Urban water metabolism information for planning water sensitive city-regions

1. Introduction

Many city-regions are facing challenges related to water resources quality and quantity (McDonald et al., 2014). These challenges are likely to intensify due to future social and environmental change such as increased urban populations and climate change (Jiménez Cisneros et al., 2014; OECD, 2015). The challenges are further compounded by business-as-usual approaches to land use planning and urban water management, including the reliance on undiversified supply systems that are not conducive to innovation (Marlow, Moglia, Cook, & Beale, 2013; Rijke, Farrelly, Brown, & Zevenbergen, 2013), limited utilisation of alternative and recycled sources of water (Kenway, Gregory, & McMahon, 2011), and fragmented urban water governance (Brown, Farrelly, & Keath, 2009; Gain, Rouillard, & Benson, 2013).

There is increased recognition that business-as-usual approaches to urban water management worldwide will not address social and environmental change, including climate change and population growth (Brown, Ashley, & Farrelly, 2011; Wong & Brown, 2009). In particular, there are calls for sustainable approaches that consider the different services and functions performed by water in both the natural and anthropogenic water cycles, and at different spatial scales (e.g., urban, peri-urban and rural scales) (Brown et al., 2011; Pahl-Wostl, 2008). Sustainable approaches are predicated on strengthening environmental protection and water security, and improving connection between water and land use planning (Brown et al., 2011; Pahl-Wostl, 2008). They also emphasise the importance of considering the system boundary in terms of the multiple functions performed by water over longer timeframes, including environmental, social, economic and cultural functions (Brown et al., 2011).

The concept of ‘water sensitive cities’ is one such approach to sustainable water resource management (Dean et al., 2016). The concept is based on the three pillars of cities as supply catchments, cities providing ecosystem services, and cities with water sensitive communities (Wong & Brown, 2009). It also focuses on promoting liveability, resilience and sustainability, in relation to both institutions and infrastructure (Ferguson, Frantzeskaki, & Brown, 2013; Wong et al., 2013). However, there are recognised limitations in the capacity of institutions to deliver the paradigm shift required to achieve the outcomes sought for water sensitive cities (Rijke et al., 2013), in terms of insufficient skills and knowledge, through to policy implementation failure and institutional entrapment (Brown et al., 2011). This paper relates to the knowledge needs of practitioners for planning water sensitive city-regions, and how urban water metabolism (UWM) evaluations may be able to service these knowledge needs. Practitioners in this paper refer to professionals engaged in urban and regional planning, environmental planning, and urban water planning and management.

Boundary, spatial scale issues regarding land use and water resource planning add complexity to UWM evaluations, especially because of existing mismatch between administrative and natural boundaries (Renouf et al., 2018). Additionally, urban water has often been left out of both river basin and catchment governance (van den Brandeler, Gupta, & Hordijk, 2019), and land use planning (Serrao-Neumann, Renouf, Kenway, & Low Choy, 2017). To address this issue, this paper uses the term city-region to emphasise the assumptions that urban areas depend on and impact water resources at a larger spatial scale often beyond traditional administrative boundaries (Neto, 2016; Serrao-Neumann, Renouf, Kenway, & Low Choy, 2017), and that planning for water sensitive city-regions requires a whole-of-government approach, in which strategic urban water management and land use planning are integrated. As a result, we recognise that land use planning can directly contribute to achieving water sensitive city-regions because it significantly influences the design and functioning of urban areas. This is supported by its role in managing urban sprawl and dwelling densities, implementing green open spaces, enabling diversified water supply infrastructure, and determining spatial layout of urban development relative to water-related infrastructure (Cesanek & Wordlaw, 2015).

