CRC for
Water Sensitive Cities

Water Sensitive Outcomes for infill developments (IRP4)

Overview of project

Monday 30 April 2018, Brisbane

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

Australian Government
Department of Industry and Science
Business
Cooperative Research
Centres Programme

IRP4 Project Objectives

(1) Develop an <u>infill performance evaluation framework</u> to understand the ‘water performance’ of infill development

What are the impacts of infill development on water-related objectives - hydrology, water efficiency, urban heat, amenity?

How can ‘water performance’ of infill development be defined, assessed and quantified?

Can “better” or “optimal” solutions for infill development be identified?

(2) <u>Case studies</u> (real projects) to inform the evaluation framework, housing design typologies

How does infill housing design typology (and associated public space) influence the ‘urban water performance’ of an urban area?

What water technologies are suited to different infill typologies and scales and help achieve optimal ‘water performance’?

(3) Improved <u>governance</u> options / arrangements for infill

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

Some background….Tranche 1 B1.2

- Evaluation framework for quantifying 'water performance' of urban areas:
  - Urban metabolism as conceptual framework
  - Urban water mass balance as method
  - Urban water performance indicators
  - Defining the urban system boundary

- Applications at different urban scales:
  - Medium greenfield (Ripley, SEQ)
  - Large city-region (SEQ, PER, MEL)
  - Small scale (IRP4 infill)

- Stakeholder feedback
- Feeding 'water performance' into planning

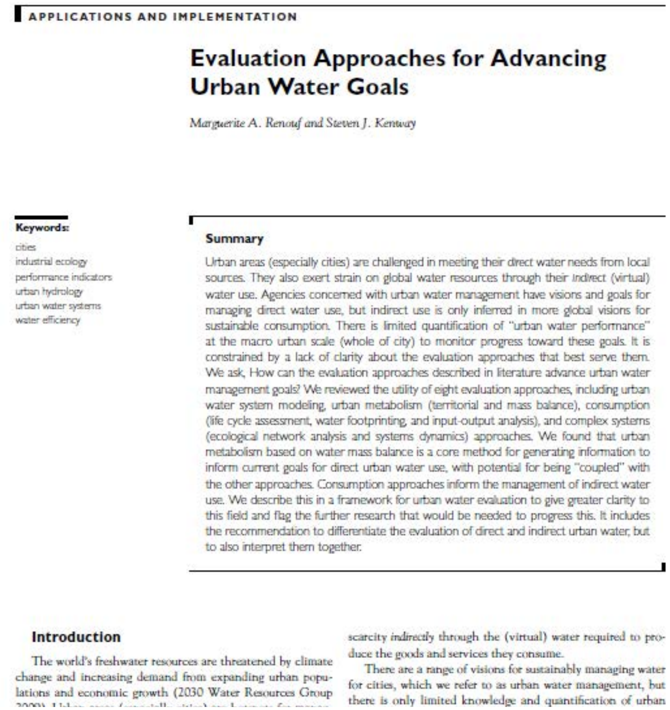
The University of Queensland
Australia

Griffith University

Research outputs

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

   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

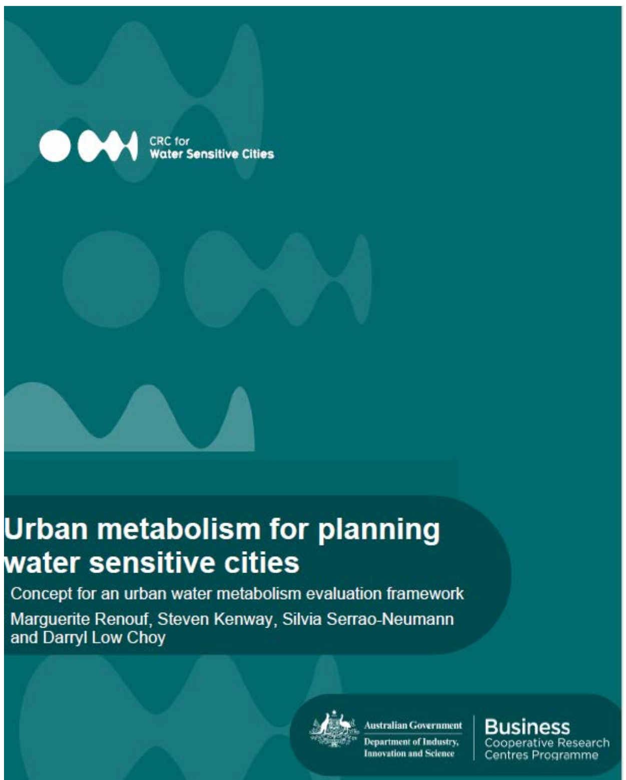
Urban areas (especially cities) are challenged in meeting their direct water needs from local sources. They also exert strain on global water resources through their *indirect* (virtual) water use. Agencies concerned with urban water management have visions and goals for managing direct water use, but 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

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



2. Concept for an urban metabolism evaluation framework

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

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Research outputs

3. Pilot application to a urban development (Ripley Valley)

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/watres

A metabolism perspective on alternative urban water servicing options using water mass balance

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rds:
hydrology
mass balance
efficiency
related energy
water recycling
water

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.

Water Research 122 (2017) 669–677

Contents lists available at ScienceDirect

Water Research

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

Urban water metabolism indicators derived from a water mass balance – Bridging the gap between visions and performance assessment of urban water resource management

CrossMark

M.A. Renouf [a, c, *], S. Serrao-Neumann [b, c], S.J. Kenway [a, c], E.A. Morgan [b, c], D. Low Choy [b, c]

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Keywords:
Resource efficiency
Water efficiency
Water-related energy
Nutrients
Urban hydrology
Sustainability

ABSTRACT

Improving resource management in urban areas has been enshrined in visions for achieving sustainable urban areas, but to date it has been difficult to quantify performance indicators to help identify more sustainable outcomes, especially for water resources. In this work, we advance quantitative indicators for what we refer to as the 'metabolic' features of urban water management: those related to resource efficiency (for water and also water-related energy and nutrients), supply internalisation, urban hydrological performance, sustainable extraction, and recognition of the diverse functions of water. We derived indicators in consultation with stakeholders to bridge this gap between visions and performance indicators. This was done by first reviewing and categorising water-related resource management objectives for city-regions, and then deriving indicators that can gauge performance against them. The ability for these indicators to be quantified using data from an urban water mass balance was also examined. Indicators of water efficiency, supply internalisation, and hydrological performance (relative to a reference case) can be generated using existing urban water mass balance methods. In the future, indicators for water-related energy and nutrient efficiencies could be generated by overlaying the urban water balance with energy and nutrient data. Indicators of sustainable extraction and recognising diverse functions of water will require methods for defining sustainable extraction rates and a water functionality index.

4. Indicators of urban water metabolism

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

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?

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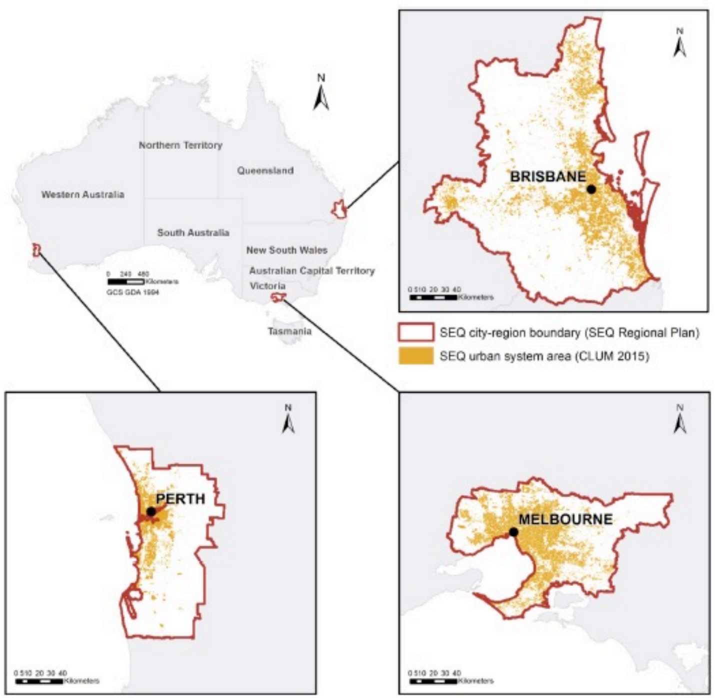

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Research outputs

6. Metabolism for connecting land-use and water planning

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

ELSEVIER

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

CrossMark

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Water sensitive cities
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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.

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. Water metabolism knowledge needs of planners

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

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.

