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Green infrastructure for sustainable urban water management: Practices of five forerunner cities

Liu Li*, Jensen Marina Bergen

[a] Department of Geosciences and Natural Resource Management, University of Copenhagen, Rolighedsvej 23, 1958 Frederiksberg, Denmark
[b] Sino-Danish Center for Education & Research, Niels Jensens Vej 2, Building 1190, 8000 Aarhus C, Denmark

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ABSTRACT

In the search for both immediate solutions and long-term transitions towards sustainability, green infrastructures (GI) are increasingly linked to urban water management. In this study, the GI-based urban water management practices of five cities famous for their progressive approach to water management were investigated. Based on reviews of open-source city plans and strategies, supplemented with information obtained directly from city managers, the purpose was to share best practices for the transition to sustainable urban water management and to gain insight into the role, if any, of GI in urban water management. An analytical frame based on transition theory was adopted. All five cities represented states of transition at the near end of a sustainable urban water management scale. Despite some overlap in challenges concerning water supply, environmental protection, and flood risk management, the development target of each city was unique, as were their solutions. GI has been applied as a way to reduce water footprints in Singapore and Berlin, to protect the environment in Philadelphia, and to help save potable water for consumption in Melbourne and Sino-Singapore Tianjin Eco-city. Despite differences in scale, GI was, in all cases, applied as a supplement to the conventional water infrastructure. All five cities reveal a strong top-down approach towards sustainable urban water management and a strong mindset on GI's role for future development. However, all five cities point to similar challenges for GI implementation, including space and cost constrains as well as barriers for inter-sectorial and stakeholder collaboration, which limit the speed of city-wide upscaling of GI solutions and full realization of GI benefits. The study indicates a need for a simultaneous change in the cognitive, normative, and regulative conditions of the urban water management regime for sustainability transition. Such a change requires a better balance between top-down and bottom-up planning to overcome barriers and foster innovation. The five cities jointly contribute to a noteworthy list of green solutions, city-wide strategies and guidelines, pilot project programs, regulations, and incentive programs, which may serve as inspiration for other cities' transition plans.

1. Introduction

Cities are simultaneously critical hot spots adding to the environmental and climatic challenges facing today's global society and essential drivers of future solutions (Grimm et al., 2008). According to Haughton (1997), a pursuit for sustainability of cities is a balancing act between cities and their environmental hinterlands, coined as the "fair shares city," with equitably balanced needs and rights through regulated flows of environmental value and compensatory systems. This is also the general goal of a sustainable city, which is a city designed with consideration towards balanced resource consumption and minimal environmental impact, inhabited by people with environmentally-friendly lifestyles and social equity (Moore, Miller, & Campbell, 2013; United Nations, 1987).

In the case of management of the freshwater resource, cities play a significant role, as they may impact both water quantity and quality through land-use change, overexploitation, and contamination (Jia, Yao, & Yu, 2013; Marsalek et al., 2006; SWITCH, 2012). To achieve sustainable urban water management (SUWM), Wong and Brown (2009) suggested that cities need to give water due prominence in urban development through an integration of the urban design process with other disciplines responsible for provision of water services; cities also need to develop social-political capital for interacting with water. Future urban landscapes need to capture opportunities and technologies to maintain the cities' resilience towards the impacts of climate change, which have already created uncertainties regarding urban water supplies and weather extremes. Future planning should also address the need to provide ecosystem services that protect downstream

* Corresponding author.
E-mail addresses: liu@ign.ku.dk (L. Liu), mbj@ign.ku.dk (M.B. Jensen).

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aquatic environments and other ecological habitats from these impacts, reversing the conventional philosophy of urban communities drawing on ecosystem services of upstream and downstream neighbors. Thus, urban landscapes must, beyond providing spatial amenities, have ecological functions that facilitate hydrological processes such as evaporation, transpiration, infiltration and detention (Wong & Brown, 2009).

The emerging tendency in developed cities to resort to urban landscaping to accommodate UWM is represented by various terms such as sustainable urban drainage systems (SUDS), low impact development (LID), water sensitive urban design (WSUD), and sponge city (Fletcher et al., 2015; Jia et al., 2013; Jia, Wang, Zhen, Clar, & Yu, 2017; MOHURD, 2014; Ren, Wang, Wang, Huang, & Wang, 2017). The common philosophy behind these terms is the use of the urban landscape for transforming the linear character of the conventional urban water management into a more cyclic approach where water supply, drainage, and ecosystems are treated as part of the same system, mimicking more natural water flows. The part of the urban landscape providing ecosystem services is often referred to as green infrastructure (GI), defined as "an interconnected network of natural areas and other open spaces that conserves natural ecosystem values and functions… and provides a wide array of benefits for people and wildlife" (Benedict & McMahon, 2006).

