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.

blueprint2012

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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.

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

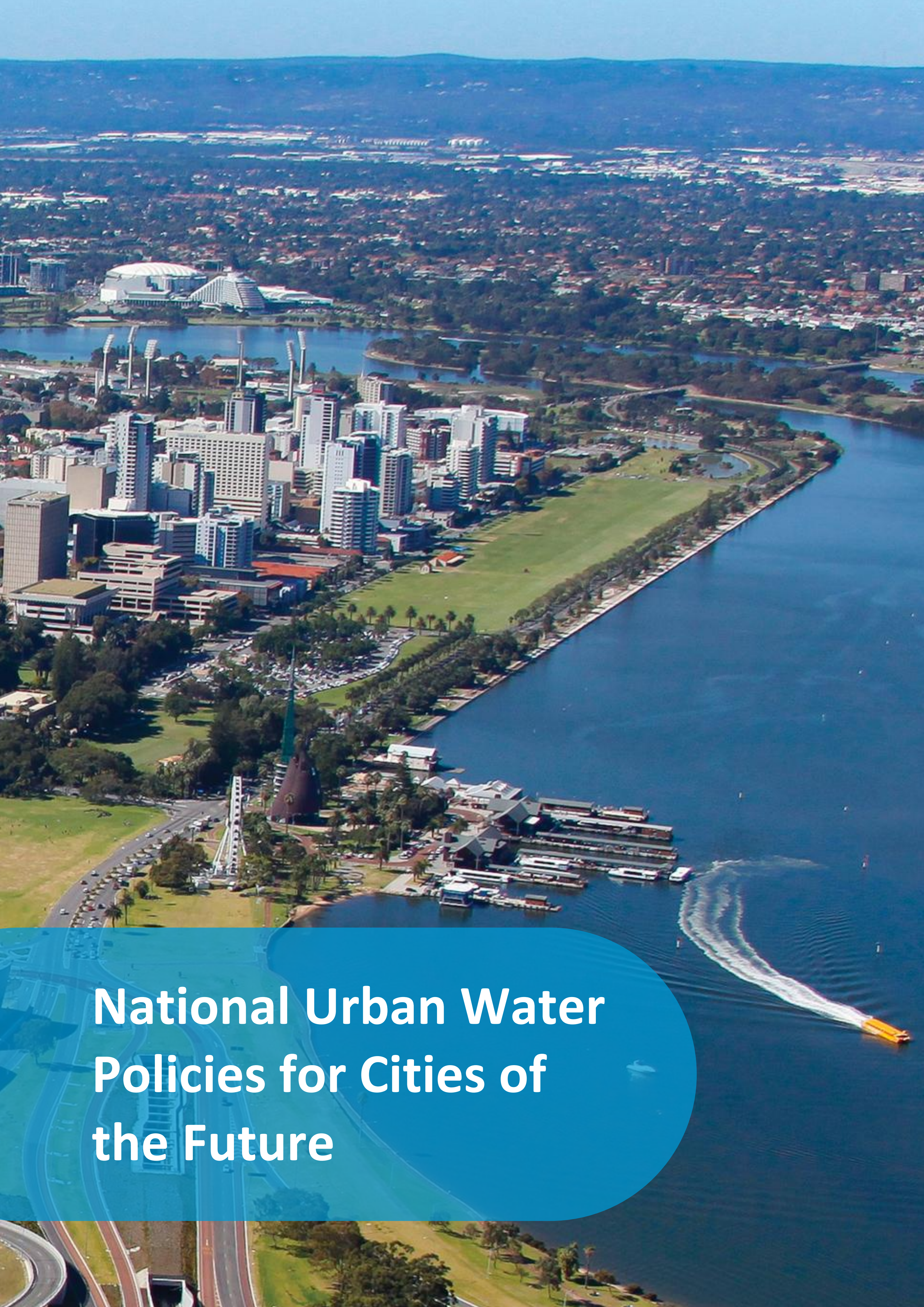
The purpose of this blueprint is to foster discussion and innovation in harnessing the potential of stormwater to overcome water shortages, reduce urban temperatures, and improve waterway health and the landscape of Australian cities in their transformation into Water Sensitive Cities.

This report is the second 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.

blueprint2012 builds on the previous version released in January 2011 and subsequent and ongoing discussions and workshops with our industry partners of the Cities as Water Supply Catchments Research Program throughout 2011.

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 2011. The blueprint outlines approaches to urban stormwater management that can be adopted today to commence the transition of our cities to Water Sensitive Cities.



National Urban Water Policies for Cities of the Future

National Urban Water Policies for Cities of the Future

Successful urban communities are extremely complex socio-physical systems that are fully integrated and 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. The ability of a city to meet current and emerging challenges in relation to achieving this harmony contributes to the strength of its economy.

The way we manage urban water, particularly urban stormwater, influences almost every aspect of our urban environment and quality of life. 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. There are several frameworks used in assessing the liveability of cities and many of them includes as criteria environment, recreation, eco-ranking based on water availability and drinkability; waste removal; quality of sewage systems; air pollution; quality of architecture; access to nature; and urban design.

The Australian Government's *Our Cities, Our Future - A National Urban Policy for a productive, sustainable and liveable future* (May 2011)[1] consolidates the various elements of productive, sustainable and liveable cities into a vision for Australian cities. Water Sensitive Cities, in which urban water cycles are designed and managed as integrated systems enmeshed with urban design and communities, form an important niche within this vision for 'cities of the future'.

The vision and concepts of a Water Sensitive City are emerging in city-shaping policies. Brisbane City Council's *WaterSmart Strategy* (2010)[2], for example, aims to guide Brisbane towards becoming Australia's most sustainable and water smart city through using *water creatively and sensitively in the design of smart spaces*.

Victoria's *Living Melbourne, Living Victoria Roadmap* (Living Victoria Ministerial Advisory Report, 2011)[3] sets a framework to transform urban water management and, in doing so, enhance Melbourne's liveability.

The Water Sensitive City requires the transformation of urban water systems from a focus on water supply and wastewater disposal (the 'taps and toilets' water utilities) to more complex, flexible systems that integrate various sources of water, operate through a combination of centralised and decentralised systems, deliver a wider range of services to communities (e.g. ecosystem services, urban heat mitigation) and integration into urban design.

Australia's Productivity Commission's (2011)[4] inquiry into the urban water sector found that the urban water sector needs economic reform to be able to make this transition. Likewise, the National Water Commission, in their 2011 *Urban Water in Australia – future directions* report[5], highlights the transformations that are required to the institutional and governance arrangements of the water sector to allow water utilities to effectively manage the more complex expectations of a Water Sensitive City.

The way we manage urban water influences almost every aspect of our urban environment and quality of life.

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: http://www.infrastructure.gov.au/infrastructure/mcu/urbanpolicy/index.aspx

2 Brisbane City Council (2010) *WaterSmart Strategy,* Brisbane City Council, Brisbane. Available at: http://www.brisbane.qld.gov.au/environment-waste/water/watersmart-strategy/index.htm

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

4 Productivity Commission (2011), *Australia's Urban Water Sector*, Report No. 55, Final Inquiry Report, Canberra. http://www.pc.gov.au/projects/inquiry/urban-water

5 National Water Commission (2011) *Urban water in Australia: future directions*, NWC, Canberra. http://www.nwc.gov.au/publications/browse-publications-on/urban-water-publications/future-directions

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 focuses on these factors through three principles (pillars), adapted from Wong and Brown (2009)[6]:

- Cities as Water Supply Catchments: meaning access to water through a diversity of sources at a diversity of supply scales;
- Cities Providing Ecosystem Services: meaning the built environment functions to supplement and support the function 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: water resources; ecosystem services for the built and natural environments; and society and urban water governance.

Following a series of practitioner envisioning workshops in Brisbane and Melbourne, Binney *et al.* (2010)[7] 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). 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.

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

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

[7] 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.

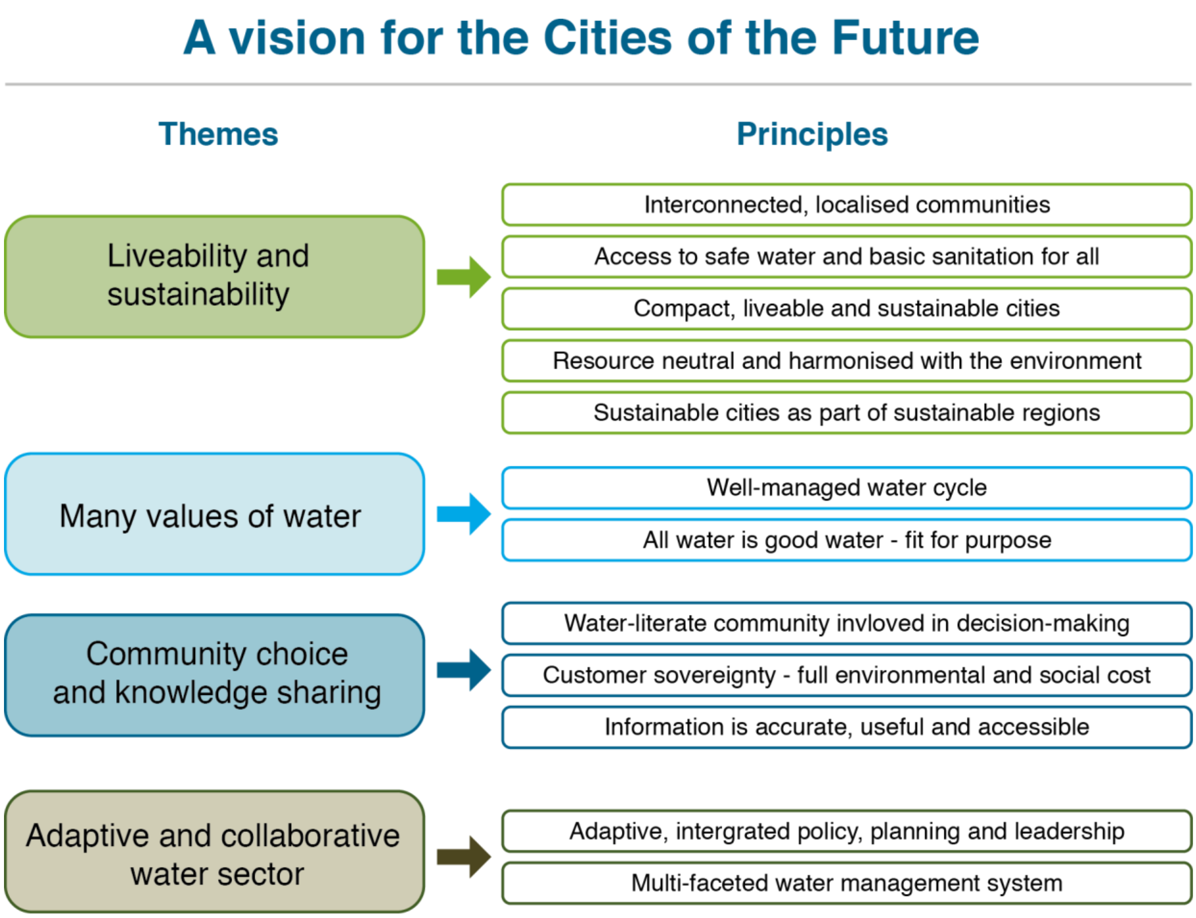


Figure 1 Principles for a City of the Future (adapted from Binney *et al*., 2010)

Table 1. Water Sensitive City attributes compared to our current urban water management paradigms. (Keath and Brown, 2009[8])

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

[8] 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 is the process and Water Sensitive Cities are the outcome. The term Water Sensitive Urban Design (WSUD) is commonly used to reflect a new paradigm in the planning and design of urban environments that are 'sensitive' to the issues of water sustainability and environmental protection. WSUD, Ecologically Sustainable Development (ESD) and Integrated Water Cycle Management (IWCM) are intrinsically linked.

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[9]) 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)[10] 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.

The words "Water Sensitive" define a new paradigm in integrated urban water cycle management that integrates the various disciplines of engineering and environmental sciences associated with the provision of water services including the protection of aquatic environments in urban areas. Community values and aspirations of urban places necessarily govern urban design decisions and therefore water management practices.

Collectively WSUD integrates the social and physical sciences and brings 'sensitivity to water' into urban design. It aims to ensure that water is given due prominence within the urban design processes.

Water Sensitive Urban Design is the process and Water Sensitive Cities are the outcome.

WSUD integrates the social and physical sciences and brings 'sensitivity to water' into urban design.

[9] 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.

[10] 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, carparks, 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, and 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.

In some cases, pollution from groundwater sources as a result of more efficient drainage attributable to the construction of drainage infrastructure has also led to the degradation of water quality in urban waterways.

The most obvious effect of urbanisation on catchment hydrology is the increase in the magnitude of stormwater 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[11]). 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.

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.

[11] 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;
- productive vegetation and increased carbon sequestration;
- improved air quality through deposition; and
- improved amenity of the landscape.

Stormwater runoff is generated across distributed areas and therefore presents the best opportunity for green infrastructure be distributed throughout the urban area for effective realisation of these multiple benefit outcomes; 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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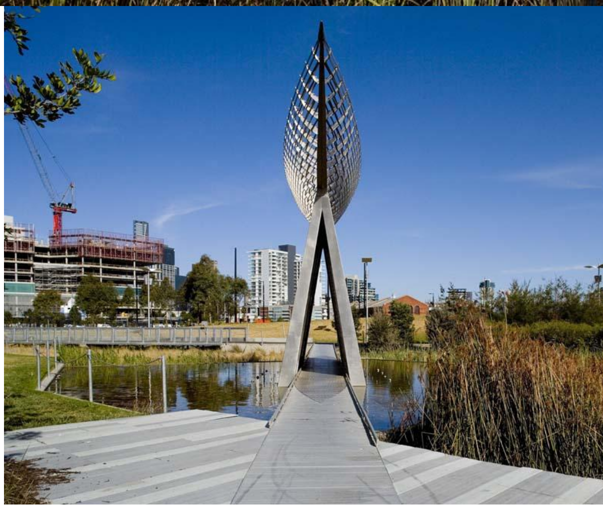

Implementing Research Insights

(Precinct Masterplanning Case Study)

Implementing Research Outcomes

(Precinct Masterplanning Case Study)

Places Victoria's (previously VicUrban) Officer development is a 340 ha greenfield site located approximately 50 kilometres south-east of central Melbourne. The Victorian Government developer's vision for Officer is to establish new benchmarks in sustainability, residential density and liveability that can be replicated in urban growth areas.

Places Victoria aspires for Officer to be a great place for people to live and work with a low environmental footprint by:

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

The town centre of the Officer development (Figure 2) is a precinct scale demonstration project of the Cities as Water Supply Catchments Program. Innovative stormwater management has the potential to support the vision and aspirations for Officer and the transition to a Water Sensitive City.

The Officer development, incorporating a designated Major Activity Centre, will ultimately incorporate homes for approximately 15,000 people and employment for approximately 5,000 people.

The case study described here provides an overview of how research insights in the following two areas have been developed and implemented as part of the Officer masterplanning and design process:

- 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.

Opportunities for research input on urban microclimate, social and institutional capacity, and the valuation of non-monetary benefits have been identified for Officer town centre, but for various reasons (including research and development timeframes) have not yet been realised.

The influence of site context and evolving development constraints on implementing research outcomes are discussed in this case study. General observations on how innovative stormwater management research can be implemented as part of future urban developments are also included.