Evaluating the benefits of greywater reuse with consideration of heat recovery

Final Project

Student Number: 43600087

Course: WATR 7501/7502

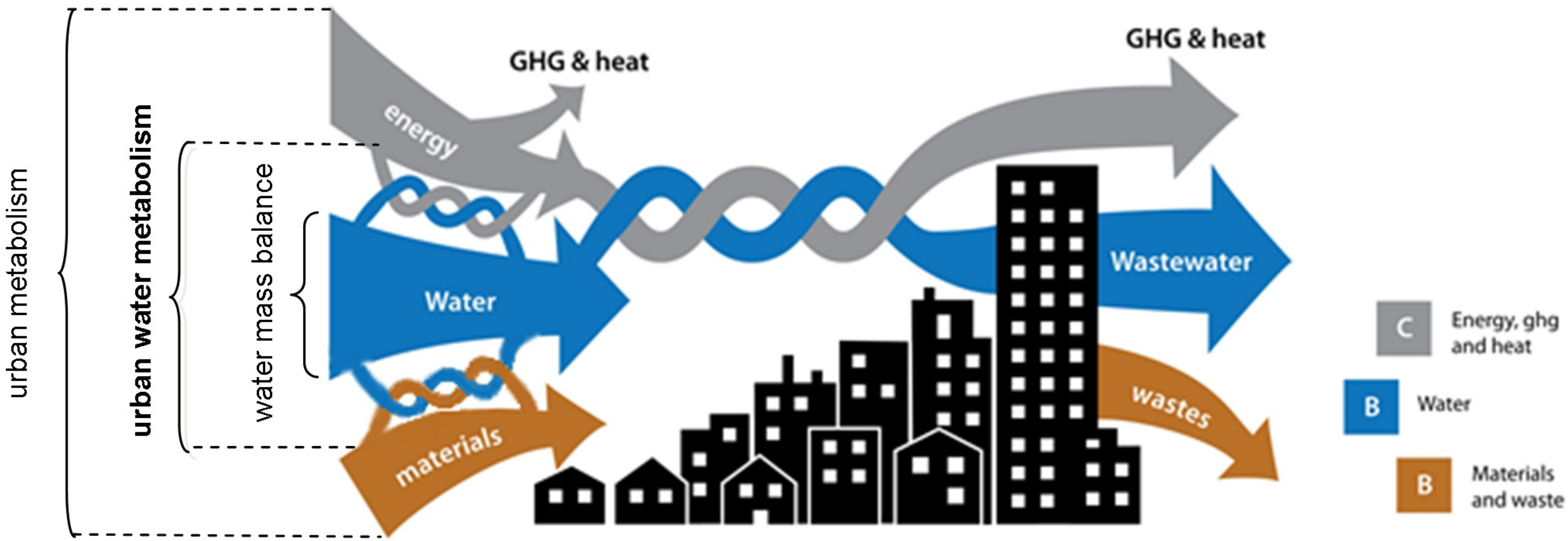
30 October 2016

9. Water-related energy

Questions:

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

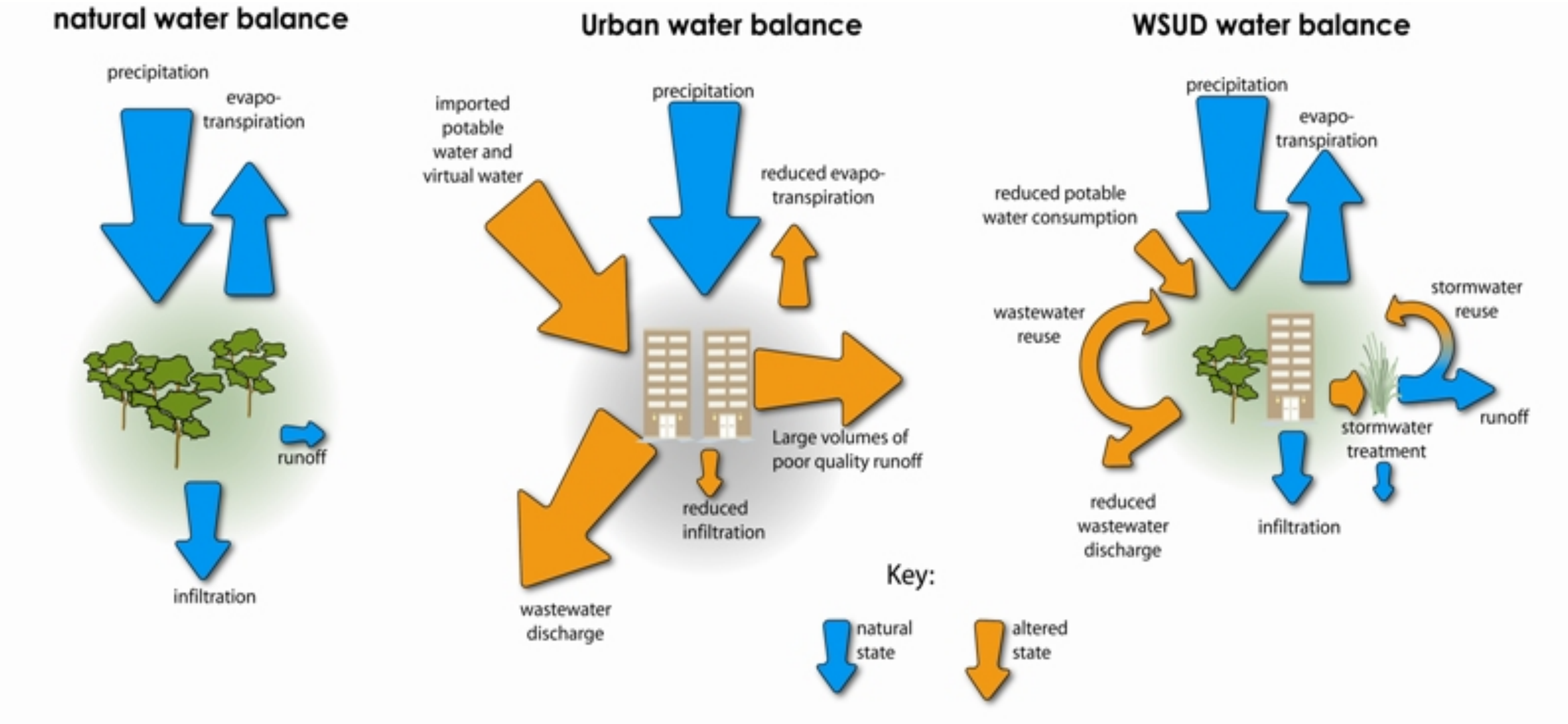
Urban metabolism and infill development



Next-generation performance-based criteria and guidelines.

Adapted from Kenway, PhD Thesis

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



Source: Water by Design

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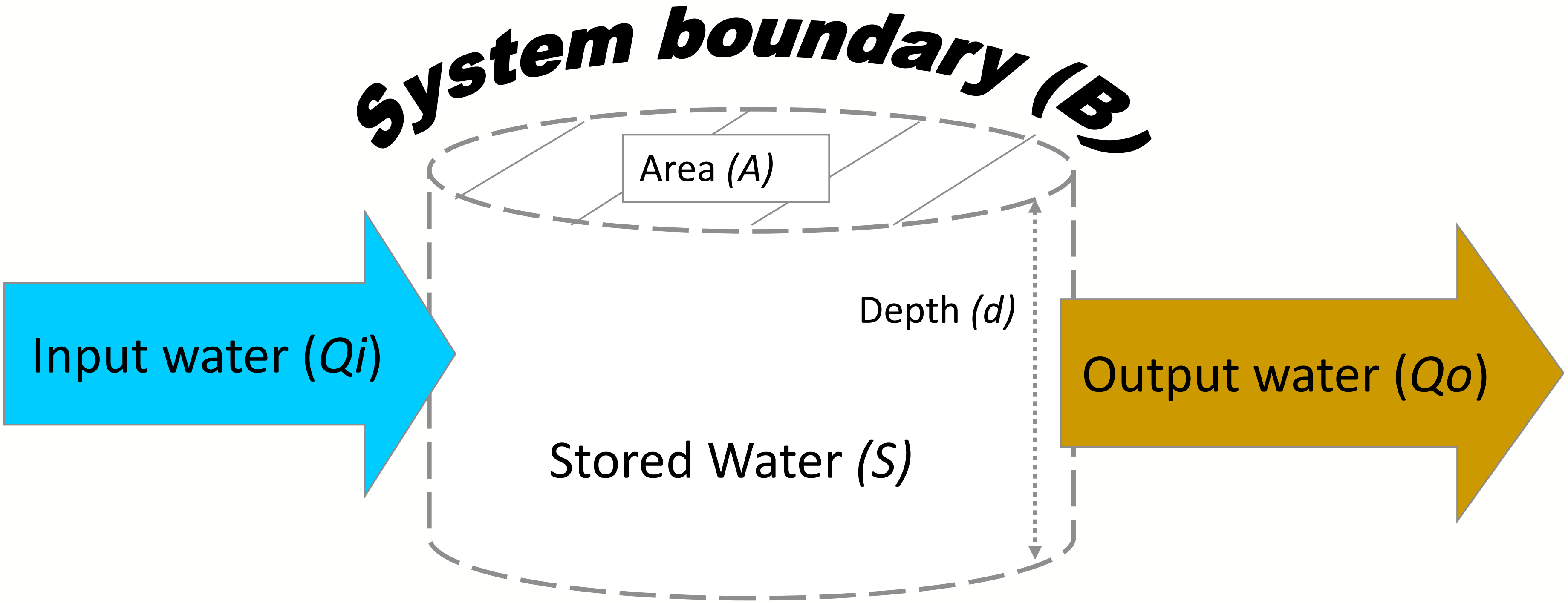
Water mass balance



