CRC for
Water Sensitive Cities

Water Sensitive Outcomes for infill developments (IRP4)

Overview of project

8 March 2018, Perth

Steven Kenway, Nigel Bertram, Geoffrey London, Marguerite Renouf and Project Team

Australian Government
Department of Industry and Science

Business
Cooperative Research
Centres Programme

R50 2675m2 11 dwellings

Infill

- Significant infill expected (up to 94% of development).
- More runoff and adverse impacts on flooding, evapotranspiration, and livability.
- Hotter, less shade, more air-conditioning and energy
- Inadequate performance basis to current processes.
- Limited new design options and limitations to current governance arrangements.

Photo Source: Geoffrey London Presentation

Project Objectives….and questions

(1) Develop a performance framework to understand infill impacts.

How can performance be defined, measured and assessed? What is the impact on hydrology, heat/energy, and liveability of new design options? What are key risks? How can "best" or "optimal" solutions be found and "move the needle"?

(2) Inform design tools, processes and typologies through engagement with real projects (case studies)

What housing/development typologies enable best outcomes? What information is critical for solutions? What technologies (eg traditional and new water sources) are best suited for different typologies and scales?

(3) Identify improved governance options / arrangements.

What governance arrangements work (or fail) and how can greater success be achieved through new measures?

Some background….Tranche 1

- What is urban water “mass balance” and “metabolism”?

- Outputs and outcomes of T1:
  1. Evaluation framework.
  2. Clarity of the ‘entity’ – the system boundary.
  3. Quantifying urban water performance using mass balance-based indicators.

- Stakeholder feedback.
- Implications for integrating into WSC values and planning.

Research outputs

1. Justification for our conceptual framework (urban metabolism) and method (water mass balance)

   Problem: Lack of clarity about the role of various evaluation approaches for understanding urban water issues

   Question: How can evaluation approaches advance urban water management goals at the macro scale?

APPLICATIONS AND IMPLEMENTATION

Evaluation Approaches for Advancing Urban Water Goals

Marguerite A. Renouf and Steven J. Kenway

Keywords:
cities
industrial ecology
performance indicators
urban hydrology
urban water systems
water efficiency

Summary

Urban areas (especially cities) are challenged in meeting their direct water needs from local sources. They also exert strain on global water resources through their indirect (virtual) water use. Agencies concerned with urban water management have visions and goals for managing direct water use, but indirect use is only inferred in more global visions for sustainable consumption. There is limited quantification of "urban water performance" at the macro urban scale (whole of city) to monitor progress toward these goals. It is constrained by a lack of clarity about the evaluation approaches that best serve them. We ask, How can the evaluation approaches described in literature advance urban water management goals? We reviewed the utility of eight evaluation approaches, including urban water system modeling, urban metabolism (territorial and mass balance), consumption (life cycle assessment, water footprinting, and input-output analysis), and complex systems (ecological network analysis and systems dynamics) approaches. We found that urban metabolism based on water mass balance is a core method for generating information to inform current goals for direct urban water use, with potential for being "coupled" with the other approaches. Consumption approaches inform the management of indirect water use. We describe this in a framework for urban water evaluation to give greater clarity to this field and flag the further research that would be needed to progress this. It includes the recommendation to differentiate the evaluation of direct and indirect urban water, but to also interpret them together.

Introduction

The world's freshwater resources are threatened by climate change and increasing demand from expanding urban populations and economic growth (2030 Water Resources Group 2009). Urban areas (especially cities) are hotspots for managing freshwater resources (Grimm et al. 2008), because their concentrated populations are drivers of resource consumption, but also centers of investment and change for enabling solutions (O'Meara 1999). For simplicity, we use the term cities, but this work relates to urban areas of various scales. Urban dwellers influence local water scarcity directly through local/regional water extraction and pollution, and also more far reaching water scarcity indirectly through the (virtual) water required to produce the goods and services they consume.

There are a range of visions for sustainably managing water for cities, which we refer to as urban water management, but there is only limited knowledge and quantification of urban water performance to guide and monitor progress toward these visions (Kennedy et al. 2007). Methods abound for evaluating the performance of water infrastructure within cities (Bach et al. 2014), but there is less maturity and clarity about methods that evaluate performance at the macro urban scale (the city itself). Recognized whole-of-city approaches are emerging for urban energy and greenhouse gas emissions (BSI 2013; WRI 2014), but there is currently no equivalent for water. For example,

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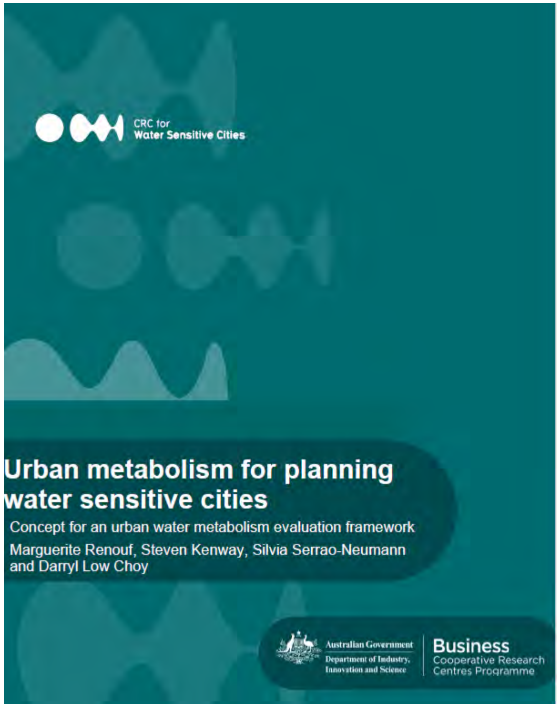
DOI: 10.1111/jiec.12456

Editor managing review: Christopher Kennedy

Volume 00, Number 0



2. Concept for an urban metabolism evaluation framework

   Problem: Lack of frameworks and methods for evaluating urban water performance at macro urban scales (city-region)

   Question: Is it possible to construct an evaluation framework that quantifies the water metabolism of a city-region to support planning?

Research outputs

3. Pilot application of the concept to a case study urban development (Ripley Valley)

Problem: Not clear if alternative water servicing options can deliver desired outcomes for the 'whole urban area', considering both the managed and natural water cycles, as well as energy

Question: What new insights about water servicing options does urban water metabolism evaluation provide?

Water Research 106 (2016) 415–428

Contents lists available at ScienceDirect

Water Research

journal homepage: www.elsevier.com/locate/wat

A metabolism perspective on alternative urban water ser[vicing] options using water mass balance

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ARTICLE INFO

Article history:
Received 22 May 2016
Received in revised form
11 September 2016
Accepted 4 October 2016
Available online 6 October 2016

Keywords:
Urban hydrology
Water mass balance
Water efficiency
Water-related energy
Wastewater recycling
Stormwater

ABSTRACT

Urban areas will need to pursue new water servicing options to ensure local supply security. Decisions about how best to employ them are not straightforward due to multiple considerations and the potential for problem shifting among them. We hypothesise that urban water metabolism evaluation based a water mass balance can help address this, and explore the utility of this perspective and the new insights it provides about water servicing options. Using a water mass balance evaluation framework, which considers direct urban water flows (both 'natural' hydrological and 'anthropogenic' flows), as well as water-related energy, we evaluated how the use of alternative water sources (stormwater/rainwater harvesting, wastewater/greywater recycling) at different scales influences the 'local water metabolism' of a case study urban development. New indicators were devised to represent the water-related 'resource efficiency' and 'hydrological performance' of the urban area. The new insights gained were the extent to which alternative water supplies influence the water efficiency and hydrological performance of the urban area, and the potential energy trade-offs. The novel contribution is the development of new indicators of urban water resource performance that bring together considerations of both the 'anthropogenic' and 'natural' water cycles, and the interactions between them. These are used for the first time to test alternative water servicing scenarios, and to provide a new perspective to complement broader sustainability assessments of urban water.

1. Introduction

An increasingly large proportion of the world's growing population will reside in urban areas, especially cities (UN, 2014). The resulting growth in demand for water coupled with climate change constraining supply or making it more erratic, means that large cities are increasingly prone to water shortages (Jenerette et al., 2006). Around a quarter of urban water supplies are estimated to be stressed, and if surface flows needed to maintain ecosystem service are considered, this would increase to a third (McDonald et al., 2014). Competition for supply with other water users, such as agriculture and environmental flows, is also expected to intensify as cities expand (OECD, 2015). This means that urban areas, particularly those whose supplies are already stretched, will need to pursue efficiency measures and alternative water servicing options, such as utilizing available water within the urban area (rainwater and stormwater) and recycling wastewaters (IWA, 2010).

Making decisions about alternative water servicing options involves numerous considerations (Xue et al., 2015). For water cycle managers these include supply security, long-term costs, public health, allocating water to competing demands, and increasingly, the environmental externalities of energy use, greenhouse gases emissions (Behzadian and Kapelan, 2015; Kenway et al., 2011b; Makropoulos and Butler, 2010), and water quality (Walker et al., 2012). For urban and regional planners and managers, considerations also include the management of flooding, urban streams degradation from increased surface water runoff, and protecting the ecological and cultural values of water. In dealing with such multiple objectives, which can be at odds with each other, it becomes important to look at urban water systems holistically (Huang et al., 2013), to avoid problem shifting and to optimise the overall

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http://dx.doi.org/10.1016/j.watres.2016.10.014
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To be submitted to Water Science and Technology

Deriving indicators of urban water metabolism from a water mass balance

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Abstract: Urban water performance indicators reported in city benchmarking programs currently do not tell us enough about how effectively water is managed in urban areas, in the context of their supporting regions, and considering both in natural and man-made water cycles. So it is difficult to quantify how well urban areas are progressing towards articulated visions, which increasingly aim for resource efficiency (for water, but also water-related energy and nutrients), water supply internalisation, restoration of natural hydrological flows, and sustainable management of water resources in the context of regional carrying capacities. We consider these to be metabolic features of urban areas, and derived a theoretic set for 'urban water metabolism' indicators in consultation with potential users (water managers and urban planners). The capacity for quantifying these indicators using data generated by an urban water mass balance was examined. Indicators of water use efficiency, supply internalisation and hydrological naturalness can be generated using existing urban water mass balance methods. Other indicators relating to water-related energy and nutrient efficiencies, regional water stress and will require method refinements to also account for water-related energy and

4. Indicators of urban water metabolism

Problem: Lack of indicators that adequately quantify how well urban areas are progressing towards the urban water management visions

Questions:

What is an ideal set of water metabolism indicators?

