(4), 373-413.

## Risk from an End-user Perspective

In the context of stormwater management, most attributes are stochastic in the sense that whether or not a promised outcome is achieved depends not only on the stormwater project itself but also on the weather. For example, while stormwater harvesting may go some way to reducing the need for compulsory water restrictions, it may not be sufficient to achieve this outcome during an extended period of no rainfall. Similarly, investment in stormwater harvesting infrastructure may eliminate the risk of flooding during a 5-year average recurrence interval (ARI) storm event but it may not be sufficient to prevent flooding in a 100-year ARI storm.

Risk is therefore an important component of decision making and examining how individuals make choices when faced with risk on single or multiple attributes helps in providing the appropriate value for the benefits provided by stormwater management projects. Gangadharan *et al.* (2013a)[94] use the methodology of economic experiments to understand how individuals' risk preferences affect what attribute levels they choose and whether these choices are correlated across different attributes. Economists increasingly rely on experiments to evaluate new institutions or policy instruments. Experiments are particularly relevant when i) instruments to be evaluated work through influencing human behaviours that cannot be easily predicted by theoretical modelling, ii) there are insufficient field data available to evaluate an instrument using econometric techniques.

The objective of experimental economics is to study how people act when faced with a range of economic scenarios. An ideal experiment has a limited number of variables, while other factors are held constant. This allows the effects of the variable of interest to be disentangled from everything else and it helps to establish causality. The use of computers often allows a greater degree of control, as the institutions and interface can be exactly replicated in different sessions. Computers also facilitate anonymity and allow complex, real-time trades and interactions.

## Investing in Water Sensitive Cities

Much of the decision-making around water infrastructure investment and design, at all levels within the water sector, has taken place in the context of water as an undifferentiated commodity (**Figure 33**). Critical water supply shortages during the last decade and future vulnerability in the face of ongoing climate change, population expansion/urban development and degrading waterways, challenge the traditional calculus of value and risk across all levels of water infrastructure investment decision making.

Emerging from this research is the common requirement for a better understanding of the non-market costs and benefits (values) related to alternative technologies (i.e. stormwater harvesting, treatment and reuse) when compared to traditional systems.

Measuring the full impact of any investment option in any given context requires a shift to value-based decision making across both space and time so that the full spectrum of costs and benefits, including the flexibility and resilience of systems, can be taken into account (**Figure 34**). If we are to move towards a Water Sensitive Community, our decision making processes now demand a new and alternate approach to valuing water and its associated investments.

*Measuring the full impact of any investment option in any given context requires a shift to value-based decision-making across both space and time so that the full spectrum of costs and benefits, including the flexibility and resilience of systems, can be taken into account.*

[94] Gangadharan, L., Harrison, G., Leroux, A., and Raschky, P. (2013a). Multi-attribute risk aversion in charitable giving. EAERE 20th Annual Conference, Toulouse and ESA World Meetings, Zurich.


**Figure 33.** Water infrastructure investment decision making environment when water is an abundant resource.


**Figure 34.** Water infrastructure investment decision making environment when future water availability is uncertain.

Four key actions are recommended in the formulation of a more rigorous method of economic evaluation of Water Sensitive Cities' initiatives:

1. **Incorporate Non-priced Impacts**

When considering different water infrastructure investment options into the future, decision makers should not only attempt to incorporate priced impacts of any proposed investment, but also non-priced impacts for parameters like liveability, sustainability, flexibility, resilience, stream hydrology, urban microclimate, and community wellbeing using non-market valuation techniques. Where real choices and behaviour of individuals with respect to water management may be observed, revealed preference valuation methods are preferred. For example, the life satisfaction approach may be used to assess the effect of water amenities on social capital and individual wellbeing. A good example of this is recent research reported in Raschky and Rivers (2012)[95] which measures the utility consequences of major flash floods in Australia from 2001-2008.

Utility consequences of flash flooding events on experienced wellbeing include psychological or intangible costs such as inconvenience and disruption; fear; stress and anxiety; and sense of loss. The empirical analysis of Raschky and Rivers (2012)[95] combines two sources of data: The main source is the household-level survey data from seven waves (2002-2008) of the Household, Income and Labour Dynamics in Australia (HILDA) survey. HILDA is a household-level longitudinal survey of 7,682 households that is nationally representative for Australia except for more remote areas. This dataset is combined with another dataset that contains detailed information about actual flash flood events in Australia. The raw data stem from the Australian Attorney General's Department, Emergency Management Disaster database. This database is a collection of all natural and non-natural disasters dating from 1622 to the present. Based on the location information in this raw dataset, Raschky and Rivers (2012)[95] assigned each flash flood event an exact position that matches with HILDA's statistical unit of classification. Multivariate regression methods are then used to estimate the marginal effects of flash floods, income and social capital on self-reported life satisfaction. Combining the estimated coefficients of these three variables enables the calculation of utility loss that an individual suffers from an average flash flood and estimation of a monetary value of this utility loss.

