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### Megacities and rivers

*Scalar mismatches between urban water management and river basin management*

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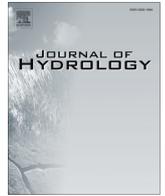
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## Research papers

# Megacities and rivers: Scalar mismatches between urban water management and river basin management



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## ABSTRACT

Due to rapid urbanization, population growth and economic drivers, megacities and metropolises around the world face increasing water challenges, such as water scarcity, degradation of water resources and water-related risks such as flooding. Climate change is expected to put additional stress on already strained metropolitan water management systems. Although there is considerable research on river basin management and on urban water management, there is hardly any on metropolitan water management. Similarly, as urban water generally emerges from and returns to river basins, it is surprising how little literature there is that explicitly connects these two spheres of governance. Hence this review paper addresses the: What does a review of the literature tell us about the overlap and reconciliation between the concepts of Integrated Water Resources/River Basin Management and Metropolitan/Urban Water Management, particularly in relation to megacities? Based on an extensive literature review, this paper concludes that the key differences between the two are in relation to their overarching framework, scope, inputs and outputs of water and in relation to dealing with extreme weather events. The literature review reveals how sustainable and integrated urban water management increasingly adopt principles and rhetoric from integrated water resource management, this has yet to translate into significant changing practices on the ground. Urban water management still often occurs independently of river basin issues. Achieving coherence between river basin management and sustainable/integrated urban water management is even more difficult in metropolises and megacities, because the latter consists of multiple political-administrative units. The article concludes that the scalar mismatch between river basin management and metropolitan/megacity water governance deserves much greater attention than it currently receives in the academic and policy debates.

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## 1. Introduction

As urban agglomerations grow, they face management challenges in terms of providing water and sanitation services to an ever-growing population, the impact of urban development on natural resources and the effects of extreme weather events (Tortajada, 2008). In the Global South, megacities, concentrating millions of inhabitants and global economic activity, urbanize faster than the capacity of public authorities to manage the territory and to provide basic infrastructure and services (Varis et al., 2006a), or to provide housing space leading some to settle in flood prone areas (Braun and Aßheuer, 2011). Cities increasingly import water from beyond their jurisdiction (Lundqvist et al., 2005).

Megacities combine many water-related challenges (OECD, 2016; Varis et al., 2006a), yet, they are scarcely discussed in the urban water or water resources management literature. They are often treated as magnified versions of cities, but their scale creates additional complexities and dynamics, including symptoms of ecological and infrastructural overload and stress, fragmented societies, higher inequality, rising informality (Kraas and Mertins, 2014; UN Habitat, 2006) and combine multiple jurisdictions characterized by the fragmentation of mandates and decision making structures, which hamper cooperation on, inter alia, land use conversion, sprawl and water governance (Kim et al., 2015).

Furthermore, while cities receive and return water to rivers, very little literature connects both urban water and river basin governance. Water resources have been governed since the earliest civilizations (Dellapenna & Gupta, 2009), leading to large infrastructure projects on river basins and cities (Brown, 2008; Braga 2001). Growing water governance challenges led to the rise

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of Integrated Water Resources Management (IWRM) and Integrated River Basin Management (IRBM), which focus on the basin scale. IRBM is a subset of IWRM<sup>1</sup>. Both are dominant paradigms used by scholars and practitioners since the 1977 United Nations (UN) Conference on Water in Mar del Plata in (WWAP, 2009). The concepts have been further developed in Agenda 21 (UNCED, 1992), in the 1992 International Conference on Water and the Environment in Dublin, and documents by the Global Water Partnership, the World Water Council, the World Water Forum, and the International Law Association's Berlin Rules on Water Resources (Savenije and van der Zaag, 2008) and UN Water (Schubert and Gupta, 2013).

