



Water Sensitive Cities Index: A diagnostic tool to assess water sensitivity and guide management actions

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ABSTRACT

Cities are wrestling with the practical challenges of transitioning urban water services to become water sensitive; capable of enhancing liveability, sustainability, resilience and productivity in the face of climate change, rapid urbanisation, degraded ecosystems and ageing infrastructure. Indicators can be valuable for guiding actions for improvement, but there is not yet an established index that measures the full suite of attributes that constitute water sensitive performance. This paper therefore presents the Water Sensitive Cities (WSC) Index, a new benchmarking and diagnostic tool to assess the water sensitivity of a municipal or metropolitan city, set aspirational targets and inform management responses to improve water sensitive practices. Its 34 indicators are organised into seven goals: ensure good water sensitive governance, increase community capital, achieve equity of essential services, improve productivity and resource efficiency, improve ecological health, ensure quality urban spaces, and promote adaptive infrastructure. The WSC Index design is a quantitative framework based on qualitative rating descriptions and a participatory assessment methodology, enabling local contextual interpretations of the indicators while maintaining a robust universal framework for city comparison and benchmarking. The paper demonstrates its application on three illustrative cases. Rapid uptake of the WSC Index in Australia highlights its value in helping stakeholders develop collective commitment and evidence-based priorities for action to accelerate their city's water sensitive transition. Early testing in cities in Asia, the Pacific and South Africa has also showed the potential of the WSC Index internationally.

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1. Introduction

There is growing emphasis globally on the importance of urban water services in enhancing a city's liveability, sustainability, resilience and productivity (Farrelly and Brown 2011; Rijke et al., 2013). Achieving these outcomes, particularly against the backdrop of climate change (Vorosmarty et al., 2010; Hoekstra et al. 2012), rapid urbanisation (Eliasson, 2015), degraded ecosystems (Bouleau et al., 2009), and ageing infrastructure

(Organisation for Economic Cooperation and Development 2014; Vaux 2015), requires a fundamental shift in the way water system services are planned, designed and delivered (Ashley et al., 2013; Brown et al., 2009). There is now broad scholarly consensus that integrated and adaptive approaches to urban water services are needed to improve flexibility and agility for coping with unpredictability and change, while delivering multi-functional benefits that support social wellbeing, healthy ecosystems and strong economies. While different terms are used to in water management literature to represent combinations of these attributes, in this paper, we refer to them as *water sensitive*.

Despite this consensus, cities around the world are wrestling with the practical challenges of shifting urban water services in a

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water sensitive direction. Guiding and motivating action for change is difficult, as existing structures and processes often reinforce conventional practices (Brown and Farrelly, 2009; Van de Meene et al., 2011). Even when there are good intentions and policy aspirations, it can be difficult to achieve coordinated and aligned action across multiple organisations (Ferguson et al., 2013a). Decision-makers within water utilities and city governments are in need of more targeted and tailored insight to guide collective local efforts to overcome existing institutional and infrastructure challenges as cities transition from conventional to water sensitive practices (Ferguson et al., 2013b). How should activities and investments be prioritised? What measures and targets can be used to monitor and assess progress? Which structures and processes support and enable cross-sectoral collaboration and inclusive planning and design solutions?

Indicators have been shown to be valuable for guiding system changes by: reducing ambiguity and enabling effective and clear communication amongst diverse interests (McCool and Stankey, 2004); assessing and quantifying performance (Spiller et al., 2012); providing early warnings (Spiller et al., 2012); giving feedback on the effects of policies (Chiras and Corson, 1997; Swanson et al., 2010), and co-constructing visions and evaluating pathways towards desired societal change (Lehtonen et al., 2016). However, the assessment of city sustainability is not a well-established practice (Marques et al., 2015), the conditions for assessing city sustainability are ambiguous (Mori and Christodoulou, 2012), and there is misalignment between future city visions and available performance indicators (Renouf et al., 2017). Moreover, complex urban challenges and stakeholder interests means processes for identifying priorities, negotiating trade-offs and tracking progress, are important aspects of sustainable water management, but often overlooked in the development and application of indicators.

Against this background, our paper presents the development of the Water Sensitive Cities (WSC) Index, a new benchmarking and diagnostic tool developed by the Cooperative Research Centre for Water Sensitive Cities¹ (CRCWSC). The WSC Index is designed to facilitate assessment of the water sensitivity of a city (from the scale of local municipality to large metropolitan centre), set targets based on best available research, and inform management responses to improve water sensitive practices. The tool can support strategic planning and decision-making, foster inter-city learning and enable governments to assess their cities' urban water management trajectories in relation to other cities.

The theoretical underpinnings of the WSC Index framework is presented in Section 2, followed by a summary of the development approach in Section 3. The WSC Index goals and indicators are outlined in Section 4. A case study application of the WSC Index in three diverse Australian cities is illustrated in Section 5. Insights from applications of the WSC Index to date and further development needs are discussed in Section 6, followed by a conclusion in Section 7. This paper will be of interest to scholars, policy-makers and practitioners of urban water management, and sustainability assessment more broadly.

2. Background

In setting out to develop a WSC Index that can meaningfully guide policy and action for driving water sensitive transitions, it is important to define what attributes of a water system will need measurement, as well as to learn from the experiences of existing indicator initiatives.

The WSC vision is underpinned by three principles of practices (Wong and Brown, 2009): (1) Understanding cities as catchments to provide resources at different scales in fit-for-purpose applications; (2) Cities providing ecosystem services to integrate urban water management into the urban landscape, providing multiple benefits such as heat mitigation, ecological health and landscape amenity; and (3) Water-conscious communities, where citizens value and are connected to their water environments and engage in water-conscious behaviours, and water, planning and design professionals work collaboratively to deliver water sensitive outcomes.

The heuristic in Fig. 1 demonstrates the transitions in water service delivery functions that are needed to respond to evolving socio-political drivers, culminating in the WSC. The first three stages of the embedded continuum describe the evolution of the water system to provide essential services such as secure access to potable water (water supply city), public health protection (sewered city) and flood protection (drained city). These are followed by the waterways city, water cycle city and ultimately a WSC, which describe the anticipated and aspirational evolution of the urban water system to deliver higher order services such as social amenity and environmental protection, provide reliable water services under constrained resources, and ensure intergenerational equity and resilience to climate change. Defining features of the WSC that go beyond the pollution management function of the waterways city, and integrated water cycle management function of the water cycle city include: water infrastructure designed sensitively into the urban landscape to deliver multi-functional liveability and ecological benefits, adaptive planning and management based on flexible, hybrid solutions to increase resilience, and communities that are active in caring for their water resources and environments.