It will be difficult to achieve water sensitive city-regions if planning policies are not informed by a holistic and quantified picture of how water is managed and transformed in city-regions, and the interventions needed to achieve water sensitive outcomes. Methods are emerging for providing such a holistic picture, in particular UWM evaluation. This method quantifies the water mass balance of urban areas to generate quantitative indicators of UWM (Kenway et al., 2011; Marteleira, Pinto, & Niza, 2014; Renouf et al., 2018). We hypothesise that the knowledge and indicators generated by UWM evaluations can inform land use and water resource planning by addressing the knowledge needs of practitioners.

Urban metabolism is a metaphor for conceptualising resource flows through urban systems, as analogous with ecosystems (Decker, Elliott, Smith, Blake, & Rowland, 2000; Fischer-Kowalski, 1998; Newman, 1999; Pincetl, Bunje, & Holmes, 2012; Wolman, 1965), with an inferred intent of emulating the higher resource efficiencies of natural systems. As an evaluation approach, it quantifies resource flows into, out of and through urban areas, most commonly energy, materials, greenhouse gases, nutrients, etc. (Kennedy et al., 2015). This paper is specifically interested in water-related flows. Metabolism studies that have focused on water, which we refer to as UWM evaluations, have used an urban water mass balance method to quantify all natural and anthropogenic flows of water through a defined urban area, from which performance indicators can be generated (Kenway et al., 2011). From such quantification, it has been possible to highlight the underutilisation of rainwater, stormwater and wastewater as water supplies for cities (Kenway et al., 2011), assess how urbanisation influences natural hydrological flows (Haase, 2009), compare the water performance of different urban areas (Marteleira et al., 2014), and consider how different water servicing options influence the water metabolism performance of urban areas at local (Farooqui, Renouf, & Kenway, 2016) or city-region scales (Renouf et al., 2018). UWM evaluation, based on water mass balance, is a core method for evaluating urban water performance (Renouf & Kenway, 2016). It has also been noted that the urban metabolism concept can inform integrated management of water supply, stormwater and wastewater systems, to reduce their environmental impacts whilst supporting social and economic benefits (Burn, Maheepala, & Sharma, 2012).

Past research that has examined urban metabolism in the context of land use planning and urban water management has mostly discussed it conceptually (Chrysoulakis, de Castro, & Moors, 2015; Chrysoulakis, Lopes, San José, Grimmond, Jones, Magliulo, Klostermann, Synnefa, Mitraka, Castro, et al., 2013). Kennedy and colleagues (2007; 2015) performed ‘top-down’ accounts of resource flows for the whole-of-city urban scale and propose it to be a framework for resource accounting and indicator development that can inform regional strategic planning by tracking resource flows and monitoring trajectories over time (Kennedy, Pincetl, & Bunje, 2011). Chrysoulakis et al. (2013) generated a ‘bottom-up’ computer simulation of resource flows at smaller urban scales, which they propose can feed into Strategic Environmental Assessment and Environmental Impact Assessment. Similarly, Pinho et al. (2012) proposed a Metabolic Impact Assessment method to assess the metabolism impacts of individual development applications to feed into Environmental Impact Assessment.

To the best of our knowledge, none of the past research has described how urban metabolism evaluations can inform land use planning and water management policy or decisions in practice, and there has been little on-ground demonstration of its use. There are some rare mentions of it being used conceptually in the master planning of urban developments (Chrysoulakis, Lopes, San José, Grimmond, Jones, Magliulo, Klostermann, Synnefa, Mitraka, Castro, et al., 2013; Kennedy et al., 2011; Mollay et al., 2011; Rueda, 2007; Suzuki & Dastur, 2010), particularly for aspects such as energy, greenhouse gas emissions, material intensity, but less so for water (Bricker et al., 2017).

The gap addressed by this paper is the lack of guidance about how the UWM evaluation can inform land use planning and water management processes in practice. It contributes to filling this gap by empirically investigating how the information provided by UWM evaluations can meet the knowledge needs of practitioners for planning water sensitive city-regions. Specifically, how can UWM evaluations support urban and water planning for water sensitive city-regions? This is important because it helps tailor the information generated by UWM evaluations to maximise their usability by practitioners, and hence is a step towards enabling science-informed strategic planning. The work was conducted in the context of Australian strategic planning systems, but the UWM knowledge needs would be applicable to other similar planning contexts.