Urban water concerns are managed through UWM within urban boundaries (Bahri, 2012). Water supply, sanitation and drainage are addressed through a linear approach, with water withdrawn, used and disposed of (GTT, 2014; Barraqué and Zandaryaa, 2011; Brown and Farrelly, 2009; Daigger, 2011; Kayaga et al., 2007; Gregory and Hall 2001). Recent concepts like Integrated Urban Water Management (IUWM), Sustainable Urban Water Management (SUWM) and, to a lesser extent, Metropolitan Water Management (MWM) emphasize integration, sustainability and the metropolitan scale, respectively. There is significant literature on IRBM/IRWM and less on IUWM/SUWM/MWM (see Fig. 1). While the literature covers topics like upstream-downstream issues (Closas et al., 2012; Savenije and van der Zaag, 2008), climate change adaptation (Barrios et al., 2009), collaboration (Watson, 2004), implementation (Closas et al., 2012; Biswas, 2008; Watson, 2004), water and sanitation services (Rees, 2006; UN Millennium Task Force on Water and Sanitation, 2005), stormwater and solid waste (Closas et al., 2012), groundwater (Foster and Ait-Kadi, 2012), irrigation (Koç, 2015), water security/water conflict (Savenije and van der Zaag, 2008), social learning (Pearson et al., 2010; Pahl-Wostl et al., 2007; Rauch et al., 2005; Marks and Zadoroznyj, 2005), there is limited literature on the urban-river basin interface (see Fig. 2). Hence, this article addresses the question: What does a literature review tell us about the overlap and reconciliation between the concepts of Integrated Water Resources/River Basin Management and Metropolitan/Urban Water Management, particularly in relation to megacities?

## 2. Methods

We reviewed the literature on IWRM/IRBM and UWM/MWM to assess how the urban-river basin interface can be understood, focusing on the framework (see 3), scope (see 4), sources of water (see 5), wastewater (see 6) and water-related extreme weather events (see 7), before drawing conclusions. We searched in ScienceDirect for the terms IWRM, IRBM, IUWM, SUWM and MWM<sup>2</sup> in titles, abstracts and key words for the period 1970–2015. We focused on scholarly literature, only occasionally using grey literature, as the aim was to assess how the academic literature has framed the urban-river basin interface<sup>3</sup>. Fig. 1 reveals the virtual non-existence of all five terms prior to 1990 followed by a steep rise for IWRM from 19 publications in 1995 to 183 in 2015. IRBM is

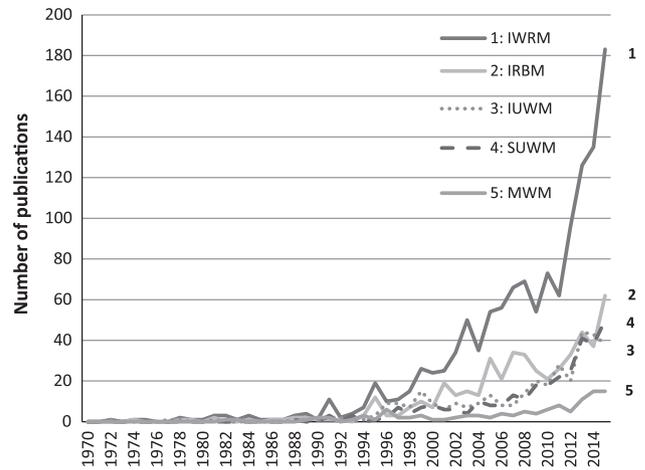


Fig. 1. Evolution of concepts between 1970 and 2015.

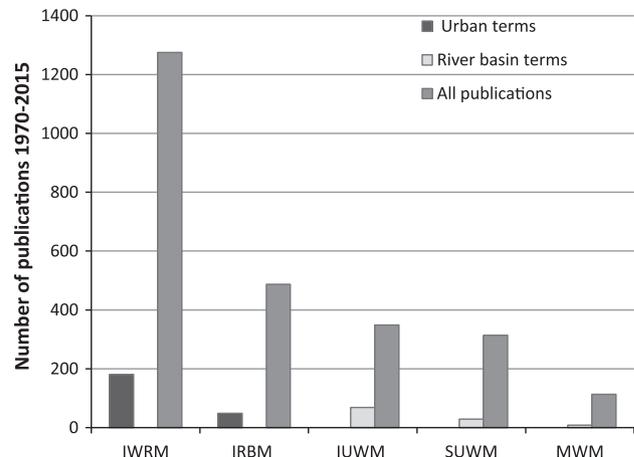


Fig. 2. The occurrence of terms related to the urban and river basin within the main concepts.

slightly ahead of IUWM and SUWM, with 62, 38 and 50 publications respectively in 2015<sup>4</sup> and there are negligible publications on MWM. When conducted with quotation marks, results for all terms were significantly lower (see Annex C); for MWM there were no results between 1970 and 2015.

Second, we analyzed the urban-river basin interface by examining the occurrence of terms in titles, abstracts and key words between 1970 and 2015 related to the urban (urban, city/ies, megacity/ies and metropolitan) in the IWRM/IRBM literature, and to the river basin (river basin, catchment and watershed) in the IUWM/SUWM/MWM literature. There was no overlap between the two sets of literature (see Fig. 2).