How can they be quantified from an urban water mass balance?

Research outputs

5. City-region application

Problem: The need to create a holistic picture of urban water management at the city-region scale to help identify water management and urban planning innovation.

‘We lose sight of the forest when we focus on the trees’

Question:

How can we characterize the water metabolism of city-regions?

What can it tell use about future opportunities for urban water management in Australian city-regions?

To be submitted to Water Research

The water metabolism of Australian city-regions – what can it tell us about the opportunities for urban water innovation?

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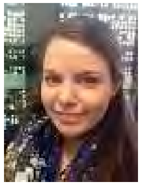
KEYWORDS

urban metabolism; water mass balance; water efficiency; water-related energy; wastewater recycling; stormwater; water sensitive urban design

ABSTRACT



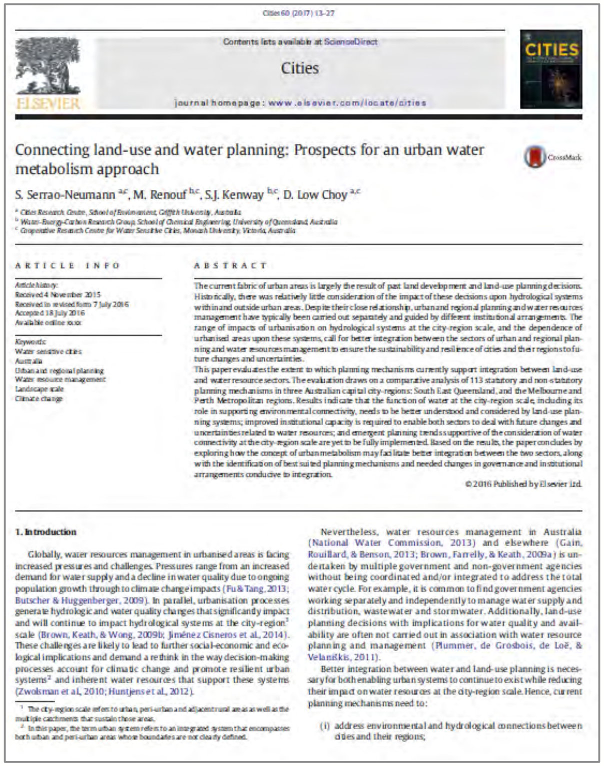
CRC for Water Sensitive Cities

Research outputs

6. Metabolism for connecting land-use and water planning

Problem: There is disconnection between urban planning and water planning, which is a barrier to how we can plan city-regions for better water outcomes

Question: How can the concept of urban metabolism evaluation can help with integrated water and urban planning?


Cities 60 (2017) 13–27
Contents lists available at ScienceDirect
Cities
journal homepage: www.elsevier.com/locate/cities

Connecting land-use and water planning: Prospects for an urban water metabolism approach

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ARTICLE INFO
Article history:
Received 4 November 2015
Received in revised form 7 July 2016
Accepted 18 July 2016
Available online xxxx
Keywords:
Water sensitive cities
Australia
Urban and regional planning
Water resource management
Landscape scale
Climate change

ABSTRACT
The current fabric of urban areas is largely the result of past land development and land-use planning decisions. Historically, there was relatively little consideration of the impact of these decisions upon hydrological systems within and outside urban areas. Despite their close relationship, urban and regional planning and water resources management have typically been carried out separately and guided by different institutional arrangements. The range of impacts of urbanisation on hydrological systems at the city-region scale, and the dependence of urbanised areas upon these systems, call for better integration between the sectors of urban and regional planning and water resources management to ensure the sustainability and resilience of cities and their regions to future changes and uncertainties.
This paper evaluates the extent to which planning mechanisms currently support integration between land-use and water resource sectors. The evaluation draws on a comparative analysis of 113 statutory and non-statutory planning mechanisms in three Australian capital city-regions: South East Queensland, and the Melbourne and Perth Metropolitan regions. Results indicate that the function of water at the city-region scale, including its role in supporting environmental connectivity, needs to be better understood and considered by land-use planning systems; improved institutional capacity is required to enable both sectors to deal with future changes and uncertainties related to water resources; and emergent planning trends supportive of the consideration of water connectivity at the city-region scale are yet to be fully implemented. Based on the results, the paper concludes by exploring how the concept of urban metabolism may facilitate better integration between the two sectors, along with the identification of best suited planning mechanisms and needed changes in governance and institutional arrangements conducive to integration.

1. Introduction

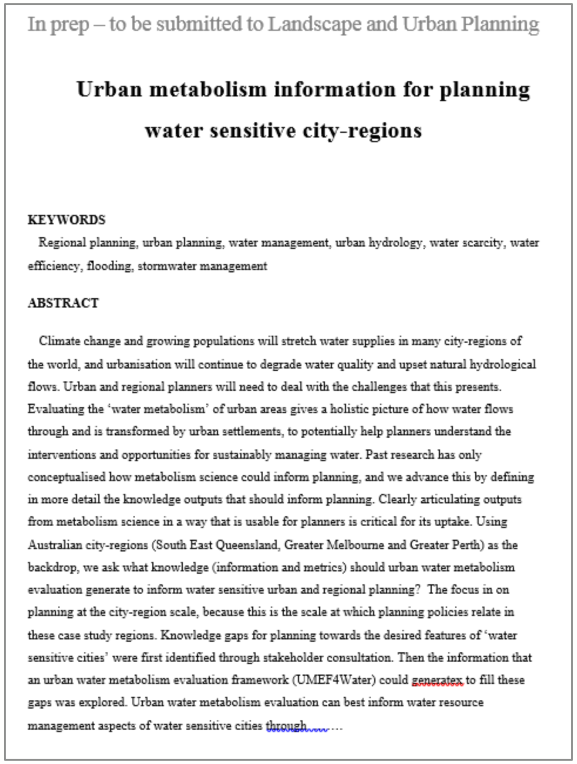
Globally, water resources management in urbanised areas is facing increased pressures and challenges. Pressures range from an increased demand for water supply and a decline in water quality due to ongoing population growth through to climate change impacts (Fu & Tang, 2013; Butscher & Huggenberger, 2009). In parallel, urbanisation processes generate hydrologic and water quality changes that significantly impact and will continue to impact hydrological systems at the city-region[1] scale (Brown, Keath, & Wong, 2009b; Jiménez Cisneros et al., 2014). These challenges are likely to lead to further social-economic and ecological implications and demand a rethink in the way decision-making processes account for climatic change and promote resilient urban systems[2] and inherent water resources that support these systems (Zwolsman et al., 2010; Huntjens et al., 2012).

Nevertheless, water resources management in Australia (National Water Commission, 2013) and elsewhere (Gain, Rouillard, & Benson, 2013; Brown, Farrelly, & Keath, 2009a) is undertaken by multiple government and non-government agencies without being coordinated and/or integrated to address the total water cycle. For example, it is common to find government agencies working separately and independently to manage water supply and distribution, wastewater and stormwater. Additionally, land-use planning decisions with implications for water quality and availability are often not carried out in association with water resource planning and management (Plummer, de Grosbois, de Loë, & Velaniškis, 2011).

Better integration between water and land-use planning is necessary for both enabling urban systems to continue to exist while reducing their impact on water resources at the city-region scale. Hence, current planning mechanisms need to:

(i) address environmental and hydrological connections between cities and their regions;

[1] The city-region scale refers to urban, peri-urban and adjacent rural areas as well as the multiple catchments that sustain those areas.
[2] In this paper, the term urban system refers to an integrated system that encompasses both urban and peri-urban areas whose boundaries are not clearly defined.


In prep – to be submitted to Landscape and Urban Planning

Urban metabolism information for planning water sensitive city-regions

KEYWORDS
Regional planning, urban planning, water management, urban hydrology, water scarcity, water efficiency, flooding, stormwater management

ABSTRACT
Climate change and growing populations will stretch water supplies in many city-regions of the world, and urbanisation will continue to degrade water quality and upset natural hydrological flows. Urban and regional planners will need to deal with the challenges that this presents. Evaluating the 'water metabolism' of urban areas gives a holistic picture of how water flows through and is transformed by urban settlements, to potentially help planners understand the interventions and opportunities for sustainably managing water. Past research has only conceptualised how metabolism science could inform planning, and we advance this by defining in more detail the knowledge outputs that should inform planning. Clearly articulating outputs from metabolism science in a way that is usable for planners is critical for its uptake. Using Australian city-regions (South East Queensland, Greater Melbourne and Greater Perth) as the backdrop, we ask what knowledge (information and metrics) should urban water metabolism evaluation generate to inform water sensitive urban and regional planning? The focus in on planning at the city-region scale, because this is the scale at which planning policies relate in these case study regions. Knowledge gaps for planning towards the desired features of 'water sensitive cities' were first identified through stakeholder consultation. Then the information that an urban water metabolism evaluation framework (UMEF4Water) could generatex to fill these gaps was explored. Urban water metabolism evaluation can best inform water resource management aspects of water sensitive cities through……

7. Metabolism knowledge needs of planners

Problem: Planners don't have urban water performance information available to them in a way that can inform policy formulation and decision making

Question: What knowledge (information and metrics) should urban water metabolism evaluation generate to inform water sensitive urban and regional planning?

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MIWM student projects

8. Communication of the urban metabolism

Problem: Metabolism information is not presented in meaningful ways, which is a barrier to its communication

Question: How has urban metabolism been interpreted and communicated?

Presented at World Water Congress 2016

How has urban metabolism been interpreted and communicated?

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Abstract

Urban metabolism is a concept increasingly being adopted to guide the planning of cities towards improved resource efficiency and hydrological performance. Stakeholder participation in the adoption of this concept will be important, and hence effective communication of the concept will be crucial for sustainable water management. This study aimed to find out *how has urban metabolism has been interpreted and communicated,* in order to inform future communication of urban metabolism research and quantifiable performance of urban areas. Literature review, structured interviews, and thematic analysis were undertaken across three continents. The research provides new understanding of how stakeholders perceive urban water metabolism. It found that there is a major gap in the shared understanding and stakeholder appreciation of urban metabolism. It found that in order to move urban metabolism forward, it will be necessary to develop a shared and common understanding, direct communication to target user audiences, and employ vitalization techniques that may be spatially linked.