$$Qi = Qo + \Delta S$$

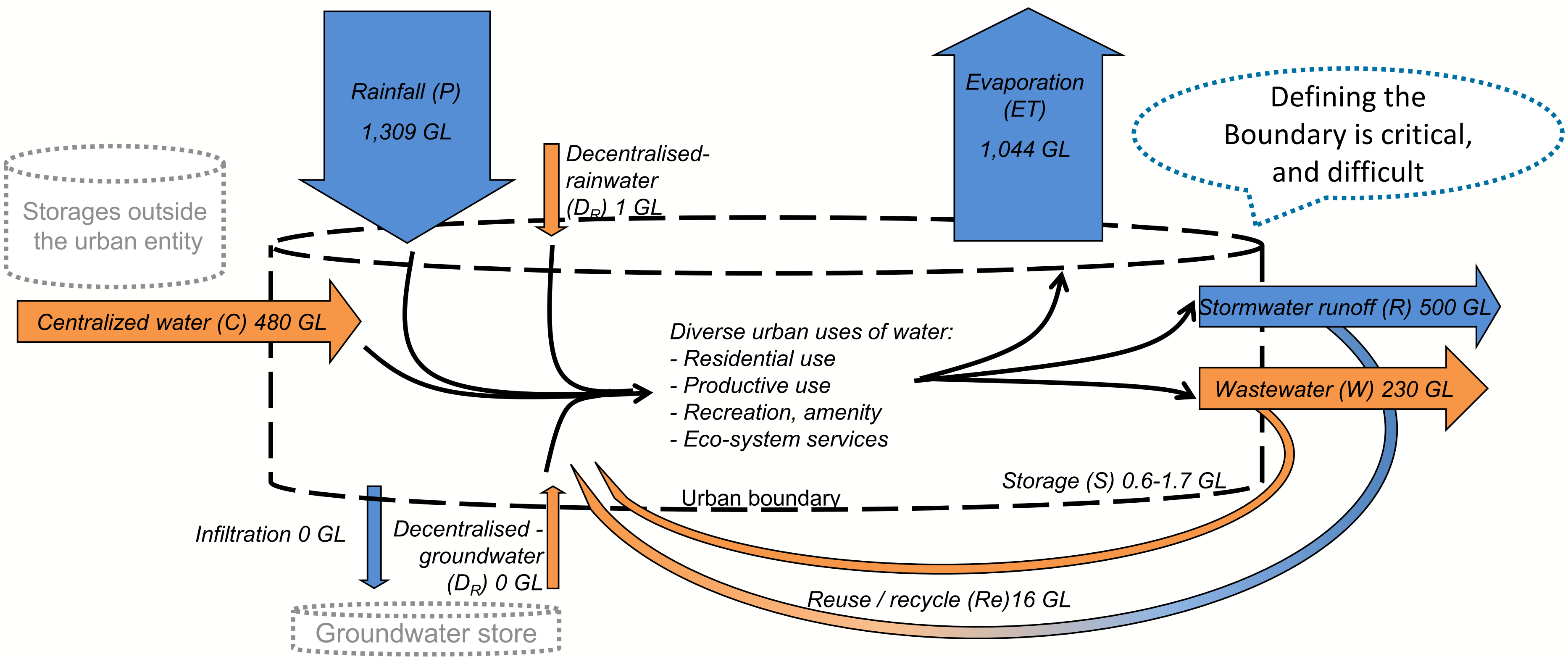
(For a given boundary and specified time period)

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

Urban water mass balance

- 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.

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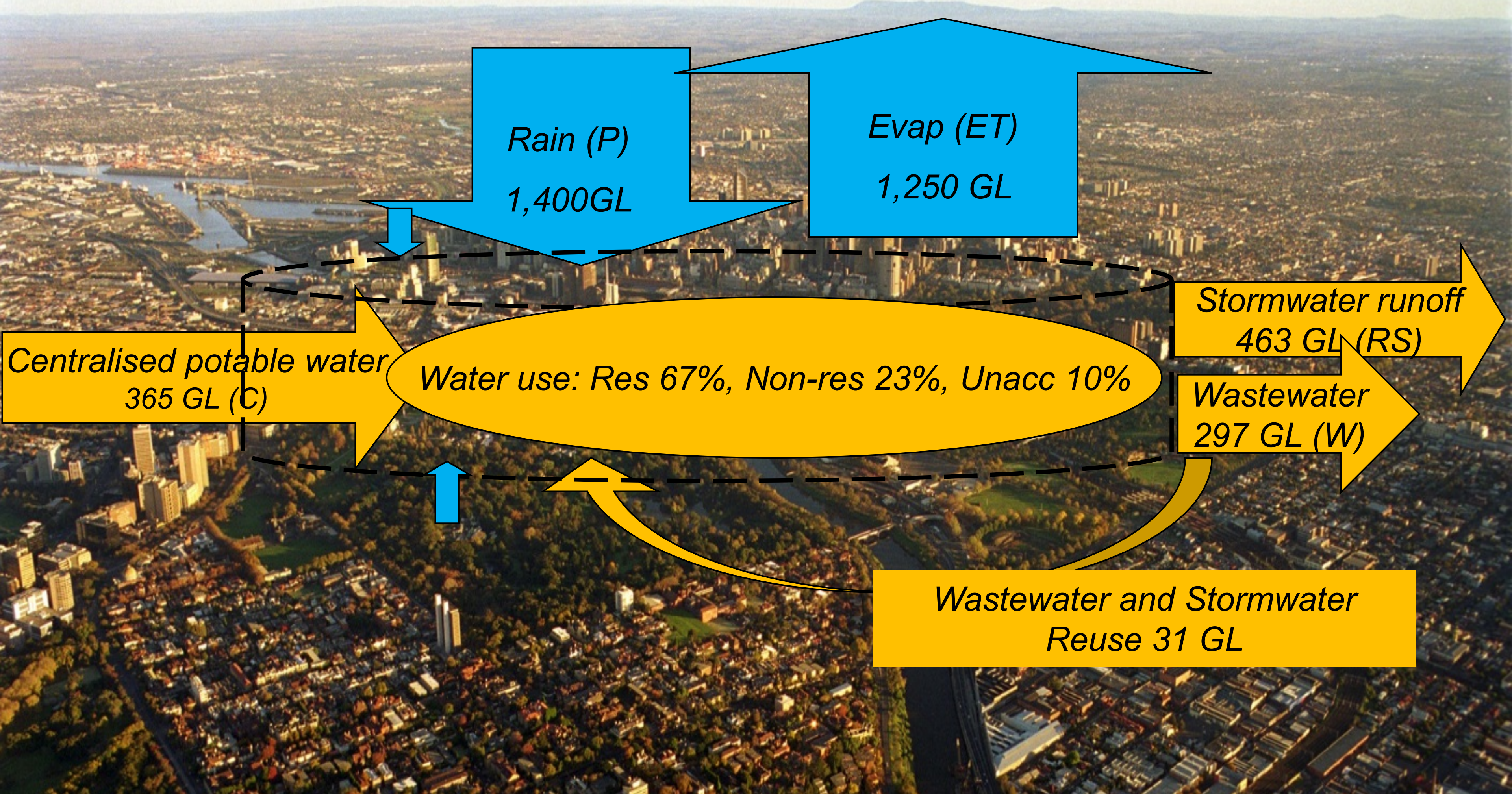
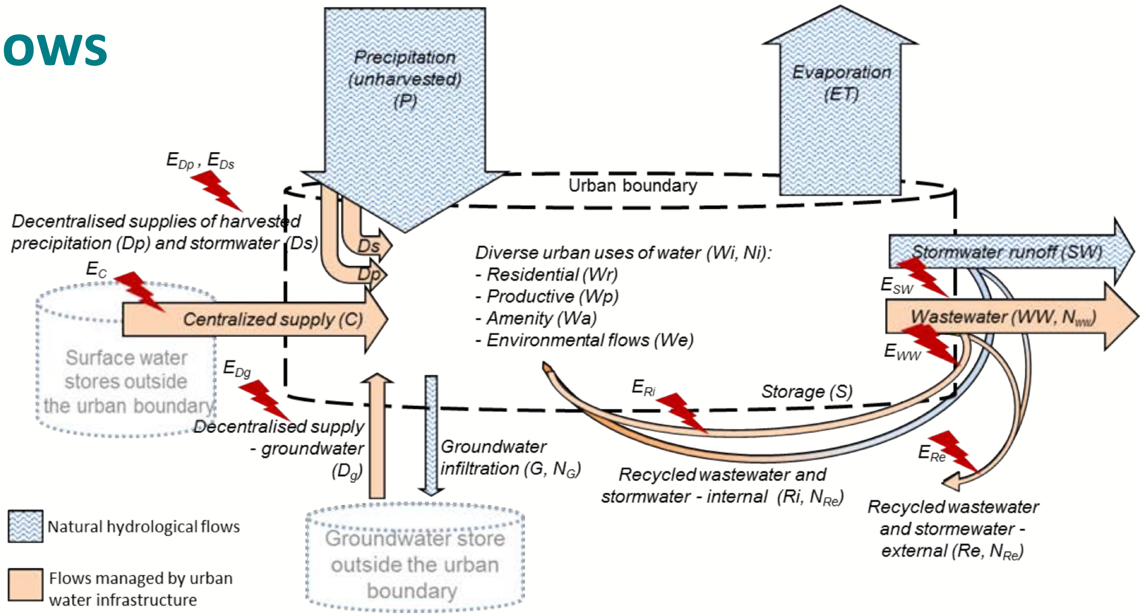
Early example of an urban water mass balance (Melbourne 2010)



	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%

Performance indicators from water mass balance

Mass balances of water-related resource flows



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

'Water performance' indicators

Water use efficiency

(*in terms of water extracted externally from the environment*)

Water supply internalization

Restoration of natural hydrological flows

Source:

Renouf, Serrao-Neuman, Kenway, Morgan, Low Choy (2017) **Water Research** Vol. 122.

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Water performance 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

Source: Renouf et al (2017) **Water Research** Vol. 122.

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

Water 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)	$\frac{SWi}{SWo}, \frac{Gi}{Go}, \frac{ETi}{ETo}$

Source:
Renouf, Serrao-Neuman, Kenway, Morgan, Low Choy (2017) **Water Research** Vol. 122.