## 3. Overarching framework

### 3.1. Goals

#### 3.1.1. IRBM

IRBM and IWRM are often used inter-changeably as they are similar: both are holistic (Molle, 2009a; Abdullah and Christensen, 2004), considering river basins and water ecosystems

<sup>4</sup> A search for synonymous terms with IRBM – *Integrated Catchment Management* and *Integrated Watershed Management* – (see Annex A) shows the same trend, rising steadily since 1990, reaching 62 (IRBM), 46 (Integrated Catchment Management) and 59 (Integrated Watershed Management) in 2015.

<sup>1</sup> WRM is defined as “a process that promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems” (Bahri 2012; citing the Global Water Partnership definition).

<sup>2</sup> Other terms, such as “urban stormwater management” and “urban runoff management”, were not included in the search because of their limited focus on the urban water cycle; and “water sensitive cities” because it is very new.

<sup>3</sup> The authors recognize that the grey literature, developed by local practitioners and stakeholders with tacit or technical knowledge from daily activities and experience, may approach this interface differently. This type of literature is still rarely included in the scientific knowledge-building process and scientific publications.

as a whole, including wetlands and groundwater (Molle, 2009a; Chenoweth et al., 2001; Jones et al., 2006); both are hydrocentric, integrating land and other related resources (Medema et al., 2008; Odendaal, 2002; Savenije and van der Zaag, 2008), human-environment relations (Molle and Mamanpoush, 2012; Molle, 2009a; Sneddon et al., 2002), upstream and downstream concerns (Molle, 2009a; Savenije and van der Zaag, 2008); multiple sectors (Jonch-Clausen, 2004), viewpoints (Medema et al., 2008; Grigg, 1999); and objectives. Third, they emphasize stakeholder participation and cross-agency coordination for equitable allocation and the protection of ecosystems (Boateng Agyenim, 2011). They differ in that IRBM has a spatial hydrological focus, emphasizing the river basin unit, while IWRM has a spatial national focus through the integration of its principles in national-level legislation, policies and institutions (GWP, 2017; Jones et al., 2006; Rahaman and Varis, 2005; Abdullah and Christensen, 2004; Watson, 2004).

However, the integration goals are unrealistic in terms of expectation (Biswas, 2008; Medema et al., 2008; Watson, 2004), and implementation (Chenoweth et al., 2001; Medema et al., 2008; Varis et al., 2006b); they assume good will and good data (Molle, 2008; Allan, 2003; Miller and Hirsch, 2003); scarcely account for uncertainty (Boateng Agyenim, 2011); ignore the political nature of water (Jonch-Clausen, 2004) and that groups may hijack the concepts to legitimize their own agendas (Molle, 2008; Wester and Warner, 2002). Moreover, river basins that cross national borders, or even state borders within federal regimes, requires cooperation between actors and institutions across these borders (Choudhury and Islam, 2015).

### 3.1.2. IUWM/SUWM/MWM

Megacities struggle with sustainably managing water shortages, contamination, disasters and conflicts and could move from UWM to IUWM/SUWM which aims at holistic governance of finite and fragile water (Vlachos and Braga, 2001), with coordinated and flexible strategic planning, decision-making processes involving stakeholder participation (World Bank, 2015; Closas et al., 2012; Varis et al., 2006b; Brown, 2005) and optimizing the interface between urban water and activities beyond the urban boundaries (i.e. rural water supply, down-stream use, and agriculture) (Mays, 2009). SUWM addresses the urban water cycle, emphasizing adaptation, decentralization, participation and integration (Marlow et al., 2013; Brown and Farrelly, 2009; Daigger, 2011). The limited MWM literature covers principles of water management for the metropolitan context, expanding decision making structures and urban water networks to suburban constituencies or peripheral municipalities (Keil and Boudreau, 2006; Kallis and Coccossis, 2002) – topics left unaddressed by the IUWM/SUWM literature.

IUWM can provide partial responses to climate change, population growth, infrastructural costs and ecological standards (Maheepala, 2010) through principles on the use of alternative water sources (i.e. water fit-for-purpose) and conservation (Vladut-Severian, 2013; Closas et al., 2012). SUWM can help restore degraded and engineered waterways, enhance resource efficiency and decentralize solutions (Marlow et al., 2013; Newman, 2009).