Numerous studies have focused on optimizing the role of GI for ecosystem services, not least UWM (Ahern, 2007; Ahern, Cilliers, & Niemelä, 2014; Pauleit, Liu, Ahern, & Kazmierczak, 2011; Young, Zanders, Lieberknecht, & Fassman-Beck, 2014). Planning multi-functional urban GI is one of the shared recommendations as a way forward. Recent studies, have an increasing focus on GI contributing to climate change adaptation, where flood control or broadly UWM is a key issue (Fryd, Pauleit, & Bühler, 2011; Gill, Handley, Ennos, & Pauleit, 2007; Lennon, Scott, & O'Neill, 2014; Sussams, Sheate, & Eales, 2015). With the increasing interests and investments of cities on GI solutions to UWM, a pragmatic approach, in line with planning for multi-functional urban GI, is to combine UWM goals with other GI's co-benefits (Lennon et al., 2014). UWM by GI may provide several key improvements in the building of sustainable cities (Liu & Jensen, 2017), including improved urban drainage, improved quality of discharge, reduced water footprint, increased livability and social-economic sustainability, increased biodiversity and ecological performance, and increased conservation of regional ecosystems. Most discussion focuses on argumentation of GI as an approach for achieving various benefits (e.g. Lennon et al., 2014), documenting evidences in specific locations (e.g. Gill et al., 2007), or developing planning or governance tools (e.g. Ahern et al., 2014; Sussams et al., 2015). A few studies attempt to search for quantitative guidance (e.g. how much GI is needed to support UWM goals) and apply it in planning practice. For example, Jia, Ma, and Wei (2011) proposed to allocate 3.13% of total land area of Beijing central region for various types of wetland (water purification wetland, flood control wetlands and cultural and scenic wetlands) for achieving a livable city and estimated ecological water demand to maintain these wetlands.

A socio-technical perspective, like the Multi-Level Perspective (MLP), can be helpful in understanding the transition process of the large urban water management system towards a more sustainable condition (Geels, 2011; Geels & Schot, 2007; Mguni, 2015). MLP operates with three levels. The *landscape* is the 'macro-level' and refers to the environmental, social-political, and economic pressures acting on the system; in the current context, these pressures would be climate change, urbanization, and public requests for increased livability. The *regime* is the 'meso-level,' referring to the configuration of responsible institutions and the physical infrastructure for which they are responsible; in this context, the meso-level includes the water authorities and utilities, and all the pipes, pumps, treatment plants, storage facilities, etc. making up the water systems. The regime operates according to its sanctioned discourse, which is controlled by the cognitive, normative, and regulative conditions, or 'pillars,' sustaining the regime. The *niche* is the 'micro-level,' encompassing innovations and alternative approaches, including the GI-based approach (Mguni, Herslund, & Jensen, 2015). For a niche approach based on GI to become the new sanctioned discourse in a transition towards SUWM, shifts in the practice within each of the three pillars are necessary (Brown, Keath, & Wong, 2009; Scott, 1995). The relation between the regime and the rest of society is, in the case of UWM, referred to as the 'hydro-social contract' (Lundqvist & Turton, 2001), representing the pervading values and expectations on how water should be managed, which has typically been shaped throughout the history of the city.

For better describing the level of transition of cities towards SUWM, Brown et al. (2009) propose a framework based on research on the historical development of the hydro-social contracts of Austrian cities, which includes six states of progression: water supply city, sewered city, drained city, waterways city, water cycle city, and water sensitive city. The first three states refer to a transition path already completed in most developed cities, while the last three states represent the desired transition path towards SUWM. A waterways city integrates water as an important aesthetic and recreational feature; eco-technologies and measures are therefore necessary to protect receiving waterways from diffuse-source stormwater pollution. A water cycle city links environmental protection, water supply security, public health protection, and flood control. A water sensitive city includes intergenerational equity, ecological integrity, and climate change resilience. Although direct comparison between cities is difficult, and perhaps irrelevant due to differences in hydro-social contracts and MLP-landscape pressures, the framework offers an opportunity to learn from a multiple-cities' view.

The aim of this study was to shed light on the potential role of GI for releasing the current pressures on urban water management systems, as well as to share best practices for UWM. The study was based on information collected from a handful of cities internationally renowned for their progressive approach to UWM, providing insight into the roles and detailed solutions of GI in UWM, as well as listing anticipated barriers for GI implementation.

2. Method

Potential case cities were listed from open sources, recommendations form experts at international conferences and personal networks. Selection criteria were high credibility on sustainability and urban water management, and the identified cities were Philadelphia, San Francisco, Portland, Vancouver, Berlin, Hamburg, Freiburg, Copenhagen, Bristol, Brussel, Stockholm, Melbourne, Singapore, Sino-Singapore Tianjin Eco-city, Masdar City, Songdo International Business District, as described further in Supplementary Material 1. After a preliminary review from open sources and literature, four existing cities – the city-state Singapore, Berlin in Germany, City of Melbourne in Australia (henceforth referred to as Melbourne), City of Philadelphia in the US (henceforth referred to as Philadelphia) – and one newly built city– Sino-Singapore Tianjin Eco-city in China (henceforth referred to as Tianjin Eco-city) – were selected as case cities. These cities represent a broad geographical distribution, are renowned for their commitment to SUWM, and data were accessible. Singapore and Berlin are internationally renowned for their water supply system. Melbourne is renowned for its Water Sensitive Urban Design strategy. Philadelphia was recommended by experts from Portland as the forerunner city in USA, working on top of results already obtained by other forerunners like Portland and Seattle. Sino-Singapore Tianjin Eco-city was selected because of its all-round ambition on striving for sustainability, including UWM. Table 1 presents an introductory overview of the five cities and their characteristics as cases.

Data were collected from open sources, including the case cities' official websites, published plans, documents, and articles. For validation of data and collection of updated material, an online questionnaire was conducted with relevant city managers of each city during the Spring and Summer 2015 (Supplementary Material 2); questionnaires

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