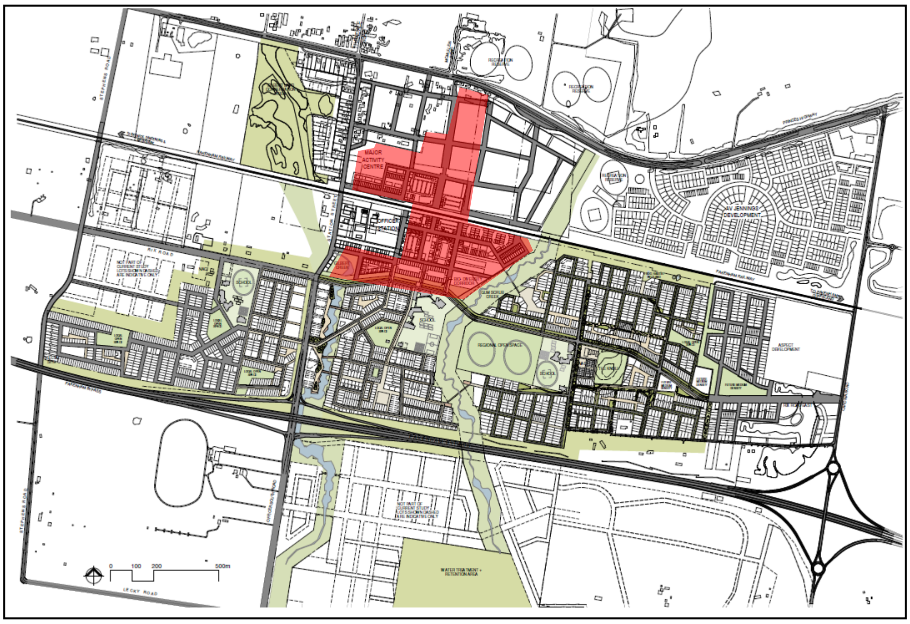

Figure 2. Places Victoria's Officer Development Site – Illustration Only (Source: Places Victoria)

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.

Ecological Sponges

An assessment of in-stream ecological responses to a range of urban development approaches (Walsh & Fletcher, 2010[12]) predicted that conventional urban development (meeting current environmental protection requirements) within the Gum Scrub Creek catchment would likely result in the severe degradation or loss of in-stream ecological values. A workshop with key project stakeholders conducted as part of the assessment 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 research program subsequently identified that conditions approaching the pre-development flow regime for the developed catchment could be achieved by incorporating ecological sponges representing 5-6% of the contributing catchment.

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

The form and vegetation of a swampy anabranch channel provides a natural template for the development of the riparian sponge concept (Figure 3).

Figure 3 Remnant Swampy Woodland at Devilbend Creek, Mornington Peninsula. The form and vegetation of this swampy anabranch channel provides a natural template for the development of the riparian sponge concept. (Photograph: Geoff Vietz)

[12] 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.

The riparian sponge would detain all low flows from the upstream urban catchment (nominally up to the 3 month average recurrence interval flow), allowing stormwater to be detained and subsequently evapotranspire from, or slowly filter through, the riparian sponge media and vegetation. Where in-situ soils allow, exfiltration of detained 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). Stormwater pre-treatment (for example, through streetscape swales or sediment ponds) would protect the ecological 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 estimated 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 harvested stormwater is 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 high nitrogen concentration) entering the waterway. The harvesting of stormwater will reduce the area required for the ecological sponges.

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 water security and environmental protection without the need to construct large storages to secure a high reliability of supply.

Spatial requirements for different ecological treatment systems (biofiltration and wetlands) were assessed. Possible spatial configurations and the likely micro-climate benefits were also considered (Figure 4). 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.

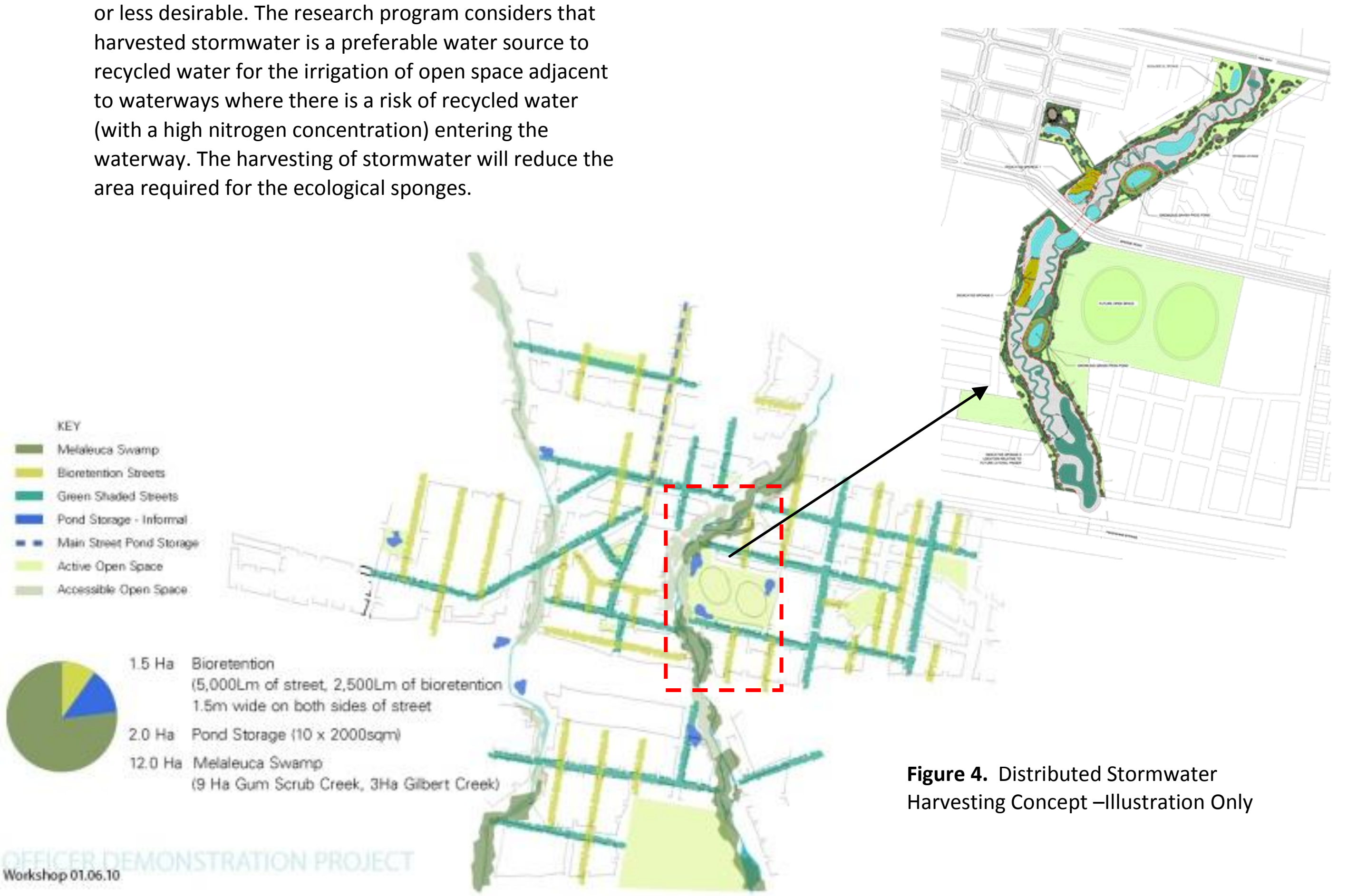

Figure 4. Distributed Stormwater Harvesting Concept –Illustration Only

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 is currently being 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 treatment system incorporating green infrastructure 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

Ecological 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 ecological sponges to be incorporated within the riparian corridor rather than developable land (we refer to these as Riparian Sponges). The strategy nevertheless include integrating 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 ignores the contribution of riparian sponges in meeting water quality and quantity objectives; however, it enabled the design and development approval process to proceed without incorporating and obtaining approval for 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.

The relatively flat topography of the site (particularly in the east-west direction) poses a common urban development challenge. With a conventional stormwater drainage design approach, there will be a 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 drainage system was adopted for this very flat site. However, the design of the waterway corridor and the innovative use of elongated sediment ponds connected to the riparian sponges helped address this challenge. The incorporation of adequate ecological sponge area to achieve the hydrological objectives could only be achieved because of the space available along the riparian corridor.

Collaborative and constructive engagement between the client, project consultants and researchers enabled a modified ecological sponge configuration to be developed to demonstrate the application of the sponge concept within the developable area and outside the riparian corridor. There is a corresponding loss of developable land but an increased distribution of ecological functions throughout the development.

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.

Notwithstanding this, the continuing commitment of Places Victoria to the aspirations of the Officer development and the aims of the research program has enabled continued investigation of stormwater harvesting options. The possibility of a pilot project within the Officer town centre is currently being explored. This project would demonstrate 'proof of concept' for a treatment process incorporating green infrastructure (biofiltration) to take stormwater to potable standard. A facilitated strategic options analysis process (developed by the Victorian Government Department of Treasury and Finance) has been undertaken for the pilot project, with the outcomes currently being finalised and considered by key stakeholders.

Observations

The case study has thus far demonstrated that high standards of ecological protection and provision of ecosystem services can be attain in greenfield developments without significant reduction in developable areas, even on very flat sites.

The innovative concept of ecological 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. This case study highlight the strategic importance of spatial planning in facilitating the implementation of water sensitive cities innovations.

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 of the research must be maintained to ensure that 'proof of concept' can be achieved for the research initiatives being demonstrated.

The outcomes of the project at Officer have not necessarily attained all of the 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 in relation to 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

Stormwater Management in a Water Sensitive City

Pillar 1: Cities as Water Supply Catchments

Stormwater is a precious resource at a diversity of supply scales

Pillar 1: Cities as Water Supply Catchments

Stormwater is a precious resource at a diversity of supply scales

Many Australian cities and towns are constructing stormwater harvesting schemes aided by Federal and State government funding. Systems that deliver water for both restricted and unrestricted irrigation of communal green spaces are particularly popular.

There remain a number of barriers that prevent wider applications of harvested stormwater, the most important being:

- Our limited understanding of the hazards of utilising urban stormwater as an alternate water source. In particular, there are very few datasets which have quantified the levels of pathogens and chemicals of concern to human health in stormwater;
- Minimal knowledge on pathogen and chemical removal in low-energy and affordable stormwater treatment systems that are based on the proven concepts of WSUD;
- Non-existent validation procedures for these types of stormwater treatment systems.

Recent research by the Cities as Water Supply Catchments Research Program has focused on these issues with key learnings outlined in ***blueprint2012***.

When designing stormwater harvesting systems with the aim of providing safe water for specific end-uses, we employ a generic risk assessment procedure (AGWR-SHR; NRMMC et al., 2009a[13] ; AGWR-MHER; NRMMC et al., 2006 [14]). This procedure has five main steps, all leading to knowledge about the required level of treatment (Figure 5).

blueprint2011 addressed the first component of this framework ("Identify issues") and provided an overview on current guidelines for the use of stormwater as a alternate water source. In addition, blueprint2011 also outlined present uncertainties in predictions of future climate scenarios in relation to rainfall and potential evapotranspiration. .

In ***blueprint2012,*** we have broadened our scope and begin to fill critical knowledge gaps in other parts of this framework. This document presents an overview of the hazards identified in urban stormwater, with particular attention being paid to micro-pollutants and pathogenic organisms. This is followed by a summary of key outcomes from research relating to the mitigation of these hazards using stormwater treatment systems, some of which are based upon the proven concepts and technologies for removal of suspended solids and nutrient in urban stormwater.

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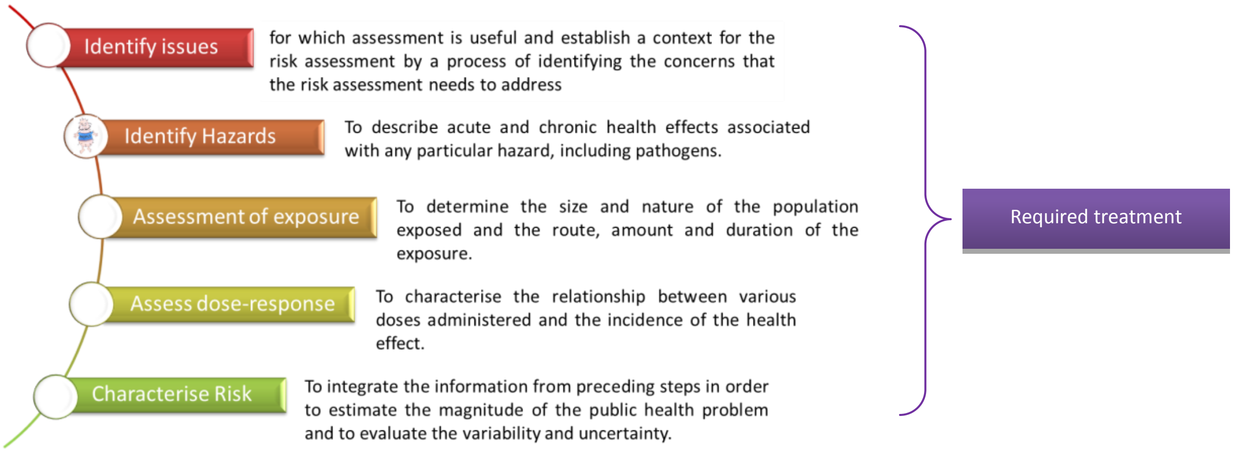

Figure 5. *The five steps in the design of stormwater harvesting schemes*

[13] 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.

[14] 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.

Current Guidelines

The Australian Guidelines for Water Recycling (AGWR) developed under the National Water Quality Management Strategy (NRMMC *et al*., 2009a[13]) at present provide the key guidance for stormwater quality and treatment. The AGWR, Managing Health and Environmental Risk - Phase 1 (AGWR-MHER; NRMMC *et al*., 2006[14]) provide fundamental guidance of managing health risks and should be used in conjunction with the relevant AGWR, Phase 2 document.

However, the most appropriate Phase 2 document will differ amongst stormwater harvesting schemes. Determination of the most relevant document to be used will be informed by taking into consideration the end use application and whether the stormwater has been stored in an aquifer prior to reuse.

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.

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[14]	• present the risk management framework including how to conduct Quantitative Microbial Risk Assessment (QMRA) • outline requirements for validation of treatment systems and monitoring requirements.
Australian Guidelines for Water Recycling: (Phase 2) Augmentation of Drinking Water Supplies[15]	• consider chemical and pathogen risk but have been established based on reclaimed wastewater being the source water • consider indirect potable reuse • 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[13]	• are applicable to new small-medium stormwater harvesting systems involving non-potable end use scenarios • 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 • 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[16]	• provides guidance on managing risks associated with water that has been stored in aquifers prior to reuse • 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.

[15] 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.

[16] 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[15]) 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[13]; 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[13])
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)[15]
Recreational exposure	• refer to Australian Guidelines for Managing Risks in Recreational Waters (NHMRC, 2008[17])

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

Quality of 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.). This is because there has been very limited monitoring of stormwater quality for pollutants of concern to human health, and hence there is insufficient information to enable sound risk assessment of identified chemical and microbial hazards.

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:

1. From artificial stormwater conveyance systems (including constructed natural drains) before interaction with other water sources or discharging into natural receiving water environments (e.g. streams); indeed, from a stream ecology view-point, this is often the preferred case (see Pillar 2)
2. From waters that predominantly receive stormwater (e.g. creeks, streams). Stormwater harvesting in this way can still benefit waterway health downstream of the harvesting point but is less desirable as the section of waterway upstream of the harvesting point would have been impacted by the changed hydrology caused by catchment urbanisation. 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.

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.

Pathogens

Pathogens are currently believed to present the most severe acute human health risk for most stormwater applications. Pathogens detected in stormwater drains and receiving waters in urban Australian catchments are presented in Table 4. 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.

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 understand pathogen variability. As a consequence, conservative estimates of pathogen concentrations are often adopted for risk assessments. This will likely result in requirement for excessive treatment but is considered necessary in light of the current low understanding of pathogen variability to ensure stormwater harvesting is safe.