Keywords: communication; integrated urban water management; urban metabolism; urban planning.

Introduction

Many urban areas are constrained locally by water (McDonald et al., 2014), and they face potential climatic extremes or change, population growth and pollution. The holistic water efficiency and hydrological performance of cities are rarely assessed and communicated (Renouf et al. 2016), and methods for doing this are only just emerging (Kenway et al. 2011). Therefore, the water efficiency and water sustainability of cities remain uncertain. Urban metabolism is a conceptual framework that aims to guide urban planning towards the greater resource efficiency observed in natural systems (Newton & Bai 2008) and although approaches and methods that quantify the material and energy flows through and metabolism performance of urban systems are emergy, often the information is not communicated in comprehendible ways to end users (Chrysoulakis et al. 2015). This paper explores how the urban metabolism concept can be interpreted and communicated, in order to inform the most effective ways of communicating the valuable information it generates.

Evaluating the benefits of greywater reuse with consideration of heat recovery

Final Project

Student Number: 43600087
Course: WATR 7501/7502

30 October 2016

9. Water-related energy

Problem: Heat recovery potential of grey water has not been adequately evaluated

Questions:

Will consideration of the heat recoverable from greywater reuse improve its viability?

CRC for Water Sensitive Cities

Key stages and essential components

2017 | 2018 | 2019 | 2020

- WP1 Project Management, Quality etc
- WP2 Typologies, guidelines and standards, and technologies review
- WP3 Framework development incorporating Tranche 1 work (mass balance, designs, heat, risks, technologies etc).
- WP4 Case study development, stakeholder engagement and collaboration, case study selection, baseline analysis, options design (lot and precinct).
- WP5 Options performance quantification, and modelling (mass balance, music/Dance and other CRC tools use and development)
- WP6 Design guideline principles (performance based) and governance implications.
- WP7 Demonstration implementation

Major Milestones

No.	Milestone/deliverable description	Lead	Due date	Work package
1	Water mass balance screening tool, used for case study (Beta)	SK	June. 2018	WP5.
2	Design typologies (catalogue/options)	NB/GL	Sept 2018	WP2.
3	Infill performance evaluation framework (draft)	MR/SK	Dec. 2018	WP3.
4	Final Landscape design options for modelling case study 1	NB/GL	Sept 2018	WP4.
5	Evaluation of infill projects in accordance with end-user agreed framework have commenced.	MR/SK	Sept. 2018	WP5.
6	Evaluation framework for infill projects is agreed by end-users.	MR/SK	Mar 2019	WP3.
7	Evaluation of infill projects with end-user agreed framework is completed.	MR/SK	Sept 2019	WP5.
8	Report on infill projects publically released	MR/SK/Team	Mar. 2020	All
9	Final project report	MR/SK/Team	Sep 2020	WP1.

Research Team

University of Queensland

Project leader
Lead performance assessment researcher
Steven Kenway

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Marguerite Renouf

Jurg Keller

Marie-Laure Pype (Postdoc)

Ka Leung Lam (RA)

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Xuli Meng (master student)

Bosco Chow (master student)

Owen Hoar (master student)

Monash University

Lead design researcher
Nigel Bertram

Lead microclimate researcher
Nigel Tapper

Oscar Sainsbury

Stephanie Jacobs

University of Western Australia

Lead design and governance researcher
Geoffrey London

Daniel Martin

Linkage to TAP project
Christian Urich

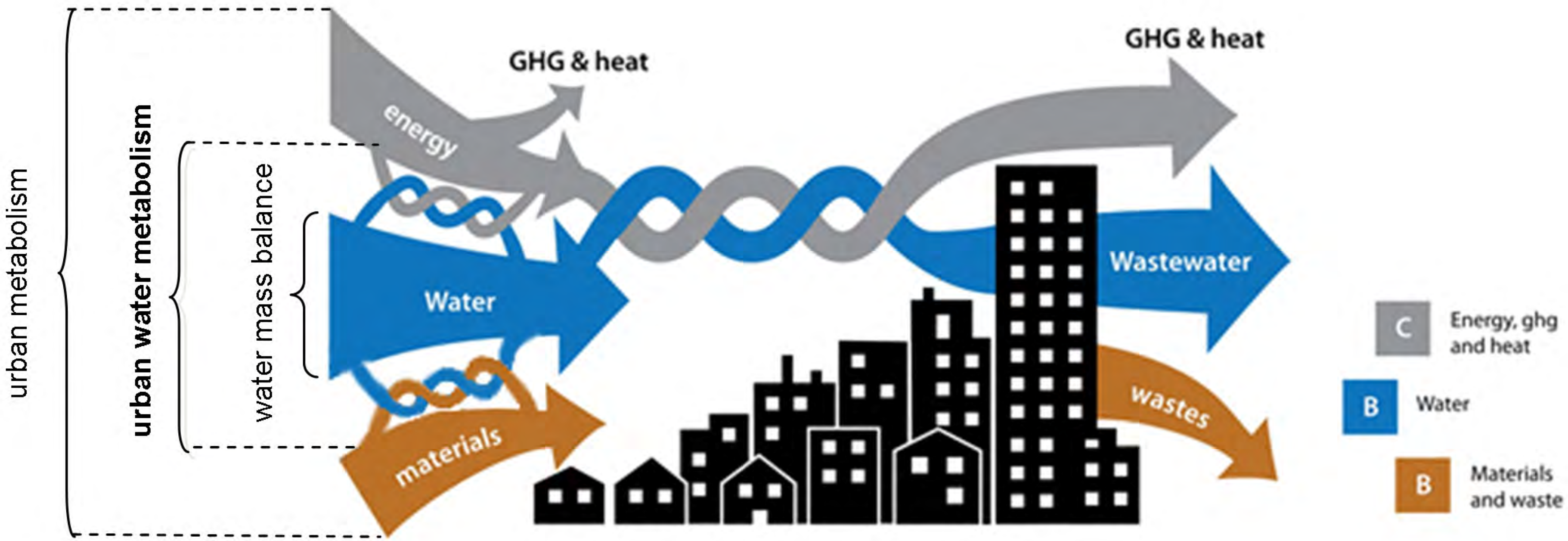
Linkages to other projects nationally
Peter Newton (Swinburne University)

PhD Students – Mojtaba Moravej (UQ (IRP4)/Monash (TAP)

Steering Committee

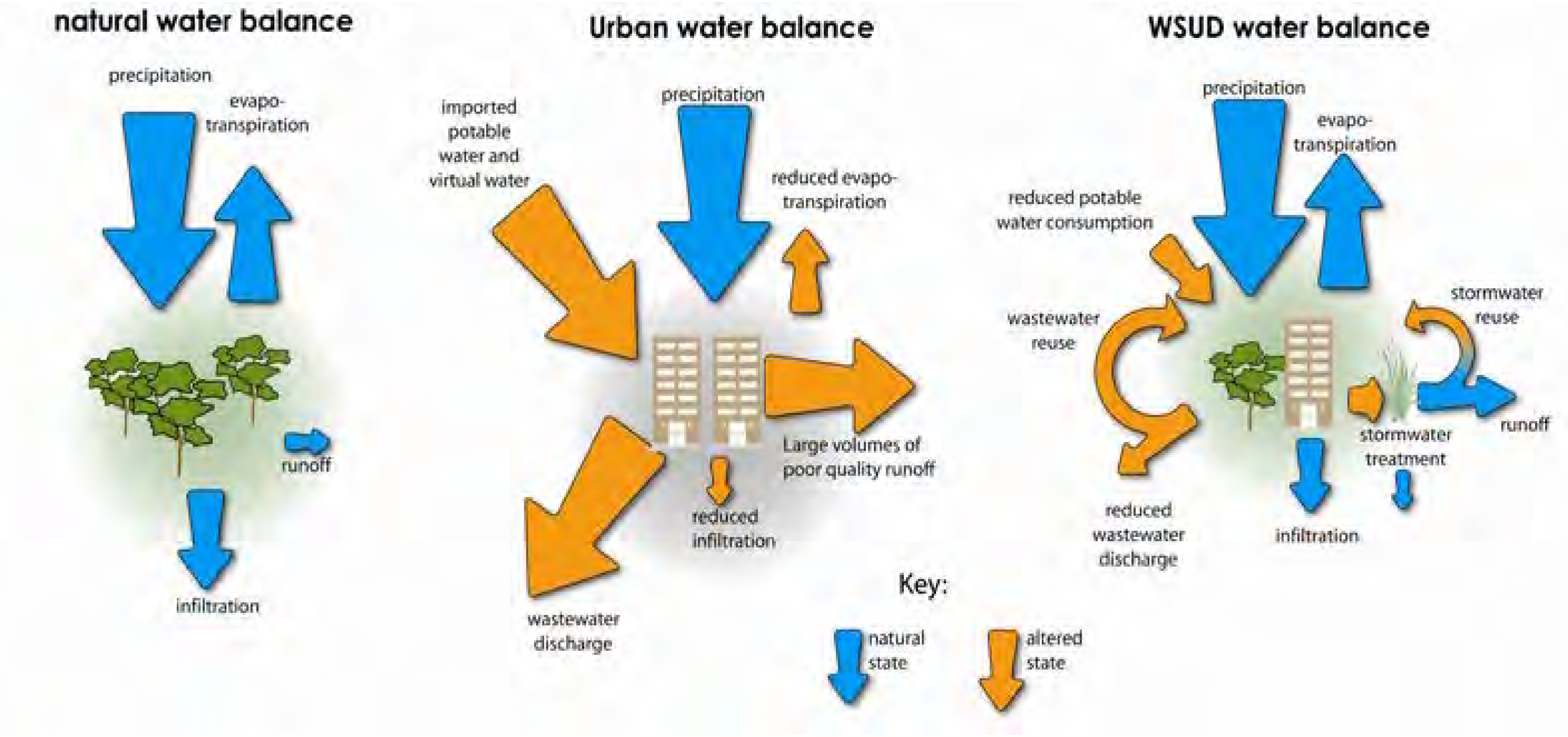
Person	Organisation	Contribution/role*
Mellissa Bradley	Water Sensitive SA	Chair of Steering/Participating Committee. Local case study/ies, garner local support.
Geoffrey London	The University of Western Australia	Project Researcher (Lead Design, Options Governance aspects, case studies).
Nigel Bertram	Monash University	Project Researcher (Lead Design, Options, Governance aspects, case studies).
Peter Newton	Swinburne University, Victoria	Connect to other work nationally. (Infill specialist research advice.
Phil Young	Brisbane City Council, Qld	Local case study/ies, garner local support.
Sadeq Zaman	Inner West Council, NSW	Local case study/ies, garner local support.
Nigel Corby	City West Water, Vic	Local case study/ies, garner local support.
Greg Ryan	LandCorp, WA	Local case study/ies, garner local support.
Nigel Tapper	Monash University	Local case study/ies, garner local support.
Pam Kerry	South East Water, Vic	Local case study/ies, garner local support.
Steven Kenway	The University of Queensland	Project Leader. Framework development, options analysis and performance quantification, case studies.
Lisa McLean	Flow Systems, NSW	Local case study/ies, garner local support.
Cintia Dotto	Water Technology, Vic	Local case study/ies, garner local support.
Nicholas Temov	Department of Planning, WA	Local case study/ies, garner local support.
Matt Stack	Department of Planning, WA	Local case study/ies, garner local support.
Marguerite Renouf	The University of Queensland, Qld	Deputy Project Leader, Project Researcher (performance framework, modelling analysis), engagement.
Andrew Allen	City of Manningham	Local case study/ies, local support