While cities and metropolitan areas are awash in indicators, which have proliferated since the 1987 Brundtland Commission report (Böhringer and Jochem, 2007; Dunn and Bakker, 2011), there are not yet agreed metrics that define the WSC concept and its constituent collection of attributes. Without such measures, stakeholders will struggle to operationalise their shared WSC vision, lack comprehensive insight on current system performance, and receive limited guidance on priorities for action to progress their water sensitive transition.

As a crosscutting issue, water-related metrics are found in indicator initiatives for sustainability, urban greening, city governance, vulnerability, resilience and liveability. These provide a useful starting point for considering the assessment of a city's water sensitive performance. Table 1 highlights the components of water sensitivity in notable water-related indicators, mapped against the six city-states in Fig. 1.

Table 1 shows that while many established indices measure multiple aspects of water service performance, they have not been designed to assess the full suite of attributes that constitute water sensitive performance. They typically either focus too specifically on a particular water servicing attribute (e.g. compliance with drinking water quality standards, level of wastewater treatment) for effective evaluation of water sensitive city policies and practices, or they are too broad in scope to pay significant attention to water. There are several notable gaps in available measures that would be important for assessing water sensitivity: a dearth of indicators for nature-based solutions, which are widely seen as important elements of urban sustainability, climate change adaptation, and land use planning (EPA, 2014); limited green or grey-green infrastructure indicators (e.g. De Ridder et al., 2004)²; and,

¹ An interdisciplinary research program funded by the Australian Government and industry partners, 2012–2021, AUD 120 million (www.watersensitivecities.org.au)

² The most prominent are the two indicators developed by the European Environment Agency (EEA) to capture the range of benefits that green infrastructure af-

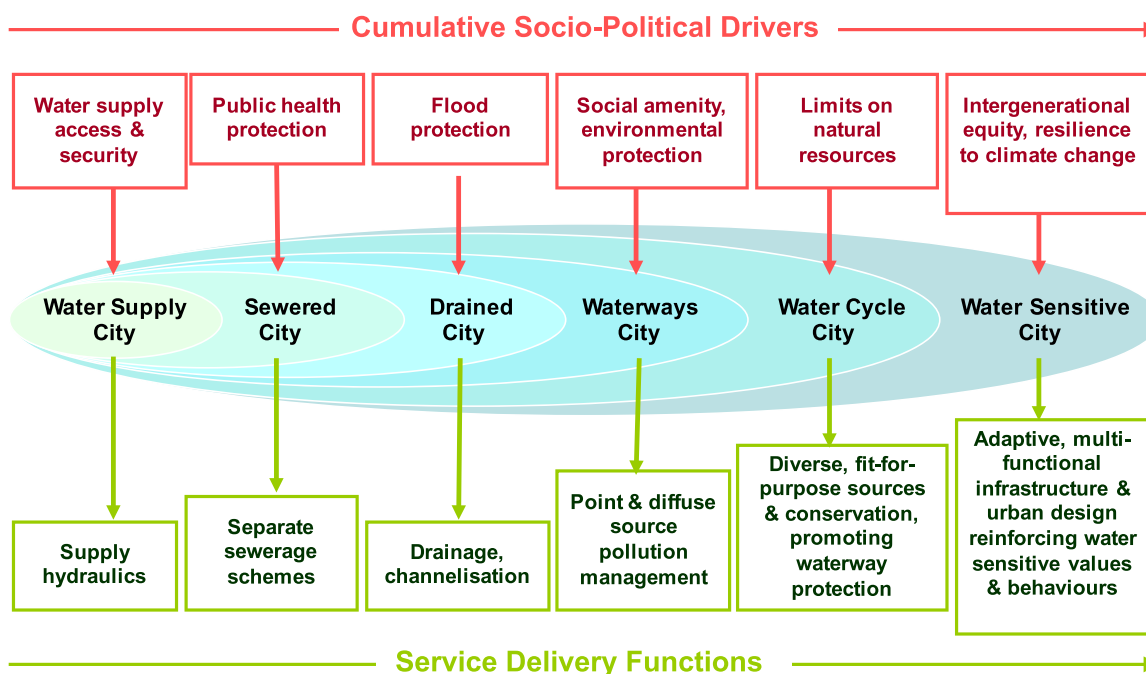


Fig. 1. Urban Water Transitions Framework (Brown et al., 2009, reproduced with permission from journal).

while stormwater is often implied within wastewater quality indicators, there are few indicators of physical, hydrological or biological changes to measure the cumulative effects of urban runoff.

Within the past decade, a handful of frameworks have been developed that facilitate a broader understanding of sustainable urban water management or have relevance to water sensitive principle (see bottom rows of Table 1). The *Ecocity Standards 'Clean and Safe Water'* examines water demand in relation to supply, emphasising resource constraints, the importance of integrated water management (including stormwater as a resource), pricing and ecological health. However the Ecocity Standards does not provide tools, guidance or methodology to enable practitioners to benchmark progress toward the ten levels proposed, which the standards recognise are context specific. The *Sustainable Cities Water Index* (SCWI) developed by Arcadis is intended to be a global ranking tool (Arcadis, 2016). The Index centres around three key sub-indices for water sustainability: resiliency, efficiency, and quality, which are further supported by a series of sub-indices and indicators such as disaster risk, water charges, green space and pollution. SCWI focuses on resources, public health and the economic dimensions of water but does not include social and governance aspects of integrated water management. Arup's *City Resilience Index* comprises 52 indicators (across 12 goals) that measure and assess multiple factors contributing to urban resilience, including water and sanitation services, flood resilience and ecosystem stewardship (Arup, 2015). There are additional indicators for leadership and strategy; economy and society; health and wellbeing, although these are broader city resilience indicators that are not specific to water. The *City Blueprint Approach* comprises three frameworks: Trends and Pressures Framework (TPF) with 12 descriptive trends and pressure indicators, the City Blueprint Framework (CBF) with 7 categories and 25 indicators, and the Governance Capacity Framework (GCF) (van Leeuwen, 2013; Feingold et al., 2018). The CBF enables a baseline assessment of the sustainability of ur-

ban water resources management and is intended as a first step or quick-scan to benchmark the sustainability of the urban water cycle and facilitate awareness of current water challenges (Koop and van Leeuwen, 2015).

Whilst each of the above frameworks provide valuable insights for improving water system planning and management, none covers the full range of social, governance, economic, liveability, multi-functional and adaptive attributes that are defining attributes of water sensitivity.