2. Research design and approach

This study applied multiple methods to a set of city-regions case studies (Yin, 2003) to identify how the information provided by past UWM evaluations can inform water sensitive city-regions planning. The methods included the qualitative identification of the knowledge needs of practitioners through scenario planning workshops and interviews, and a synthesis of the knowledge outputs from UWM evaluations from a review of past studies. These were brought together and compared within a framework of UWM objectives, to understand how UWM evaluations can meet practitioner's knowledge needs and inform land use and water planning (Figure 1).

[insert Figure 1 near here]

2.1 Case study city-regions

The paper focuses on the strategic planning areas defined by current regional plans of three Australian capital city-regions: South East Queensland (SEQ), Melbourne (MEL) and Perth (PER) Metropolitan regions (Queensland Government, 2016; Victorian Government, 2014; Western Australian Government, 2015) (see Figure 2). Australian capital city-regions offer suitable case studies because they are highly urbanised, have rapidly growing urban populations, and are prone to recurrent climate extremes such as floods and droughts that are likely to be exacerbated by climate change (Reisinger et al., 2014). They are located within distinct climatic zones with different annual rainfall patterns and geological formations relevant to both surface and groundwater resources (Dowdy, 2015; Grose et al., 2015; Hope et al., 2015). The federation system in Australia means that water and land use planning in each of these regions are subject to different institutional arrangements set by the respective state governments, but with implications for local governments and water corporations (see Table 1). Thus, they provide a valid sample of Australian city-regions, representing a range of climatic, and land use and water governance conditions.

[insert Figure 2 near here]

[insert Table 1 near here]

2.2 Data collection and analysis

Two full-day scenario planning workshops were held in each case study region between May and September 2016. The workshops developed explorative scenarios (Börjeson, Höjer, Dreborg, Ekvall, & Finnveden, 2006) for each region to test a selection of existing plans, strategies and policies related to urban and regional planning and water resource management. During these workshops, existing vision statements for water sensitive city-regions in each case study area (Department of Infrastructure and Planning, 2009; Department of Transport Planning and Local Infrastructure, 2014; Office of Living Victoria, 2013; Rogers, 2015; SEQ Water, 2015) were validated by workshop participants, to provide context for semi-structured interviews that followed. From these visions, which are underpinned by the water sensitive cities concept proposed by Wong & Brown (2009), a set of desired objectives for urban water management had previously been described (Authors et al. 2017) (Table 1). These objectives and features align with urban water management goals predicated on a total water cycle perspective and articulated by urban water industry bodies and international development agencies (ADB, 2016; IWA, 2016; OECD, 2015; UK Water Partnership, 2015). They provided the framework for the empirical data collection in the subsequent semi-structured interviews.

The interviews aimed to identify the knowledge and information that are needed to support planning for water sensitive city-regions in relation to these objectives. Data were collected through fifteen semi-structured interviews with seventeen practitioners. Interviewees were purposely selected (Zhang & Wildemuth, 2009) from workshop participants and comprised practitioners from government (state and local government) and non-government agencies with direct and indirect roles in urban water management, natural resource management and land use planning in each of the case study regions (see Table 2). Interviews lasted around one hour, were audio recorded and transcribed verbatim.

[insert Table 2 near here]

In-depth content analysis (Bowen & Bowen, 2008) was performed using NVivo software to identify what information and metrics interviewees thought UWM needs to generate to support planning for water sensitive city-regions. Table 3 summarises the key codes used for the content analysis.