The information provided here demonstrates that pathogens may be present in urban stormwater and may infect via other exposure routes than ingestion (which is currently the focus in most guidelines); this preliminary observation suggests that it may be prudent to include inhalation and dermal exposure routes in future risk assessments, especially for certain end-uses where these exposure routes are prevalent (such as spray irrigation, car washing, etc.).

Our understanding of pathogen risks in stormwater is very limited; therefore conservative estimates of pathogen concentrations should be adopted for risk assessments

Table 4. *Pathogens of human health concerns detected in stormwater in urban Australian catchments*

Pathogen	Route of exposure	Location	Tot. samples	Detects	Comments	Reference
Adenovirus	Ingestion, inhalation	Stormwater drain	6	6	Storm event	18
		Receiving water	11	4	Dry weather	19
			12	11	After storm event	
Campylobacter sp.	Ingestion	Stormwater drain	54	48	Dry weather	20
			5	2	Dry weather	21
			6	6	Storm event	18
		Inlet to reedbed filter	3	2	Storm event	22
			6	1	Storm event	23
		Receiving water	11	10	Dry weather	19
			12	12	Storm event	
			11	11	Dry weather	24,*
			48	2	Storm event	
			6	5	Storm event	25,*
Cryptosporidium	Ingestion	Stormwater drain	5	2	Dry weather	21
		Inlet to reedbed filter	6	5	Storm event	22
		Receiving water	11	9	Dry weather	24,*
			48	30	Storm event	
			6	5	Storm event	25,*
Giardia	Ingestion	Inlet to reedbed filter	1	1	Storm event	22
		Receiving water	11	5	Dry weather	24,*
			8	36	Storm event	
			6	4	Storm event	25,*
Legionella sp.	Inhalation	Stormwater drain	54	1	Dry weather	20
Rotavirus	Ingestion, inhalation	Inlet to reedbed filter	1	0	Storm event	22
Staphylococcus aureus	Dermal contact, ingestion, inhalation	Stormwater drain	54	54	Dry weather	20

* Data used to inform AGWR-SHR

[18] On-going research: Cities as Water Supply Catchment Program in collaboration with Urban Water Security Research Alliance
[19] Sidhu J.P.S., Hodgers L., Ahmed W., Chong M. and Toze S. (2011) Prevalence of human pathogens and indicators in stormwater runoff in Brisbane, Australia. *Water Research* (*submitted*).
[20] Lampard J., Chapman H., Stratton H., Roiko A. and McCarthy D.T. (2012) Pathogenic bacteria in urban stormwater drains from inner-city precincts. Proceeding of the 7th International Conference on Water Sensitive Urban Design, 21-23 March 2012, Melbourne.
[21] Warnecke M. and Ferguson C. (2010) Characterisation of human health risks derived from stormwater. Report prepared by Ecowise Environmental for the Smart Water Fund.
[22] Page D. and Levett K. (2010) Stormwater harvesting and reuse risk assessment for various end uses. CSIRO: Water for a Healthy Country National Research Flagship. Accessible at http://www.clw.csiro.au/publications/waterforahealthycountry/2010/wfhc-stormwater-reuse-risk-assessment.pdf
[23] Page D., Vanderzalm J., Barry K., Levett K., Kremer S., Neus Ayuso-Gabella M., Dillon P., Toze S., Sidhu J., Shackleton, M., Purdie M. and Regel R. (2009) Operational residual risk assessment for the Salisbury stormwater ASTR project. CSIRO: Water for a Healthy Country National Research Flagship. Accessible at http://www.csiro.au/files/files/psgp.pdf
[24] AWQC. (2008) Pathogens in stormwater. Report prepared by P. Monis for the NSW Department of Environment and Climate Change and the Sydney Metropolition Catchment Management Authority. Australian Water Quality Centre, Adelaide. Contract AWQC 070108.
[25] Roser D. and Ashbolt N.J. (2007) Source water quality assessment of pathogens in surface catchments and aquifers. Cooperative Research Centre for Water Quality, Research Report 29.

Chemicals

Chemical hazards in stormwater potentially pose a human health risk. This is mostly the case where high and/or long-term exposure of individuals can be anticipated such as when used for potable purposes.

Chemicals are not extensively covered in the Australian Guidelines for Water Recycling: (Phase 2) Stormwater Harvesting and Reuse (Table 2) because these guidelines specifically focus on low exposure end-uses, such as drip irrigation. They are, however, almost always relevant to the ecological health of receiving waters (Table 3)

A literature review (Lampard *et al.*, 2010[26]) showed that exceedances of the AGWR-ADW guideline values (NRMMC *et al*., 2008[15]) 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.

Limited data to date from the Cities as Water Supply Catchments program (Figure 6 and Figure 7) is comparable to previous findings (e.g. Fletcher *et al.*, 2004[27]). Once the dataset is completed it will be further analysed with regards to linking the observed water quality to catchment land use and other characteristics.

The abundant list of pollutants listed in the AGWR-ADW is tailored to the water quality hazards likely to be encountered in sewage-derived water sources. There are a high number of miscellaneous organic compounds that have been reported in stormwater that are not addressed explicitly in the current regulation. In addition, there have been concerns voiced about 'unknown unknowns'. To overcome this, the Cities as Water Supply Catchments program employs a battery of in vitro bioanalytical tools in a two tier approach to evaluate stormwater for the presence of potentially hazardous substances. This option evaluates the biological adverse effect rather than individual compound concentrations (which can be costly and does not give any indication of toxicity). While results to date are preliminary only, they can use to compare different urban water sources.

Figure 8 shows results on baseline toxicity (general toxic effects as a sum of the organic compounds present) between stormwater and water from a wide range of other sources. The preliminary data on chemicals suggests that untreated stormwater is comparable to treated sewage and that whenever stormwater is planned to be used for high exposure scenarios such as potable use, extensive tertiary treatment similar to comparable schemes based on secondary effluent water reuse should be considered.

Preliminary data on chemicals suggests that untreated stormwater is comparable to treated sewage and that whenever stormwater is planned to be used for high exposure scenarios such as potable use, extensive tertiary treatment similar to comparable schemes based on secondary effluent water reuse should be considered.

[26] 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.
[27] Fletcher T., Duncan H., Poelsma P. and Lloyd S. (2004) Stormwater flow and quality, and the effectiveness of non-proprietary stormwater treatment measures – a review and gap analysis. CRC Catchment Hydrology, Technical Report 04/8.

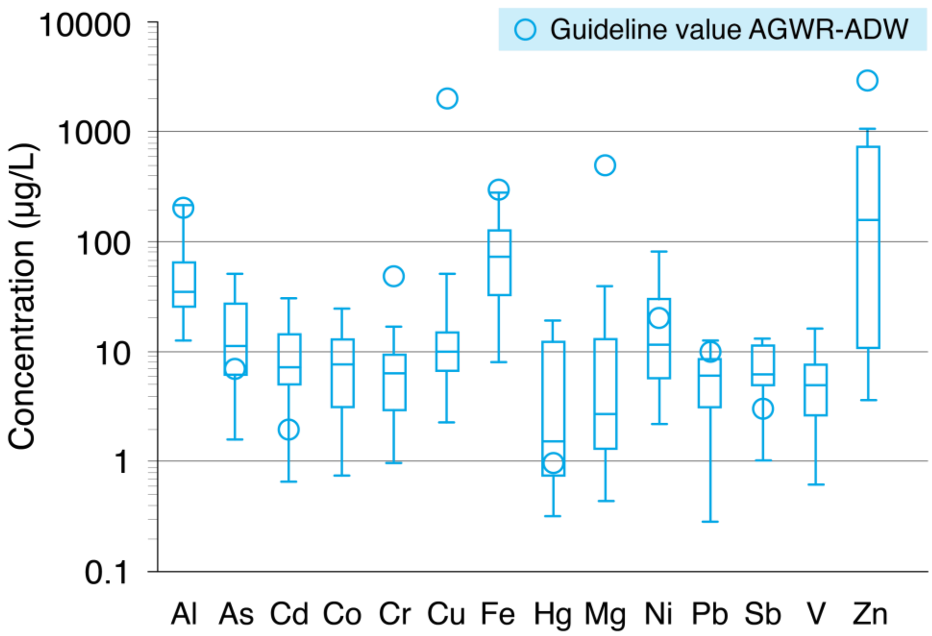

Figure 6. Dissolved metal event mean concentrations in stormwater samples from 4 stormwater sites in QLD, NSW and VIC (total n=15). Box represents 25%-50% and 50%-75% quartiles, whiskers mark the 5% and 95% range. AGWR-ADW guideline values are marked as circles (note that Co and V do not have a guideline value).

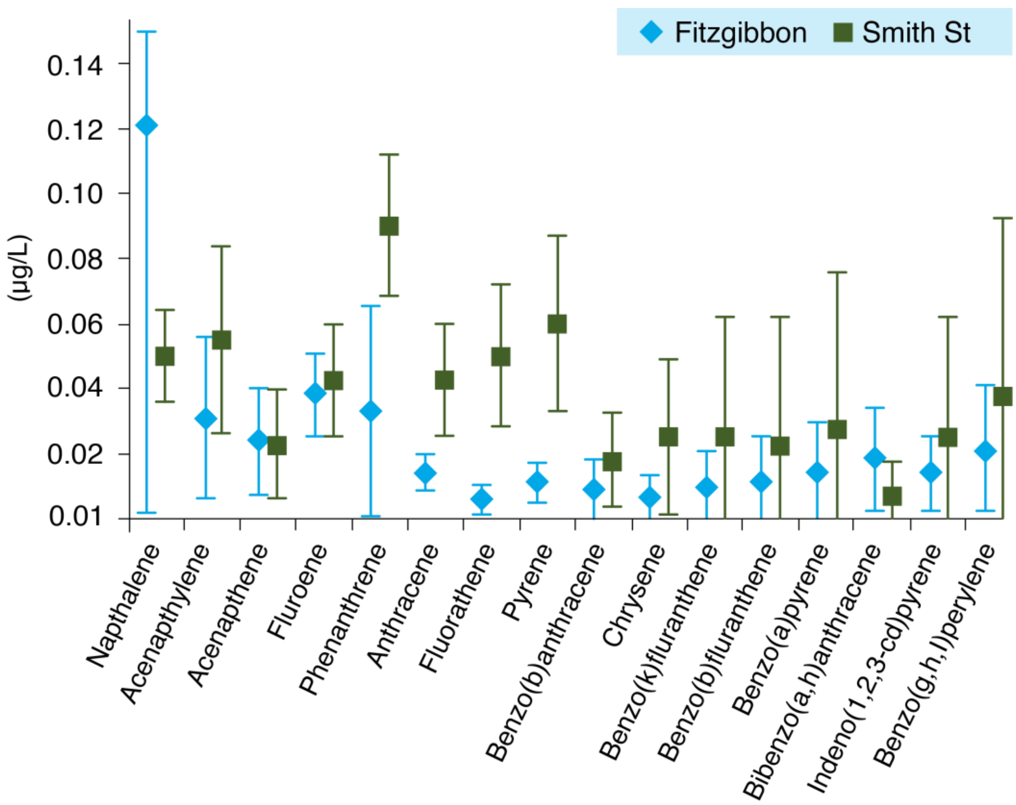

Figure 7. Dissolved PAH event mean concentrations for Fitzgibbon site (QLD, n=4) and Smith Street site (VIC, n=4). Error bars show the variation between 4 sampling events at each site (± one standard deviation). As can be seen different catchments have different contamination patterns, even within the same contaminant group.

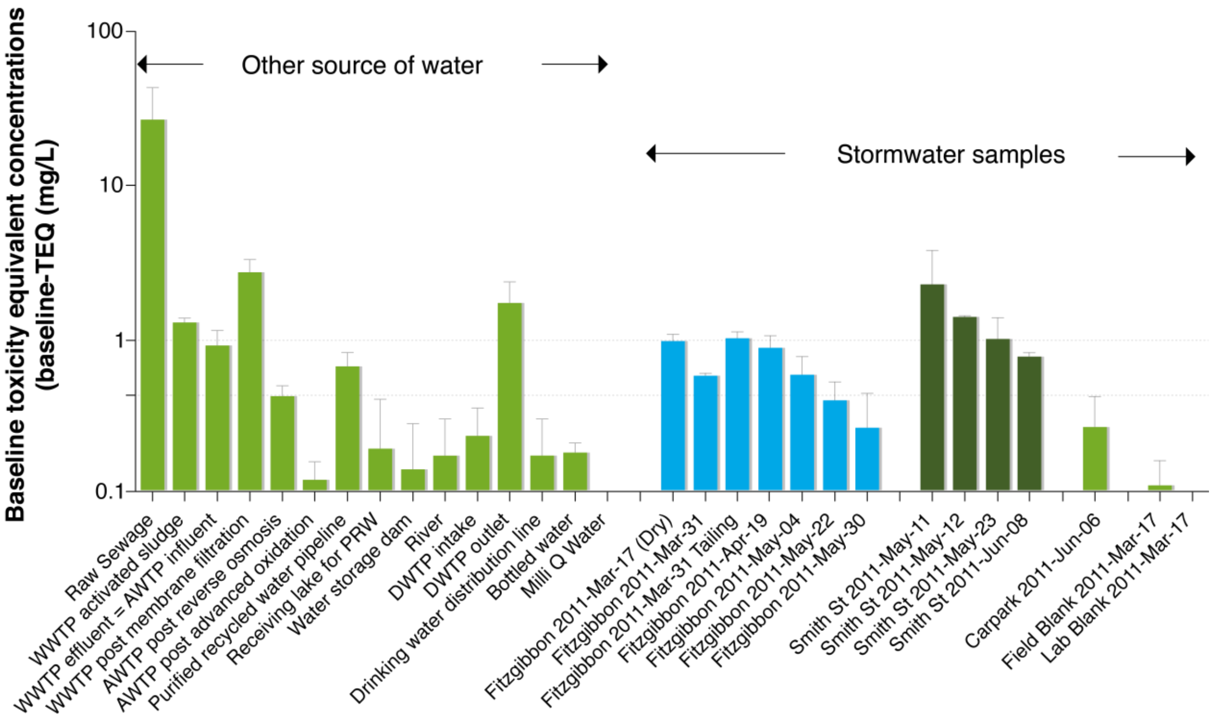

Figure 8. Baseline Toxicity of stormwater samples compared with various sources of water. Data of other water sources is cited from Macova *et al*. (2011)[28].

[28] Macova M., Toze S., Hodger L., Mueller J.F., Bartkow M. and Escher B. (2011) Bioanalytical tools for the evaluation or organic micropollutants during sewage treatment, water recycling and drinking water generation. *Water Research,* 45: 4238-4237.

Technologies for Mitigating Risks

Stormwater harvesting systems should be designed to safely collect, treat, and store stormwater. Stormwater collection can be done using traditional gutter-pipe-channel systems or linear WSUD systems, such as swales and biofilters. When the reduction of water losses is a priority, WSUD technologies systems should be smaller than 5% of the impervious catchment area, to reduce evapotranspiration volumes, while the underlying in-situ soil should be of low porosity or the system should be lined.

If runoff collection and storage is by means of a local shallow aquifer, the WSUD systems should not be lined and infiltration into the aquifer should be actively promoted after sufficient treatment to ensure appropriate stormwater quality and protection of the receiving environment. The risks of infiltration systems in close promixity to buildings and other structures should be also considered in this process.

Aquifer Storage and Recovery should be explored as the first preference when site conditions are favourable since such schemes are usually the most cost effective. Schemes involving other form of storages (e.g. underground and 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[29]. The optimal volumetric reliability for sites where the mean annual runoff volume is also a limiting factor would be much lower. The site rainfall variability and demand regime (i.e. seasonal or non-seasonal) are the most important factors in determining the storage size required.

In determining the optimal storage volume for stormwater harvesting, a detailed storage behaviour modelling analysis using a 10 year time series is recommended.