Beyond these thematic gaps in existing water-related metrics in relation to water sensitive objectives, there are emerging critical perspectives on indicators highlighting their limited uptake and impact on policy and practice (Boyko et al., 2012; Lehtonen, 2013; Turnpenny et al., 2014; Diehl et al., 2016). There are various explanations for this disconnect. First, indicators often fail to meet the needs of policy and decisions-makers, as the development process does not adequately engage them or identify their information requirements (Brennin, 2007; Dunn and Bakker, 2011; Norman et al., 2012). Second, data collection methods vary between government agencies and across sectors, which can impact on the scale of assessment that is possible, and is further compounded by the scalar mismatch between administrative and hydrological boundaries (van der Zaag and Gupta, 2008; van den Brandeler et al., 2019). Third, spatial and temporal data gaps³ can make indicators difficult to calculate and limit the ability to develop baselines and threshold values, monitor trends, or understand the broader impacts of climate change and land-use practices (Hak et al., 2007). Fourth, indicator projects require long-term commitment of resources (both financial and staff) to ensure continued relevance and provide end-user support (Mayer, 2008; Dunn and Bakker, 2009). Other limitations of indicators include inadequately capturing the system's complexity with its associated subjectivity and inherent biases (Barnett et al., 2008;

ford urban areas. These include climate adaptation and mitigation, multiple ecosystem services (e.g. biodiversity), and improvements to public health and wellbeing through proximity to green urban spaces.

³ Existing datasets can be incomplete, have different parameters, and use different sampling standards and frequencies. Inconsistent data collection methods and data storage protocols limit the usability of datasets and impede data sharing and integration of datasets between different users.

Table 1

Notable water-related indicators. These references cite in this table (Chaves and Alipaz, 2006; Cohen and Sullivan, 2010; Falkenmark et al., 1989; Gerten et al., 2011; Gleick, 2009; Hara et al., 2009; Jiménez-Cisneros, 1996; Okazawa et al., 2011; Smits and Steedndijk, 2013; Sullivan, 2002; Sullivan and Meigh, 2006; U.S. Environmental Protection Agency 2002).

Index and indicator examples	Water Supply City	Sewered City	Drained City	Waterways City	Water Cycle City	Water Sensitive City
Water Stress Index (Falkenmark, 1989)						
Drinking Water Quality Index (e.g., UN, WHO and CCME)						
Water Availability Index (Jiménez-Cisneros, 1996)						
Climate Vulnerability Index (Sullivan and Meigh, 2005)						
Green-Blue Water Scarcity Index (Gerten et al., 2011)						
Percentage of city population served by wastewater collection and treatment (e.g. UN and OECD Statistics)						
Basic Human Needs Index (Gleick, 2009)						
International Wealth Index (Smits and Steedndijk, 2013)						
The Water, Economy, Investment and Learning Assessment Indicator (WEILAI) (Cohen and Sullivan, 2010)						
The Green City Index (Economist Intelligence Unit and Siemens AG)						
Sustainable Society Index						
Swedish Sustainability Index for Municipal Water and Wastewater Services						
Global reporting Initiative 303: Water and Effluents (2018)						
Canadian Environmental Sustainability Indicators (2019)						
Environmental Vulnerability Index (UNEP)						
Environmental Performance Index (Yale University)						
The Watershed Sustainability Index (Chaves and Alipaz, 2006)						
Index of Watershed Indicators (US EPA 2002)						
Sustainable Development of Energy, Water, and Environment Systems (SDEWES) City Index						
Water Poverty Index (Sullivan, 2002; Sullivan et al., 2003)						
Water Security Status Indicators (Norman et al. 2012)						
Flood Vulnerability Index (Hara et al., 2009)						
Flood risk indicator (e.g. HM Land Registry, UK)						
Global Flood Risk Index (Okazawa et al., 2011)						
Aqueduct Water Risk Atlas (World Resources Institute)						
Canadian Water Sustainability Index (PRI, 2007)						
Wellbeing/Stress Index (IUCN)						
Indicators of Urban Green Infrastructure (European Environment Agency 2017)						
Sustainable Cities Water Index (Arcadis 2016)						
Clean and Safe Water - Ecocity Standards Level 1						
City Resilience Index (Arup and the Rockefeller Foundation)						
City Blueprint (van Leeuwen 2013; Feingold et al., 2016)						

Pintér et al., 2005; Sagar and Najam 1998; Mayer, 2008), as well as overlooking processes of negotiation and prioritisation that are critical for sustainability planning (Starkl et al., 2013). Furthermore, poorly constructed indicators can be misinterpreted, risking misleading or overly simplistic policy messages (OECD, 2003). These interrelated challenges mean that multifaceted indicators are often unwieldy, impractical and costly in terms of both the time and resources needed to gain valuable insights and improve decision making (Norman et al., 2012)

Drawing on these insights, and in a quest to address the identified challenges through design features to support its uptake in practice, the development of the WSC Index aimed to create a tool that: (1) is reliable and scientifically robust, (2) takes a holistic and integrative approach to assessing water sensitivity; (3) is applicable at both metropolitan and municipal council scales; (4) enables benchmarking and comparison across diverse contexts, and (5) has

clear benefits and meets the practical needs of decision-makers, policy-makers and practitioners.

3. Development of the WSC Index

The WSC Index was developed over a two-year period (2014–2016) in the phases depicted in Fig. 2: prototyping, refinement and piloting, trialling and industry release. The development process was guided by an industry steering committee and an internal working group consisting of CRCWSC leaders and key researchers from across the range of disciplines covered by the WSC Index. These inputs aimed to ensure that both scientific and end user considerations informed and shaped the tool.

The prototype framework for the WSC Index was developed drawing on existing water indicators and supplemented with emerging knowledge from CRCWSC research, including insights

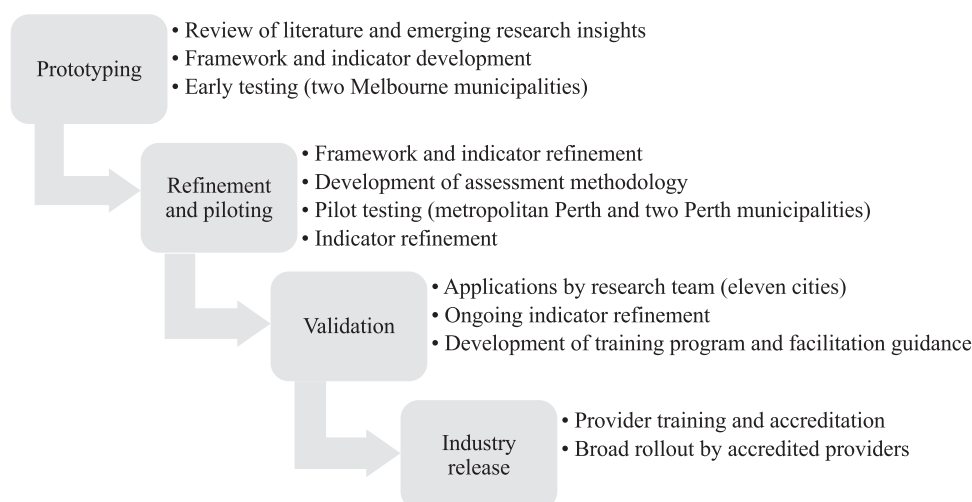


Fig. 2. Steps taken to develop the Water Sensitive Cities Index.

from water sensitive city envisioning processes (Ferguson et al., 2013b). The inventory and analysis of existing indicators identified more than 230 individual indicators from over 50 frameworks, organisational initiatives (e.g. the Global Indicator Facility⁴) and academic research (e.g. Sullivan et al., 2003). These spanned multiple scales, from global assessments (e.g. Vorosmarty et al., 2010), to national measures (e.g. PRI, 2007) and to municipal level initiatives (such as city report cards). The indicators most closely aligned with attributes of the WSC are shown in Table 1. For WSC performance objectives that did not have an existing associated indicator that adequately represented its intent (particularly for those more closely aligned with the water cycle city and water sensitive city), we developed a new measure that could be used to qualitatively distinguish between low and high water sensitive performance. Scientific expertise and emerging knowledge from the CRCWSC's research network and projects were drawn on to develop these new indicators and integrated them into the prototype framework for the WSC Index.