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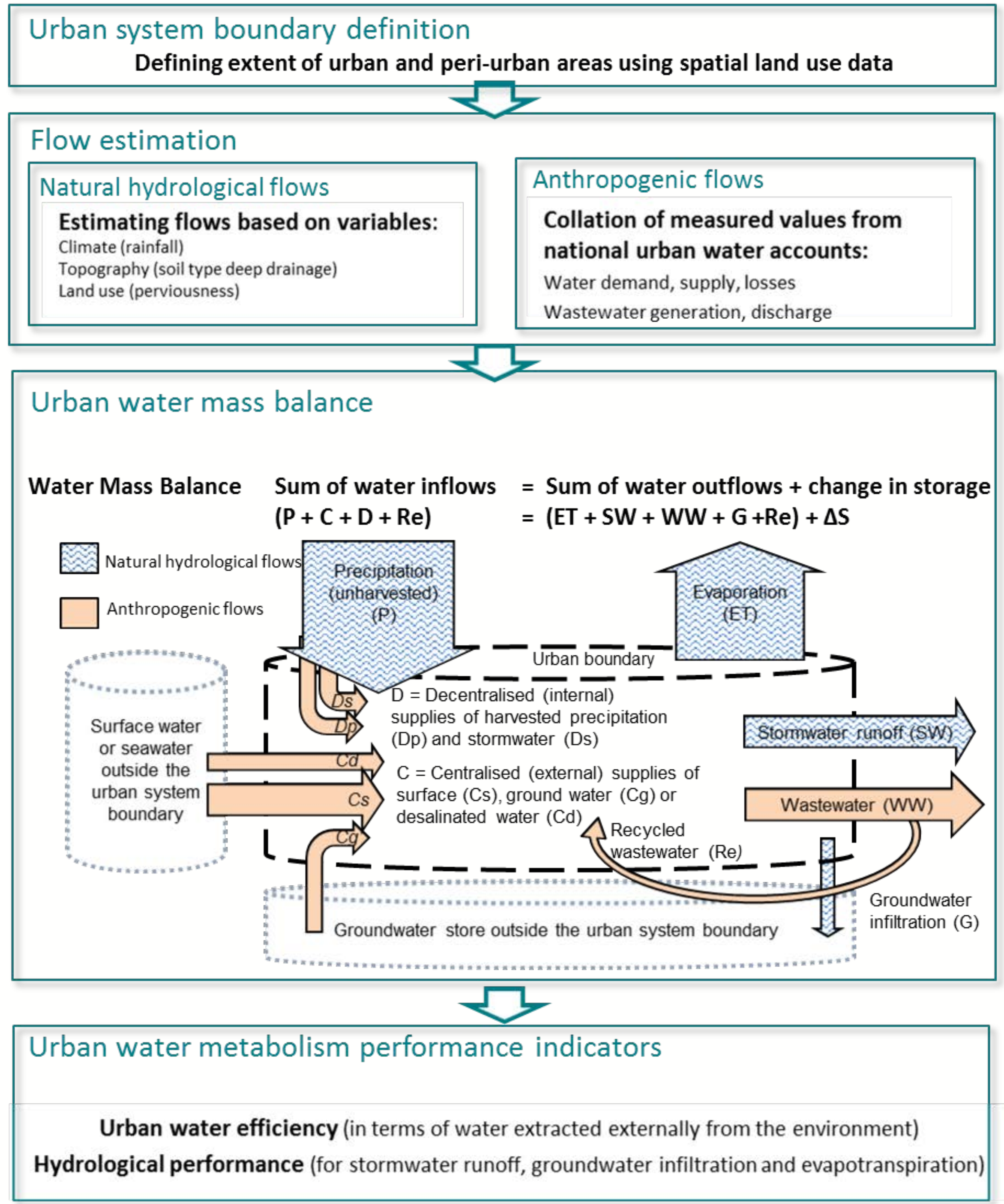
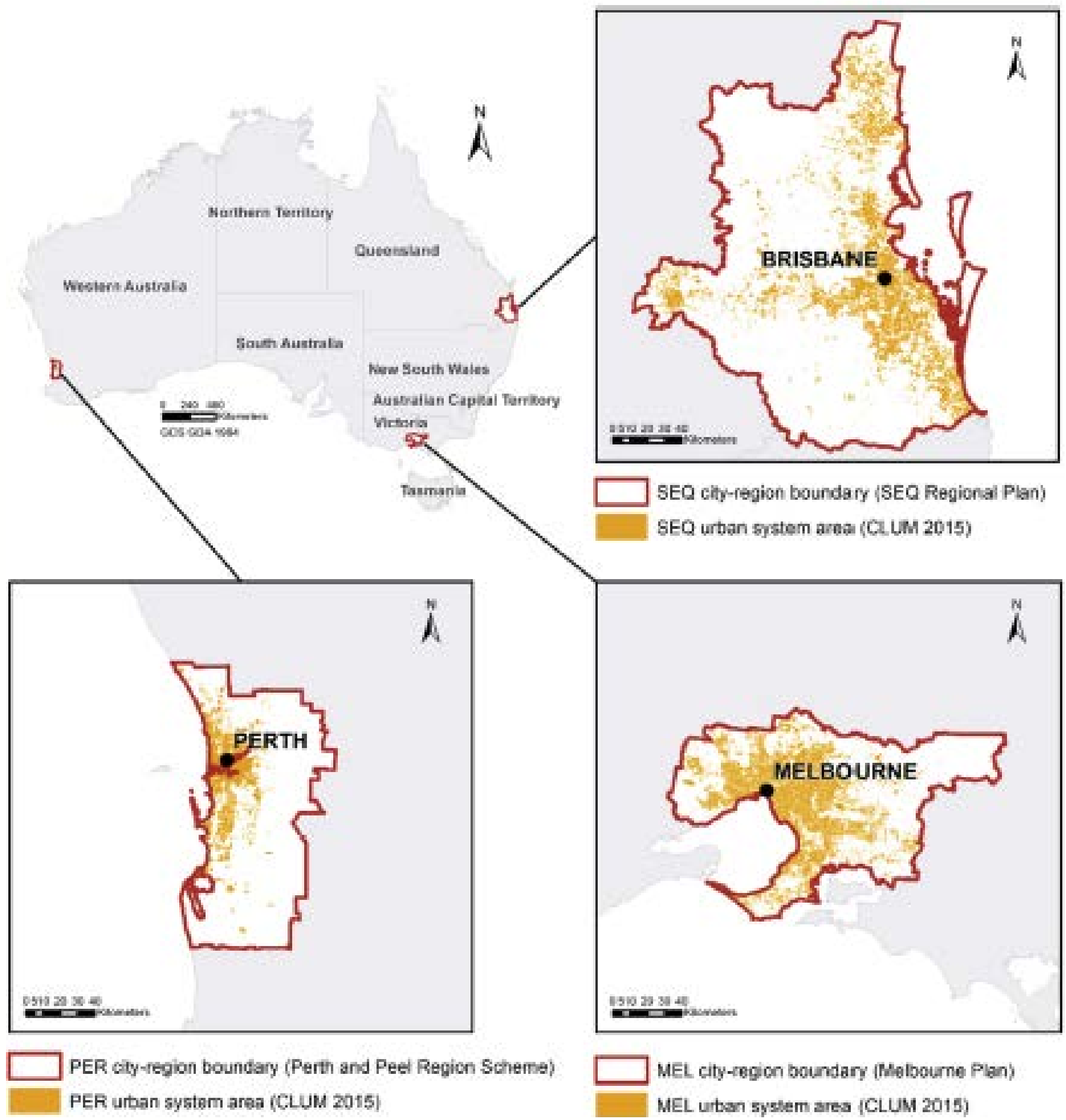
Urban metabolism evaluation framework (UMEF) for water



Source:
Renouf, Kenway, Lam, Weber, Roux, Serrao-Neuman, Morgan, Low Choy (2018) **Water Research** Vol. 137.

Screening water sensitive opportunities at city-region scale

What is the 'urban entity' we are evaluating?



Source:
Renouf, Kenway, Lam, Weber, Roux, Serrao-Neuman, Morgan, Low Choy (2018) **Water Research** Vol. 137.

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Screening water sensitive opportunities at city-region scale