While SUWM and IUWM principles are increasingly influential (Pearson et al., 2010), their application is limited (Brown, 2008). UWM continues to respond to urban needs at the expense of basin-wide concerns, and is affected by technological path dependency, institutional fragmentation, and limited political incentives (Brown, 2008). IUWM does not clearly address water allocation to uses outside urban areas, such as irrigation and hydropower, which may have enormous implications for water availability (Maheepala, 2010). While IUWM promotes municipal participation in basin-wide planning spaces, these usually lack implementing

powers (Braga, 2001). SUWM encourages innovative solutions, but these may be energy intensive (e.g. desalination, pumps for rain tanks) or risky (e.g. wastewater reuse) (Marlow et al., 2013). Investment and technological “lock in” delays the uptake of alternatives (Ibid). Moreover, like IWRM/IRBM, IUWM/SUWM do not address power relations, political will and implementation challenges.

## 3.2. Approach

### 3.2.1. IWRM/IRBM

IWRM/IRBM is process-oriented and participatory (Dzwauro et al., 2010) promoting hard and soft approaches that go beyond technical solutions (Abdullah and Christensen, 2004; Chenoweth et al., 2001). These include regulatory approaches (e.g. permits) and economic approaches (e.g. payment for ecosystem services) involving multiple actors, including user associations, environmental NGOs and affected communities.

By being inclusive, IWRM/IRBM may be able to challenge centralized expertise and decisions when water-related challenges require adaptive, polycentric (Molle, 2009a; Sneddon et al., 2002) and contextual solutions (Jonch-Clausen, 2004; Xie, 2006; Jonch-Clausen and Fugl, 2001). However, even when many stakeholders are included in participatory forums, experts dominate debates and shape decisions (van den Brandeler et al., 2014).

### 3.2.2. UWM/MWM

Traditional UWM is technocratic (Rauch and Morgenroth, 2013; Brown and Farrelly, 2009), promoting standardized and large-scale technological solutions rather than sustainable technologies and practices (GTT, 2014; Farrelly and Brown, 2011). However, SUWM aims at integrating infrastructure and biophysical systems (e.g. stormwater treatment and rainwater harvesting systems), thereby considering social, economic, environmental and political contexts (Brown and Keath 2008a,b; Mitchell, 2006; Vlachos and Braga, 2001). It combines large, centralized infrastructure with alternative and distributed technologies and participation (Closas et al., 2012; van de Meene et al., 2011; Younos 2011). Similarly, IUWM uses structural and non-structural measures (i.e. new knowledge and information technologies, education programs, water pricing and regulations) (Vladut-Severian, 2013; Maheepala, 2010).

Despite paradigm shifts towards greater sustainability and integration, the path dependent nature of the water sector means that UWM remains technocratic. Retrofitting existing infrastructure is challenging and can lead to stranded assets (OECD, 2015; Marlow et al., 2013; Brown, 2008). Learning within the basin level is not easily transferred to urban decision-making processes (Pearson et al., 2010).

## 3.3. Organizational

### 3.3.1. IWRM/IRBM

At an organizational level, IWRM/IRBM embraces (a) decentralization and subsidiarity (Xie, 2006; Molle, 2009a); (b) transparent participatory decision-making, including access to information (Jones et al., 2006; Rahaman and Varis, 2005); and (c) Community Basin Organizations (CBOs) to River Basin Organisations (RBOs) (Huitema and Meijerink, 2014; Molle, 2009a).

Decentralization and participation, by allowing for local actors with knowledge of the local environment and local users' needs, may lead to superior equity and efficiency in resource management (Andersson and Ostrom, 2008). However, natural hydrological borders rarely coincide with political-administrative borders (Bahri, 2012; OECD, 2016) resulting in a scalar mismatch between institutional and hydrological logic, a blurred allocation of responsibilities across multiple scales (OECD, 2016) and poor cooperation,

particularly in megacities with many stakeholders and interests (Li et al., 2015; Sorensen, 2011; Feiock, 2009; Aguilar, 2008).

### 3.3.2. UWM

UWM organizations are generally centralized and hierarchical (Porse, 2013; Farrelly and Brown, 2011; Elzen and Wieczorek, 2005; Saleth and Dinar, 2005), although in the South, they are complemented by informal water services (Ahlers et al., 2013). SUWM/IUWM promotes decentralization, the devolution of administrative functions, co-management with communities and the private sector, and flexible institutional frameworks (i.e. public-private partnerships) (Closas et al., 2012; Bahri, 2012).