The prototype was tested with two councils (City of Knox and City of Port Phillip) located in Melbourne, Australia. This provided detailed feedback on its usability, functionality, benefits and reliability, which led to a range of refinements and enhancements. Numerous indicators were consolidated to reduce the overall number and therefore the time and effort burden for assessment. We refined the assessment methodology in consultation with our industry partners, whose feedback was that a data-driven approach was unwieldy, inefficient and unlikely to be broadly adopted in practice—reconfirming earlier insights from literature that time-intensive and costly benchmarking processes impede uptake (Norman et al., 2012). Instead, we judged that practitioners—equipped with system knowledge and available evidence, and guided by a well-facilitated assessment process—would reach a sufficiently robust score for the purposes of benchmarking, prioritisation and action planning.

To this end, we developed an assessment methodology based on deliberation by local experts of available evidence to determine indicator scores. The indicator descriptions were clarified through rewording to simplify language in accordance with the prototyping participant feedback; ease of understanding was considered particularly crucial for an assessment methodology based on facilitated discussion to ensure a reliable and consistent approach to scoring across diverse cities. We developed the conceptual basis for

analysing results through a number of different frameworks that would support the development of management responses. We also developed web-based software to support visualisation and interpretation of the WSC Index results.

The revised WSC Index was piloted in three locations within Greater Perth as a single metropolitan area in Australia (one case at the metropolitan scale and two cases of municipal Council areas). An 18-month industry trial period followed the pilot cases (2016–2018), during which time the WSC Index was applied to an additional 11 Australian cities. Assessments were conducted by members of the research team, who had in-depth knowledge of the framework and indicators and could provide consistent guidance to workshop participants in helping them understand the indicators and decide on the most appropriate scores. Again, minor refinements were made to the indicator rating descriptions over this period to provide greater clarity in response to participant feedback. In preparation for broad industry release of the WSC Index in early 2018, a training program and facilitation guidance were prepared. Eight industry practitioners were trained by the research team to become accredited WSC Index providers (see Supplementary Material for details on the training and accreditation process). To date, WSC Index workshops have been facilitated by accredited providers to assess water sensitive performance and develop management responses in more than 50 cities (see Supplementary Material for the list of cities that have been benchmarked).

4. Presenting the WSC Index

The WSC Index offers users the ability to benchmark cities at the metropolitan or municipal scale, based on performance against a range of urban water indicators across the societal, biophysical and ecological dimensions that characterise a WSC. These insights enable cities around the world to be ranked according to their water sensitivity, as well as diagnose key areas of strength and weakness. This enables governments to assess their cities' urban water management trajectories in relation to other cities, identify priorities for management actions and learn from other cities that are experiencing similar challenges or opportunities. The WSC Index is accessed through a web interface that provides visualisations of the results to facilitate understanding and support communication with broad audiences, including policy-makers, service providers and community.

⁴ Source: <https://www.iso.org/organization/660833.html>

4.1. WSC Index goals and indicators

The seven WSC Index goals are: (1) Ensure good water sensitive governance, (2) Increase community capital, (3) Achieve equity of essential services, (4) Improve productivity and resource efficiency, (5) Improve ecological health, (6) Ensure quality urban spaces, and (7) Promote adaptive infrastructure. 34 indicators span these goals, collectively representing the full suite of WSC objectives that have emerged over the last ten years in the Australian water context⁵ (Table 2).

Scoring for each indicator is based on a rating from 1 to 5, assigned according to the description that best fits the city's current situation. Half scores (1.5, 2.5, ...) can be assigned where the conditions are between the integer descriptions. However, scores of finer granularity (1.1, 1.2, ...) are not assigned, since the degree of accuracy that would be implied by such scores has little meaning in the context of the WSC Index's key purpose of identifying a city's relative strengths and weaknesses to inform priorities for management actions.

While some indicators use quantitative thresholds to inform the score (3.1, 3.2, 3.3, 4.2, 4.3, 6.3), the majority are based on qualitative thresholds. This enables assessment through evidence-based judgement and provides opportunity for local expression of how the indicator may manifest in different contexts. Once priority indicators for action have been identified through the assessment process, attention can be given to defining quantitative measures relevant to the local context that correspond to its 1–5 rating so that more accurate tracking of progress can be done. As further WSCs research is conducted, including city and water practitioners testing and applying their own measures, it is anticipated that further indicator ratings descriptions could be updated to be more quantitative.

This measurement approach relies on clear methodological structure and detailed scoring guidance to ensure consistency of application for diverse conditions. Table 3 provides an example of an indicator rating description and associated scoring guidance that has been developed to prompt due consideration of relevant evidence, and to limit ambiguity when deciding on a score. The full rating descriptions for each indicator are provided as Supplementary Material.

4.2. Assessment methodology

While the WSC Index framework can be applied in diverse ways to provide value to city stakeholders, the CRCWSC has developed and certified a workshop process methodology for using it to benchmark the water sensitive performance of cities. It has trained and accredited providers in this methodology (see Supplementary Material for details on the accreditation process) to ensure that the assessment approach—including how discussion amongst workshop participants is facilitated and how final indicator scores are decided on—will be consistent, regardless of who is facilitating the workshop. Cities that are assessed by an accredited provider are considered to have official benchmarks and have their scores included in the database of WSC Index results. This is creating an invaluable dataset for enabling consistent benchmarking and comparison, helping cities learn from each other as they implement management actions and supporting meta-analysis across cities to inform new research insights.

The certified assessment methodology requires involvement of at least 15 and up to 50 participants who represent different interests, functions and responsibilities from various rel-

evant organisations—and different departments within those organisations—with water-related responsibilities in the geographic and/or socio-political area being benchmarked. Participant organisations in applications to date have included local municipalities, water utilities, consultants, developers, research institutes, and government departments including planning, environment, water, health, sports and recreation, parks and wildlife.