A treatment train should be constructed for stormwater treatment and harvesting. The appropriate elements of the treatment train depend on the intended end-uses as summarised in Table 5. The guidance on treatment train however reflects the limitations imposed by current guidelines, our current understanding of the levels of harmful pollutants in stormwater, how these are removed through treatment systems and our level of WSUD technological development.

One of the important role of WSUD stormwater treatment elements is the reduction of the highly temporally variability of pollution concentrations found in stormwater to predictable and consistently narrower range of pollutant concentrations. They are thus effective systems for treating stormwater before storages in all schemes to maintain good water quality during storage and reduce further treatment cost before use, i.e.

- 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 further treatment is also necessary.

Since the publication of *blueprint2011*, we have continued to focus our research efforts at advancing stormwater biofilters (Figure 9) and filters 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 5).

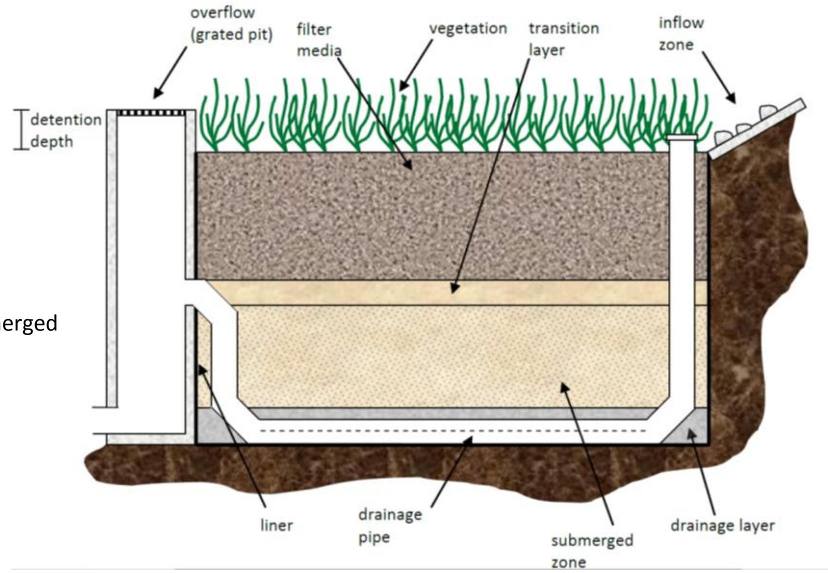

Figure 9. Biofilter design with submerged zone as recommended by FAWB (2009)[30]

[29] 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.

Table 5. 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[13]). The conservative uses of stormwater treated with WSUD technologies reflect those imposed by current guidelines (***blueprint2011***).

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 ****	
Pre-treatment	Screens					Before storage
	GPTs					
Preliminary	Oil and sediment separators					
	Swales*					
	Tanks**					
	Sediment basins					
	Ponds and lakes**					
Secondary	Infiltration systems*					
	Wetlands**					
	Biofilters*,**					
	Stormwater filters					
Advanced***	Sand filters					After storage
	Aquifers**					
	Suitable drinking water technologies (e.g. microfiltration, reverse osmosis, and advanced oxidation)					

* Could also be used for collection

** Could also be used for storage

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

**** 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.

Stormwater Biofilters

Pathogen Removal

Biofilters designed in accordance to guidelines developed by the Facility for Advancing Water Biofiltration (FAWB, 2009[30], Figure 9) have been tested both in laboratory and field conditions for removal of stormwater microorganisms, focusing primarily on pathogen indicators and to a small extent on reference pathogens. Key preliminary observations are outlined below with experiments ongoing, (Chandrasena *et al*. 2011[31], 2012a[32], 2012b[33]):

- Vegetation types can significantly influence pathogen removal (Figure 10). Certain plant exudates can be antimicrobial, which directly affects the die-off of stormwater microorganisms within the biofilters. In a laboratory scale experiment, biofilters with *Leptospermum continentale* showed consistently over 1.5 log reduction of *E. coli*, which was generally much higher than for other tested plants. This was especially the case after biofilters experienced longer dry weather periods (Figure 10), showing that this plant may have mechanisms of increasing the die-off rate of microorganisms between events. Leptospermum continentale was also found to be very effective in removal of nutrients[34].
- Presence of submerged zone positively affects the overall removal of pathogens (Figure 11) – Submerged zone water is generally of higher quality than water treated during an event, since water detained in the submerged zone is afforded additional treatment during the intervening dry periods (this is the case for almost all pollutants). This benefit is more pronounced for the more frequent events with smaller rainfall/runoff volumes.
- Stormwater detention within biofilter promotes microorganism die-off and this can be particularly significant during inter-event period

While the above findings were confined to observations of *E. coli* behaviour in biofilters, it is encouraging to note that field data collected so far have shown that the removal of *Campylobacter*, a pathogenic bacteria, is comparable (Figure 12). The field tests showed that current biofiltration design with a saturated zone (as per FAWB guidelines, 2009[30]) has the capacity to provide around a 1 log reduction of *Campylobacter*, even when designed and vegetated for optimal nutrient reduction (Chandrasena *et al*., 2012b[33]).

Very preliminary studies of Protozoan (*Clostridium perfringens*) removal , both in lab and field conditions, have shown over 1.5 log reduction in all tested biofilter types.

The removal of *FRNA coliphage*, which is a commonly used indicator for viruses, in all lab and field tests showed around 3 log reductions. However, these findings are still to be confirmed against real viruses since the measured *Adenoviruses* and *Enteroviruses* were barely detected in both the inflow and outflow of the field study.

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[30] Facility for Advancing Water Biofiltration (2009), Stormwater Biofilration Systems - Adoption Guidance, Monash University, June 2009, ISBN 978-0-9805831-1-3

[31] Chandrasena K.K.G.I., Deletic A., Ellerton J. and McCarthy D.T. (2011) Removal of *Escherichia coli* in Stormwater Biofilters, *12th International Conference on Urban Drainage (ICUD). Porto Alegre, Brazil, Sept 11-16, 2011.*

[32] Chandrasena K.K.G.I., Deletic A., Ellerton J. and McCarthy D.T. (2012a) Advancing stormwater biofilters for *Escherichia coli* removal, *Water Science and Technology (in press).*

[33] Chandrasena K.K.G. I., Filip S., Zhang K., Osborne C., Deletic A. and McCarthy D.T. (2012b) Pathogen and Indicator Microorganism Removal in Field Scale Stormwater Biofilters. *7th Int Conference on WSUD. Melbourne, Australia, Feb 21-23, 2012.*

[34] Pham, T., Payne, E.G., Fletcher, T. D., Cook, P. L., Deletic, A. and Hatt, B. E. (2012). The influence of vegetation in stormwater biofilters on infiltration and nitrogen removal: preliminary findings. 7th International Conference on Water Sensitive Urban Design. Melbourne, Australia.

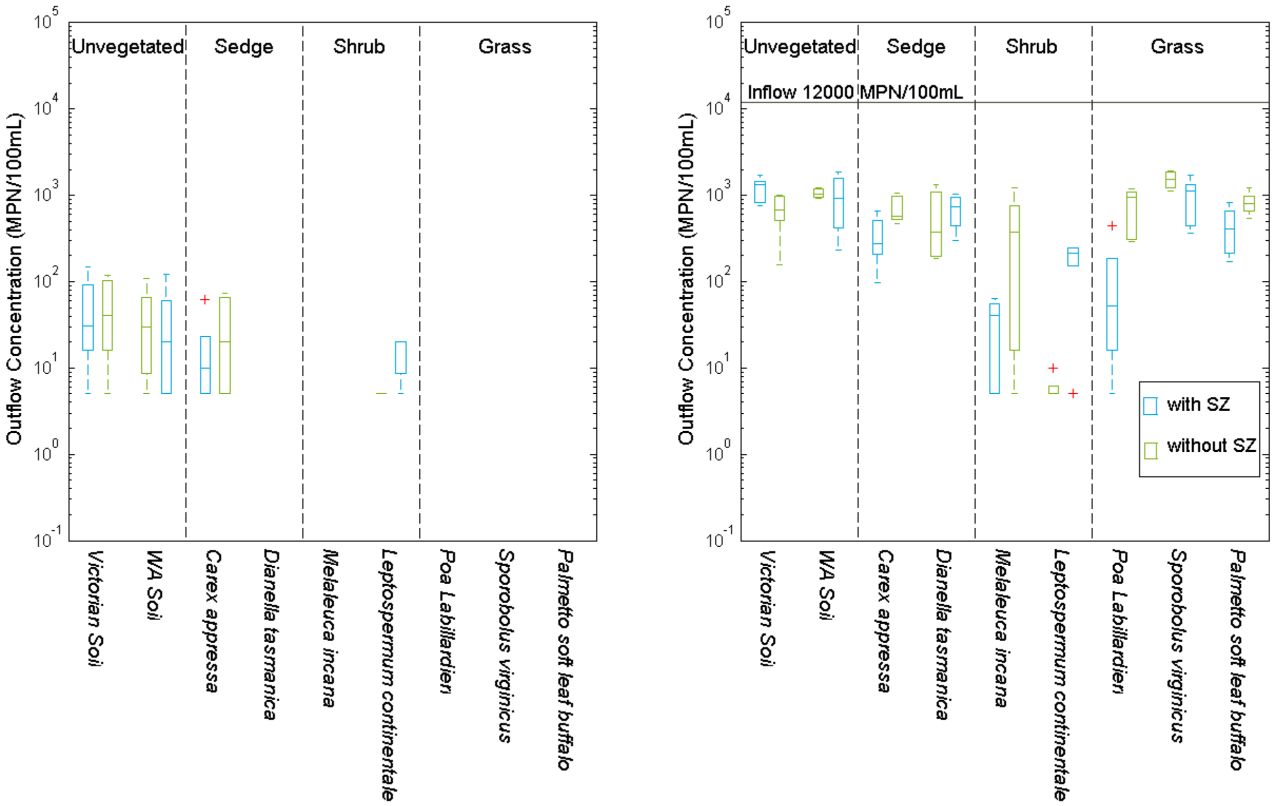


Figure 10 Event Mean Concentrations of E. coli at outflows of laboratory biofilter columns: (left) during a stormwater event with typical inflow E. coli levels, and (right) after a short dry weather period when dosed with clean water with no E. coli (SZ = submerged zone) (adapted from Chandrasena *et al*., 2012a[31])

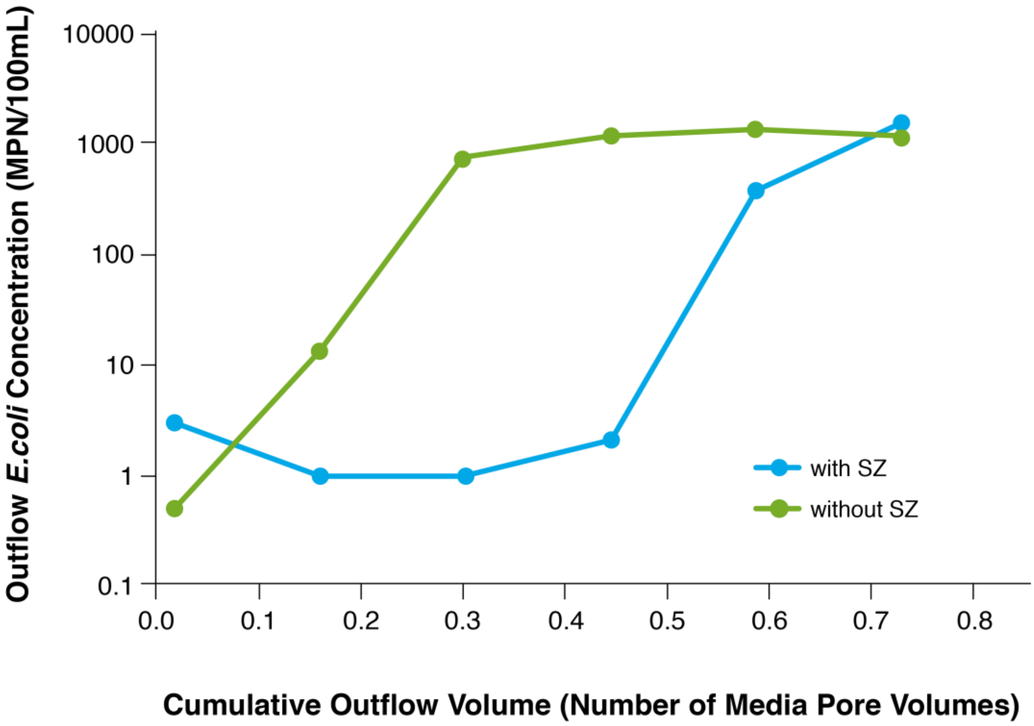


Figure 11. Outflow *E. coli* concentration variation with the cumulative outflow volume, in biofilter columns with and without SZ=submerged zone (inflow *E. coli* levels are 10,000 MPN/100 ml)

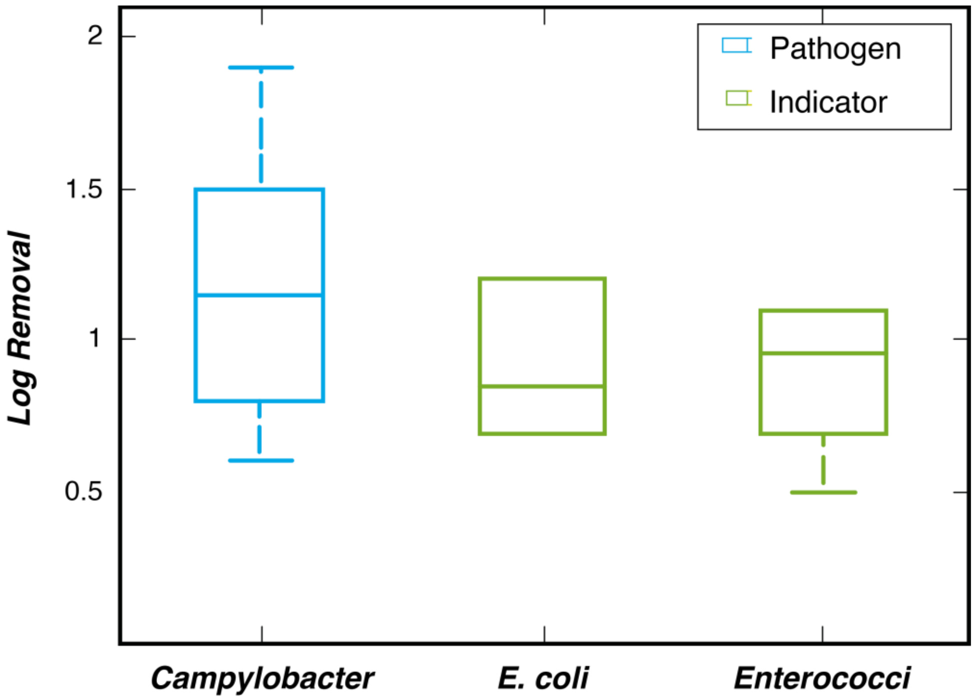


Figure 12. removal of bacteria by two field scale biofilters during storm events of 1 year recurrent period (adopted from Chandrasena *et al.*, 2012b[33])

Chemical Removal

Investigation into the removal efficiency of micropollutants by biofilters (Zhang *et al.*, 2012[35] and Feng *et al*., 2012[36]) led to the following preliminary 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[15] values, despite inflow concentrations being considerably high and generally above the guideline values.
- *Pesticides and herbicides* - although at the start of their life biofilters have good removal capacity, chemicals such as triazines (including simazine, atrazine and prometryn) may accumulate in the filter media, with a high possibility of them breaking-through after a short operational timeframe. There is also an indication that the systems can be easily 'flushed' by non-contaminated stormwater, and therefore could possibly work well for control of spills of these chemicals. 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) and Total Petroleum Hydrocarbons (TPHs), phenols and phthalates were never detected in the outflows, despite their high levels in the inflows, indicating their excellent removal by biofilters. However, at this stage, it is not clear whether they are accumulating or degrading in the media over time.