Urban metabolism and infill development



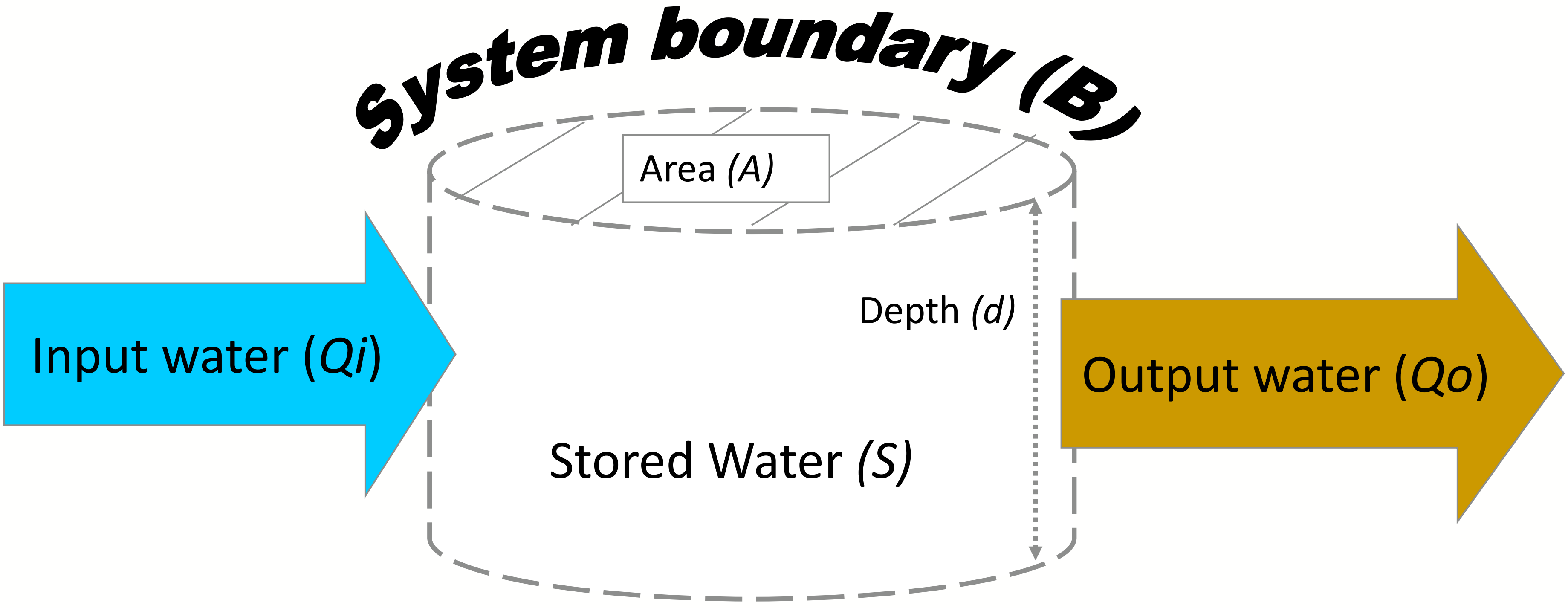
Next-generation performance-based criteria and guidelines.

Water Balance and Water Sensitive Urban Design (Water by design)



CRC for Water Sensitive Cities

The water mass balance



$Qi = Qo + \Delta S$

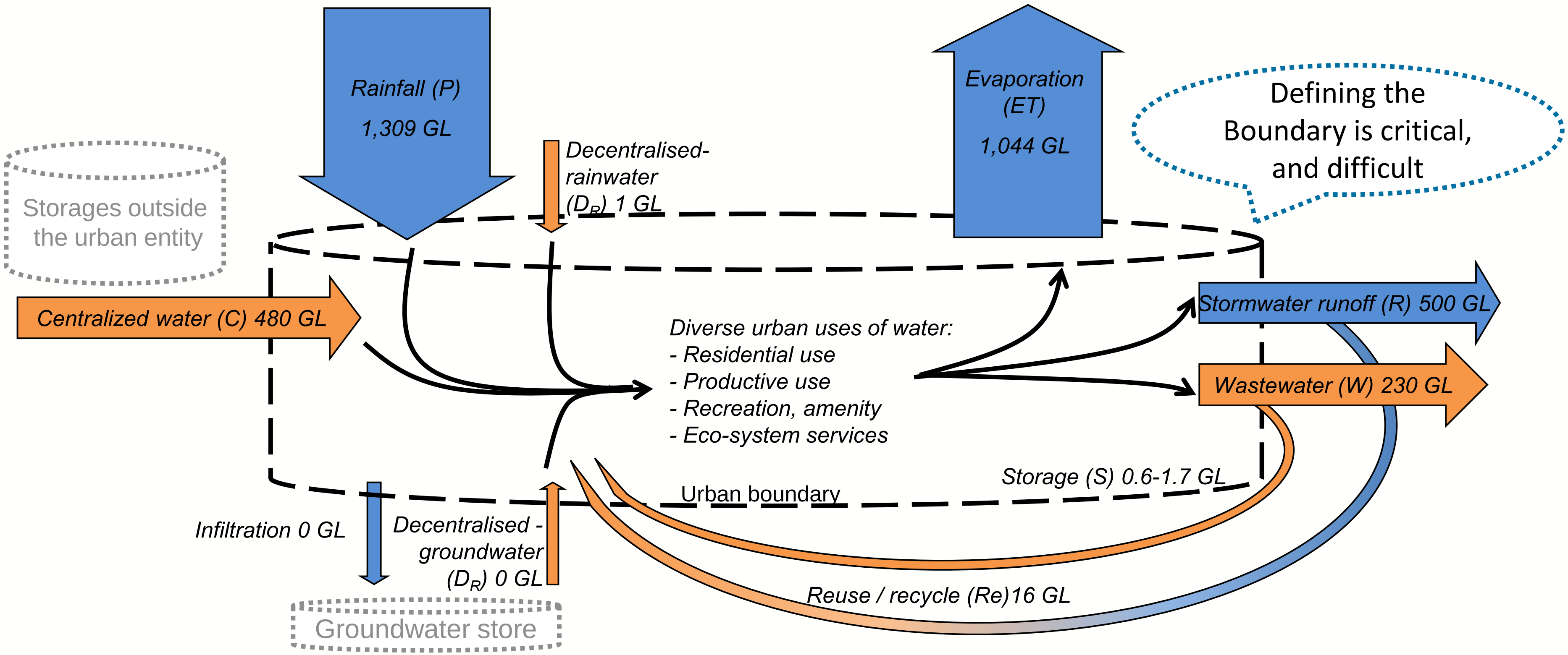
(For a given boundary and specified time period)

Kenway, S., Gregory, A. and McMahan, J. 2011. Urban Water Mass Balance Analysis. Journal of Industrial Ecology, 15, 693-706.

Urban water metabolism evaluation framework .. water mass balance example

- Quantifies managed and natural water flows (performance)
- Requires a defined boundary of the "city-entity"
- Includes a city water balance and a city water budget

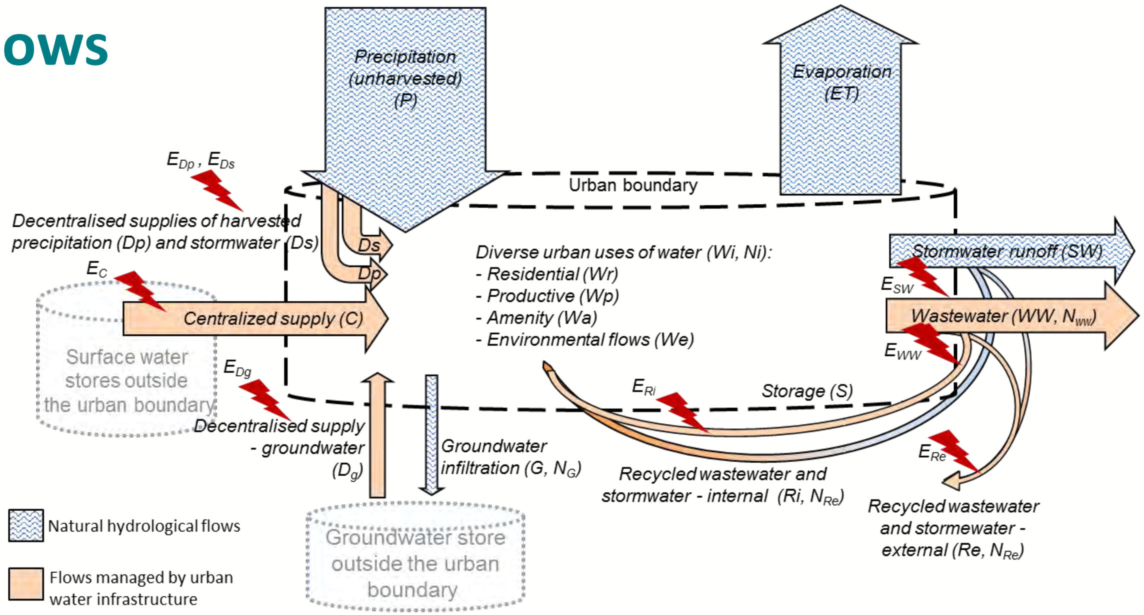
$$C + D + P = W + Rs + G + ET + \Delta S$$



Source: Kenway, S., Gregory, A. and McMahan, J. 2011. Urban Water Mass Balance Analysis. Journal of Industrial Ecology, 15, 693-706.