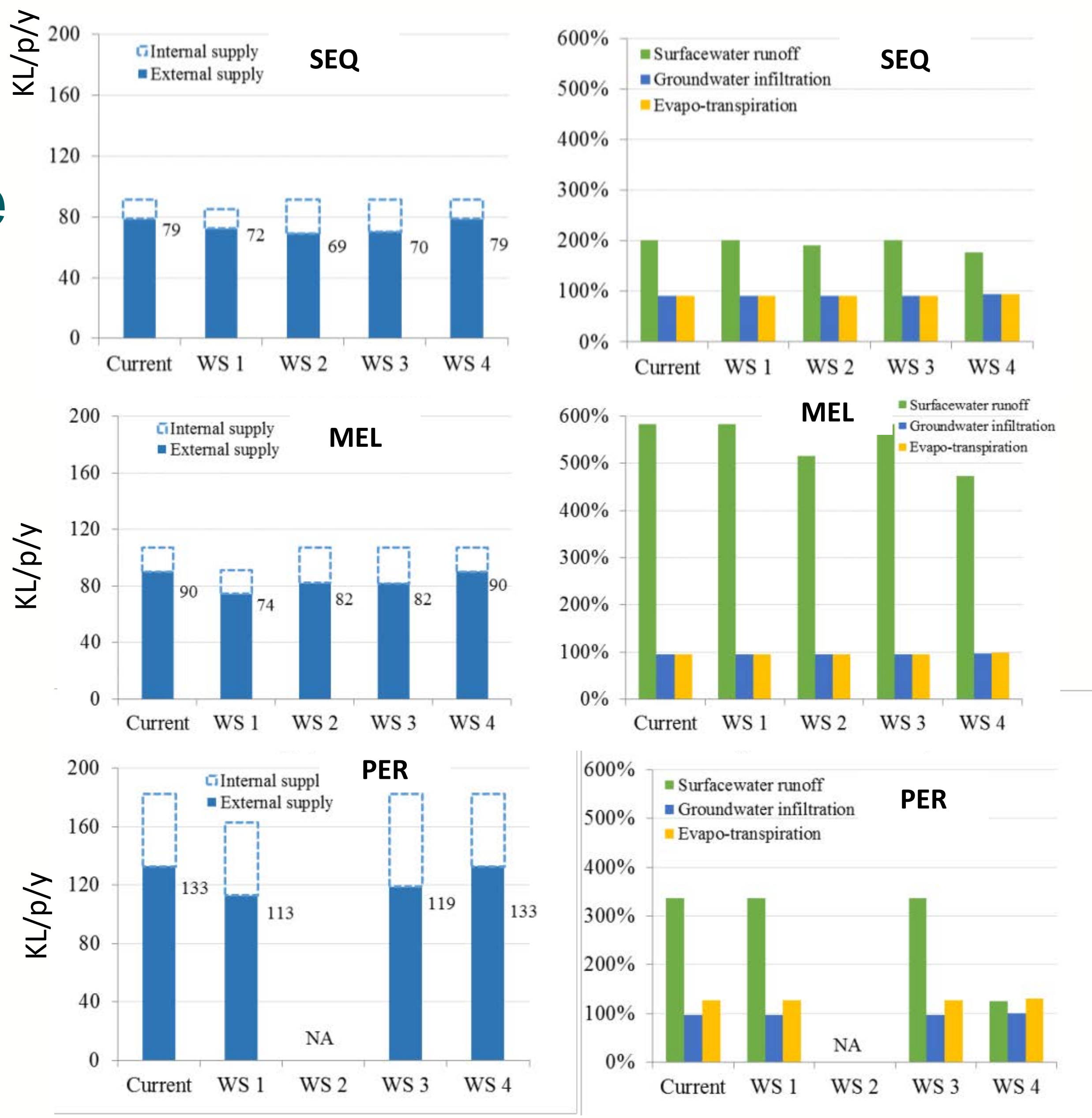
What degree of intervention may be required to make noticeable progress?

Current= 2013/2014
WS 1 = reduced demand
WS 2 = internal harvesting
WS 3 = wastewater recycling
WS 4 = increased perviousness

Source:
Renouf, Kenway, Lam, Weber, Roux, Serrao-Neuman, Morgan, Low Choy (2018) **Water Research** Vol. 137.

Water efficiency (Including supply internalization)

Hydrological performance (flows relative to pre-developed state)



Feedback….

- “Good for bringing multiple water sector stakeholders together. Particularly stormwater and centralized water.” (*I.C.C.*).
- “Useful for 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.”

CRC Reports (online)

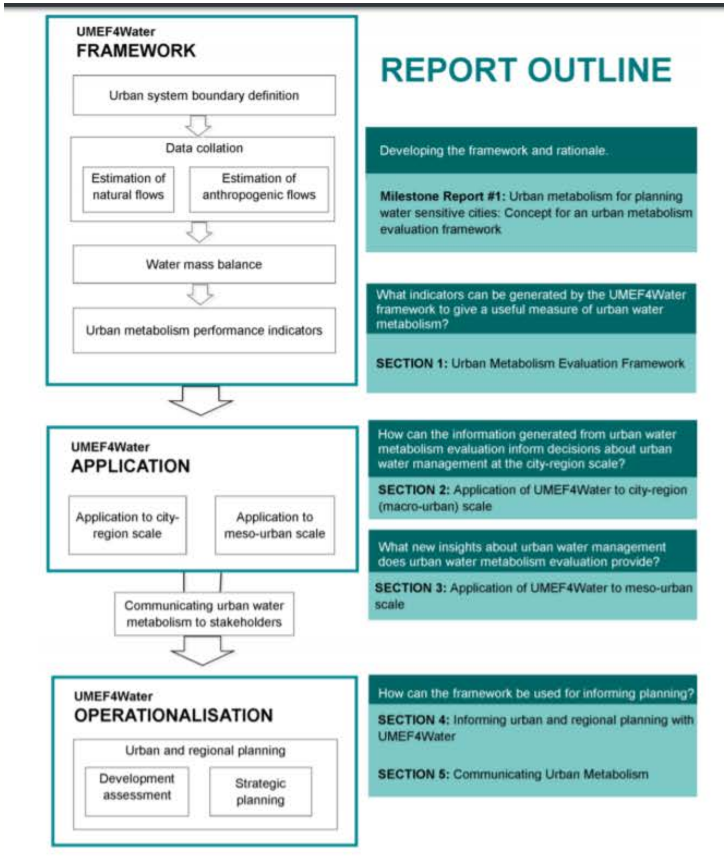
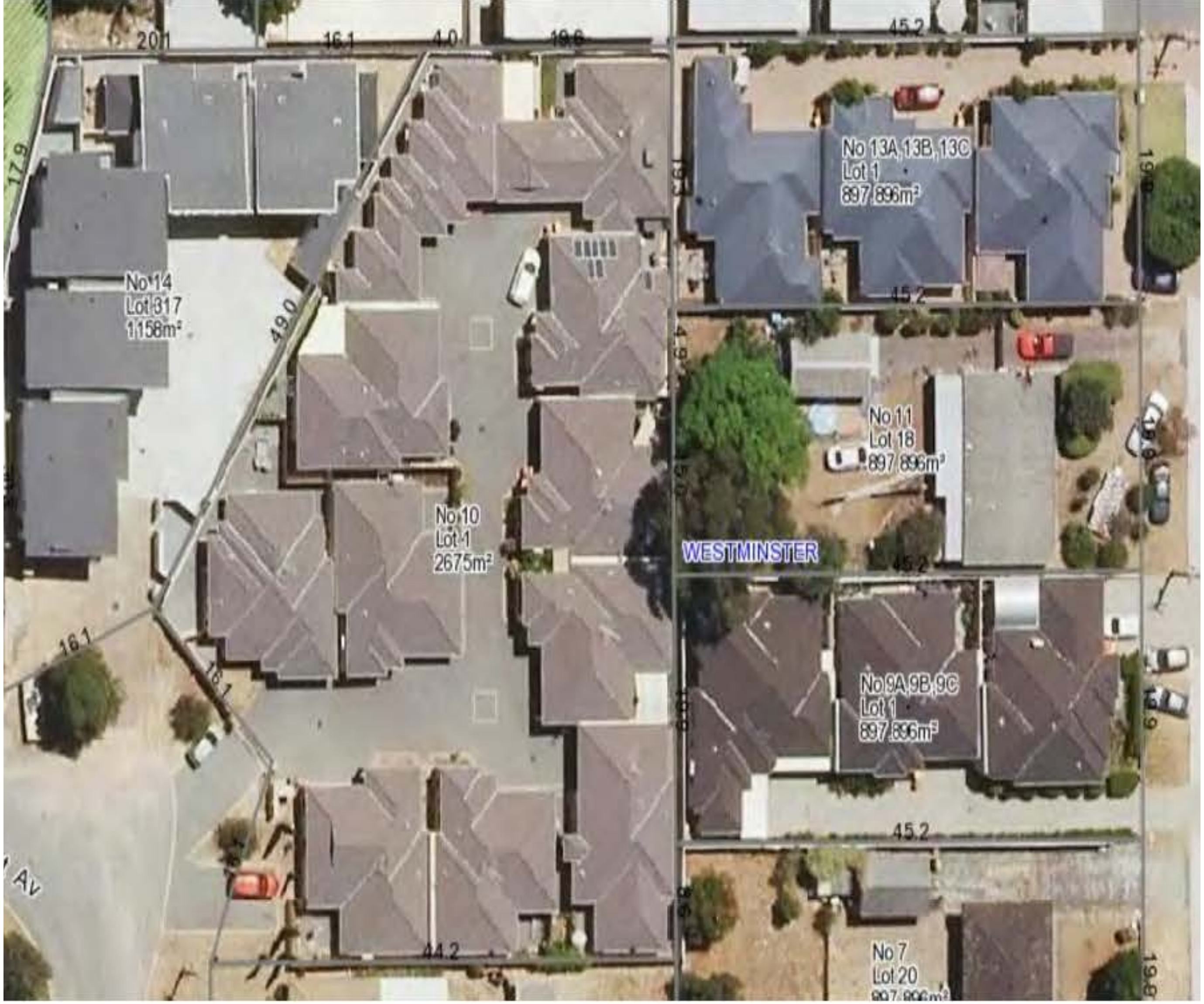


Figure 3: Structure of the report with research questions.

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



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

IRP4 Project Objectives

(1) Develop an infill performance evaluation framework to understand the 'water performance' of infill development

What are the impacts of infill development on water-related objectives - hydrology, water efficiency, urban heat, amenity?

How can 'water performance' of infill development be defined, assessed and quantified?

Can "better" or "optimal" solutions for infill development be identified?

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How does infill housing design typology (and associated public space) influence the 'urban water performance' of an urban area?

What water technologies are suited to different infill typologies and scales and help achieve optimal 'water performance'?