Fig. 3 presents an overview of the assessment methodology. Prior to the workshop, participants are provided with the framework and definitions of the indicators in the WSC Index framework. They are asked to consider indicators they have particular knowledge on and to collect relevant evidence to contribute in workshop discussions; providers will often engage with their main client contact to suggest an appropriate distribution of indicators among participants. While full preparation by participants is not necessary for a successful workshop, and the robustness of the scoring is not compromised if there has been less preparation for some indicators, workshop discussions are enriched if participants have done this pre-thinking.

During the workshop, scoring is done goal by goal. A workshop duration of one-day requires some of the goals to be scored concurrently by splitting the participant group in two separate rooms, with participants freely choosing which goals they can best contribute to the assessment of. Within each goal, approximately 15 min is spent per indicator. The facilitator introduces the indicator, explaining its intent and providing any local interpretations and examples needed to provide clarity. Participants initially individually score the indicator using a live polling system, drawing on their own tacit knowledge, understanding of evidence, or opinion if they do not have access to relevant information. Through facilitated discussion, participants then explain their scores and substantiate their view with supporting evidence. Participants deliberate the insights and information provided and decide on the final score based on (near-)consensus. There may be some disagreement amongst participants on the final score, although rarely by more than 0.5 difference in the applications to date. This is not considered problematic, however, as accuracy of the score itself is less important than having a sound basis for identifying a city's relative strengths and weaknesses, and understanding the issues that need to be addressed through management actions. At this point, the degree of confidence in the score is noted for reference in the development of management actions and WSC Index applications in the future: 'high' means consensus and supported by strong evidence, 'medium' means consensus but lack of evidence, and 'low' means lack of both consensus and evidence.

The assessment method allows a diversity of perspectives and opinions to be revealed and explored, while inviting critical reflection on the available evidence to then lead to a collective decision on the score. At the end of the workshop, overall results are shared with the participants and preliminary reflection amongst the group is facilitated to begin the process of collective sense-making and identification of priorities. This process is typically expanded after the workshop by the WSC Index provider, who may prepare a report that provides more in-depth analysis of the results and recommended strategies and actions.

Instead of the collaborative workshop process described above, the scoring could be undertaken by an informed individual or expert panel, for example. However, a cautionary note: a single individual is unlikely to have the necessary in-depth understanding or access to evidence across all goals and indicators to provide a reliable assessment, and there is a risk that the results would not be considered valid amongst key stakeholders without wider participation. An expert-driven assessment also means that city stakeholders miss out on participating in the dialogue that leads to the scoring, which applications of the WSC Index to date have shown

⁵ Early testing internationally shows that the suite of indicators is relevant in other contexts, although potentially with some refinements. This is discussed further in Section 6.

Table 2

WSC Index goals, indicators and strategic objectives.

<i>Goal 1: Ensure good water sensitive governance</i>	
1.1 Knowledge, skills and organisational capacity	Strengthen the capabilities of individuals and organisations to adopt water sensitive practices through science, experimentation, learning and training.
1.2 Water is key element in city planning and design	Improve urban planning and design frameworks and processes to drive the implementation of water sensitive solutions through urban development.
1.3 Cross-sector institutional arrangements and processes	Encourage collaboration and coordination across organisations, sectors and levels of government to plan and implement water sensitive solutions.
1.4 Public engagement, participation and transparency	Communicate effectively with citizens and encourage their meaningful involvement in planning, decision-making and design processes.
1.5 Leadership, long-term vision and commitment	Articulate a water sensitive vision that links to broader city aspirations, and commit to delivering the vision through policy, strategic plans and investment.
1.6 Water resourcing and funding to deliver broad societal value	Invest in water sensitive practices that will deliver the highest community value, including consideration of externalities and non-market values.
1.7 Equitable representation of perspectives	Ensure inclusiveness and representation of a diversity of perspectives in governance arrangements and decision-making
<i>Goal 2: Increase community capital</i>	
2.1 Water literacy	Improve community knowledge about the water cycle and water issues so they can adopt water sensitive behaviours and participate in decision-making.
2.2 Connection with water	Foster pride and connectedness of people with water through improved understanding and appreciation of water's role in landscape.
2.3 Shared ownership, management & responsibility	Empower community to be an active participant in creating, operating and maintaining decentralised parts of the water system.
2.4 Community preparedness and response to extreme events	Support citizens to cope with and recover from impacts associated with storms, floods, drought and heatwaves.
2.5 Indigenous involvement in water planning	Recognise Indigenous water values and interests in water system planning and management and involve Indigenous people in water system governance.
<i>Goal 3: Achieve equity of essential services</i>	
3.1 Equitable access to safe and secure water supply	Provide safe, secure and affordable water supply services that meet the World Health Organization's (WHO) standards for drinking water quality.
3.2 Equitable access to safe and reliable sanitation	Provide safe, reliable and affordable sanitation services that meet the standards for sanitation defined by the WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation.
3.3 Equitable access to flood protection	Manage flood risk in a way that is affordable, including reducing nuisance flooding and protecting citizens and infrastructure from major floods.
3.4 Equitable and affordable access to amenity values of water-related assets	Enhance amenity values associated with urban landscapes through water sensitive solutions and provide affordable access to water and water-related landscape features.
<i>Goal 4: Improve productivity & resource efficiency</i>	
4.1 Optimised resource recovery	Optimise the recovery of water, energy, heat and nutrients through circular design of water systems.
4.2 Low GHG emission in water sector	Maximise the use of alternatives to high carbon emitting energy sources in water system infrastructure.
4.3 Water-related business opportunities	Stimulate investment in new business opportunities through innovation in the water sector.
4.4 Low end-user potable water demand	Support low end-user potable water demand relative to the local scarcity or abundance of water.
4.5 Broad community benefits from water services	Stimulate beneficial outcomes of water-related services for other sectors beyond water.
<i>Goal 5: Improve ecological health</i>	
5.1 Healthy and biodiverse habitat	Design water systems to help protect, restore and create well-functioning ecosystems that contribute to ecological resilience.
5.2 Surface water quality and flows	Improve and protect the quality of surface waters and marine environments.
5.3 Groundwater quality and replenishment	Improve and protect the quality of groundwater-connected environments.
5.4 Protect existing areas of high ecological value	Protect existing areas of high ecological value from the impacts of catchment urbanisation.
<i>Goal 6: Ensure quality urban space</i>	
6.1 Activating connected green - blue space	Plan and design the urban form to create many distributed, connected and well-maintained green spaces and waterways.
6.2 Urban elements functioning as part of the urban water system	Plan and design the urban form (such as green walls, roofs, retarding basins in parks) to function as an integral part of the water system.
6.3 Vegetation coverage	Provide significant vegetation coverage (e.g. tree canopies) supported by the water system.
<i>Goal 7: Promote adaptive infrastructure</i>	
7.1 Diverse fit-for-purpose water supply	Provide a flexible and adaptive water supply system appropriate to the quality water and demand requirements of the end user.
7.2 Multi-functional water infrastructure	Provide multi-functional water infrastructure that seamlessly integrates into the urban landscape.
7.3 Integration and intelligent control	Optimise water system network performance through the use of intelligent control systems.
7.4 Robust infrastructure	Remove sensitivities and vulnerabilities in the water system network through redundancy measures and by-pass systems.
7.5 Infrastructure and ownership at multiple scales	Optimise water system performance through the integration of centralised and decentralised infrastructure.
7.6 Adequate maintenance	Improve maintenance policies and practices to ensure the long-term integrity of all water system infrastructure, including natural and green infrastructure assets.