[insert Table 3 near here]

2. 3 Review of knowledge generated from UWM evaluations

We then synthesised the findings from past UWM evaluations to understand the knowledge that can currently be generated. In particular, we drew on five studies that have applied an UWM evaluation framework to urban systems within the case study regions, to provide a consistent backdrop. They represent UWM evaluations at different urban scales – that is: a medium-scale greenfield urban development (30 km^2) (Farooqui et al., 2016), infill development within an urban catchment (30 km^2) (Meng, 2018), cities (1,200 – 1,800 km^2) (Kenway et al., 2011) and city-regions (up to 4,000 km^2) (Renouf et al., 2018). For each study, we identified and categorised the knowledge generated according to the framework of UWM objectives.

3. Results and Discussion

The results from comparing practitioner's knowledge needs (from interviews) against knowledge generated by UWM evaluations (from the review of past studies) are reported in Table 4. Comparison shows how UWM evaluations can currently support urban and water planning in relation to each of the four UWM objectives set out in Table 3. We found that existing methods for UWM evaluation can currently support the knowledge needs of planners in terms of understanding hydrological flows, quantifying water efficiency, and understanding the opportunities for water efficiency and supply internationalisation. Further work is needed to support knowledge needs for managing environmental flows in waterways, understanding the sustainability of urban water extraction from the environment, accounting for nutrients mobilised in urban waters, accounting for the diverse functions of urban water, and deriving benchmarks and targets for urban water performance. Further details on the empirical findings from the interviews and the review of past studies that support these observations are contained in the Supplementary Material A.

[insert Table 4 near here]

Scholars have argued that planning for water sensitive city-regions requires innovative, sustainable urban water management approaches (Brown et al., 2011; Wong & Brown, 2009). From the findings (see Table 2 and Supplementary Material A) we deduce that there are five ways in which the knowledge generated by UWM evaluations could inform the objectives of water sensitive city-regions. These are: (i) resource efficiency and hydrological performance benchmarks and targets for urban developments; (ii) tailoring programmes that promote resource efficiency (e.g., nutrient offset schemes); (iii) making a business case for regional blue-green space networks for improved hydrological performance; (iv) small and large-scale infrastructure innovation; and, (v) social and institutional innovation in urban water management (e.g., integrated water resource management).

3.1 Resource efficiency and hydrological performance benchmarks and targets for urban developments

Previous research that has used the urban metabolism concept noted its potential contribution to promoting resource efficient land use and water planning (Chrysoulakis, Lopes, San José, Grimmond, Jones, Magliulo, Klostermann, Synnefa, Mitraka, & Castro, 2013; Newman, 1999; Pincetl et al., 2014). Findings from this research build on this by more clearly identifying the information that practitioners need for promoting resource efficiency and improved hydrological performance. Interviewees from the planning and natural resource management sectors in the three case study regions indicated that there is no formal process that they can draw on to benchmark the quality of residential and commercial developments in terms of resource efficiency (see Table 4 *d3*), and protection of natural hydrological flows, respectively (Table 4 *a1*). That is, one that assesses these objectives in terms of building design and density, outdoor landscaping and subsequent use of resources such as water, energy and nutrients. Hence, it is difficult for regulators to advocate for more sustainable urban developments, or for buyers, residents and renters to be able to compare available options in terms of resource efficiency and hydrological performance. This is a result of the lack of specific rules enshrined in local planning schemes, which in Australia reflect state government planning provisions, making it compulsory for developers to adopt designs that follow sustainability principles. Without these rules and regulations, the choice and implementation of sustainable designs occur at the discretion of developers as part of their risk avoidance, management practices (Shearer, Coiacetto, Dodson, & Taygfeld, 2016).

Whilst there are a number of existing resource efficiency benchmarking related tools available to practitioners (Chrysoulakis, Lopes, San José, Grimmond, Jones, Magliulo, Klostermann, Synnefa, Mitraka, Castro, et al., 2013; Fu, Wang, Schock, & Stuckert, 2016; Kılkış, 2016), they don't consider water-related performance and don't have a holistic perspective based on the UWM concept (Behzadian & Kapelan, 2015; Fagan, Reuter, & Langford, 2010; Mini, Hogue, & Pincetl, 2014; Pediaditi, Doick, & Moffat, 2010). Additionally, the value of tools can be compounded by data availability and quality (Pincetl et al., 2014), and method used to generate assessment (e.g., selection of indicators, understanding of sustainability, measurement subjectiveness) (Pediaditi et al., 2010). The interviews with practitioners from all sectors identified an interest and demand for water-related assessment that informs policy implementation related to development control and land use planning, including for setting targets, and that can support regulation and enforcement of water performance (Table 4 *b* and *d*).