(3) Improved governance options / arrangements for infill

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

Research Team

University of Queensland

Project leader
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Bosco Chow (master student)

Owen Hoar (master student)

Monash University

Lead design researcher
Nigel Bertram

Lead microclimate researcher
Nigel Tapper

Oscar Sainsbury

Stephanie Jacobs

Linkage to TAP project
Christian Urich

Linkages to other projects nationally
Peter Newton (Swinburne University)

University of Western Australia

Lead design and governance researcher
Geoffrey London

Daniel Martin

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

Research team

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Project Leader

Nigel Bertram
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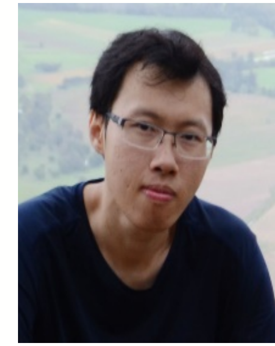
Geoffrey London
Research Lead, UWA

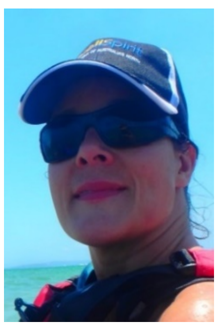
Marguerite Renouf
Research Lead, UQ

Oscar Sainsbury
Building design typologies

Beata Sochacka
Water demand, project management



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

Mojtaba Moravej
Hydrological impacts, embodied water

Bosco Chow
Technology

Stephanie Jacobs
Urban heat

CRC for Water Sensitive Cities

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

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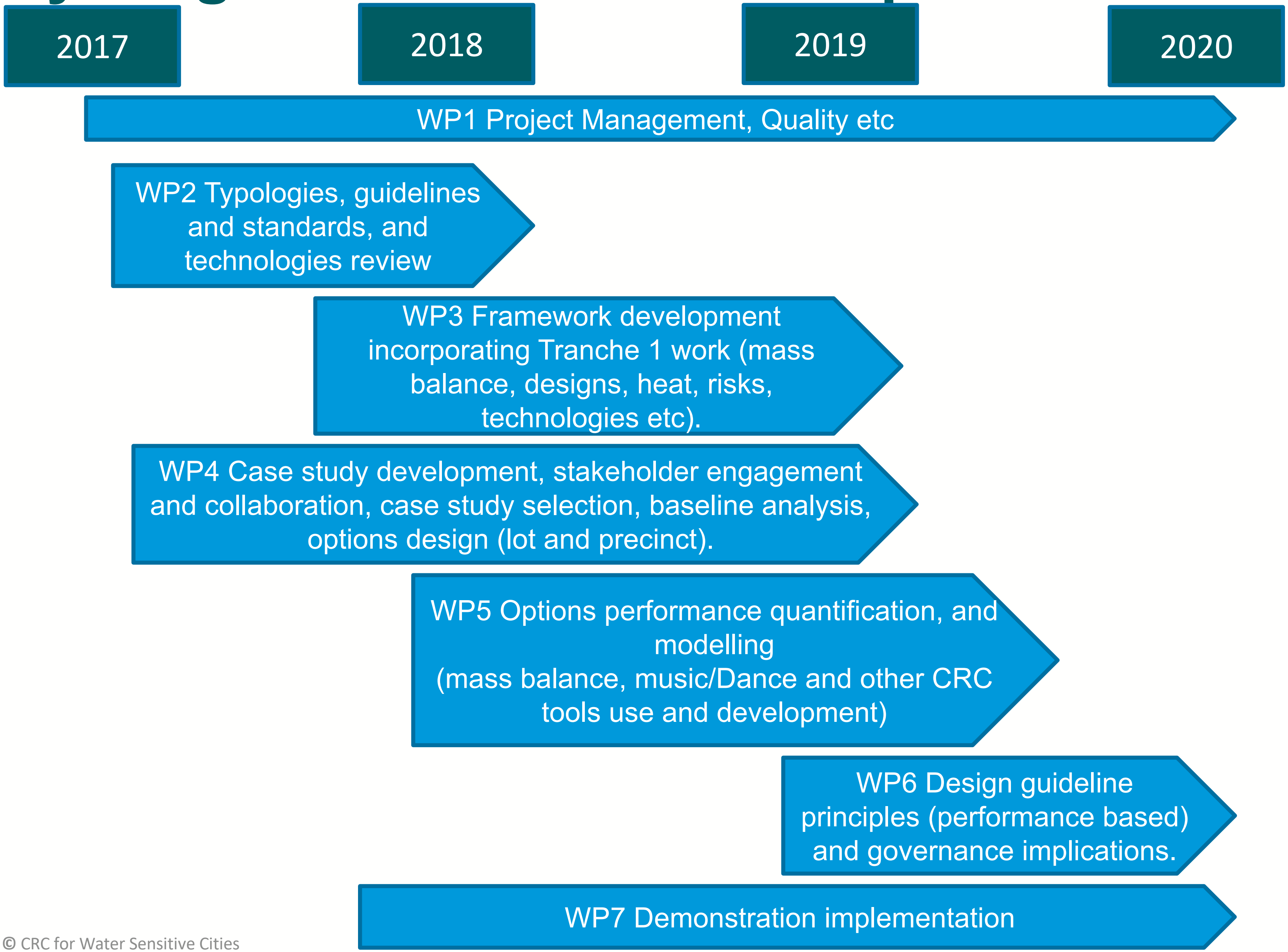
Key stages and essential components



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.

Typologies and design….illustrative

Development Typologies

A. Suburban lot subdivision

Building as usual backyard redevelopment model.

B. Small infill combination

Small co-op's of neighbours and/ or 'like' minded combinations of residents and occupants on small to medium scale lots (possibly amalgamated)

C. Block infill site + courtyard model

Medium scale developments (with additional public value)

D. Suburban precinct

Dispersed precinct in suburban residential setting

E. Mixed-use precinct

Larger scale mixed use development or redevelopment within a structure plan

F. Employment cluster

Large dispersed cluster of amenities and employment opportunities within a state government framework (often too big to be in structure plan)

G. Major urban renewal

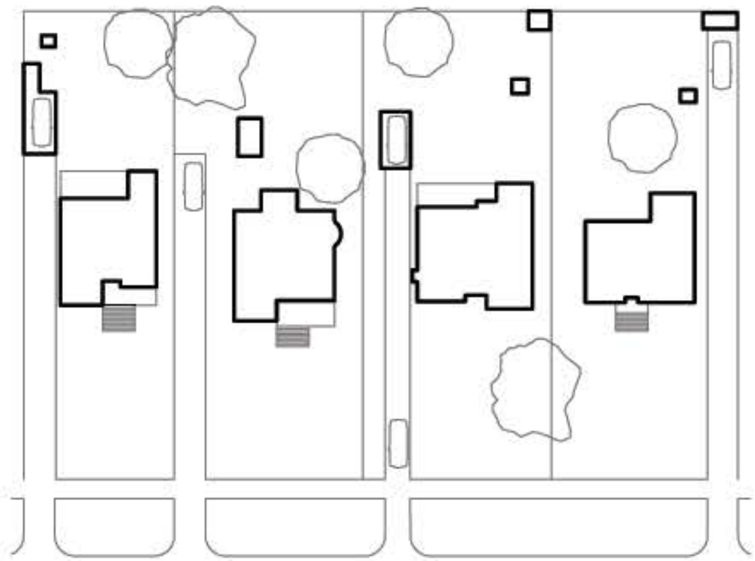
Large high density urban development sites designated for large population and employment opportunities. (often scrape and rebuild)

How do we "shift" knock-down rebuild to more sustainable precincts

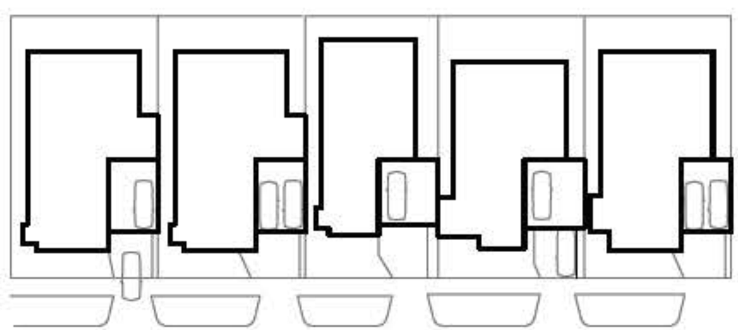
Base Source figure: Nigel Bertram

The Missing Middle
SINGLE DWELLING
TWO DWELLINGS
TERRACES
DUAL OCCS
MULTI DWELLING TERRACES
MULTI DWELLING HOUSES
DUAL OCCS
MANOR HOUSES
RESIDENTIAL FLAT BUILDINGS

a. Suburban lot subdivision



1940's (Heidelberg)