How can we evaluate urban water metabolism?

Mass balances of water-related resource flows



Water Mass Balance

Sum of water inflows = Sum of water outflows + change in storage

(P + C + D + Ri) = (ET + SW + WW + G +Ri + Re) + ΔS

Performance indicators

Restoration of natural hydrological flows

Water supply internalization / decentralization.

Functionality of water

Resource efficiency

- Water use efficiency

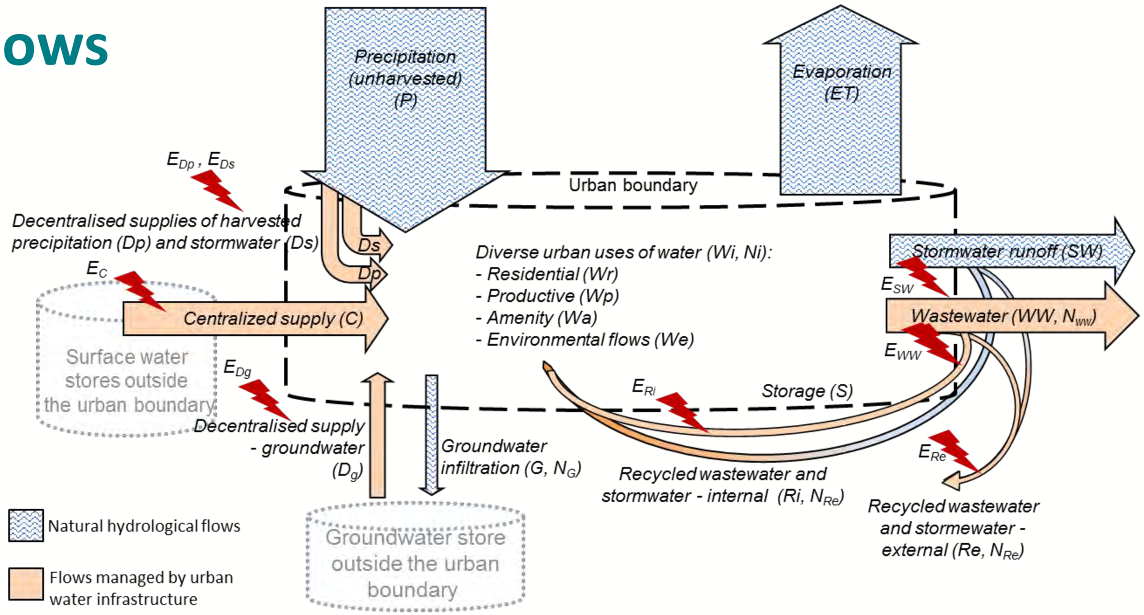
Want to know more?

Renouf, M.A., Kenway, S.J., Serrao-Neumann, S. and Low Choy, D. (2016) Urban metabolism for planning water sensitive cities. Concept for an urban water metabolism evaluation framework, Cooperative Research Centre for Water Sensitive Cities. http://watersensitivecities.org.au/publications/technical-reports/

Renouf, M.A., Kenway, S.J., Serrao-Neuman, S., Morgan, E.A. and Low Choy, D. (Submitted) Deriving indicators of urban water metabolism from a water mass balance. Water Research.

How can we evaluate urban water metabolism?

Mass balances of water-related resource flows



Water Mass Balance	Sum of water inflows	= Sum of water outflows + change in storage
	(P + C + D + Ri)	= (ET + SW + WW + G +Ri + Re) + ΔS
Water-related Energy	Total energy use	= Sum of energy use for water management
	E_{TOT}	= $E_C + E_D + E_{WW} + E_{SW} + E_{Ri} + E_{Re}$
Water-related Nutrient Balance	Sum of nutrient inflow	= Sum of nutrient outflow
	$(N_{Wi} + N_{ri})$	= $(N_{WW} + N_{Ri} + N_{Re})$

Performance indicators

Restoration of natural hydrological flows

Water supply internalization / decentralization.

Functionality of water

Resource efficiency

- Water use efficiency
- Water-related energy efficiency
- Water-related nutrient efficiency

Want to know more?

Renouf, M.A., Kenway, S.J., Serrao-Neumann, S. and Low Choy, D. (2016) Urban metabolism for planning water sensitive cities. Concept for an urban water metabolism evaluation framework, Cooperative Research Centre for Water Sensitive Cities. http://watersensitivecities.org.au/publications/technical-reports/

Renouf, M.A., Kenway, S.J., Serrao-Neuman, S., Morgan, E.A. and Low Choy, D. (Submitted) Deriving indicators of urban water metabolism from a water mass balance. Water Research.

Tool developed in Tranche 1…

Urban metabolism evaluation framework (UMEF) for water

Want to know more?

Renouf, M.A., Kenway, S.J., Lam, K.L., Weber, T., Roux, E., Serrao-Neunann, S., Low Choy, D. and Morgan, E. (2018) **Understanding urban water performance at the city-region scale using an urban water metabolism evaluation framework.** Water Research. Accepted 29/01/2018.

Renouf, MA, Sochacka, B, Kenway, SJ, Lam, KL, Serrao-Neumann, S, Morgan, E, Low Choy, D (2017) **Urban metabolism for planning water sensitive city-regions. Proof of concept.for an urban water metabolism evaluation framework**. Cooperative Research Centre for Water Sensitive Cities, Melbourne, Australia: Available from https://watersensitivecities.org.au

Urban system boundary definition

Defining extent of urban and peri-urban areas using spatial land use data

Flow estimation

Natural hydrological flows

Estimating flows based on variables:

Climate (rainfall)
Topography (soil type deep drainage)
Land use (perviousness)

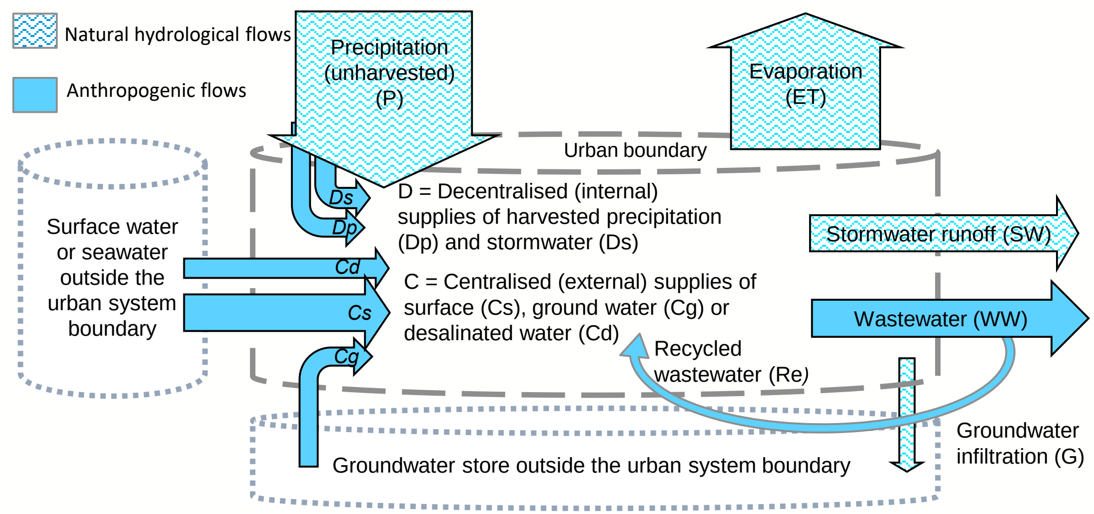
Anthropogenic flows

Collation of measured values from national urban water accounts:

Water demand, supply, losses
Wastewater generation, discharge

Urban water mass balance
(adapted from Kenway et al. (2011) and Farooqui et al. (2016))

Water Mass Balance	**Sum of water inflows**	**=**	**Sum of water outflows + change in storage**
	(P + C + D + Re)	**=**	**(ET + SW + WW + G +Re) + ΔS**



Urban water metabolism performance indicators
(adapted from Renouf et al.))

Urban water efficiency (in terms of water extracted externally from the environment)

Hydrological performance (for stormwater runoff, groundwater infiltration and evapotranspiration)

Metabolism performance indicators

Indicator	Description	Equation
Urban water efficiency	Total external water use per capita per year (kL/capita/yr)	$\frac{C}{Population}$
Water supply internalisation	Proportion of total urban water demand met by internally harvested / recycled water	$\frac{D + Re}{D + Re + C}$
Hydrological performance	Ratio of post- (i) to pre-urbanised (o) annual flows of stormwater runoff (SW), evapotranspiration (ET, and groundwater infiltration (G)	$\frac{SWi}{SWo}, \quad \frac{Gi}{Go}, \quad \frac{ETi}{ETo}$

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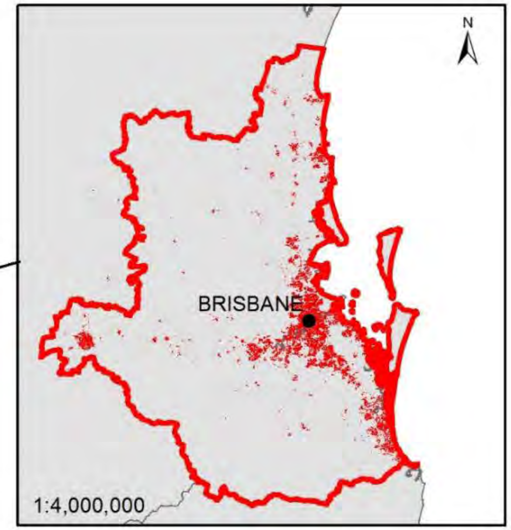
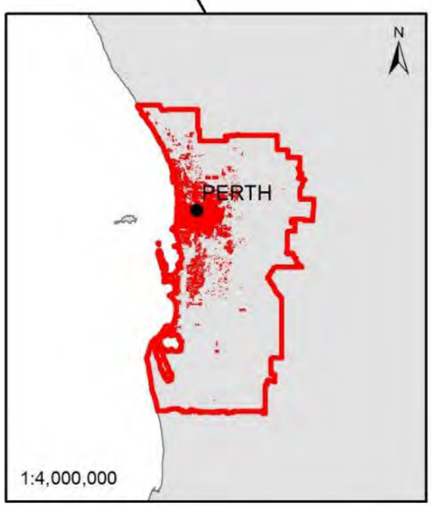
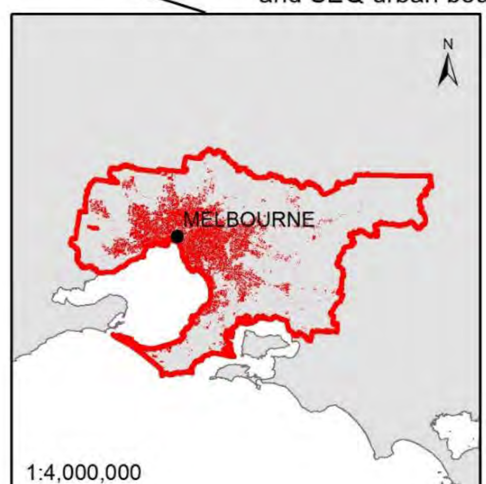
What is the ‘urban entity’ we are evaluating?