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

Advancing Stormwater Harvesting Practice

In advancing stormwater harvesting practice in the future, the assessment of potential human health risks and the identification of appropriate treatment options to provide water that is fit for purpose are required. This includes:

- identifying hazards present in raw source water and WSUD treatment devices (including. aqueous, colloidal and particulate phases) and assess human exposure;
- identifying catchment and climate characteristics that influence the quality of stormwater;
- characterising risk for multiple end use scenarios; and,
- informing the further development of new guidelines to manage risks associated with new end uses for stormwater, including potable use.

These are ongoing research to advance the development of WSUD systems to the point that they can reduce pathogenic and chemical risks to minimal levels. There is great potential in biofiltration technology to deliver the potential of stormwater as a viable alternative resource, i.e.:

- Selected plant species can enhance further pathogen and chemical removal in stormwater biofilters;
- Suitable filter media that can effectively trap and inactivate pathogens, and therefore could be incorporated in both stormwater filters (such as unplanted sand filters) and biofilters.

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

[35] 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 Int Conference on WSUD. Melbourne, Australia, Feb 21-23, 2012.*

[36] 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 (in press).*

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.

Historical time series of rainfall and evaporation are often used to design stormwater harvesting schemes. Simulation of treatment trains and storage sizes should be undertaken using rainfall data series of at least ten years with a small system simulation time step determined in relation to catchment size (e.g. 6 minute time steps for typical urban developments). Larger time steps (e.g. monthly and daily) are too coarse and should not be used.

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 temperature, predictions of future trends in climatic conditions including seasonal 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.

Designing resilient stormwater harvesting schemes needs to focus on ensuring that they are adaptive to a wide range of possible seasonal rainfall and water demand scenarios. It is recommended that numerous 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. CSIRO provides figures for the 10th percentile, 50th percentile and 90th percentile estimates of rainfall change and potential evapotranspiration (amongst a range of other climatic parameters) for three CO_2 emission scenarios for 2030, 2050 and 2070 (CSIRO and Australian Bureau of Meteorology, 2011[37]). Figure 5 shows typical information available from CSIRO. This information may be used to develop hypothetical time series of rainfall and evapotranspiration using the historical time series as a base.

Current attempts to adjust historical time series of seasonal and event rainfalls and evaporation do not adequately reflect the uncertainties of future climate predictions

[37] CSIRO and Australian Bureau of Meteorology (2007) *Climate change in Australia: technical report 2007.* CSIRO. 148 pp, accessed online Jan 15, 2011: http://climatechangeinaustralia.com.au/index.php

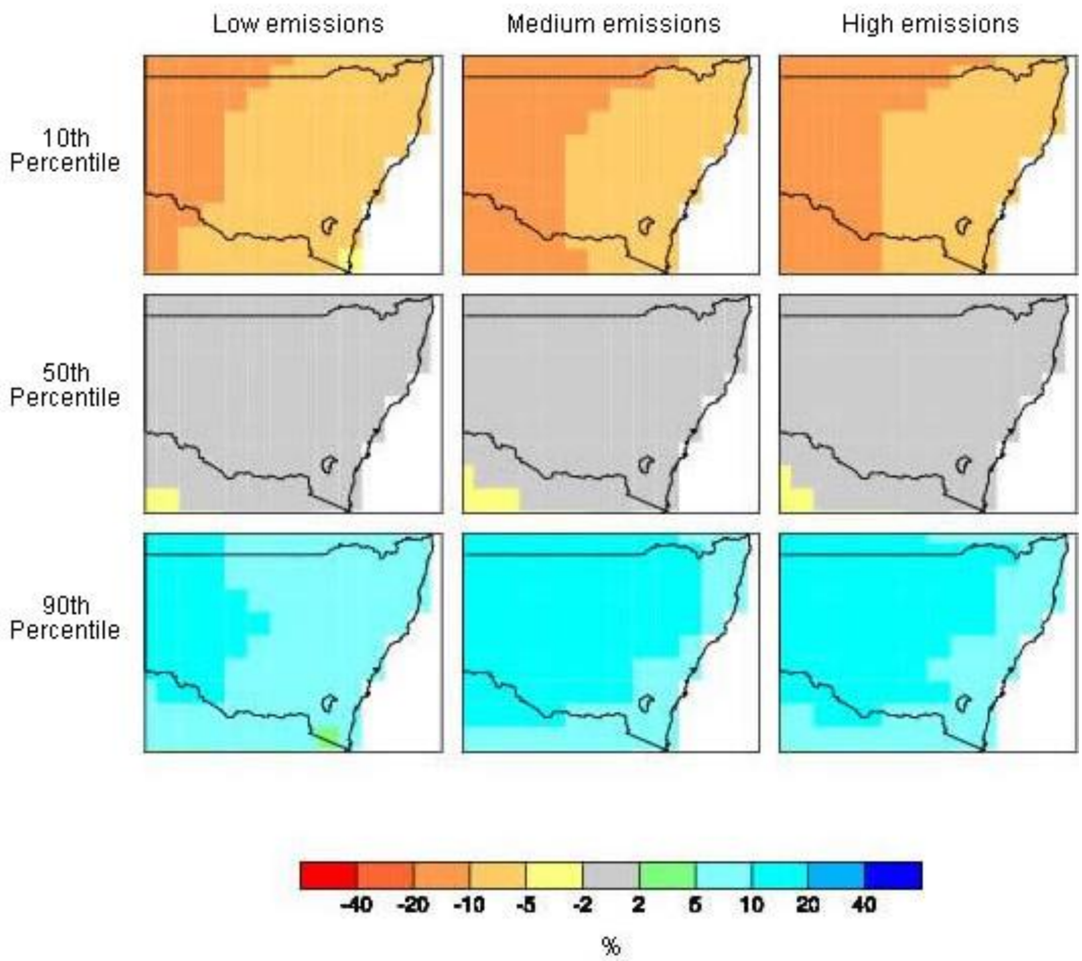


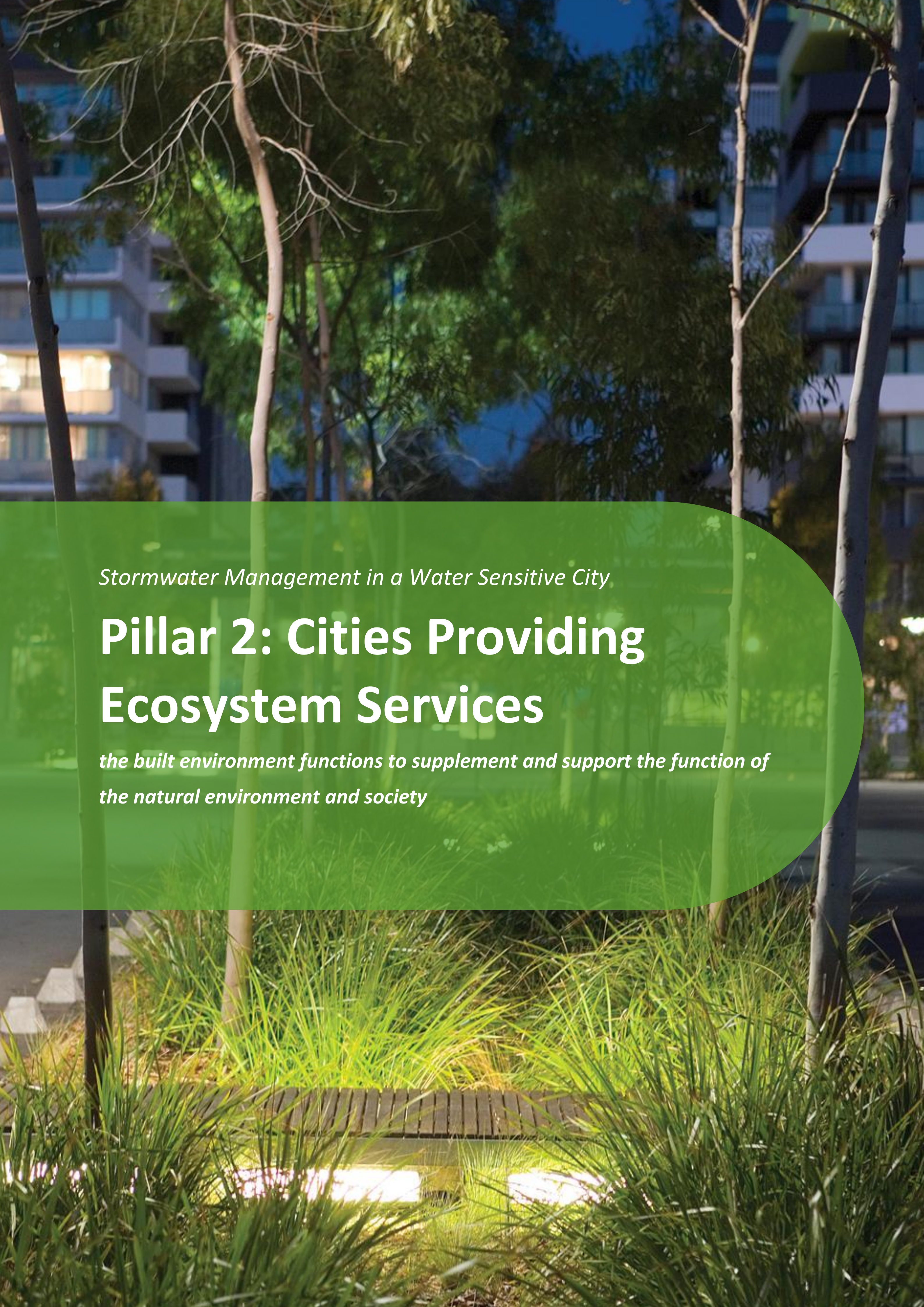
Figure 5. *Prediction of changes in summer rainfall in NSW (CSIRO[37])*

At present, there is no 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.

Dynamical downscaling is a physically consistent way to construct rainfall projections at high resolution. However, it is computationally expensive to use to estimate uncertainties because the calculations are simply too large to repeat many times.

For this reason, established methods for dynamical downscaling are unable to provide robust estimates of rainfall uncertainty. These problems may be overcome to some degree by a combination of dynamical stochastic downscaling. The uncertainty in downscaled climate projections of rainfall, and their subsequent propagation through hydrological models of stormwater harvesting, must be properly quantified and will be a focus of the Cities as Water Supply Catchments Research Program.

Designing resilient stormwater harvesting schemes needs to focus on ensuring that they are adaptive to a wide range of possible seasonal rainfall and water demand scenarios.



Stormwater Management in a Water Sensitive City

Pillar 2: Cities Providing Ecosystem Services

the built environment functions to supplement and support the function of the natural environment and society

Pillar 2: Cities Providing Ecosystem Services

the built environment functions to supplement and support the function 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 cities to provide ecosystem services. These ecosystem services refer to the benefits human populations derive from ecosystems (including terrestrial and aquatic systems) and include:

- evapotranspiration to reduce urban heating and improve human thermal comfort;
- altered hydrological regimes to decrease total stormwater runoff and improve flow regimes (more natural high-flows and low-flows) for urban waterways;
- waterway channel complexity and appropriate levels of stability that supports a healthy ecological condition;
- productive vegetation that can provide increased carbon sequestration and shade to reduce heat loading on people;
- improved air quality through pollution removal by vegetation, and
- improved amenity of the landscape.

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

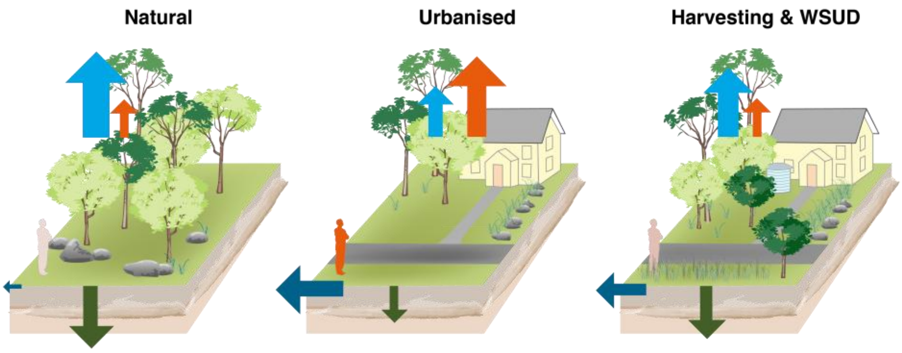
The hydrologic cycle – the movement of water between the atmosphere, the terrestrial biosphere and running water environments – provides a natural framework for understanding the effects of urbanisation and the potential for stormwater harvesting to be exploited to modulate against those effects (Figure 13).

Changes in the ways in which rainfall is intercepted and cycles back into the atmosphere or moves into surface waters or groundwater, underpin many of the impacts of urbanisation.

Urbanisation removes vegetation and introduces impervious surfaces, reducing the amount of water that is evapotranspired back into the atmosphere. Evapotranspiration is an important component by which radiant energy is dissipated and the reduction in this function associated with urbanisation makes cities hotter.

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 that alter stream channel form and reduces biodiversity.

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.



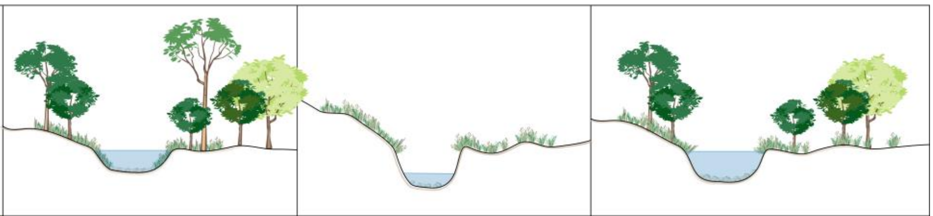
Stream channel form and biodiversity			
Groundwater recharge	High	Low	Moderate
Evapotranspiration	High	Low	Moderate
Atmospheric heating and heat storage in buildings	Natural	Hotter	Closer to natural
Human thermal comfort	Neutral	Hot	Slightly warm
Surface runoff	Low and infrequent	High and frequent	Infrequent and moderate
Stream hydrology	Natural	'Peaky'	Moderated (both high flows and low flows)
Riparian vegetation	Intact	Degraded	Restored
Channel form	Natural	Severely degraded	Uncertain (may need intervention)

Figure 13. 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

Stormwater harvesting combined with filtration, infiltration and irrigation can reduce runoff volumes to close to pre-development levels whilst also helping to restore baseflows and return natural soil moisture levels to urban landscapes. Storing water in tanks, draining roofs or larger-scale storages for passive irrigation, or in rain-gardens, reduces runoff volumes and increases the amount of time that it takes for water to reach stream channels, reducing the peakiness of flows. In addition, stormwater treatment and harvesting systems can reduce stormwater pollutant loads and concentrations, to a level appropriate to the protection of local receiving waters.

Riparian infiltration systems can help to restore ecosystem functions, and can contribute to stream health and public amenity. A healthy riparian zone can also be used to maintain floodplain engagement, reduce channel incision and maintain geomorphic stability. In addition, stormwater quality management measures such as roof gardens, bio-retention systems, constructed wetlands and ponds can provide effective stormwater detention to varying degrees and therefore can reduce drainage infrastructure requirements.

Restoring the natural urban water balance to encourage higher rates of evapotranspiration (through irrigation) and naturally cool the urban landscape can often be a primary mechanism for minimising the exposure of urban residents to extreme heat and uncomfortable climates. Human thermal stress can be reduced through 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 into dense urban areas, distributed in space, integrated with the built environment and designed for maximum benefit for human thermal comfort (i.e. cooling and shade).