To this end, UWM evaluations can fill gaps in knowledge and be complementary to, or used in combination with, other sustainability tools and methods. Specifically, our findings indicate that UWM evaluations can quantify the resource efficiency and hydrological performance of urban areas to inform how they may be improved. For example, harvesting and use of fit for purpose water supplies sourced from within the urban area to improve overall water efficiency (Farooqui et al., 2016; Pincetl et al., 2014), or decreasing imperviousness to restore hydrological flows toward more natural conditions (Renouf et al., 2018). A limitation of current UWM evaluations identified in our study however, is their inability to provide metrics for other more complex functions within the urban context, including functions conducive to maintaining and improving urban liveability such as recreation, urban heat island mitigation, visual amenity etc.

3.2 Tailoring programmes for resource efficiency

While there have been several studies using urban metabolism to test the efficacy of policies in terms of resource efficiency, they have focused on energy and carbon emissions (Behzadian and Kapelan, 2015; Chrysoulakis et al., 2013; Pincentl et al, 2014), and its potential to inform programmes targeting improved sustainability and liveability outcomes is still being developed (Pincentl et al. 2014). Nonetheless, Pincentl et al. (2014) illustrated how UWM evaluations could guide water efficiency programmes by coupling analysis of the flows with pricing mechanisms to demonstrate that lower-income residents in Los Angeles have the highest water elasticity as a result of price sensitivity. A key conclusion of their study was that to ultimately reduce water use overall, programmes should primarily target reduction in water use of wealthier residents.

Interviewees in this research confirmed the potential role of UWM evaluations in informing the programmes that incentivise water resource efficiency, especially to deal with land use planning and urban water management legacy issues and retrofitting of existing urban areas. In particular, interviewees from local government land use planning departments highlighted challenges to improve resource efficiency around particular sectors (e.g. industrial and commercial) that currently lack interests or incentives to do so (beyond simple pricing indicators) (Table 4 *d4*). UWM evaluations, when combined with economic and social data, could indicate opportunities for demonstrating where water sensitive interventions might have the most impact. For example, in an analysis of a greenfield master plan development Farooqui et al. (2016) showed that harvesting and use of rainwater/stormwater and the recycling of wastewater only improves the water efficiency of the urban area if the scale of implementation is maximized. Hence, to achieve greater resource efficiency, our research indicated that specific programmes could provide incentives to encourage use of alternative water sources.

UWM evaluations can potentially provide broader assessment of resource efficiency beyond just water, but also water-related energy and nutrients, and so test alternative interventions across broader sustainability criteria (Behzadian and Kapelan, 2015; Chrysoulakis et al., 2013).

3.3 Making case for regional blue-green space networks for improved hydrological performance

Urbanisation increases impervious surfaces and reduces vegetation cover, therefore decreasing the capacity of the environment to absorb runoff from rainfall and increasing risks of flooding and damage to urban ecosystems (Wang, Palazzo, & Carper, 2016; Whitford, Ennos, & Handley, 2001). It also contributes to declining water quality, decreases the capacity of natural filtration and exacerbates the urban heat island effect (Norton et al., 2015;

Wong et al., 2013). As a result, there have been increased calls for the establishment of networks of green and blue space networks at the city-region scale to restore and maintain hydrological and vegetation connectivity, thereby mitigating these effects (Benedict & McMahon, 2002; Demuzere et al., 2014; Norton et al., 2015; Sander & Zhao, 2015).