Table 3
Example indicator rating descriptions and scoring guidance.

Goal	3	Achieve equity of essential services
Indicator	3.4	Equitable and affordable access to amenity values of water-related assets
Ratings:	1:	Water-related assets do not provide amenity benefits in most areas of the city. Enjoyment of available amenity benefits of assets comes at a relatively high cost for some households.
	2:	Water-related assets provide amenity values in some areas of the city. These areas are not easily accessible and enjoyment of these benefits comes at a relatively high cost for some households.
	3:	Water-related assets provide amenity values in large areas of the city. These areas are mostly accessible and come at a moderate cost for some households.
	4:	Water-related assets provide amenity values in most areas of the city. These areas are highly accessible and enjoyment of these benefits comes at low cost.
	5:	Water-related assets provide amenity values in all areas of the city and are implemented to improve lower socio-economic areas. These areas are highly accessible and enjoyment of these benefits comes at no cost.
Key definitions		<ul style="list-style-type: none"> • <i>Water-related assets</i>: natural assets (e.g. rivers, creeks, bays, beaches) and built assets (e.g. constructed wetlands, retarding basins, reservoirs, biofilters, cycle paths and walking trails beside water assets) • <i>Accessibility</i>: people can readily access the amenity in terms of location (distribution and distance to travel), affordability (financial and time cost), universality (all people including those with a disability)
Guiding questions		<ul style="list-style-type: none"> • What amenity values are associated with water-related assets? Where are they located? Are they easily accessible? • Are the amenity values of most water-related assets accessible to different income groups? Are there admission costs? • How are the relative costs to enjoy such amenities distributed between different income groups?
Examples of relevant features that may be observed		<ul style="list-style-type: none"> • Waterways and water-related assets that are channelised may have few attractive elements and exclude people • Retarding/detention basins may be single purpose and protected by fencing or alternatively, may be landscaped and incorporate community facilities such as trails and shelters • Water reservoirs may incorporate parklands
Examples of evidence		<ul style="list-style-type: none"> • Coastline or inlets backing onto private property with no public access means low accessibility • Policy documents and strategic plans • GIS maps of the distribution of water assets with high amenity values

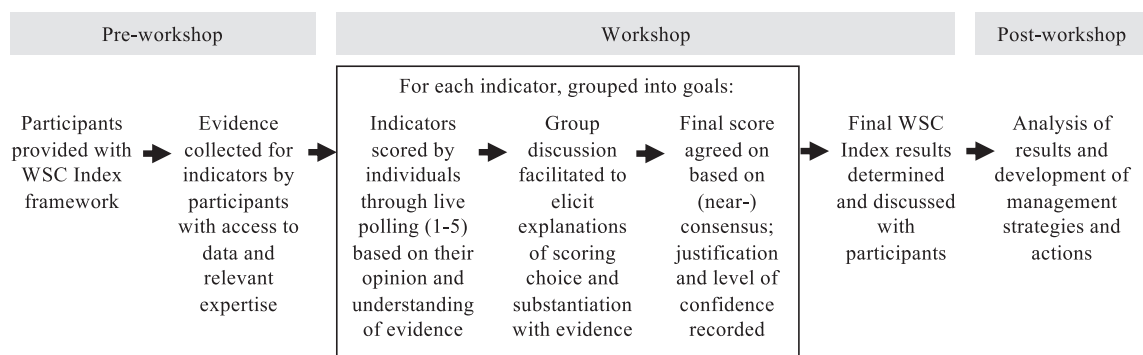


Fig. 3. Participatory process for applying the Water Sensitive Cities Index.

to be an effective way to share knowledge and generate commitment to action to improve scores.

5. Illustrative case study applications

We now demonstrate application of the WSC Index by presenting three case study cities in contrasting contexts, ranging from metropolitan scale (Greater Sydney; Hammer et al., 2018), regional city (City of Greater Bendigo; Rogers et al., 2018), to municipal council (Moonee Valley City Council; Lloyd et al., 2016).

5.1. Comparing WSC Index results

Table 4 briefly outlines the context of each city and compares their WSC Index results in order to highlight key insights the tool was able to reveal, leading to discussion of how these insights supported the development of specific management responses across the different contexts. The radar charts show the cities' performances against the seven WSC goals.

5.2. Interpreting WSC Index results

When interpreting the results in Table 4, it is important to remember that the purpose of the WSC Index and the intent of the assessment methodology is not to determine precise scores. Rather,

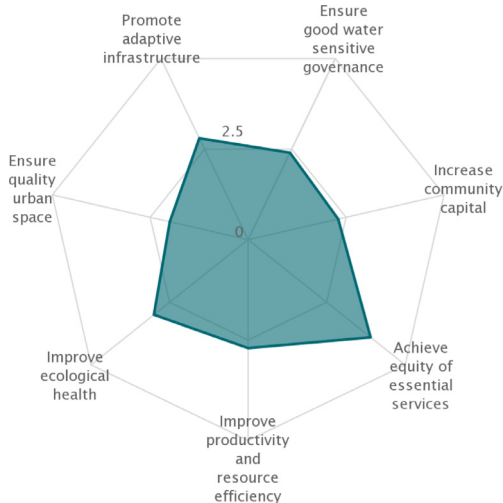
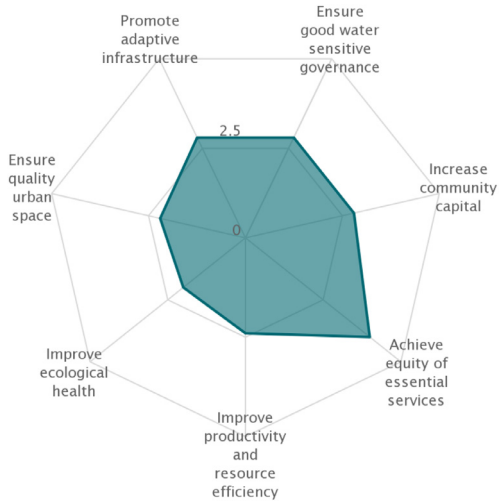
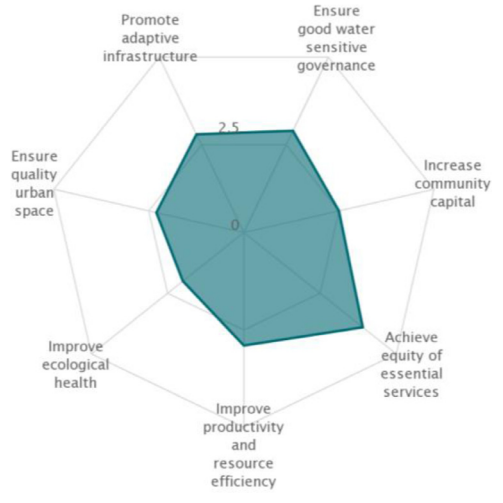
it is to understand the water sensitive performance of the system relative to an aspirational benchmark or other comparable cities, so that opportunities for management responses can be identified. Hence, while the results may be expressed with a precise number between 0 and 5, where 0 indicates the lowest and 5 the highest performance relative to the water sensitive city aspirations, it is important to attribute meaning from the results with careful reference to the specific indicators that are diagnosed to be performance enhancing or inhibiting. Comparing performance across cities will require analysis of the types of ongoing challenges and potential management responses for specific indicators, rather than drawing sweeping insights based on their aggregated scores. The following analysis will show how such comparison can reveal valuable detail on key aspects of a city's urban water services.