SEQ city-region boundary (SEQ Regional Plan) and SEQ urban boundary (CLUMP 2015)

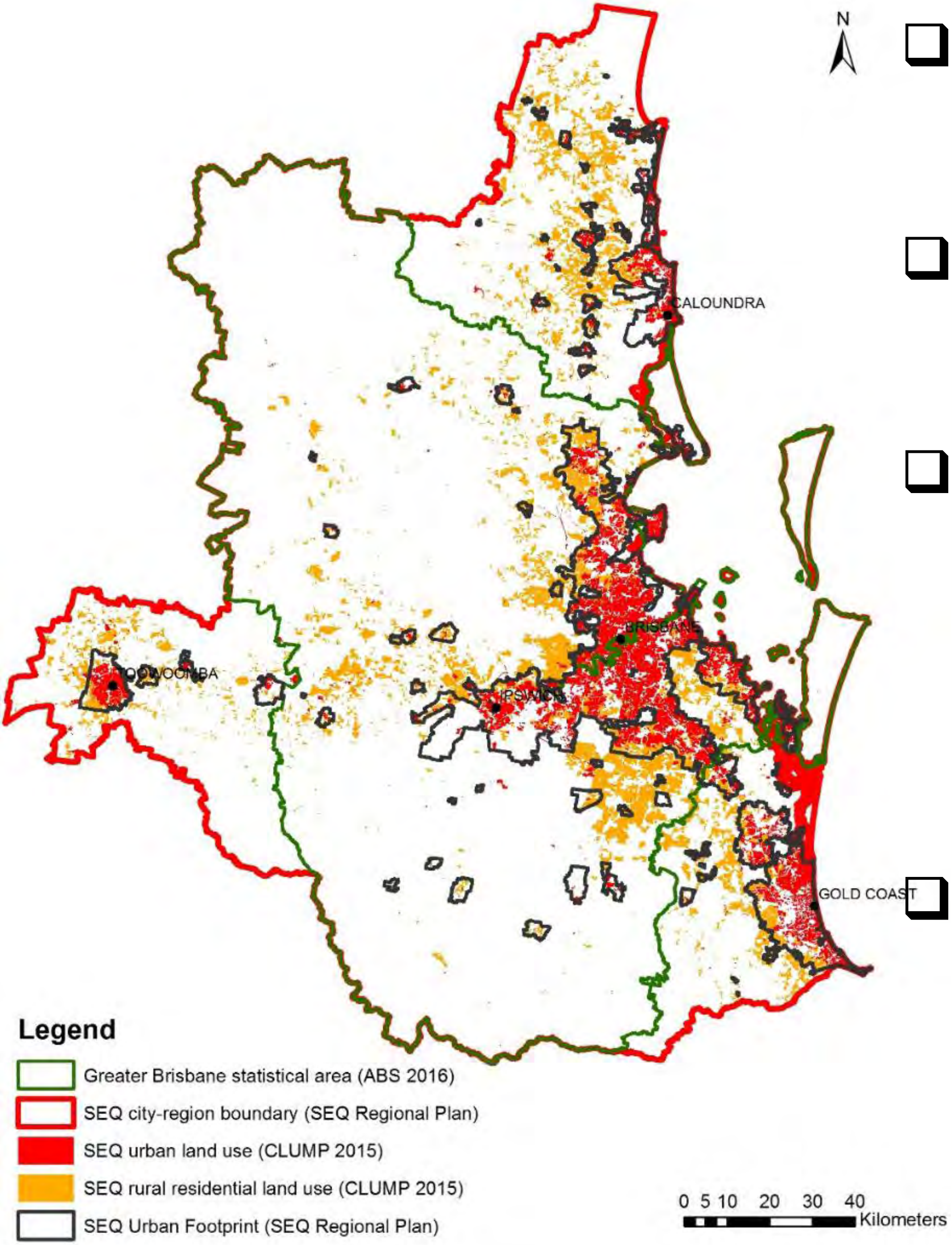


PER city-region boundary (Perth & Peel Region scheme) and PER urban boundary (CLUMP 2015)



MEL city-region boundary (Melbourne Plan) and MEL urban boundary (CLUMP 2015)

System boundaries - SEQ



- ❑ Assess mass balance in context of region.
- ❑ Delineate urban area and supporting region.
- ❑ Urban = residential, commercial, manufacturing, industrial, public services, utilities.
- ❑ Peri-urban = Rural residential.

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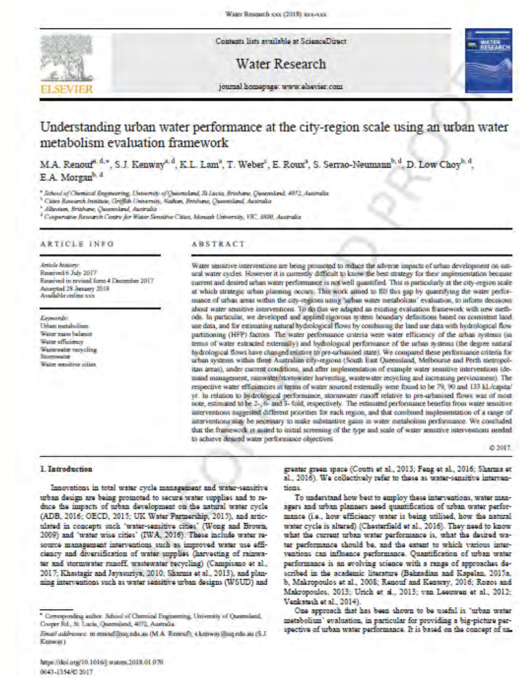
Screening of Water Sensitive Opportunities applied to city-regions



Water Research xxx (2018) xxx-xxx
Contents lists available at ScienceDirect
Water Research
journal homepage: www.elsevier.com

Understanding urban water performance at the city-region scale using an urban water metabolism evaluation framework

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ARTICLE INFO

Article history:
Received 6 July 2017
Received in revised form 4 December 2017
Accepted 28 January 2018

ABSTRACT

Water sensitive interventions are being promoted to reduce the adverse impacts of urban development on natural water cycles. However it is currently difficult to know the best strategy for their implementation because current and desired urban water performance is not well quantified. This is particularly at the city-region scale at which strategic urban planning occurs. This work aimed to fill this gap by quantifying the water perfor-

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Water metabolism indicators aligned to urban water management objectives

Visions for urban water management

- IWA's Water Wise City
- Water Sensitive Cities
- ABD's Asian water development outlook
- UK Water Partnership
- Singapore's ABC program
- China's Sponge City program

OBJECTIVES	INDICATOR		CAN DO?
Resource efficiency	**Overall urban water efficiencies**	total residential use of 'environmental[3]' water per person per year	NOW
	Energy for urban water	Energy input to urban water system	MAYBE NOW
	Nutrient recovery from urban water	proportion of the nutrient load in wastewater that is beneficially utilised	LATER
Water supply internalisation	**Water supply internalisation**	proportion of water demand met by harvested / recycled water	NOW
Restoration of more 'natural' hydrological flows	**Hydrological performance**	post-urbanised hydrological flows/fluxes relative to pre-urbanised flows/fluxes	NOW
Sustainable management of freshwater resources			
	Regional pollutant stress index	point-source and diffuse nutrient loads discharged to waters relative to sustainable discharge rates	LATER
Functionality of water	**Supporting diverse functions**	water needed to maintain desired functions relative to water budgeted for the functions	LATER

New Report
Urban metabolism application

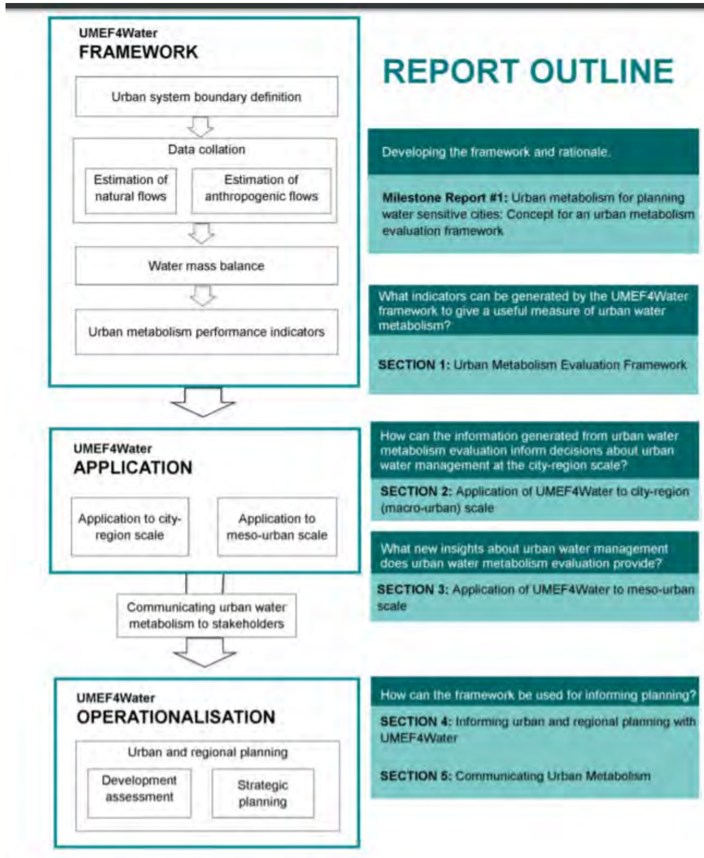

Figure 3: Structure of the report with research questions.