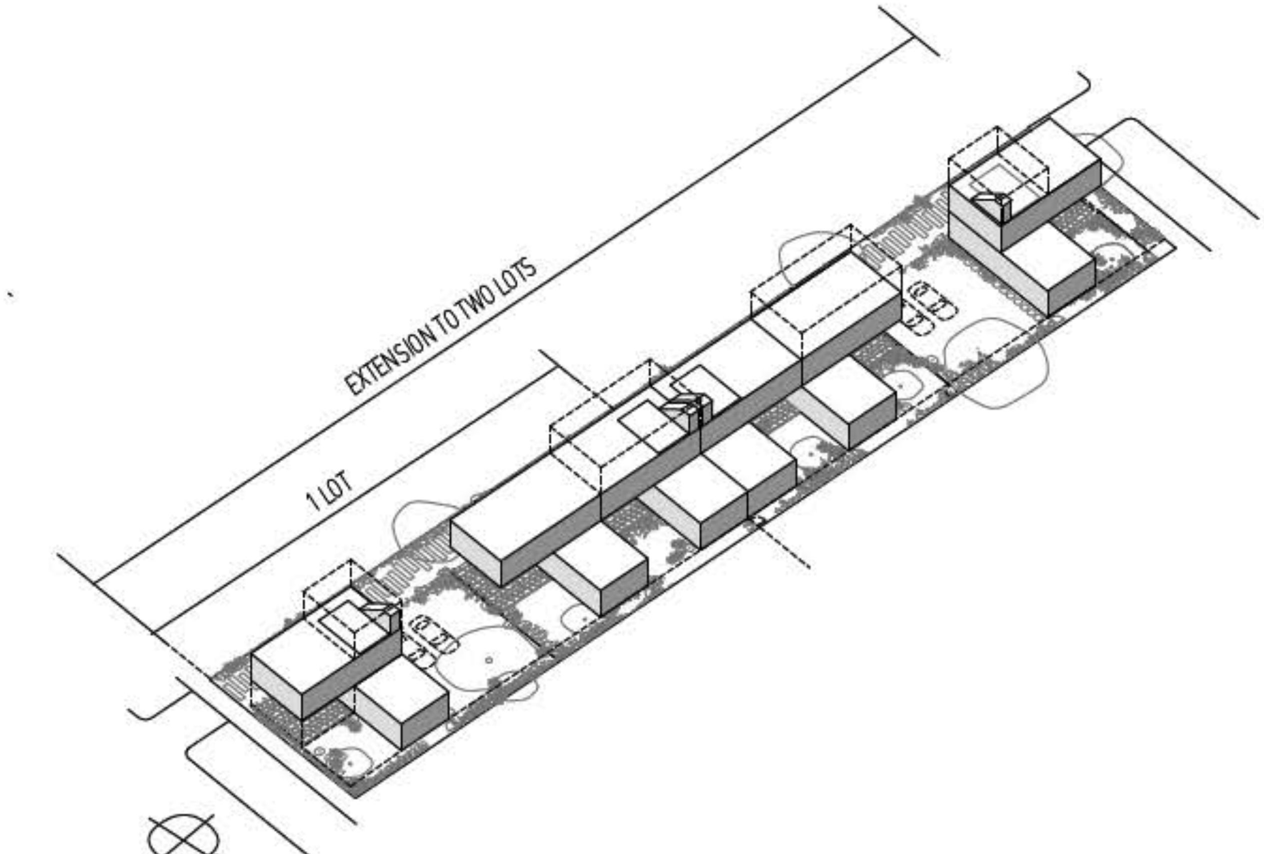


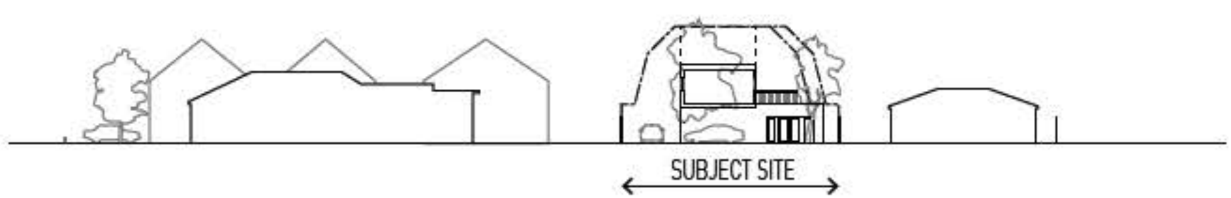
2010's (Truganina)

Slide source: Nigel Bertram

a. Suburban lot subdivision

Infill Opportunities 2012
Monash Architecture Studio





Slide source: Nigel Bertram

a. Suburban lot subdivision

Infill Opportunities 2012
Monash Architecture Studio

d. Suburban precinct

AHURI Housing Models for Greyfield
Precincts 2012- 2015
Melbourne
Monash Architecture Studio

Slide source: Nigel Bertram

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d. Suburban precinct

Traumhaus Funari 2015
Mannheim, Germany
MVRDV

Slide source: Nigel Bertram

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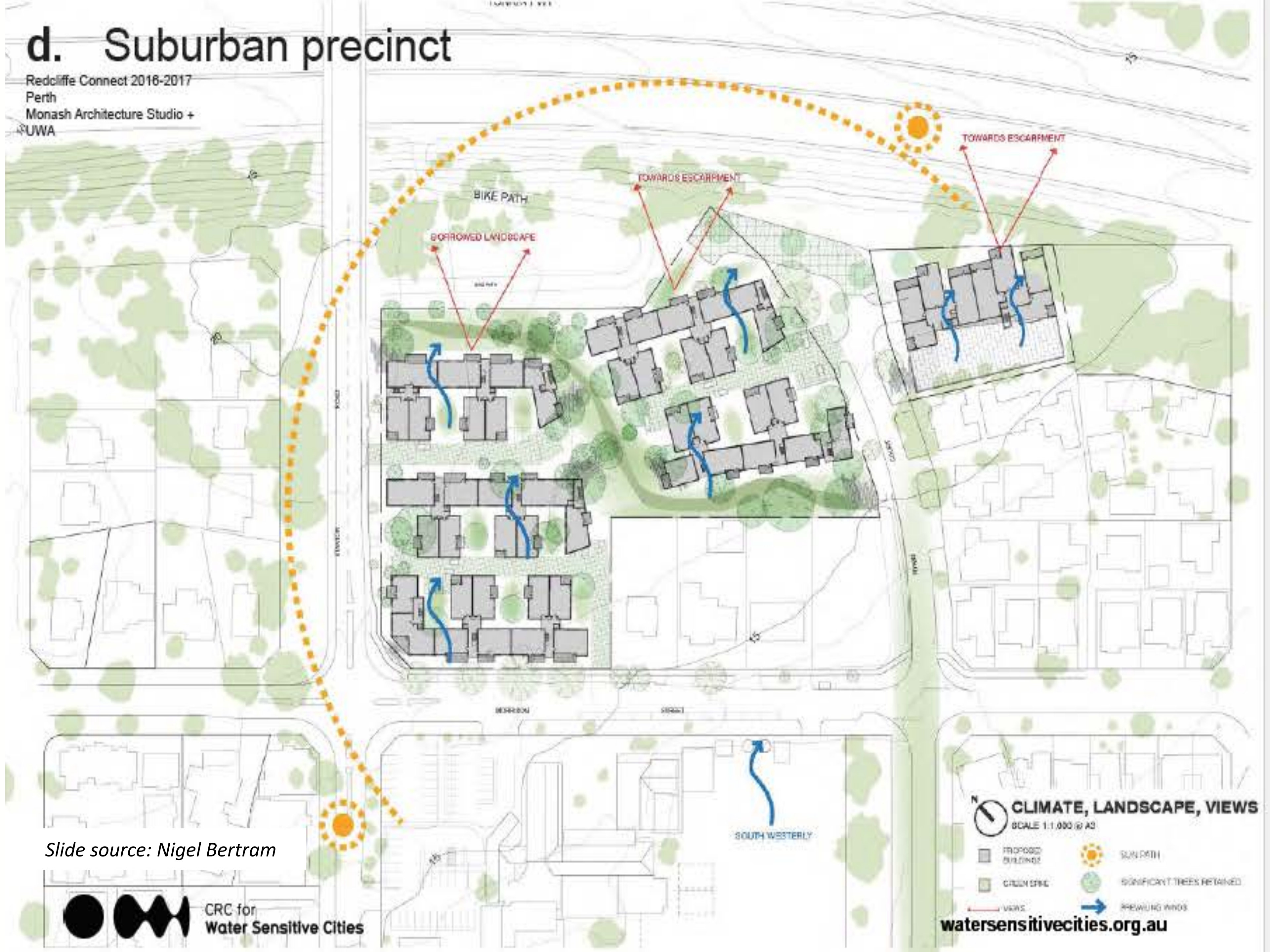
d. Suburban precinct