This may make UWM more inclusive, incorporating many views, interests and environmental values into water policies (Brown, 2008). However, the IUWM/SUWM literature remains largely prescriptive, and empirical studies reveal a failure to go beyond ad hoc demonstration projects and enhance inter-organizational capacity (Brown and Farrelly, 2009; Mitchell, 2006; Harding, 2006). Water management institutions tend to be path dependent, resistant to change, and have low adaptive capacity (Marlow et al., 2013; van de Meene et al., 2011). Moreover, the UWM literature barely considers metropolitan water governance (see Fig. 1), although there is growing recognition of this gap and the need to examine metropolitan best practices by differentiating on population size and the (non)existence of governance arrangements (OECD, 2016).

## 4. Scope

### 4.1. Mandates

#### 4.1.1. IWRM/IRBM

As IWRM/IRBM aims to integrate stakeholder needs and interests at basin level, its mandate concerns all water-related activities (e.g. basin-wide evaluation, planning, strategy implementation, monitoring, water allocation mechanisms, water quality maintenance, basin guidelines, negotiation/ dispute resolution mechanisms, flood warning and mitigation, and community development) (Chenoweth et al., 2001). These mandates are shared between many actors, including RBOs and other multi-stakeholder platforms, but often not clearly delimited (Jønch-Clausen and Fugl, 2001) and their scope and depth may differ per country. RBOs exert more or less influence on planning and policy, depending on the case, but have limited enforcement and regulatory powers (Molle, 2009a).

#### 4.1.2. UWM

Drinking water supply, sewage collection and treatment, and urban drainage – are core UWM functions (Barraqué and Zandaryaa, 2011; Engel et al., 2011) supplemented by flood mitigation and control of waterborne diseases (GTT, 2014). UWM generally ignores up and downstream impacts of UWM (Engel et al., 2011) with different agencies purchasing and importing water, purifying and distributing it, and treating and discharging wastewater (Pataki et al., 2011).

The IUWM/SUWM literature advocates broadening mandates to incorporate ecosystem health, basin management, biodiversity conservation, conflicts and competing water uses, wastewater treatment and disposal, risk prevention, and integrating all urban activities (Coccosis and Nijkamp, 2002; GTT, 2014). Since 1990, water and rivers have gained in prominence in urban planning (Levin-Keitel, 2014) and urban river rehabilitation projects and linear parks have multiplied (de Haan et al., 2015; Deason et al., 2010) through Low Impact Development (LID) Best Management Practices (BMPs) such as infiltration basins, grass swales and green

roofs, which manage stormwater runoff quantity and quality as close as possible to the source and reduce impacts on downstream receiving rivers (Jia et al., 2013). However, such projects are usually municipal projects and rarely extend beyond city boundaries.

While IUWM emphasises urban-rural relationships (Bahri, 2012), it does not transfer responsibilities for UWM to the basin scale. Overall, responsibilities often remain unclear, fragmented and overlapping, leading to tensions between professionals and politicians with different values and views (OECD, 2016; Brown, 2008). Meanwhile, MWM integrates the basin dimension technocratically for infrastructural needs, such as inter-basin water transfers or dam projects (Chelleri et al., 2015; Martínez et al., 2015).

### 4.2. Users

#### 4.2.1. IRBM

IWRM/IRBM considers all users and economic interests within a river basin, including domestic, agricultural, industrial and recreational users (Savenije and van der Zaag, 2008; Snellen and Schrevel, 2004). The agricultural sector is the largest user of water resources in most countries, followed by the energy sector (i.e. hydropower), making the water/food/energy nexus crucial for integrated water management, particularly in the context of climate change (OECD, 2016; Biswas, 2008). Domestic and recreational users represent a relatively small portion of total water use.

IWRM/IRBM strives for a fair allocation of water resources among upstream and downstream users, between current and future generations, and for both human and ecosystem needs (Harrington et al., 2009; Molle and Mamanpoush, 2012; Molle, 2009b). In river basins with low population densities, ecosystems such as grasslands or woodlands may be major water users (Harrington et al., 2009). However, in heavily urbanized basins, water resources allocation can be a source of competition and conflict between urban and rural users (OECD, 2016; Molle and Mamanpoush, 2012; Butterworth et al., 2010). Downstream users are particularly vulnerable to variations in the water regime occurring in upstream areas (Molle, 2009b). Users differ in their access to natural or financial resources and in their political power (Molle, 2009b; Molle et al., 2007; Swyngedouw and Kaïka, 2002). Effective and legitimate norms and instruments for water allocation among users are therefore crucial in heavily urbanized basins, but are often lacking, especially in cases with large informal economies (OECD, 2016; Butterworth et al., 2010; Watson, 2004).