While the literature confirms the role of green and blue spaces in mitigating the impacts of urbanisation on waterways and associated habitats, stakeholders from local government land use planning and stormwater management, and water corporations indicated that there remain significant barriers to improve the way in which these spaces are planned for and implemented (Table 2 *c*). Typically, planning and implementation of green and blue spaces is carried out separately by different government agencies and levels (e.g. local governments deal with stormwater management, state governments deal with water resource planning and allocation, water corporations deal with water supply and wastewater management). As a result, blue spaces (or blue infrastructure) (Salinas Rodriguez et al., 2014) such as water sensitive urban designs (WSUDs) are not considered a type of urban open space in land use planning. Nonetheless, there is significant research that confirms the role of WSUDs for increasing urban green spaces. Benefits include flood mitigation, water pollution control through nutrient stripping, reducing runoff, reducing waterway erosion and sediment accumulation; whilst also complementing other functions attributed to green spaces such as amenity, habitat provision, urban cooling and recreational opportunities (Donofrio, Kuhn, McWalter, & Winsor, 2009; Leonard et al., 2014; Williams & Wise, 2006). UWM evaluations can inform the planning of blue-green spaces by quantifying hydrological performance indicators. They describe the extent to which stormwater runoff, evapotranspiration, and infiltration to groundwater have altered relative to pre-urbanised flows (Farooqui et al., 2016).

Additionally, as space is contested in highly urbanised city-regions there is increasing need to implement multifunctional blue-green spaces (Ashley, Nowell, Gersonius, & Walker, 2011; Selman, 2009). Specifically, there is increasing attention paid to enhancing multifunctional blue-green spaces in metropolitan regions as a means to make urban regions more sustainable, equitable and liveable (Pincetl & Gearin, 2005). However, information regarding the extent to which and placement within regional catchments of blue-green spaces to achieve desired multi-functionality is still lacking (de Groot, 2006). Our research also indicated such limitation in UWM evaluations due to the lack of reliable indicators that can be used to account for diverse functions of water simultaneously, especially functions that carry subjectivity to their metrics such as recreational and cultural functions. However, UWM evaluations can inform the extent to which the water budgeted or allocated to these functions is sufficient to maintain each function.

3.4 Small and large-scale infrastructure innovation

Planning for small and large infrastructure in the context of environmental and social uncertainty and change is complex. In particular, it is imperative that urban design and urban water systems take into consideration resource efficiency in light of their increasing role in promoting urban resilience and liveability for uncertain futures (Skinner, 2017). It is also argued that locked-in centralised, large-scale and capital-intensive urban water management technologies comprise a key barrier to sustainably managing urban water (Marlow et al., 2013; Rouillard et al., 2016). With respect to infrastructure innovation, scholars point to the existing gap in technologies and associated supporting infrastructure for water supply diversification and internalisation (Brown et al., 2009). These comments alone suggest that planning for small and large-scale infrastructure requires a major shift from a supply and demand to a whole-of-water cycle approach, including the integration between water and land use planning and management taking into consideration the city-region scale (Neto, 2016).

Findings from this research concurred with these comments as many interviewees (especially from water corporations) identified the need for innovation to occur for both small and large-scale infrastructure, to enable their city-regions to sustainably managing their water resources. With respect to small infrastructure, land use planners and stormwater managers highlighted the challenge and barriers to promote innovative urban design for improving resource efficiency (e.g. sustainability benchmarking) and multi-functionality of water (blue-green infrastructure) (Table 2 *c* and *d*), respectively. In parallel, interviewees from the water sector also confirmed the difficulty to implement flexible water systems that adopt a fit-for-purpose approach (i.e. use of non-potable water for non-drinking purposes). One of the key contributions that UWM evaluations could bring to promote this innovation is their ability to assess supply diversification and internalisation at multiple scales (e.g. precinct, neighbourhood, city-region) - that is, the proportion of water demand that is met by internally harvested or recycled water which can be calculated by the urban water mass balance that accounts for all water supplies and all water demands.