The WSC Index goal scores (averaged across component indicators) in the three cities ranged from 2 to 4, indicating a moderate level of overall performance. However, looking at the scores on the individual goal and indicator level reveals contrasting performances.

All three cities scored highest on *Achieve equity of essential services*, which is not surprising given the generally high performance of Australian water utilities in the provision of basic water supply and sanitation services. Bendigo is reliably serviced by a network of drainage systems managed by the local government agency. On

Table 4

WSC Index results for three illustrative case studies.

	Greater Sydney	City of Greater Bendigo	Moonee Valley City Council
<i>Context</i>	Large coastal metropolitan area inhabited by 4.7 million people, forecast to grow to 8 million by 2050 (Greater Sydney Commission, 2018)	Regional inland city inhabited by 93,000 people, forecast to grow to over 170,000 by 2050 (Department of Environment, Land, Water and Planning, 2016).	Inner city suburbs covering 43 km ² , inhabited by 124,700 people, forecast to grow to 180,000 by 2040 (Moonee Valley City Council, 2017).
<i>WSC Index application</i>	July 2017 as part of the validation period. Involved 50 government and non-government participants from water, planning, environment and development sectors.	October 2017 as part of the validation period. Involved 36 participants from the local council, water utility, state government department, catchment management authority, private developers, and Indigenous community representatives.	April 2016 as part of the validation period. Participants represented a diverse range of internal stakeholders as well as external stakeholders (including representation from the local council, water utilities and state government department.
<i>Radar results</i>			

Note: The scores in the radar diagrams range from 0 (lowest performance, centre of the radar) to 5 (highest performance, outer edge of the radar). The midpoint value of 2.5 is indicated as a grey line in the middle of the radar to show the relative performance of a city to this midpoint score across the different goals. The shaded blue areas show the overall performance of the city—the larger the shaded area the higher water sensitive performance.

this aspect, Bendigo performed slightly better than Sydney and Moonee Valley. Sydney's lower drainage performance reflects an uneven distribution of flood protection across the city, with some inhabitants at greater risk of flooding (Hammer et al., 2018). While a range of flood-related risk analyses and strategies were being implemented at the municipal or sub-catchment levels, they were not strategically aligned with one another, limiting opportunities for learning and scaling up at the catchment level. Meanwhile, in Moonee Valley, rainfall events generally do not disrupt everyday activities, although there are known localised flooding issues and inconsistent planning controls, which has resulted in some overland flow paths being built over.

Sydney demonstrated higher performance for *Improve ecological health* than Bendigo and Moonee Valley. While point-source pollution in Bendigo is well-managed, and there is growing acknowledgement of the need to manage diffuse-source pollution, adoption of new industry standards for stormwater management are yet to be mainstreamed in established suburbs. Similarly, in Moonee Valley compliance to best practice stormwater discharge guidelines can also be improved. While major waterway corridors are accessible to community, active recreation infrastructures such as bicycle and walking paths can be increased along smaller blue-green assets (e.g. ponds, wetlands).

Moonee Valley shows the highest relative performance for *Improve productivity and resource efficiency* compared to Sydney and Bendigo. This reflects a range of efforts by the municipality to implement decentralised alternative supplies, stormwater harvesting projects for reuse in local parks, and ongoing WSUD working groups with multidisciplinary representation. Whilst these achievements are encouraging, there remains significant room for improvement to reach a high level of water cycle performance in the municipality. Volume of water reuse, for instance, remains low compared to mains water. Sydney has diversified its water sources, although significant challenges remain in implementing stormwater harvesting and other recycling measures as a viable option at scale. Bendigo has also promoted diversification of water sources, including rainwater tanks, bores and wastewater recycling and reuse. However, water demands in Bendigo have grown in recent years and remain quite high.

Despite evidence of some improvement in water management and urban design approaches, attainment of an ideal WSC state across the three cases remained elusive. In Sydney, although the overall score for water security and public health was high, there is a clear need to integrate governance innovations to increase the city's overall water sensitivity. For Bendigo, while there is evidence of strategic city greening and investments in stormwater harvesting projects, there remains relatively few examples of other water sensitive infrastructure, such as raingardens. The benefit of nature-based solutions for mitigating urban heat, for instance, has not been understood by many residents and overall tree canopy cover appears to have been reduced. In Moonee Valley, evidence showed that the municipality's approach in advancing water sensitive practices has been driven by demand management following Australia's Millennium Drought (1997–2010). While this period saw widespread installation of water saving fittings, fixtures and appliances, water usage has since bounced back to 200–250 l/person/day across residential and industrial sectors. To reach a WSC state, management actions that lead to multi-functional outcomes need to be implemented more widely across the three cities.

5.3. Using WSC Index results

Experience in assessing the water sensitive performance of more than 50 cities to date shows the WSC Index results can be used in a variety of ways to inform the development of manage-

ment actions and strategies in response to key priorities. Examples from this paper's three illustrative cases are given here.

Application of the WSC Index in Sydney generated high-level strategic recommendations that identified priority issues for the short- to medium-term. The city-wide benchmarking, informed by perspectives from a range of municipal council areas, enabled a systematic understanding of the drivers, challenges and opportunities for improved water sensitivity. The process also strengthened relationships among participants through engaging in new types of discussions with different people and organisations and sharing lessons and experiences from across the city. While it was useful to have a metropolitan-wide WSC Index result, participants and facilitators of the Sydney application reflected that the aggregated scores at the metropolitan level disguised a high degree of variation in performance across the large geographical and administrative region. Participants therefore saw value in follow-up applications of the WSC Index at the sub-city and/or municipal scale to derive more tailored management actions in response to local issues.