#### 4.2.2. UWM

UWM considers all city users, sometimes including informal users, such as residents of informal settlements, particularly where legal frameworks for water management have incorporated principles such as the human right to water (i.e. South Africa). However, in other cities, providers only serve registered consumers, as is the case of Hyderabad in India (Nastar, 2014) despite the growing recognition of the human right to water globally and in India (Obani and Gupta, 2015).

While SUWM/IUWM highlight the need to consider upstream and downstream users, and non-urban users (GTT, 2014; Closas et al., 2012; Gabe et al., 2009), no specific instruments or arrangements are promoted to implement equitable water allocation among all users within a river basin. Additionally, SUWM/IUWM is increasingly considering ecosystems as water users, for instance through efforts to maintain the minimum ecological water requirement (EWR) (Jia et al., 2011), but in rapidly growing metropolises this creates tensions due to the need to provide housing and water and sanitation services (Brandeler et al., 2014).

### 4.3. Demand VS supply

#### 4.3.1. IRBM

IWRM/IRBM aim to incorporate supply and demand management (Butterworth et al., 2010). Water demand is partly managed by water rights and concession titles, which consider water availability and priority of uses (Butterworth et al., 2010). As water resources fluctuate between wet and dry seasons and demand varies according to peak demands, cropping patterns, etc. adequate planning and management of both supply and demand is crucial (Savenije and van der Zaag, 2008).

River basins vary from perennial to seasonal with implications for water availability. When basins become heavily urbanized, appropriate supply and demand management is required. However, when demand exceeds supply, surface and groundwater resources become over-exploited and contaminated and development prospects are affected (Barrios et al., 2009; Tortajada, 2008).

#### 4.3.2. UWM

UWM has generally managed supply (Kayaga et al., 2007) emphasizing economies of scale, cost recovery, and access to affordable, safe drinking water (OECD, 2015; Brown, 2008). In Western countries, abundant water and the single-use water modality led to treated water being indiscriminately used for all purposes (GTT, 2014; Kayaga et al., 2007; Younos, 2011), resulting in underuse of recycling and reuse technologies (Pataki et al., 2011; Brown, 2008). Outdated urban infrastructure also lead to water losses and health risks (GTT, 2014; Kallis and Coccossis, 2002; Vlachos and Braga, 2001).

While the supply-centric model dominates, the literature argues that this approach is unsustainable and costly (McDonald et al., 2011; Kallis and Coccossis, 2002; Pataki et al., 2011). IUWM/SUWM recognize that different urban water uses (i.e. urban agriculture, industry and the environment) have different supply quality need and an appropriate match is needed (GTT, 2014; Brown and Farrelly, 2009) while also targeting users' attitudes (by information, pricing, etc.) (Kallis and Coccossis, 2002). Large metropolises like London incorporate investment and ecological costs within equitable water tariffs combining cost-recovery with cross-subsidization (Ibid).

Demand management and reuse may eliminate the need for new sources and reduce energy use and sewage volume (Closas et al., 2012); but implementation is slow due to institutional barriers, such as uncoordinated institutional frameworks, insufficient resources (capital and human), technological path dependencies and the risk of stranded assets (Brown and Farrelly, 2009).

## 5. Inputs: water sources

### 5.1. IRBM

Holistic IWRM/IRBM incorporate all basin water sources (including rainwater and snowmelt) as it considers the hydrological cycle as a unitary whole (Harrington et al., 2009; Savenije and van der Zaag, 2008). It calls for awareness of the interactions of different types of water (blue water, green water, grey water, etc.) for equitable use and distribution of costs and benefits (Savenije and van der Zaag, 2008).

The focus has, however, largely been on “blue water” (i.e. surface and groundwater), often ignoring “grey water” (i.e. water after basic treatment), and “green water” (i.e. water in the unsaturated zone of the soil and plants which has critical ecosystem services, and is sensitive to land degradation) (Hayat and Gupta, 2016; Molle and Mamanpoush, 2012; UNEP, 2012).