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[95] Raschky, P.A. and Rivers, G. (2012). Valuing flash floods and the role of social capital using the life satisfaction approach, *mimeo*, Department of Economics, Monash University, Melbourne.

A number of non-market benefits associated with stormwater harvesting are not easily observed through real choices and behaviour. However, a stated preference valuation method may be used to value these benefits. Of course, while using any of these valuation methodologies, decision makers must bear in mind that the context of the proposed infrastructure is important, and that markets and prices are absent for a reason, so any non-market valuation method employed needs to pass a 'reasonableness' test. A common criticism of non-market valuation techniques is that inferences are often drawn from limited datasets. Values derived from stated preferences may suffer from hypothetical bias. Hypothetical bias may be minimised through careful selection of the survey method, for example by using conjoint choice analysis, and survey design. Gangadharan *et al.* (2013b)[96] have designed a novel choice experiment in which they address the issue of hypothetical bias as well as the more complex aspect of determining the willingness to pay for multiple attributes of water management. At the beginning of the choice experiment the respondents are told that one of their choices will be randomly picked for real, i.e. the respondent has to pay the price of his or her chosen option in the randomly picked set. An example of a potential choice set is shown below (**Figure 35**). Respondents are asked to choose one of the three options (Status Quo, Option A or Option B) in each set. Each option differs by attribute levels (for example, good vs. bad stream health) and the associated cost to implement this option. Individual respondents are asked to make a number of choices. Their decisions simply reflect individual pay-offs between different attribute levels and the associated costs. These trade-off choices are then used to calculate the monetary values that individuals assign to each attribute. The full results of this conjoint choice analysis will be presented in the next version of this blueprint.


**Figure 35.** An illustration of a decision task given as part of a choice experiment.

[96] Gangadharan, L., Leroux, A., and Raschky, P. (2013b). A field experiment on valuing attributes of storm water. Manuscript in preparation, Monash University.

### 2. Prioritise Important Parameters

Decision makers should prioritise which parameters and associated values are most important to the stated objectives of the proposed infrastructure investment, and then reflect these relative priorities in the valuation modelling exercise. For example, while improved air quality may have important societal value in an urban context, the impact of additional green vegetation on air quality in a proposed rural infrastructure context would have negligible impact on the overall valuation story for that particular investment.

Emerging priority parameters associated with urban stormwater management are linked to the earlier discussion on liveability and include, but are not limited to, the benefits of:

- micro-climate management to increase resilience to future extreme heat conditions and reduce heat related morbidity and mortality;
- green and blue natural landscapes on mental health and facilitating physical recovery from illness;
- more healthy natural ecosystem in urban environments; and
- green infrastructure in improving air quality.

### 3. Incorporate the Impact of Temporality

Decision makers should attempt to incorporate the impact of temporality on the proposed infrastructure investment into the valuation tool, since the value of any investment will depend upon the embedded ‘optionality’ that is associated with it. For example, while a large-scale, fixed, centralised water infrastructure investment will dominate ‘least cost’ decision rankings, it would be unlikely to fare so well relative to alternate flexible and/or decentralised water infrastructure investment options when temporality is added into the valuation frame.

The value of stormwater benefits could change over time and this can be captured using well-designed choice and field experiments (Gangadharan, Leroux and Raschky, 2013b)[96]. While the choice experiment as shown above in **Figure 35** allows researchers to calculate a societal, monetary value for non-market benefits associated with stormwater management, the combination with a field experiment helps reveal how this willingness to pay varies between relatively water-abundant and relatively water-scarce areas as well as how this willingness to pay would vary over time (e.g. before and after a heavy rain season).

### 4. Incorporate the Notion of Risk

Experimental evidence from the laboratory suggests that risk matters in terms of individual decision-making. Similarly, the risk of failing to deliver on some non-market benefits from stormwater harvesting could impact significantly on how these benefits are valued by individuals. It is therefore important to allow for outcome-related risk within the evaluation framework. **Figure 35** demonstrates how this could be done within the context of a choice experiment. Here two of the attributes of stormwater harvesting are subject to outcome-related risk (Water restrictions and Stream health). By changing the probability with which outcomes occur between decision tasks and observing individual’s choices, one can infer how much individuals value a reduction in outcome-related risk and how averse they may be to the correlation of outcome related risks.