Stormwater harvesting ultimately provides an additional and abundant source of water to support the greening of cities. These green infrastructures provide benefits in creating more liveable and resilient urban environments. Through urban planning and design that is sensitive to the water environment, urban stormwater systems can contribute to creation of beautiful public urban spaces that promotes social engagement and cultural expression involving the water environment.

A distributed application of stormwater systems is most effective in protecting urban ecosystems because it helps to restore base flows and also provides a cooling benefit integrated across the landscape, making it possible to achieve multiple objectives.
A suite of water sensitive urban design tools, including stormwater harvesting, allows us to reduce the impacts of urbanisation and these are discussed in more detail below.

The relative importance of stressors to urban aquatic ecosystems

Hydrology is a primary driver of the geomorphic and ecological condition of waterways. Streams with even a small amount of conventionally drained urbanized catchment are invariably physically and ecologically degraded, with lost biodiversity and ecological function, such as nutrient retention. Unless catchment interventions are made to return to or approach a natural flow regime and water quality, geomorphic and in-stream ecological responses to works aimed at restoring channel complexity and stability (erosion occurring at natural rates), along with riparian condition are likely to be limited by urban-stormwater-induced flow and water quality disturbances.

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[38]). Doing so will allow subsequent local-scale works to be most successful.

In catchments with higher levels of urbanisation, dealing with catchment-scale influences will require longer timeframes, and in-stream and riparian interventions in the meantime will 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.

[38] 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

Designing to achieve hydrologic restoration

Given the underpinning nature of hydrology, harvesting and stormwater treatment systems need to be designed to deliver flow regimes consistent with the ecological requirements of receiving waters. At the site scale, the indicators proposed in *blueprint2011* remain appropriate. At the catchment or stream scale, hydrologic targets should be based on ecologically important components of the flow regime or flow-duration curves as outline in Table 6

Table 6 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.*, 201241).

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Table 6 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[41]).

Indicator	Reference	Description	Hydrologic Impacts Characterised
Flow pulse frequency	(Clausen & Biggs, 1997[39])	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[40])	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[39], Hamel *et al.*, 2012[41])	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[42])	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.

[39] 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.
[40] Konrad C.P. (2000) The frequency and extent of hydrologic disturbances in streams in the Puget Lowland, Washington. University of Washington.
[41] 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).
[42] 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, stormwater treatment & retention

An integrated strategy of stormwater harvesting combined with 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 many of the water balance components back towards their natural levels (Figure 14). Burns *et al*. (2012)[38] 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 Little Stringybark Creek project (see www.urbanstreams.unimelb.edu.au) is empirically testing the feasibility of such approaches at a range of scales – from allotment to precinct.

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

- 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 (Figure 15). The greater than natural frequency and magnitude of stormflows will lead to erosion and degradation.

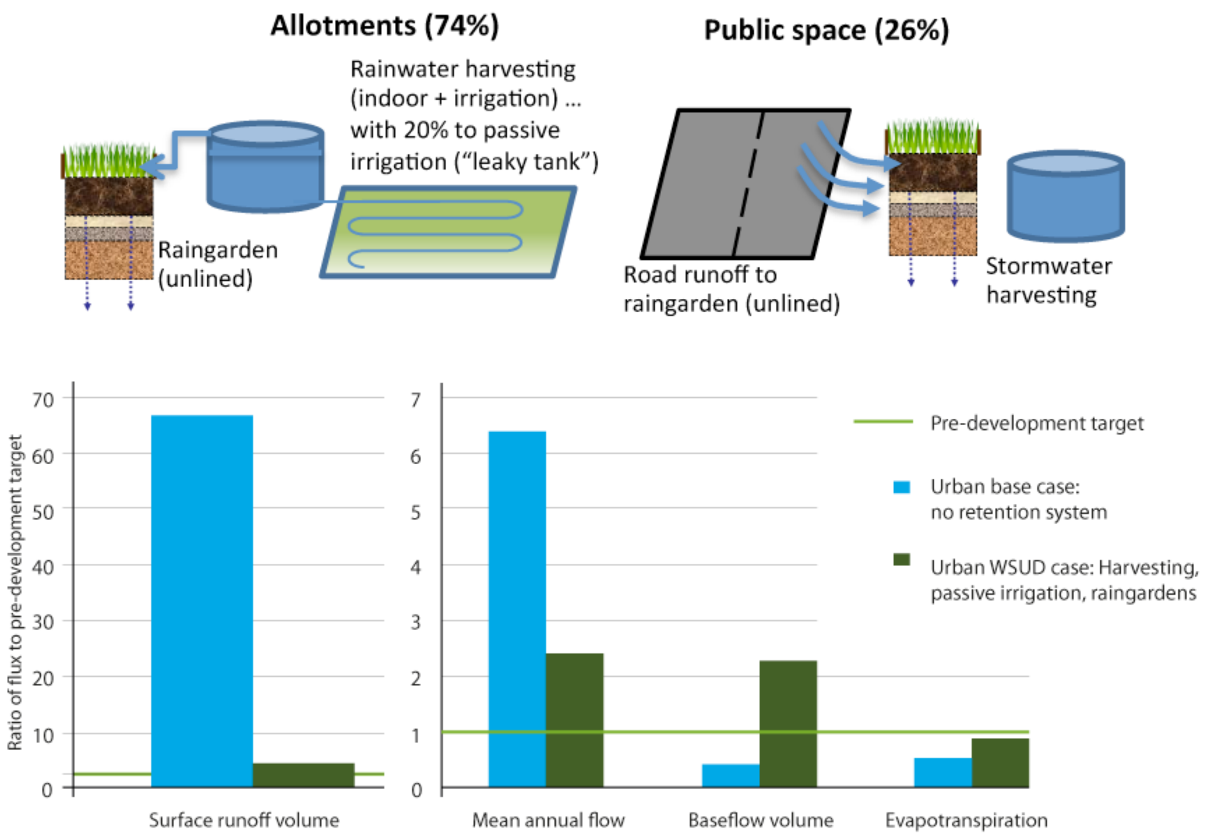

Figure 14. Example of the combination of stormwater harvesting and stormwater retention systems to restore urban water fluxes for a typical medium density development (allotments and public space represent 74% and 26% of the area, respectively). Modelling showed that fluxes could be returned to near their pre-development levels for low, medium and high density developments, using application at a wide range of scales.

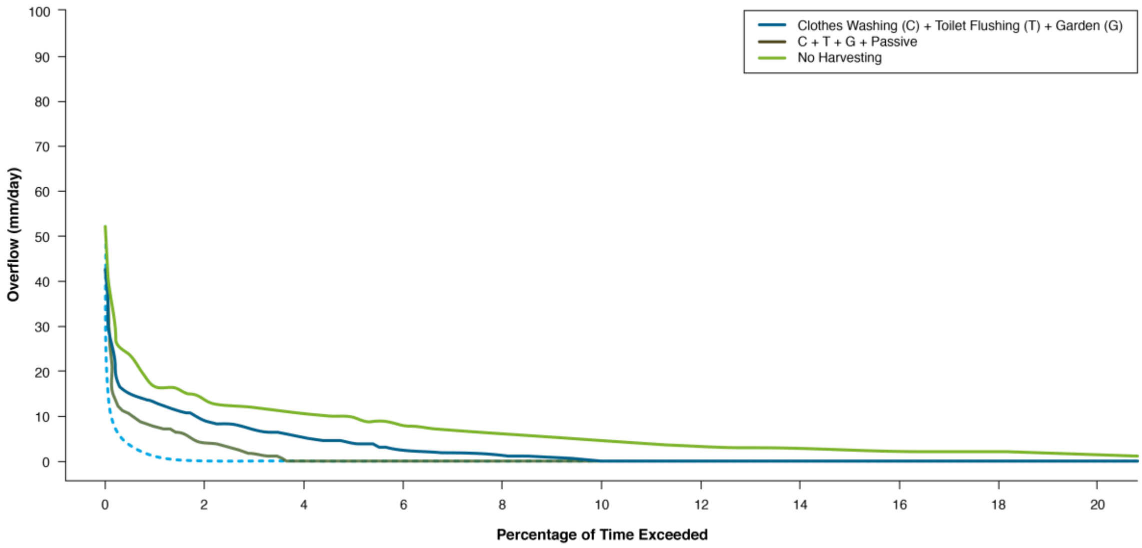

Figure 15. Overflow duration curves for a typical allotment-scale harvesting scenario from a roof, considering a range of demand types (C= clothes washing machine, T = toilet, H = hot water, Passive = use of tank for passive irrigation of garden, designed to draw down 20% of tank volume between events). Overflow duration curves are also shown for the conditions: 1) no harvesting (green line) and 2) the pre-development situation (pervious). Source: Burns *et al*., in prep.

Baseflow restoration

Drainage of impervious runoff through conventional drainage systems directly to receiving waters must act to reduce baseflows, as water is prevented from infiltrating to soils and is delivered to streams only during rainfall. Anthropogenic inputs into stormwater systems such as leakage of water supply 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 ensure appropriate volume and pattern of filtered flows.

Other cities where infiltration of stormwater is actively encouraged have seen the progressive rise in the local groundwater table attributed to the loss of evapotranspiration due to urbanisation.

It is thus important to understand the local context in setting hydrological objectives. Where baseflows have been lost, infiltration and over-irrigation can be used. Irrigation can be effective because it can be distributed over a wide area at low cost, increasing both evapotranspiration and infiltration (Figure 14). 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[41]).

The role of riparian zones

The relative influence of the riparian zone on stream ecological condition depends on removing 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[43]).

[43] 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.

Geomorphic degradation and recovery

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 contribute to physical complexity and consequently hydraulic diversity. Once harvesting and stormwater retention have been applied to limit hydrologic disturbance, restoration of such features are more feasible, even if the channel has been widened and incised as a result of past urban stormwater impacts.

Substrate sediments in the bed of the stream are known to play an important role in stream ecology. Urban impervious surfaces and lined drainage systems reduce sediment supply to streams, and increased urban stormwater flows and reduced floodplain engagement increase the capacity of streams to transport sediments. As a result urban streams usually have much reduced coarse bed sediments (comprising coarse-grained mobile sediments such as sand, gravel, pebbles and cobbles). Once flow regimes are restored, sediment supply may become a limiting factor, reducing the potential to retain sediment in the channel, and limiting any level of stream recovery through accumulation of substrate sediments. Little is known of the role of reduced sediment supply following urbanisation in stream degradation and this remains an important research question to be addressed. However, we know that reducing transport capacity (by reducing flow peaks and thus erosion potential) is a prerequisite to any eventual geomorphic restoration.

Such restoration might involve direct interventions such as targeted re-introduction of appropriately-sized sediments (e.g. gravels) along with creation of in-stream sediment traps. Protection of headwaters in their natural state may also be critical, as these headwaters are a likely important source of coarse-grained sediment supply. Where the channel is already greatly disturbed, in-stream works to reduce shear stress may also be undertaken, so that the sediment transport capacity is reduced, allowing coarse sediments to persist and provide important habitat.

The proof is in the stream

To test our hypothesis that ecological function and biodiversity of urban streams can be restored through stormwater harvesting and better stormwater management, we are retrofitting 200 ha of suburban Mt Evelyn to restore Little Stringybark Creek. To date we have installed 179 rainwater tanks, 89 raingarden / infiltration systems across 131 properties (of a total of 750 in the catchment), and have a works program in place to triple this level of retention in 18 months. We are monitoring the hydrological, water quality and ecological responses of the creek and its tributaries and hope to be able to report on the first of our findings in ***blueprint2013***.

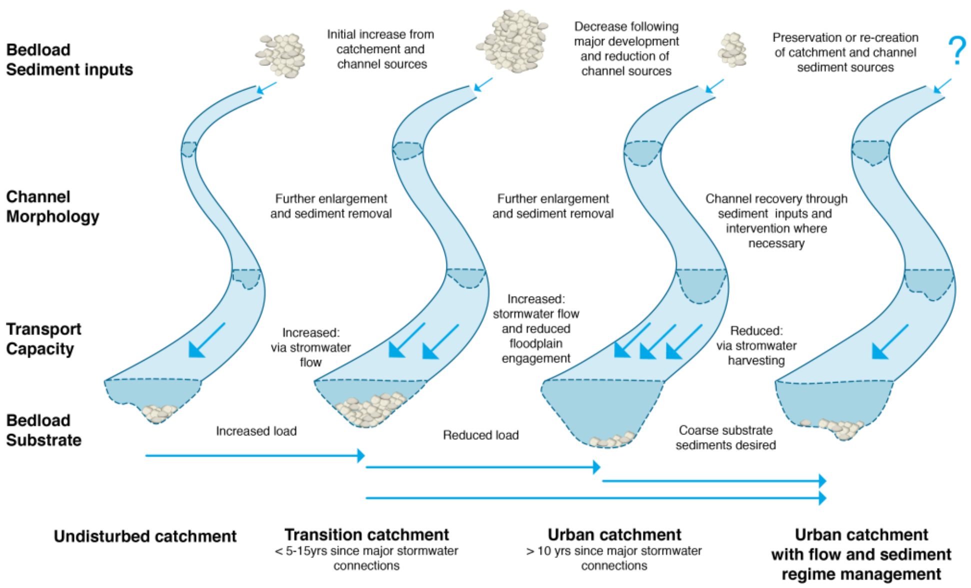

Figure 16. Phases of geomorphic degradation by double-edged sword of increased sediment transport capacity and ultimately reduced sediment supply in a conventionally drained urban catchment, and the potential for recovery through flow regime management. Consideration of the supply of coarse-grained sediments, though poorly understood in urban settings, will assist recovery potential. (Source: Vietz et al., 2012[44]).

[44] Vietz, G., Stewardson, M., Walsh, C., and T. Fletcher. 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.

Reducing heat exposure in urban areas

The response of urban populations to their climatic environment depends on a unique combination of the population vulnerability, climatic exposure, and ability to adapt. With regards to extreme heat, responses commonly target managing highly vulnerable populations, and encouraging adaptation.

Heatwaves are predicted to increase in frequency, duration and intensity around Australia in the coming decades. Increases in the number of 'hot' days above current mortality-heat thresholds are also expected. Between the present and 2040 under an A2 emissions scenario the number of days exceeding the maximum temperature thresholds are predicted to more than double in Melbourne, Brisbane, and Adelaide, double in Hobart and increase by approximate 30 - 50% in Sydney, Perth and Darwin, with significant impacts on population health, unless adaptation occurs.

Reducing exposure to stressful thermal environments in urban areas essentially revolves around urban planning and design approaches that are sensitive to a changing climate (particularly in relation to emerging trends in urban heat through influencing urban micro-climatic conditions. WSUD presents an opportunity (amongst other approaches) to support more thermally comfortable urban environments.

Prioritising WSUD approaches

Different approaches and technologies are available to re-integrate stormwater back into the urban landscape that, in combination with green infrastructure, can improve urban climates at a range of scales. Current research is quantifying the changes in temperature and human thermal comfort (HTC) associated with various WSUD-Green infrastructure combinations. This work is revealing the significant capacity, particularly during the day, for urban cooling and improvement in human thermal comfort associated with these technologies and is helping to prioritise their implementation.

Our preliminary research results are reinforcing the benefits of street trees in improving HTC at the street scale during the day through significant reductions in mean radiant temperatures (a measure of the influence of radiative energy on the body) from tree canopy shading. Urban street tree monitoring in Bourke St, Melbourne, has shown that during spring (October 2011), on average, mean radiant temperatures were up to 18°C lower at midday under tree canopy shade. Maximum mean radiant temperature reductions were up to 38°C at midday on a clear sunny spring day, demonstrating the capacity for considerable improvements to HTC from tree canopy shading.