3.5 Social and institutional innovation in urban water management

A key principle of sustainable water resource management is flexibility to enable diversification of water sources (rainwater, surface water, groundwater, wastewater, stormwater etc) and its suitability for different fit-for-purpose uses (drinking, outdoor use, environmental flows) (Brown et al., 2009). However, for diversification to be implemented significant social and institutional barriers need be overcome. On the social front, there remains substantial public unacceptance of using recycled water, especially attributed to concerns regarding public health risks but also due to the lack of institutional support for initiatives seeking a total water cycle management perspective (Brown et al., 2009; Dean, Fielding, Lindsay, Newton, & Ross, 2016). It is argued that social innovation to support sustainable water resource management requires engaged citizens (Dean, Fielding, & Newton, 2016). Literature has found that knowledge about water is one of the factors that triggers citizen engagement, albeit variations in the level of engagement and motivation to act may still occur (Dean, Lindsay, Fielding, & Smith, 2016; Fielding & Roiko, 2014).

On the institutional front, there has been substantial research into the flaws of traditional urban water management approaches with increased agreement on the need for innovation centred on water governance that is both collaborative and participatory (Braga, 2001; Pahl-Wostl, 2008; Tan, Bowmer, & Baldwin, 2012). While the limitations of siloed management and the need for integrated water management are well-recognised, achieving this on-the-ground is challenging. In particular, existing governance and institutional arrangements support business-as-usual approaches (Bettini & Head, 2013), and transitioning to new arrangements will require time and harnessing of opportunities to innovate and experiment (Bettini & Head, 2016; Ferguson, Brown, Frantzeskaki, de Haan, & Deletic, 2013; Rijke et al., 2013). There is also agreement that for technological innovation in urban water management to be adopted and implemented there needs to be supportive governance arrangements and political leadership (Rouillard et al., 2016).

Our findings confirmed the need for both social and institutional innovation (see Supplementary Material A). Interviewees from the water and natural resource management sectors identified the need to change people's behaviour on how they use water and the overall lack of understanding, or caring, about the water cycle and how their water usage impacts on others. They also pointed to challenges concerning evolving community expectations about accessing water resources in terms of both quality and quantity. Many also noted that governance arrangements remained siloed and expressed frustration that although they saw the need for linking land use planning and water management, their organisations only had responsibility for certain areas. They recognised the need for collaboration across sectors and institutional actors, but often found it hard to justify this within their business models. Those within water corporations, for example, found it necessary to constantly justify anything that wasn't related directly to water supply and demand.

UWM evaluations could help build arguments for extending responsibilities on sustainable water performance for all sectors of society because they recognise the different functions of water and their role in maintaining much sought urban liveability (Behzadian and Kapelan, 2015; Chrysoulakis et al., 2013). While this could also support greater institutional collaboration and breakdown traditional siloed roles, it is important to acknowledge that better understanding of the relationship between flows of resources, commodities and energy and their impact on social-ecological systems alone may not be sufficient as these relationships are 'shaped and transformed by power, politics, and human practices' (Cousins, 2017, p. 378). Barriers to the full implementation of information generated by UWM evaluations are therefore a reality and need be acknowledged considering how power interests driven by short-term electoral cycles plague the Australian planning system (and elsewhere), and discard evidence-based policy (Tangney & Howes, 2015). When water resources are at stake, public opinion and science literacy also play a significant role in supporting, or rejecting, sustainable alternatives (Dean, Fielding, & Newton, 2016; Morgan & Grant-Smith, 2015). Additionally, our research indicated that UWM evaluations are still in their early stages of unpacking their full potential to provide an indicator of water use per unit of function.