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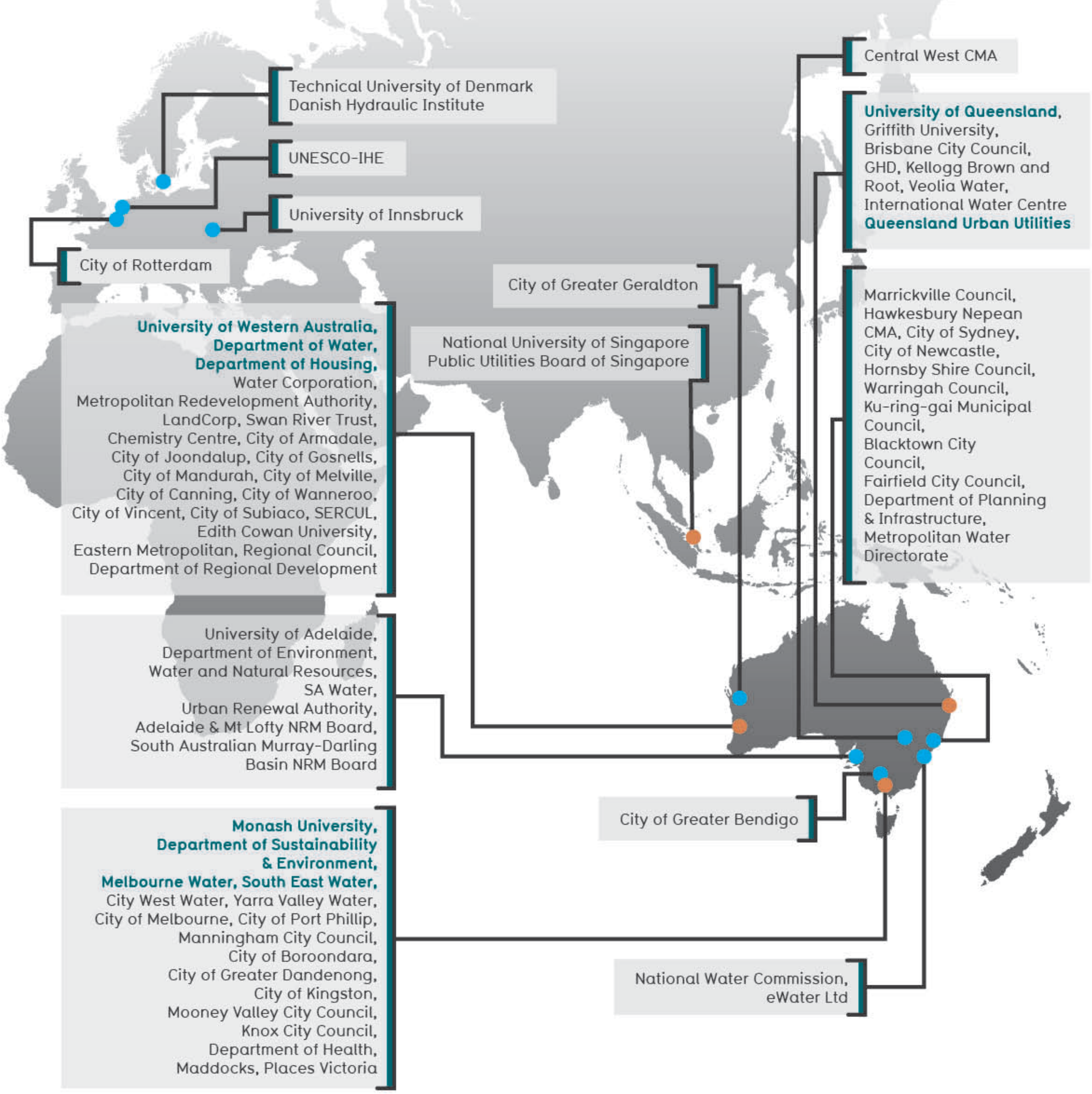
# CRC for Water Sensitive Cities: Partner Organisations

**30** Local Governments
**14** State Government Departments/Agencies **(3 Essential Participants)**
**12** Research Organisations **(3 Essential Participants)**
**8** Water Utilities **(3 Essential Participants)**
**4** Land Development Organisations
**4** Private Companies
**1** Federal Government Agency
**1** Community Group
**1** Training/Capacity Building Organisations



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