### 5.2. UWM

UWM relies on bulk water supply from surface and groundwater from within or beyond the basin, treating these rivers as never-ending sources of water (GTT, 2014), exhausting them and then turning to dams and inter-basin water transfers (OECD, 2015; Richter et al., 2013). Megacities such as Los Angeles, Mexico City and São Paulo import water from sources beyond their watersheds and struggle to maintain a reliable flow (OECD, 2015; van den Brandeler et al., 2014; Barrios et al., 2009).

IUWM/SUWM promote the use of alternative sources to blue water through decentralized infrastructure and technologies, such as rainwater harvesting systems and stormwater treatment, which can support aquifers, waterways and vegetation (GTT, 2014; Marlow et al., 2013). However, such initiatives remain scattered and limited. Land use regulation and preserving catchment areas is needed but less emphasized than in the IWRM/IRBM literature (Closas et al., 2012; Bahri, 2012).

## 6. Outputs: wastewater

### 6.1. IRBM

IWRM/IRBM call for adequate wastewater management to protect water resources and ecosystem services through collecting and treating wastewater before discharge, wastewater recycling, and waterway restoration (Martínez-Santos et al., 2014). This may involve (de)centralized infrastructure, but also regulating and reducing diffuse pollution, most of which derives from agricultural activities, (Xepapadeas, 2011).

### 6.2. UWM

Conventional UWM has encouraged the transport and discharge of wastewater beyond city borders; protecting urban health, while ignoring environmental sustainability, population growth, urbanization, industrialization and climate change (Makropoulos et al., 2008; Kayaga et al. 2007). IUWM/SUWM links wastewater to the urban water cycle through infrastructural and institutional integration by seeing wastewater as an opportunity for reuse in industrial activities, urban irrigation and groundwater recharge (GTT, 2014; Closas et al., 2012; Jia et al., 2005).

However, combined sewers continue to affect human health and ecosystems (Porse, 2013), especially in megacities which concentrate humans and polluting activities. Often, the priority is only providing drinking water. Moreover, IUWM/SUWM can mainly be applied in formal settlements, and its approach to informal settlements focuses on the need for land use management and land tenure (Porse, 2013).

## 7. Extreme weather events

### 7.1. IWRM/IRBM

IWRM/IRBM's holistic approach should, in theory, include concerns related to extreme weather events, such as flooding and landslides. However, only 64 publications (out of 479) between 1988 and 2015<sup>5</sup> covered these issues, revealing a focus on the competitive uses of water rather than on water as a hazard.

Academic and policy research on IWRM/IRBM increasingly reflect concerns about climate change and its potential effects on the basin (Barrios et al., 2009). While the literature emphasizes

<sup>5</sup> These terms included “flood\*” OR “landslide” OR “hazard” OR “extreme weather” OR “risk management” OR “risk reduction”.

the urgency to link IWRM/IRBM and Adaptive Management (AM) (Hurlbert and Gupta, 2016), AM is often developed at the municipal level, where actors responsible for disaster management are located. Moreover, though both emphasize multi-stakeholder participation and knowledge sharing (Medema et al., 2008), climate change may require proactive responses that are incompatible with IRBM's more reactive approach.

## 7.2. UWM

Regarding water-related extreme weather events, UWM focuses on stormwater management, promoting centralized, structural approaches to swiftly remove rainwater through drains and sewers and expel it beyond city boundaries (Porse, 2013; Makropoulos et al., 2008). This approach of many municipal authorities has created dependence on hard infrastructure, with cities with fewer financial and human resources more vulnerable to extreme weather events. In the context of climate variability and change, cities risk being more frequently and intensively exposed to heavy precipitations and floods or drought (Jha et al., 2012).

IUWM/SUWM advocate hybrid systems to reduce runoff and pollution (e.g. through infiltration by green infrastructure, pollution abatement, or urban landscape improvements) (Porse, 2013). Urban water programmes that incorporate principles of mitigation and adaptation are multiplying (Bahri, 2012). However, the Adaptive Management (AM) literature gives more emphasis to developing adaptive capacity to cope with uncertain climate impacts (Medema et al., 2008). Empirical cases discussing IUWM implementation show that aspects such as climate change impact assessment on water resources and flood risk and climate proofing urban infrastructure are lacking (Nascimento et al., 2008).