https://watersensitivecities.org.au/content/urban-metabolism-for-planning-water-sensitive-city-regions/

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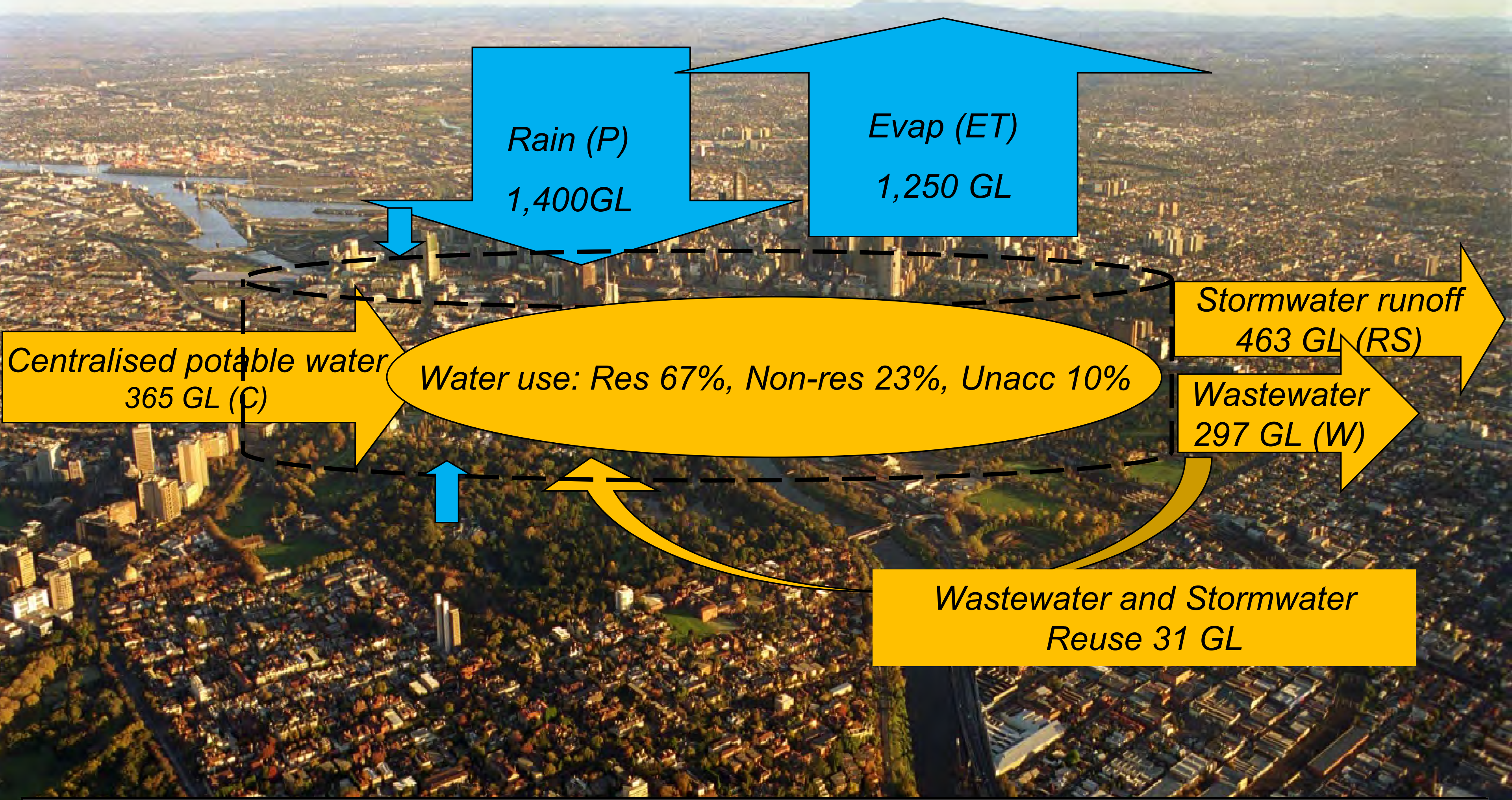
Mass Balance Framework supports quantitative performance indicators (eg Melbourne 2010)



	Potential to meet centralised demand from			Current use of available resource		
	Rainfall	Wastewater	Stormwater	Rainfall (D/P)	Wastewater (Re/W)	Stormwater (Re(s)/Rs)
Melbourne	384%	81%	127%	0.5%	7%	2%

Feedback….

- "Good for bringing multiple water sector stakeholders together. Particularly stormwater and centralized water." (*I.C.C.*).
- "Helps identify points of waste and is good for options screening. Good for big picture, strategic assessment, and setting city targets." (*B.C.C. – City Design*).
- "Helps give meaning to myriad current indicators." (*B.O.M.*).
- "We need to measure the impact of stormwater harvesting programs against the whole system in order to appreciate how effective they will be."
- "Critical for identifying where the water cycle impacts on energy and nutrient by creating a foundation balance."

Implications for integrating into WSC values for urban planning, and operationalising

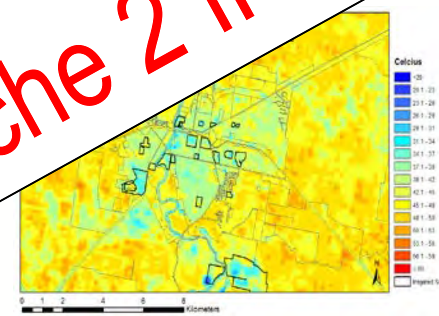
- Embedding in regional/local planning processes, national reporting and data systems, creates a driver for WSC.
- Gives evidence for integrated planning and system/city management, and fills a current gap of lack of performance quantification of "the city".
- Can be used to shape long-term city and/or precinct / suburb, or catchment goals.
- Boosting local and national capacity for analysis (government, utilities, B.O.M.,) will be needed.
- Build on to create multi-faceted outcomes including energy and nutrient management in the city.

CRC-funded Urban Climate Research Program : key research questions and approach Tranche 1

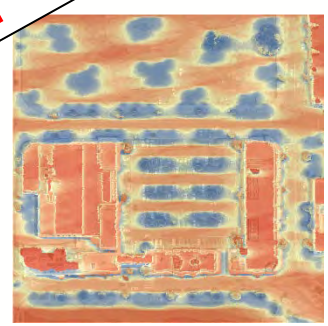
- How effective are storm water harvesting technologies, tree c… green infrastructure and water sensitive urban design (W… improving urban climates **at a range of scales**?
- What are the key configurations required to r… save lives under heat wave conditions a… thermal comfort and liveability?

What learnings/tools from Tranche 1 might be applied to Tranche 2 IRP4?