Redcliffe Connect 2016-2017
Perth
Monash Architecture Studio +
UWA



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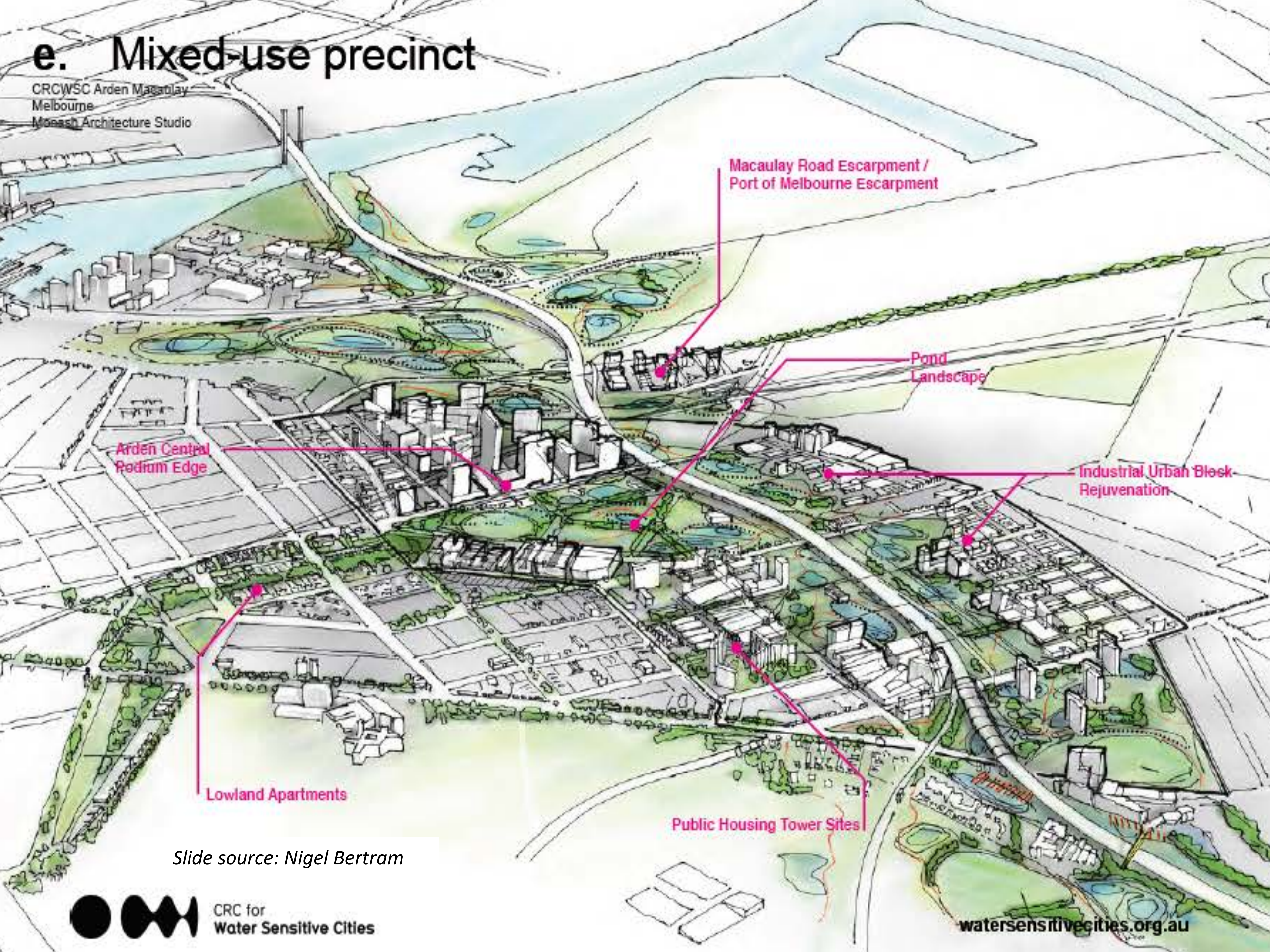
e. Mixed-use precinct

CRCWSC Arden Macaulay
Melbourne
Monash Architecture Studio



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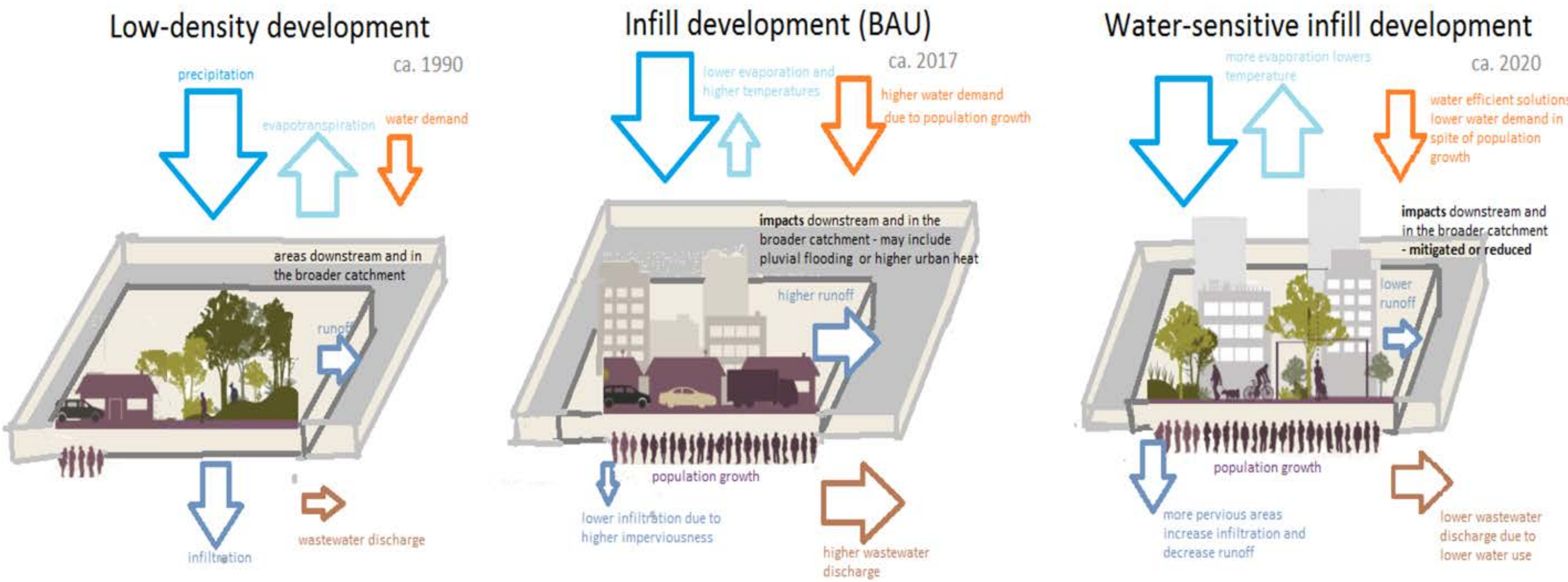


Source:
CRC WSC, IRP4 Fact Sheet

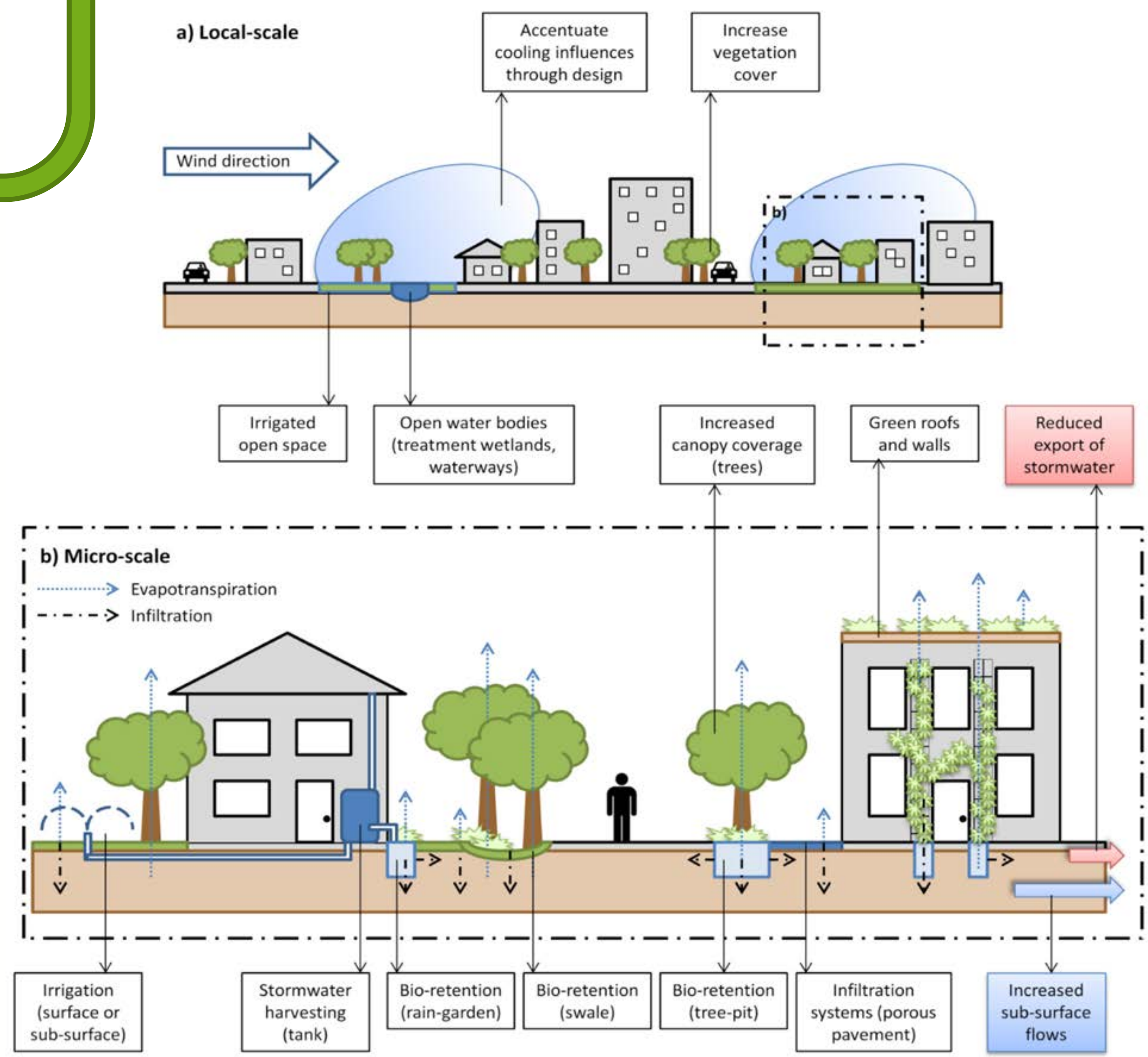
Micro-climate Research and scale of approach

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)

Publications

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- 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.
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- Kenway, S.J., A. Gregory, and J. McMahon, (2011). **Urban Water Mass Balance Analysis.** *Journal of Industrial Ecology.* 15(5): p. 693-706.
- 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.au
- 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.

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2012 - 2021

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