Fit-for-place urban design should maximise the thermal benefits of WSUD. Our recent research has highlighted the large micro-scale variability of climate across a neighbourhood. Airborne thermal imagery collected during our summer 2011 field campaign at Mawson Lakes, Adelaide reveals large variations in surface temperature across relatively small distances (Figure 17) with clear temperature contrasts between built and natural surfaces, highlighting the need for distributed technologies throughout the landscape for more effective neighbourhood cooling. Integrating WSUD into the landscape can greatly assist in reducing surface temperatures. Our monitoring of experimental and installed green roofs has shown that they lower surface temperatures markedly compared to traditional roof types, with a consequent reduction in air temperatures in the near vicinity. These thermal benefits are maximised at warmer times of the year.

Preliminary analysis of air temperature during the Mawson Lakes campaign (not shown) has reinforced that denser urban/suburban environments are warmer at night and should be prioritised for WSUD implementation, particularly for areas where people congregate. Air temperatures across the neighbourhood varied by up to 8°C at times, with the maximum differences occurring near sunrise. Further analysis intends to assess how micro-climates vary in response to different urban configurations to help inform fit-for-place urban design to maximise the thermal benefits that WSUD could provide.

Research is ongoing to further quantify the benefits of WSUD on urban climates at a range of scales. Drivers of temperature at the micro-scale are complex and it is often difficult to disentangle specific contributing factors in observational studies. Urban climate models at a range of scales are a useful tool for scenario modelling, and help understand dominant micro-climate drivers. During 2011 we have reviewed and assessed the performance of available micro-scale climate models and conclude that there is currently very limited capacity to accurately represent WSUD in micro-scale urban climate models. Consequently this is an area that we are prioritising for further work in 2012.

Urban climate modelling capacity is more advanced at the local- to city-scale, as is the capacity for modelling WSUD effects on climate. However accurately parameterising urban land surface schemes in climate models is a challenge and further refinements are necessary. Observational studies can help in parameterising and validating models. We have two local- to city-scale modelling projects underway to assess and prioritise the effectiveness of WSUD and green infrastructure and will be in a position to report on progress in during 2012. In the meantime a strong indication of the effectiveness of water in cooling the environment is provided by our observational work using thunderstorms as analogues for landscape irrigation. For rural landscapes of <10% imperviousness we observe a characteristic surface temperature cooling of 0.6°C for every millimetre of rainfall delivered, while landscapes >10% imperviousness show a surface temperature cooling responsiveness of approximately half that of the rural. These results were from a discrete thunderstorm event in the Melbourne region and in ongoing work we are seeking to generalise these results.

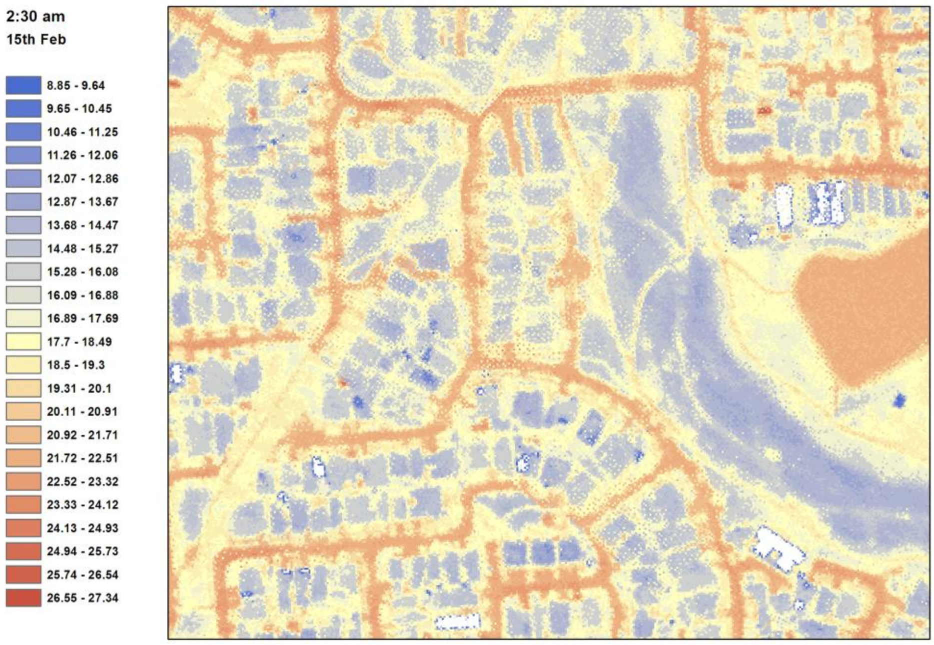

Figure 17. Uncorrected airborne thermal image from Mawson Lakes at 2:30 am on 15th February 2011, depicting high variability in surface radiometric temperatures across different land use types

Strategic integration of WSUD into the landscape

Priority areas to target for application of WSUD remain locations of high population vulnerability (see next section), denser urban environments with little or no vegetation that are areas of high heat exposure, older and less efficient housing stock, and areas of high human activity.

Research is further emphasising the importance of considering the target time for cooling and HTC benefits. Initial findings are suggesting that some WSUD approaches and technologies may be more effective at cooling and providing HTC benefits at different times of the day. Design and implementation of WSUD approaches for intentionally modifying urban climates will need to respond to specific location requirements (e.g. targeting an outdoor event during the day). WSUD will need to be optimised to provide maximum benefit across the diurnal course depending on requirements.

Human health and thermal comfort considerations

The risks of extreme summertime heat for urban populations can be reduced by

(i) using climate and health based approaches such as threshold temperatures to predict health-threatening heatwaves,

(ii) mapping population vulnerability and urban heat islands during heat events and

(iii) identifying what the thermally comfortable temperature ranges for Australian populations are by measuring HTC in outdoor urban areas.

Urban heat mitigation strategies can then be directed towards developing urban areas that are thermally comfortable for the local population.

At a city scale measuring population vulnerability to extreme heat events using an index of risk based on social, health and environmental factors enables identification of 'hotspots' and the development of targeted mitigation strategies that are both population and place specific. **Figure 19** shows a population heat vulnerability map for Melbourne and **Figure 19** the distribution of land surface temperatures for different times during the 2009 southeast Australian heatwave. Clearly there is considerable overlap of heat and vulnerability.

Temperature thresholds are specific temperatures above which mortality or morbidity increases. Temperature measures include daily maximum, minimum and mean temperature as well as Apparent Temperature, which includes a measure of humidity. This is important for tropical and subtropical cities where summers are warm to hot and wet. Southern Australian cities experience extreme heat events associated with dry continental air masses. In Australian capital cities daily maximum temperature for either a single day or the average maximum temperature for 3-days provide the best estimate of increased risk of death due to heat.

Our group is currently finalising a report to the National Climate Change Adaptation Research Facility (NCCARF) that establishes heat-mortality thresholds and heat vulnerability maps for all Australian capital cities. Even small reductions in temperature (such as associated with WSUD) can save lives (Nicholls et al. 2007[45]). The locational-specific information will help identify the best WSUD approaches for effective cooling. Our NCCARF work on heat and mortality also extends to the predicted impacts of climate change.

Thermally comfortable outdoor summer temperatures in Sydney have been previously described as lying between 23.8 to 28.5°C using a physiologically relevant thermal comfort index (OUT SET*) (Spagnola & De Dear, 2003[46]). We have conducted similar studies in the Adelaide suburb of Mawson Lakes and in three locations in Victoria (one CBD, 1 urban fringe, 1 rural town). Preliminary data analysis of our outdoor thermal comfort surveys indicated that comfortable outdoor air temperatures in Mawson Lakes are between 25°C and 26°C and in Victoria a little lower at 19°C to 23°C.

Designing outdoor environments that take advantage of air circulation particularly downwind from water sources, implementing green infrastructure as well as street orientation and tree planting to avoid mid-day sun, will provide cooler environments that are more comfortable during hot weather.

[45] Nicholls N., Skinner C., Loughnan M. and Tapper, N. (2007) A simple heat alert system for Melbourne, Australia. *International Journal of Biometeorology*, 52(5): 375-384.
[46] Spagnolo J.C. and De Dear R.J. (2003) A human thermal climatology of subtropical Sydney. *International Journal of Climatology*, 23: 1383-1395.

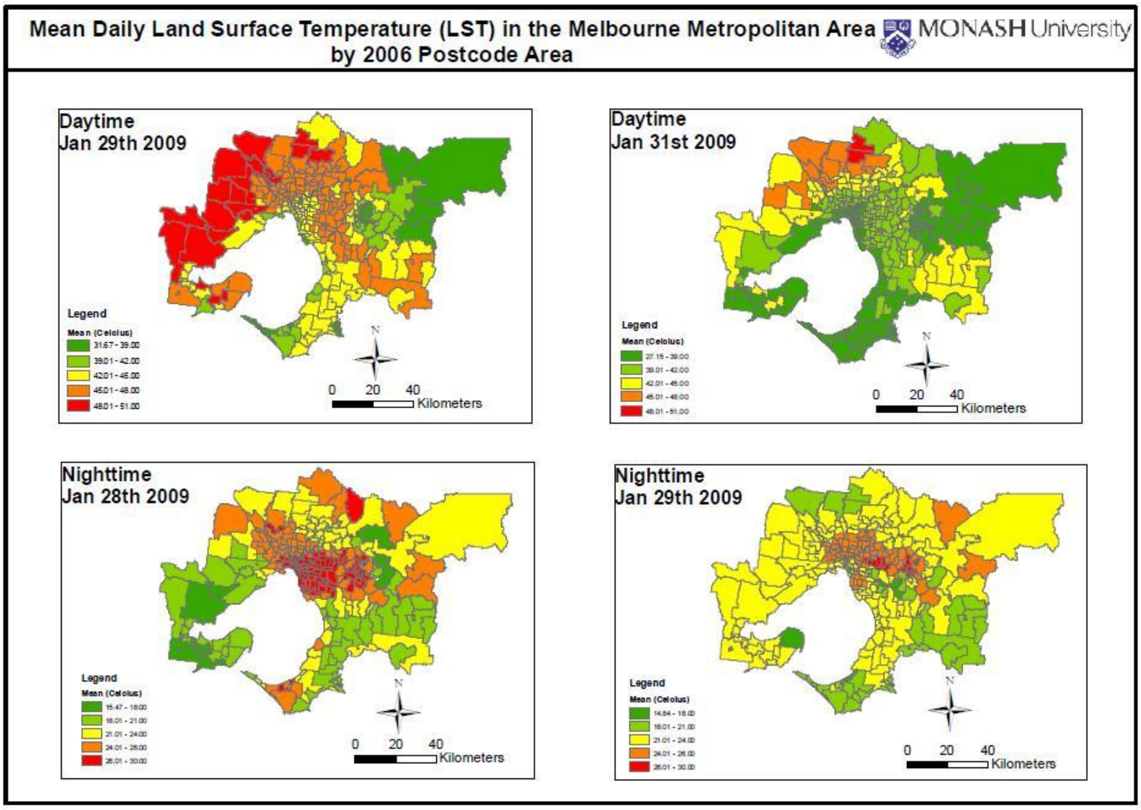

Figure 18. Daytime and night-time land surface temperature maps for Melbourne during the south east Australian heatwave of January 2009 (Queensland University of Technology, 2010[47])

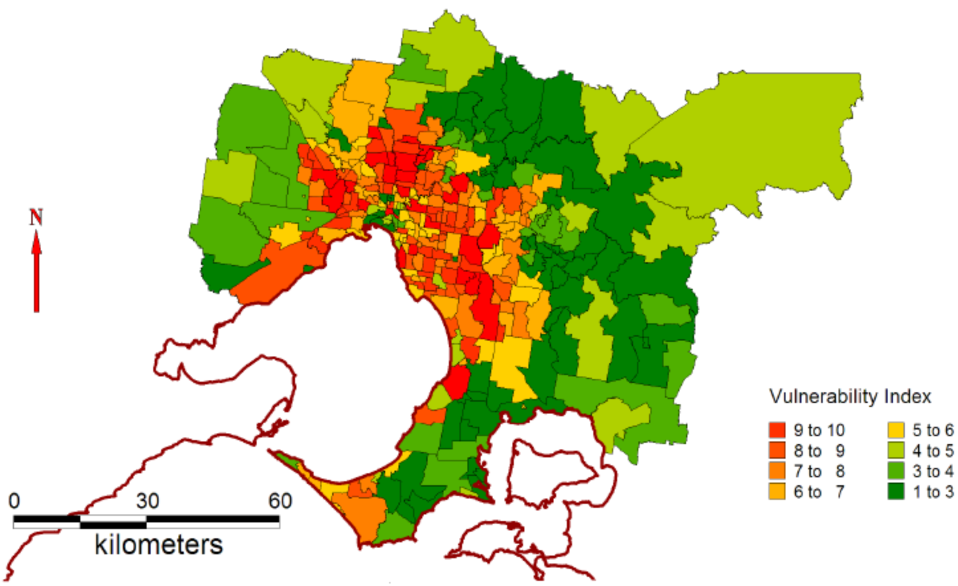

Figure 19. Heat vulnerability index map of Melbourne by 2006 Postcode Area. Index developed from a range of risk factors that include age, health status, type of housing and socio-economic status (Loughnan *et al*., 2009[48]).

[47] Queensland University of Technology (2010) Impacts and adaptation response of infrastructure and communities to heatwaves: the southern Australian experience of 2009. Report for the National Climate Change Adaptation Research Facility, Gold Coast, Australia.

[48] Loughnan M.E., Nicholls N. and Tapper N. (2009) A spatial vulnerability analysis of urban populations to extreme heat events in Melbourne Australia. Victorian Department of Health, Melbourne. Accessible at http://www.health.vic.gov.au/environment/downloads/heatwaves_hotspots_project.pdf

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

As highlighted in ***blueprint2011***, 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 20 (van de Brugge and Rotmans, 2007[49]).

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.

Brown and Clarke (2007)[50] identified a suite of nine key enabling factors that facilitated the emergence of WSUD as an alternative framework for integrated urban water cycle management and sustainable urban water management. These factors can be used by policy makers to 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.

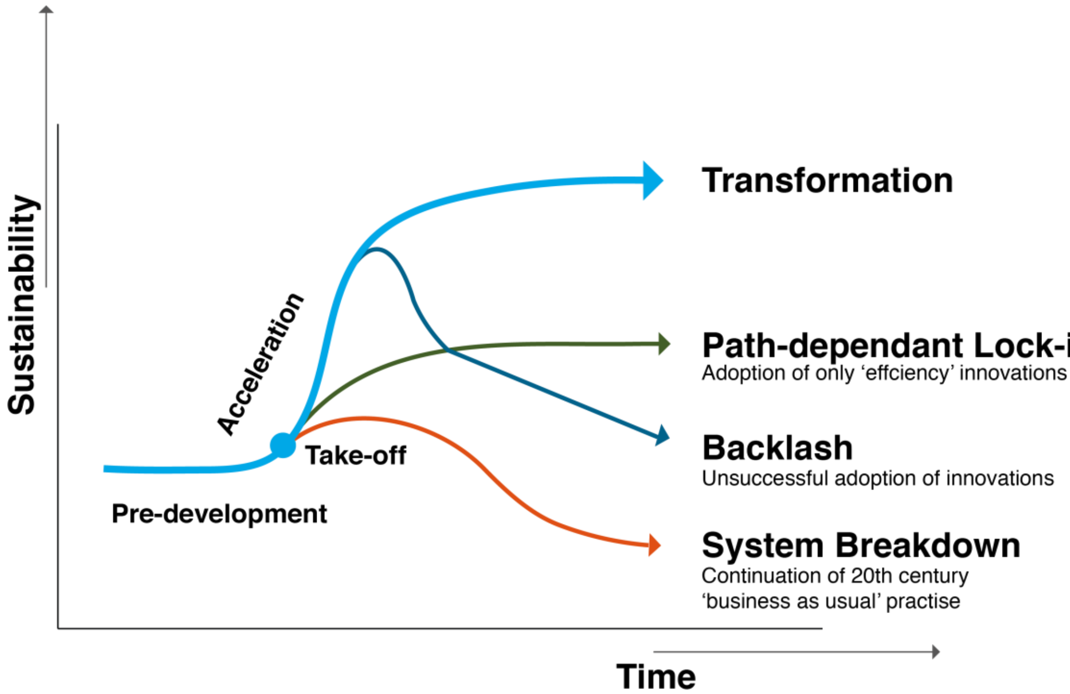

Figure 20 Technological-diffusion pathways (Source: van de Brugge and Rotmans, 2007)

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

[50] 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.