4. Conclusions and new directions for planning water sensitive-city regions

This paper investigated how UWM evaluations could support land use and water planning towards water sensitive city-regions. The paper was predicated on the assumption that UWM evaluations of city-regions can generate a holistic picture of and quantification for water flows through city-regions, thereby helping practitioners to develop the interventions that will be required to sustainably manage water resources at the city-region scale. Challenges related to urbanisation and climate change will continue to confront planning for water sensitive city-regions and opportunities for proactive action and innovation should not be missed. To this end, the paper compared knowledge needs identified by practitioners from three Australian capital city-regions (South East Queensland, Melbourne and Perth) and knowledge generated by past UWM evaluations to propose five strategic initiatives to support the achievement of water sensitive city-regions. These included resource efficiency and hydrological performance benchmarks and targets for urban developments; tailoring programmes for resource efficiency; making a case for regional blue-green space networks for improved hydrological performance; small and large-scale infrastructure innovation; and social and institutional innovation in urban water management.

Our findings indicated that UWM evaluations could inform the abovementioned strategic initiatives in a number of ways, especially for setting benchmarks and targets and devising resource efficiency programmes. Notably, we highlighted how UWM evaluations could be used in combination with other assessment tools to provide much needed metrics that can support benchmarking and targets for urban developments with respect to resource efficiency and hydrological performance. Such metrics could also be useful for the design of incentive programmes targeting specific areas (neighbourhoods, commercial precincts etc.) within a city-region to maximise overall resource efficiency. For example, UWM evaluations can assist practitioners to understand the current and potential water efficiency for the whole urban area by quantifying flows and associated efficiency indicators. This in turn could enable practitioners to derive specific efficiency targets for local developments to achieve the desired water efficiency. Additionally, these evaluations could provide important evidence to support changes in water resource management policies to suit regional bio-physical characteristics. For example, the Perth region relies heavily on groundwater and is progressively considering diversification of its water supply. Stormwater harvesting and greywater use for urban cooling however, are not an option because the region’s rainfall is not reliable year around. Hence, wastewater recycling has received increase attention instead. Conversely, the Melbourne region has greater interest in both stormwater and greywater recycling because its climatic characteristics favour such strategies.

Additionally, UWM evaluations have a significant capacity to inform infrastructure innovation and provision, especially considering their ability to assess supply diversification and internalisation at multiple spatial scales within the city-urban landscape. Outputs from UWM evaluations also offer important potential in communicating water sensitive city-regions objectives with society and decision makers, particularly regarding sustainable uses of water and energy resources and their importance to improved and continuous urban liveability. For example, UWM evaluations can indicate how much water demand and water use can be reduced for defined urban areas by simulating a range of scenarios related to demand management, rainwater and stormwater harvesting, and wastewater recycling. This information can assist practitioners to make decisions concerning water management to address future urban growth and associated requirements for small and large infrastructure funding and design. This information could also be used to encourage greater uptake of, and remove barriers to, more sustainable solutions by decision makers as opposed to business as usual approaches. While the regulatory frameworks of the three case study areas differ with respect to both land use and water resource planning, their respective uptake of innovative technologies has been consistently *ad hoc*. Because political interests driven by short term electoral cycles and response to public opinions continue to prevail above technical, scientific-based solutions in all three regions, practitioners tend to welcome any supporting evidence that can enable improved narratives towards innovation and sustainable alternatives.

Our study also indicated that there are current limitations to UWM evaluations that require more research to further develop their full potential for planning water sensitive city-regions. In particular, there is a critical gap in knowledge regarding the understanding of how water resources can be quantified per unit of function to challenge business-as-usual approaches to decision making which mostly consider water supply and demand. This includes innovation towards the implementation and consolidation of blue-green space networks in a highly contested urban space. Under this new paradigm, water is valued holistically and its multiple functions recognised in water resource governance, water infrastructure planning and design, and land use planning, as well as by the communities that depend on it. This information is especially important for practitioners to assess urban and regional liveability outcomes under a social-ecological system perspective – that is, considering the whole water cycle to deliver sound environmental and water quality outcomes, and enhance ecosystem services that support social and economic needs.

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