Bendigo participants engaged in a further process to prioritise indicators for strategic action following the benchmarking workshop. Stakeholders have since committed to an ongoing network of WSC champions who meet regularly and follow up on agreed actions. The WSC Index and associated processes has led the leaders of key agencies to establish a clear mandate for implementing the changes needed to improve the scores of these priority indicators. They plan to reassess Bendigo in three years to monitor their progress towards their water sensitive aspirations.

For Moonee Valley, a nine-point action plan was developed using the WSC Index results, which has provided an overarching framework to guide initiatives across the municipality to advance towards the WSC. These actions span on-ground practices, enabling structures, and socio-political capital.

6. Discussion

Applications to date, including both municipal and metropolitan cities, have shown that the WSC Index can provide reliable, meaningful insight across different contexts—including coastal and inland locations, temperate and tropical climates, dense and sparse populations, major cities and regional centres, within Australia and internationally. While workshop participants in different cities found that some indicators were less relevant at the municipal scale and some were more challenging to uniformly apply at the metropolitan scale, there was value in scoring all indicators for the selected scale of application to lead to meaningful insights about the area's water sensitivity and point to management actions to improve scores.

The design of the WSC Index as a quantitative framework with qualitative rating descriptions and a process-based assessment methodology has helped it be applicable across diverse contexts. The indicator descriptions allow for contextual interpretations of the indicators, while maintaining a robust universal framework that enables city comparison and benchmarking. The scoring approach means it is feasible to benchmark any city where there is sufficient stakeholder interest, even in situations where there is a lack of quantitative data. This is because the evidence needed to determine the WSC Index scores is typically readily accessible—for example, in the form of organisational policies, strategies and reports, or in the tacit knowledge of key individuals.

Early testing Indonesia, South Africa, China, Fiji and Myanmar showed the potential value of the WSC Index for developing cities. Elaboration on this is beyond the scope of this paper, beyond suggesting that refinement through further international testing would be valuable to ensure the indicator and rating descriptions are sufficiently robust for universal application. For example, it may be

that finer granularity is needed in the lower rating scores for some indicators, or that additional indicators may be needed to suit the particular conditions of developing city contexts (for example, informal settlements).

The participatory assessment methodology became a central focus for the WSC Index's development and application—a novel finding of this research. Emphasis on a well-facilitated process was initially to ensure providers were consistent in how they engaged participants in scoring deliberations. However, applications of the WSC Index to date have revealed a range of unanticipated benefits from the assessment process that would not have been achieved through a desktop assessment methodology. Workshop participants consistently report that the WSC Index framework and workshop process: (a) increased their understanding of WSC principles, concepts, solutions and practices, (b) introduced them to people who would be important to collaborate and coordinate with to achieve water sensitive outcomes, (c) facilitated new cross-sectoral conversations between stakeholders, (d) helped the group develop a collective understanding of their water system context and key drivers, (e) led the group to articulate a shared set of aspirational outcomes for their future water system, and (f) gave them insight into relevant policies, programs and other initiatives from other departments and external organisations. These insights reinforce findings from studies on the value of participatory processes (e.g. Olsson et al., 2006, Rijke et al., 2013) and point to a promising direction for the design of other indicator initiatives beyond water—particularly those aiming to drive system change through collaboration and learning across multi-sectoral policy-makers, strategists and practitioners.

Further development of the WSC Index could integrate diagnostic filters that interpret the goal and indicator scores in different ways, depending on the interest, perspective and communication needs of the end user. For example, the indicator scores could be analysed through the urban water transition framework (Fig. 1, Brown et al., 2009) to determine a city-state benchmark. This would allow a city's results to be interpreted with respect to their progress towards the water supply city, sewerage city, drained city, waterways city, water cycle city and, ultimately, the WSC, helping to give meaning to their results in relation to city-state aspirations. Another potential diagnostic filter is the United Nations Sustainable Development Goals (SDGs) (United Nations, 2015), with which the WSC Index has many points of alignment. Their integration could help city stakeholders assess how improvements to their city's water sensitive performance may contribute to the achievement of SDG targets, and vice versa. These and other diagnostic filters would support users to gain critical insights into the current state of the urban water services and develop management actions that will address key priorities.

Finally, meta-analysis of city data collected through the assessment process, beyond simple overlaying of results for visual interpretation and ranking of aggregate scores, would help to gain comparative insight the water sensitive strengths and weaknesses of cities in diverse contexts. Meta-analysis of data collected longitudinally would also generate insight on the effectiveness of management actions in improving a city's water sensitivity, providing an invaluable database for research into water sensitive city transitions.

7. Conclusion

This paper presents, for the first time, a framework for defining water sensitive performance across the full range of technical, social, ecological, governance, economic, liveability, multi-functional and adaptive attributes that are becoming recognised as important features of future water systems. In building on established indicators and developing new measures that address gaps in ex-

isting water-related metrics, the WSC Index offers a robust and industry-relevant tool and process for diagnosing a city's strengths and weaknesses in relation to its water sensitive aspirations, and guiding management responses that will help improve a city's water sensitivity. Rapid uptake of the WSC Index in Australia highlights its value in helping stakeholders develop collective commitment and evidence-based priorities for action to accelerate their city's water sensitive transition.

We have demonstrated application of the WSC Index through three illustrative case studies, showing how it can be used to generate insights for benchmarking a city's water sensitive performance, setting operational targets for improvement, developing management responses, and monitoring progress towards its water sensitive aspirations. Comparing the case study results across the seven WSC Index goals reveals which specific aspects of urban water servicing and management responses can be enhanced to strengthen water sensitive principles. The case applications also show the suitability of the WSC Index tool across a range of biophysical and socio-political contexts, including large metropolitan scale, regional city, and municipality with different climates and demography.

The outlook for the WSC Index as a valuable benchmarking and diagnostic tool to support the assessment of urban water services in practice appears positive, with applications continuing across Australia. There has also been increasing interest from international cities; further testing and refinement of the WSC Index in diverse contexts will help realise its full potential as a global tool. There may also be additional diagnostic filters that would provide new ways of interpreting and communicating the WSC Index results. Innovation in the assessment methodology may present opportunity to increase the flexibility of application, for example by utilising online collaboration platforms, especially relevant in the current COVID-19 pandemic. Finally, there would be value in complementing the WSC Index's focus on material outcomes of water sensitive practices with transitions-focused frameworks that can provide guidance on the process of change itself, such as how to drive organisational cultural change, enhance collaborative practices, and establish enabling institutional structures.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Supplementary materials

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