Nine Key Enabling Factors for Fostering Technological Diffusion

Nine key enabling factors have been identified by Brown and Clarke (2007)[51] as essential ingredients for fostering system-wide transformation in urban water management (Figure 21). Policy makers should facilitate a mix of technology/strategy-push and demand-pull through supporting the development and interplay of a multi-sectoral network of issue leaders and enabling context factors.

Practice leaders can qualitatively assess the strength of these enabling factors at a project, organisational and regional scale to identify deficits and opportunities for designing incentives to seed the transition to a Water Sensitive City.

Nine key enabling factors have been identified as essential ingredients for fostering system-wide transformation in urban water management.

1. Socio-Political Capital
Community, Media and Political

2. Champions
Vison
Multi-sectoral Network

3. Accountability
Coordination Processes
Water Cycle
Land-use Planning

4. Reliable & Trusted Science
Academic Leadership
Technology Development

5. Market Receptivity
Business Case for Change

6. Bridging Organisations
Facilitates Science - Policy
Facilitates Capacity Building

7. Binding Targets
Measurable System Target
Science, Policy and Development

8. Strategic Funding Points
Dedicated External Funds

9. Demonstration Projects
Experimentation
Technology Development
Policy and Institutional Learning

Figure 21. Nine key enabling factors for fostering technological diffusion (Adapted from Brown and Clarke, 2007[51])

[51] 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.

Receptivity towards changing practices

The concept of receptivity (Table 7) is a useful analytical tool to interpret urban water practitioners' and the broader community's readiness to accept stormwater harvesting, treatment and reuse. Table 7, describes the four attributes which characterise receptivity: 'awareness', 'association', 'acquisition' and 'application'. Collectively, these attributes can be used to target the design of future policy initiatives to meet the needs of policy recipients. This analytical approach has previously been used in generating a solid understanding of the broad-scale perceptions of urban water industry practitioners regarding their willingness to adopt alternative water sources, technologies and uses (see Brown *et al*., 2009[52]).

Table 7. *Receptivity attributes (Adapted from Brown et al., 2009[52])*

AWARENESS	ASSOCIATION
Knowledge of problem and needs	Association with needs and potential benefits
ACQUISITION	**APPLICATION**
Capacity to acquire new skills, systems, technologies, learn behaviours, etc.	Incentives to apply and implement the new approach

This concept has more recently been applied to understanding a) the risk perceptions of urban water (decentralised) urban water systems and b) the level of receptivity amongst land developers to the widespread adoption of WSUD approaches in metropolitan areas.

This research has revealed important leverage points for consideration in future policy design supporting the uptake of WSUD.

A). Practitioner Risk Perceptions

Risk perception, as opposed to the outcomes of technical risk assessments, can influence the uptake of innovative water sensitive technologies and practices (e.g. Brown *et al*., 2009[52]; Farrelly & Brown, 2011[53]). A survey of more than 600 urban water practitioners from across Australia examined their perceptions of risk in relation to the uptake of stormwater harvesting, treatment and reuse, among others.

Overall, practitioners' attitudes towards stormwater harvesting and treatment technologies were favourable. More specifically, practitioners are confident in the ability of stormwater harvesting and treatment technologies to deliver their intended water service; however, stormwater harvesting technologies are considered to be less proven than stormwater treatment technologies.

Moreover, practitioners revealed they hold major concerns regarding the establishment and maintenance costs involved in applying stormwater treatment and harvesting technologies. These financial costs were perceived to have a higher risk than potential public health impacts. Furthermore, government agencies were identified as being the least tolerant of risk.

The overall assessment of practitioner perception of risks is presented in Table 8. The major risk profiles have been categorised against the receptivity framework and attention needs to be primarily directed towards improving the perception of risks related to acquisition (i.e. skills) and application (i.e. incentives). This is a good starting point for helping decision-makers understand where to focus future initiatives and appropriate strategies.

B). Land developers receptivity to WSUD

The uptake of WSUD is heavily reliant on land developers incorporating this approach into their new projects. A mix of greenfield and urban renewal projects, located in Melbourne were analysed to identify the level of land developers' receptivity to adopting WSUD (see Brookes, 2011[54]). Based on the receptivity concept as summarised in Table 9, Brookes (2001) presents a suite of recommendations which may support the mainstream adoption of WSUD by private land developers. Overall, the recommendations focus on:

- building awareness amongst land developers;
- understanding the costs of a WSUD approach to ensure it is competitive with traditional approaches;
- transferring knowledge/lessons learned to land developers through trained professionals; and,
- facilitating the application of WUSD through the development of a strategic plan for WSUD across a metropolitan area (Table 9)

52 Brown, R., Farrelly, M. and Keath, N. (2009) Practitioner perceptions of social and institutional barriers to advancing a diverse water source approach in Australia. *International Journal of Water Resources Development,* 25(1):15-28.
53 Farrelly M. and Brown R. (2011) Rethinking urban water management: experimentation as a way forward? *Global Environmental Change*, 21: 721-732.

54 Brooks K. (2011) The Role of the Private Land Developer in Mainstreaming Water Sensitive Urban Design. Masters Thesis, School of Geography and Environmental Science, Monash University, Australia.

Table 8. *Major Risk Profiles as Perceived by Urban Water Practitioners*

Water system	Public health risk	Environmental risk	Supply failure risk	Flooding risk	Aesthetic risk	Technological risk	Management failure risk	Political risk	Risk of loss of end-user commitment	Risk of constrained future innovation	Compliance risk	Capital cost risk	Maintenance/ operations cost risk	Commercial risk	Risk of reputation loss
New dams				n/a											
Seawater desalination plants				n/a											
Indirect potable reuse schemes				n/a											
Direct potable reuse schemes				n/a											
Stormwater harvesting technologies			n/a												
Stormwater quality treatment systems			n/a												
On-site greywater systems				n/a											
Rainwater tanks				n/a											

M≤ 1, median=1	1<*M*≤2, median=1	1<*M*≤2, median=1, Sig. risk >10%	1<*M*≤2, median=1, Sig. risk >20%	1<*M*≤2, median=2, Sig. risk >10%	1<*M*≤2, median=2, Sig. risk >20%	*M*>3, median=3, Sig. risk >20%

Note: Water practitioners rated the perceived risk of each water system on a 4-point scale, coded as 0, no risk; 1, slight risk; 2, moderate risk; 3, significant risk. *M*, mean perceived risk. n/a, not applicable.

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Table 9. *Recommendations for mainstreaming the adoption of WSUD by private land developers (Brookes, 2011)*

Awareness	Association	Acquisition	Application
• Training in designing and implementing strategies. • A strategic plan for decentralised urban water management in your city. • A rating tool (or modify an existing tool) for residential developments.	• A rating tool (or modify an existing tool) for residential developments. • Review of existing charges for urban water management.	• Training in designing and implementing WSUD strategies. • Review existing charges for urban water management. • Foster improved capacity of local government for WSUD.	• Certify individuals who attend courses on designing/ implementing WSUD. • Mandate the use of accredited WSUD professionals in developing an urban water management strategy.

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 22). Critical water supply shortages in the face of ongoing climate change, population expansion/urban development and degrading waterways, challenges the traditional calculus of value and risk across all levels of water infrastructure investment decision making.

Emerging from the above 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 23). 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.

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

I. 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 and urban microclimate, 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 hedonic pricing methods may be used to assess the effect of water amenities on the value of nearby properties. However, for a number of non-market benefits of stormwater harvesting real choices and behaviour are not easily observed. To value these benefits a stated preference valuation method may be used. However, 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. In addition, 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. Inferences made using limited data is a common criticism of non-market valuation techniques.

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

II. Prioritise important parameters

Decision makers should also 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.

III. 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.

Figure 22. *Water Infrastructure Investment Decision Making Environment when Water is an Abundant Resource*

Figure 23. *Water Infrastructure Investment Decision Making Environment when Future Water Availability is Uncertain*

Advancements from ongoing research activities within this pillar will include a computational valuation model that embeds both the expanded space and temporal considerations (with the appropriate caveats around context for its applications). Further, issues of hypothetical bias and risk aversion will be addressed.

Framework for evaluating and improving governance strategies

To support future decision-making and contribute towards improved urban water governance, an evaluative tool is now available to assess contemporary and prospective strategies supporting the development of water sensitive cities. This evaluative governance framework shown in Figure 24 provides a useful approach for determining the effectiveness of established governance mechanisms and helps predict the likely success of future institutional reforms (structural and non-structural) (see Rijke *et al.*, submitted[55]).

The framework comprised of three areas critical to examining/assessing current governance practices:

- Identifying the purpose of existing and planned governance strategies (e.g. policy objectives).
- Mapping the socio-economic and political settings.
- Assess the efficacy of existing governance strategy outcomes.

Future research will be directed at formulating a conceptual governance framework that can be used to characterise and assess the formal and informal networks in urban water management systems. This can be used by policy makers to identify effective strategies for facilitating innovative and water sensitive practices.

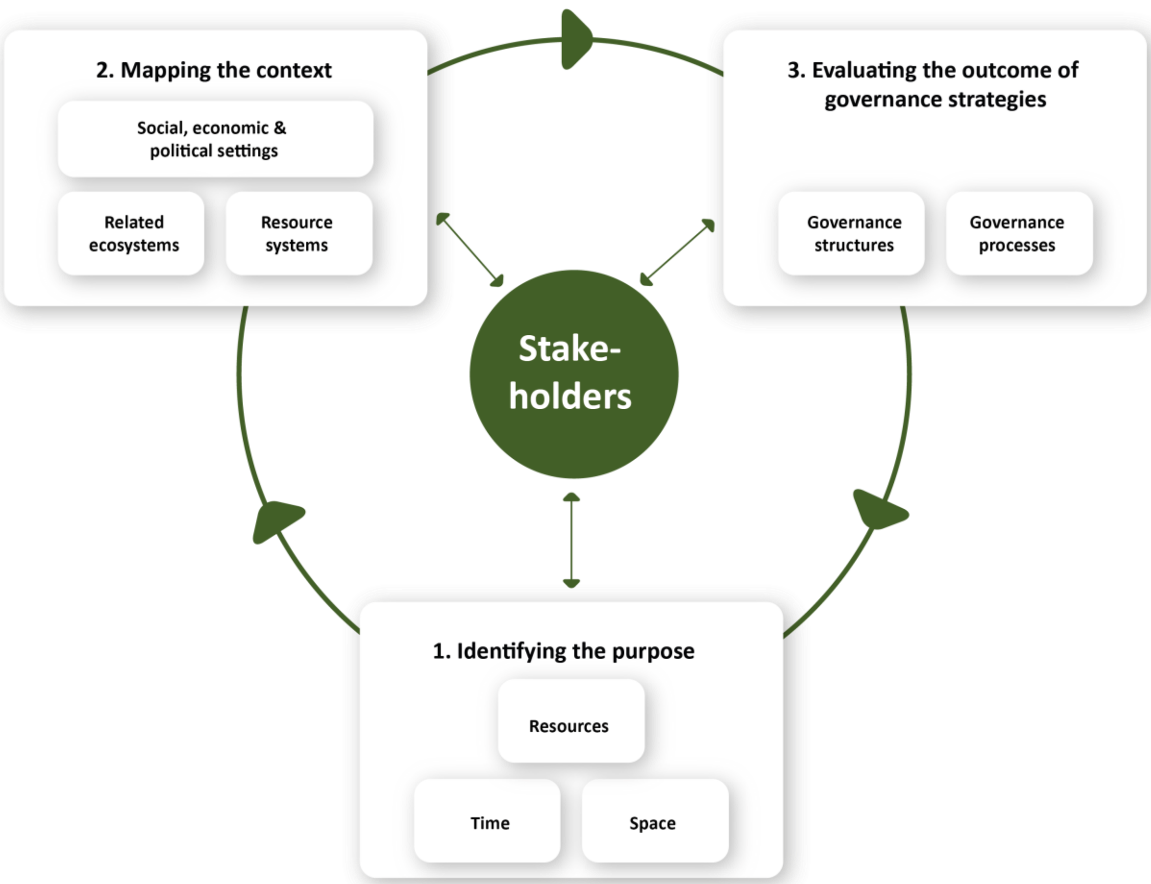

Figure 24 A framework for evaluating current governance practices (Rijke *et al*., 2012[55])

[55] Rijke J., Brown R.R., Zevenbergen C., Ashley R., Farrelly M., Morison P. and van Herk S. (2012) Fit-for-purpose governance: a framework to make adaptive governance operational. *Environmental Science and Policy* (submitted)

Co-Governance of decentralised systems

Incorporating decentralised technologies and practices alongside the conventional large-scale, centralised infrastructure, will require a new level of engagement with a variety of different stakeholders. When considering future governance arrangements for such systems, one must consider the function of key variables including: resources, technology, end-user and provider, risk perceptions, connectedness of technology (i.e. to other infrastructures) and the physical scale of the system. All these are understood to influence the scope of governance arrangements for decentralised water systems.

Three dominant modes of governance currently operate in the urban water sector: top-down, market-based and transitions-networks (Table 10). Recent insights from urban water practitioners' suggests that a hybrid approach involving all three modes of governance is required to achieve water sensitive cities (van de Meene *et al*., 2011[56]).

Policy designers should develop a mix of policy tools/incentives which capture each of the modes of delivery, for these different tools act to reinforce one another. The appropriate mix depends upon context and the overall aim of the governance strategy – here the evaluative governance framework (Table 10) will be of use.

Future research will be exploring these concepts in more detail to help identify appropriate pathways for improving the adoption of decentralised water systems. A governance typology of co-governance arrangements for decentralised urban water systems is envisaged. This will be a guidance tool for policy-makers and practitioners to organise and support projects in collaboration with communities.

Table 10. *Governance modes for policy-making. Adapted from (Elzen & Wieczorek, 2005[57])*

	Top-Down	Markets	Transition-networks
Perspective	Hierarchical, centralised organisation	Local actors	Interaction between actors
Relationship	Hierarchical	Autonomy	Mutually dependent
Interaction	Adoption of formulated goals	Self- organised around autonomy	Interactive information exchange
Discipline	Classic Political Science	Neo-classical Economics	Sociology, Innovation, New Institutional-ism
Instruments	Formal rules, regulations and laws	Financial incentives (e.g. subsidies, taxes)	Learning processes and networks

[56] van de Meene S.J., Brown R.R. and Farrelly M.A. (2011) Towards understanding governance for sustainable urban water management. *Global Environmental Change*, 21: 1117-1127.
[57] Elzen B. and Wieczorek A. (2005) Transitions towards sustainability through system innovation. *Technological Forecasting and Social Change*, 72: 651-661.

Incentives and Institutional Design

When looking at a particular water infrastructure investment decision, the valuation exercise is limited to the bounds of the decision in question. However, once a total valuation estimate for a given investment is settled upon, how that value is distributed among the stakeholders associated with that investment in a given water infrastructure landscape, will be informed by each stakeholder's decision and control rights (and by implication, incentives), over both existing and proposed infrastructure. Each stakeholder's willingness to invest in and/or co-operate in the implementation of any proposed new infrastructure will depend upon how decision and control rights and economic incentives can be renegotiated in light of the new valuation story. This task is critical to the successful implementation of any new proposed water infrastructure investments at any of individual, community, state or federal levels.


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