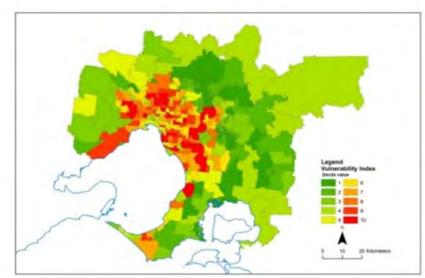
…ervations



Remote sensing



Modelling



Database mapping

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Scale of approach

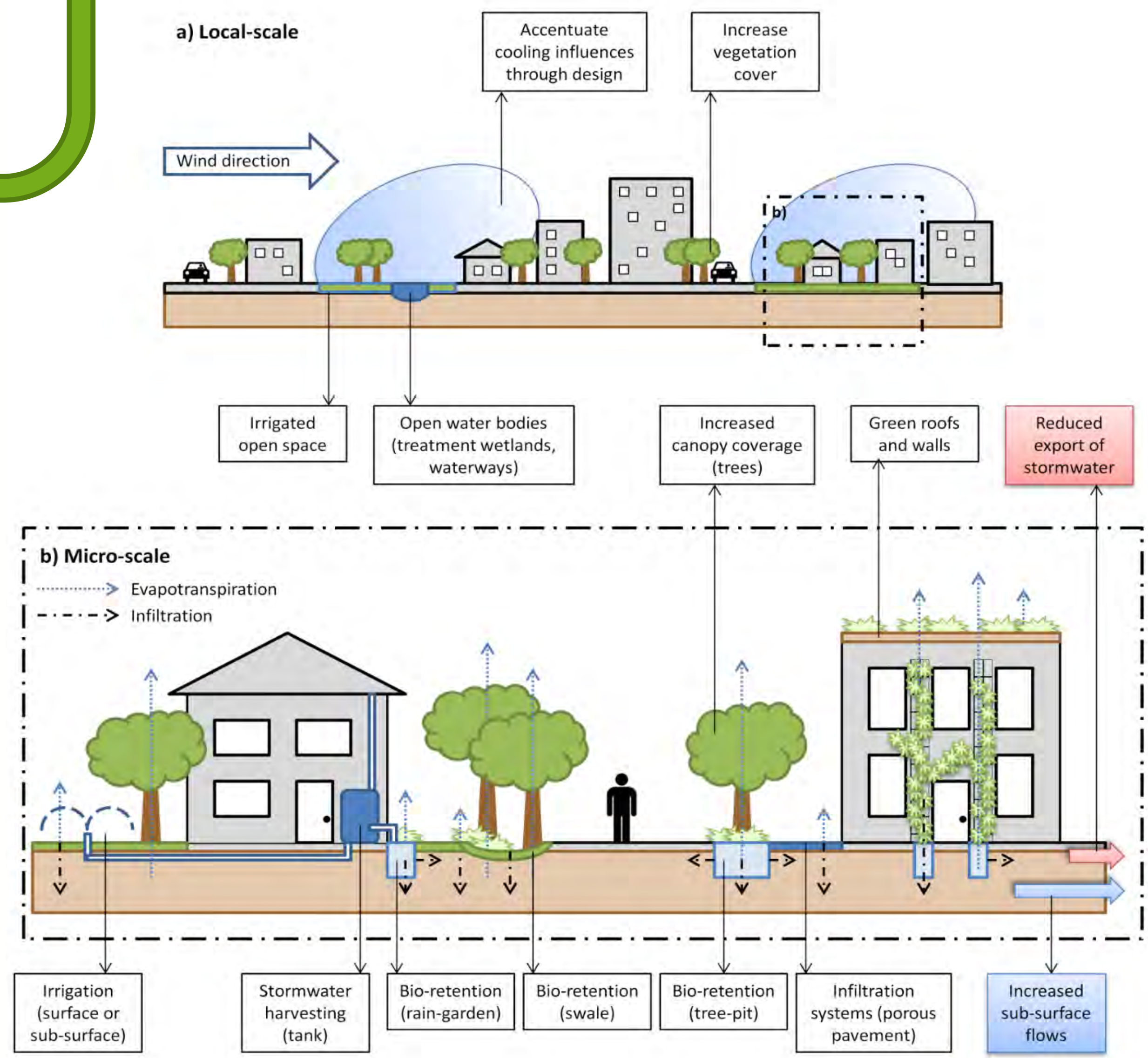
Reduce local-scale air temperature

Limit heat-health impacts

Role of water and green infrastructure

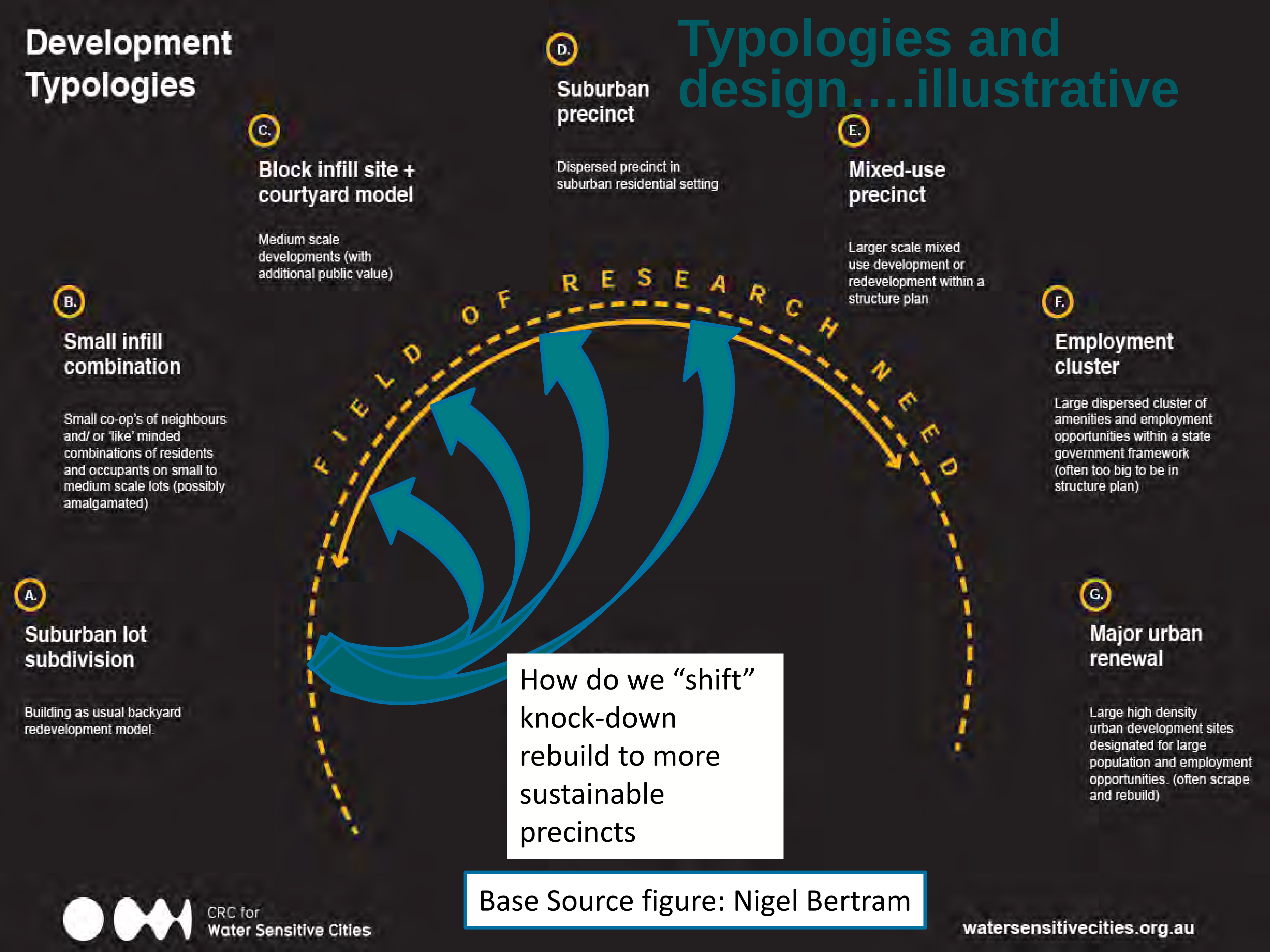
Reduce micro-scale air temperature and *radiant* temperature

Improve human thermal comfort



Coutts, Tapper, Beringer, Loughnan, Demuzere (2013)

Typologies and design….illustrative



Case studies

Illustrative success – **criteria** for water-sensitive infill:

- Hydrological performance etc (including heat)
- Increase in density (economic aspect)
- Increase in diversity (social aspect)
- Space for water and big trees (environmental aspect)
- Upgrade in technology (technological aspect)

- How does the site contribute to the precinct to make it sustainable? And vice versa? What is it that is being contributed and how?

Three well positioned and endorsed by Committee to progress to next level:

- Adelaide – City of Salisbury
- Perth – Knutsford/Hamilton Hill
- Brisbane – Norman Creek/Coorparoo (Site visit Nov 2017).

Site visit and workshops 6-8 March 2018

Co-investment/co-contribution discussions occuring.

Focus of various researchers in IRP4…. (*illustrative/w.i.p.*)

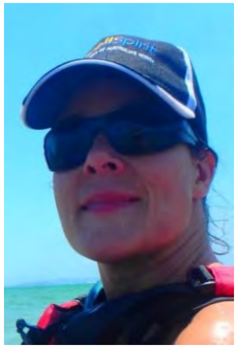
Mojtaba Moravej
Hydrological impacts, embodied water

Beata Sochacka
Water demand, design, project management

Marguerite Renouf
Framework, Stakeholders, Mass Balance

Stephanie Jacobs (climate), Oscar Sainsbury (Design), Bosco Chow (Wastewater technologies) …..

Ka Leung Lam
Water mass balance and framework



Marie-Laure Pype
Technology suitability

Daniel Martin
Principles for infill

Owen Hoar
Performance framework and groundwater

Xuli Meng
Hydrological performance

Kyle Wang
Water data value

Publications / Further reading

- Renouf, M. A., et al. (2017). **Urban water metabolism indicators derived from a water mass balance.** Bridging the gap between visions and performance assessment of urban water resource management. *Water Research* 122: 699-677.
- Farooqui, T.A., M.A. Renouf and S.J. Kenway (2016) **A metabolism perspective on alternative urban water servicing options using water mass balance.** *Water Research* 106, 415-428.
- Renouf, M.A. and S.J. Kenway (2016) **Evaluation Approaches for Advancing Urban Water Goals.** *Journal of Industrial Ecology*.
- Kenway, S.J., A. Gregory, and J. McMahon, (2011). **Urban Water Mass Balance Analysis.** *Journal of Industrial Ecology.* 15(5): p. 693-706.
- Renouf, M.A., Kenway, S.J., Lam, K.L., Weber, T., Roux, E., Serrao-Neunann, S., Low Choy, D. and Morgan, E. (2018) **Understanding urban water performance at the city-region scale using an urban water metabolism evaluation framework.** *Water Research. (in press)*
- Serrao-Neumann, S., M. Renouf, S.J. Kenway and D. Low Choy (2017) **Connecting land-use and water planning: Prospects for an urban water metabolism approach.** *Cities* 60, 13-27.
- Renouf, MA, Sochacka, B, Kenway, SJ, Lam, KL, Serrao-Neumann, S, Morgan, E, Low Choy, D (2017) Urban metabolism for planning water sensitive city-regions. Proof of concept.for an urban water metabolism evaluation framework. Cooperative Research Centre for Water Sensitive Cities, Melbourne, Australia: Available from https://watersensitivecities.org.auLam, K.L.,
- S.J. Kenway and P.A. Lant (2017**) City-scale analysis of water-related energy identifies more cost-effective solutions.** *Water Research* 109, 287-298.

Research outputs – conference papers, presentations, podcasts, tools.

- Renouf, M.A. Farooqui, T.A. Kenway, S.J. (2016). Macro-scale urban hydrological performance indicators. International Water Association, *World Water Congress*, Brisbane 2016. International Water Association, Brisbane 2016.
- King, S, Kenway, S, Renouf, M, 2016, in press accepted April 2016. How Has Urban Metabolism Been Interpreted And Communicated? International Water Association, *World Water Congress*, Brisbane 2016. International Water Association, Brisbane 2016.
- Kenway, S, Renouf, M, Serraro-Neuman, S, Morgan, E, Low Choy, D (2016). The concept and analytical framework of urban metabolism is advancing water sensitive and low-impact cities. *Low Impact Development Conference*, Beijing, China.
- Morgan, E A. Farooqui, T. Serrao-Neuman, S., Renouf, M.A, Kenway, S.J., Low Choy, D. How can water mass balance analysis inform water sensitive urban planning? A case study of a greenfield urban development. International Water Association, *World Water Congress*, Brisbane 2016.
- Three high quality Masters Students final projects and reports (Communication of metabolism, Implications of scale for grey water analysis).
- Plenary presentation: An integrated urban water cycle as the key to minimising the energy footprint? Possibilities, incentives and bottlenecks. Session T2.2.1 Daegu, Korea, 12 April 2015.
- Master of Integrated Water Management (International Water Centre) ~ 60 professionals trained in urban water mass balance and metabolism analysis 2014-2016.
- ABC Science Show, Ockham's Razor podcast. December 2014 Urban Metabolism will help us manage the water needs of future Australian cities.
- Detailed city analysis, scenario analysis, analytical tool/model (ZUMBA).

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