## 8. Analysis and conclusions

The literature on water resources management and urban water management has undergone a paradigm shift within academic and policy circles towards incorporating concerns about integration and sustainable development. Table 1 synthesises and compares IWRM/IRBM and IUWM/SUWM. Their overarching frameworks

have moved closer towards each other, as they have evolved to share many similar goals, approaches and institutional settings, emphasizing human and ecosystem relations, coordinated management across sectors and scales, decentralized and alternative infrastructure, knowledge sharing, etc. The convergence of both frameworks reflects their shift towards more networked governance, at least on paper if not in practice. Climate change-related water risks for urban areas have highlighted the urgency of bringing these frameworks together, optimizing the interface between urban water and activities beyond the urban boundaries for a more coherent and effective approach. A key issue for both frameworks remains the integration of adaptive capacity concerns and, particularly, shifting towards proactive planning. For this, IWRM/IRBM and IUWM/SUWM should focus more extensively on learning, leadership, multiple approaches, redundancy, autonomous ability to respond and fair governance.

Yet, significant differences remain between IWRM/IRBM and IUWM/SUWM in terms of scope, mandates, users and supply/demand management are strongly linked to the scale of implementation. Differences in how they address inputs, outputs and extreme weather events are also linked to issues of scale. For instance, addressing floods is a greater priority in urban areas, while ecosystem preservation is typically conducted beyond city boundaries, and thus beyond cities' competence. Therefore, while in theory both IWRM/IRBM and IUWM/SUWM claim to consider the river basin as a whole, in practice IUWM/SUWM have limited influence beyond political-administrative boundaries, while IRBM has little influence within cities.

As cities use water, urban water management should be part of basin management. While publications on IWRM and IRBM included terms related to the urban scale in only 14% and 10% of texts respectively (see Fig. 2), over half were published since 2010 (see Annex C), indicating a growing interest in urban issues. While the mismatch between hydrological and political-administrative borders implies that including river basin management into IUWM/SUWM may be virtually impossible, the IUWM literature seems to give greater attention to the basin scale. This may indicate a rising scholarly interest in bridging the urban/river basin nexus.

**Table 1**  
Comparing the main characteristics of IWRM/IRBM and IUWM/SUWM.

Main characteristics	IWRM/IRBM	IUWM/SUWM
(1) Overarching framework	Goals	-Integration/holistic-Sustainable development/ecosystem approach-Multi-objective
	Approach	-Hard and soft infrastructure-Multi-stakeholder (ie. experts, planners, biologists, community representatives)-Working with nature/ecosystem approach
	Organizational	-Decentralized-Participatory decision making-River basin as unit
(2) Scope	Mandates	-Everything, including services, but maybe less attention to industry and people, and less on water-related risks
	Users	-All users within a river basin. A significant percentage are farmers ( $\pm 70\%$ ). Then industrial, and then urban/domestic
	Demand VS Supply	-Both supply and demand
(3) Inputs (water sources)	-All sources within the basin (including rainwater)	-Bulk water supply (surface or groundwater)-Alternative sources
(4) Outputs (wastewater)	-Importance of wastewater collection and treatment for protecting ecosystem services	-Part of urban water cycle (also as an opportunity)
(5) Extreme weather events (flooding, drought, etc.)	-Not a primary concern in traditional IRBM-Increasing inclusion of CC concerns-Approximation to Adaptive Management, but deliberative/participatory forums may be unequipped for dealing with rapid changes	-Focus on stormwater management-Hybridized systems-Increasing inclusion of CC concerns and adaptation

Integrating IWRM/IRBM and IUWM/SUWM is critical for their successful implementation and is urgently needed, not least in the context of the challenges faced by megacities (Barraqué and Zandaryaa, 2011; Maheepala, 2010). However, existing literature on megacities mainly focuses on the size and scope of water-related challenges (GTT, 2014) but not on how IWRM/IRBM or IUWM/SUWM apply to multi-jurisdictional conurbations (OECD, 2016). Metropolitan regions have an added layer of complexity as they usually have numerous mayors primarily concerned with their constituents' best interests, yet collectively affect the basin through their urban water policies. While there is no silver bullet, strengthening coordination mechanisms between local governments on issues such as the protection of catchment areas, bulk water resource allocation and macro-drainage across the metropolis and its rural hinterlands is urgently needed, particularly in the Global South. As megacities both affect and are affected by local and regional hydrological systems it is crucial that IWRM/IRBM and SUWM/IUWM become better integrated and take into consideration the additional complexity of megacities and the challenges regarding how the financing of water governance systems should be managed and shared.

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### Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at <https://doi.org/10.1016/j.jhydrol.2018.01.001>.

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