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RESEARCH ARTICLE

# The socio-ecological practice of building blue-green infrastructure in high-density cities: what does the ABC Waters Program in Singapore tell us?

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**Abstract**
Blue-green infrastructure (BGI) is the network of green spaces that provides multiple water-related ecosystem services. This article explores the Active, Beautiful, Clean (ABC) Waters Program as a socio-ecological practice that builds BGI for the high-density city-state of Singapore. Launched in 2006, the ABC Waters Program aims to simultaneously improve the recreational value, physical appearance, and water quality of all waters in Singapore through 2030. Driven by the quest for water security and the pursuit of a higher quality of life, the program involves sustainable stormwater management and waterway enhancement to enrich the functions of the existing aquatic and terrestrial green spaces. The ABC Waters Program provides valuable lessons for other high-density cities to overcome land scarcity as a constraint on BGI. With a shortage of green spaces, high-density cities should strive to optimize the existing green spaces in the provision of ecosystem services and to leverage cultural ecosystem services to engage citizens and gain public support. The case study on the ABC Waters Program also reveals a research gap in the socio-ecological practice research on BGI planning and design. The fundamental question of what qualifies as BGI has yet to be answered, and it is rarely discussed to what degree urban waterways can be considered BGI.

**Keywords** ABC Waters Program · Blue-green infrastructure · Green infrastructure · Waterway enhancement · Singapore · Socio-ecological practice · Sustainable stormwater management · Urban ecosystem services · Urban water management

## 1 Introduction

Socio-ecological practice is conceptualized by Xiang (2019, p. 1) as “the human action and social process that take place in specific socio-ecological context to bring about a secure, harmonious, and sustainable socio-ecological condition serving human beings’ need for survival, development, and flourishing.” It has been an evolving enterprise in the profession of planning and design, from McHarg’s (1969) notion of “design with nature”—that environmentally sensitive areas should be protected from development—in the early days to the explicit linkage between ecosystem and human health today through the notion of ecosystem services (e.g., Coutts and Hahn 2015; Tzoulas et al. 2007). Socio-ecological practice explicitly considers ecological principles and incorporates ecosystem functions for human wellbeing. The role of human wellbeing needs to be emphasized in socio-ecological practice for it to be widely embraced in urban design and planning.

Natural systems in the city used to be seen as either troublesome or merely decorative. The recent recognition of their importance to urbanism has brought increasing attention to the concept of green infrastructure (GI). The most cited definition of GI is “an interconnected network of green space that conserves natural ecosystem values and functions and provides associated benefits to human populations” (Benedict and McMahon 2002, p. 12). While the concept has been further elaborated and various definitions emerged (e.g., Austin 2014, p. 4; Rouse and Bunster-Ossa 2013, p. 11), the essence of GI has been the interrelationship between green spaces, ecosystem functions, and human wellbeing. In the urban context, GI can be understood as the network of green spaces that provide multiple ecosystem services

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for human wellbeing. GI planning and design is a socio-ecological practice key to urban sustainability and resilience.

Urban green spaces are known to provide ecosystem services (Bolund and Hunhammar 1999). In reality, the degrees to which urban green spaces provide ecosystem services vary vastly, and most of the existing urban green spaces were designed only for recreation. The socio-ecological practice of GI planning and design requires explicit consideration of ecosystem functions to support a much wider array of ecosystem services. Deliberate efforts are needed to enhance the ecosystem services of urban green spaces, including parks, stream and river corridors, planting strips, etc., to transform them into genuine *infrastructure* or what Benedict and McMahon (2002) call "life support system" (p. 12), without which urbanism would be compromised.

This article focuses on a particular type of GI—blue-green infrastructure (BGI), defined here as the network of green spaces that provides multiple water-related ecosystem services, such as water supply, water quality treatment, flood hazard mitigation, and water-based recreation (see Haase 2015, p. 5; Liao et al. 2017, p. 204). BGI comprises aquatic green spaces, e.g., rivers, streams, canals, ponds, wetlands, and reservoirs; as well as terrestrial green spaces that are purposefully designed for stormwater management, e.g., rain gardens, bioswales, and green roof. Managing waterbodies and stormwater runoff is an important part of urban water management, which traditionally is isolated from urban planning and design and other urban functions (Lundy and Wade 2011, p. 653). Conventional urban water management has been preoccupied with large-scale, capital-intensive engineering solutions that are often single functional; for example, storm drains function only for stormwater conveyance and levees only for flood prevention. BGI focuses on decentralized, nature-based solutions that are often multi-functional; for example, rain gardens can function for not only stormwater quality treatment, but also flood mitigation and environmental education.

While BGI is a relatively new term, the utilization of water-related ecosystem services is not new. Floodplain restoration has been a measure to flood mitigation, constructed wetlands have been used to treat domestic graywater, and nature-based solutions have been promoted for stormwater management. Most of the relevant literature are based on the Western contexts, where urban densities are relatively low. However, the provision of BGI in high-density city can be more challenging because of limited and even declining green spaces to begin with (see Jim 2004, p. 312). While high-density cities can benefit from the knowledge generated in the West, socio-ecological practice research within the high-density context could provide insights into how to overcome density-related challenges.

The city-state of Singapore—with a population density of 7804 persons per square kilometer[1]—is among the most crowded cities in the world. In 2006, Singapore's national water agency, the Public Utilities Board (PUB), launched the Active, Beautiful, Clean (ABC) Waters Program with an ambition to simultaneously improve the recreational value, physical appearance, and water quality of all waters in Singapore through 2030. It is a holistic water management program, addressing both waterbodies and stormwater runoff in the catchment. Although neither GI, BGI, nor ecosystem services are mentioned, the ABC Waters Program exemplifies a shift from gray infrastructure to BGI in urban water management, showcasing a BGI-building program for a high-density city. Despite the ABC Waters Program has been carried out for more than a decade and has received several international awards, its literature remains limited to the technical aspects of stormwater management (e.g., Goh et al. 2017; Quek et al. 2015). Lim and Lu (2016) provide a comprehensive review of the program, but only as a stormwater management program. Complementing the existing literature, this article examines the ABC Waters Program as a socio-ecological practice, which builds BGI for Singapore through retrofitting the existing terrestrial and aquatic green spaces. The objective is to gain insights into how high-density cities could build BGI with limited green spaces and to identify the research gap in BGI planning and design as a socio-ecological practice.

The case study on ABC Waters Program relies heavily on relevant policy documents and scholarly literature, as well as face-to-face interviews and email correspondence in 2013 and 2015. The interviewees include three high-ranking officials and four senior members at PUB, who were heavily involved in the program; a high-ranking official at another public agency, who used to lead PUB when the program was launched; and two members of a river-related local NGO. In the remainder of this article, the ABC Waters Program is first introduced, and then, two key lessons for other high-density cities are drawn. Finally, I discuss a research gap in BGI planning and design as a socio-ecological practice.

## 2 The ABC Waters Program

In the past decades, Singapore's surface water management—a responsibility of PUB—focused solely on efficient drainage for flood control and water collection for water supply. Except for the very few in nature preserves,

[1] Department of Singapore Statistics. https://www.singstat.gov.sg/find-data/search-by-theme/population/population-and-population-structure/latest-data. Accessed on September 29, 2018.

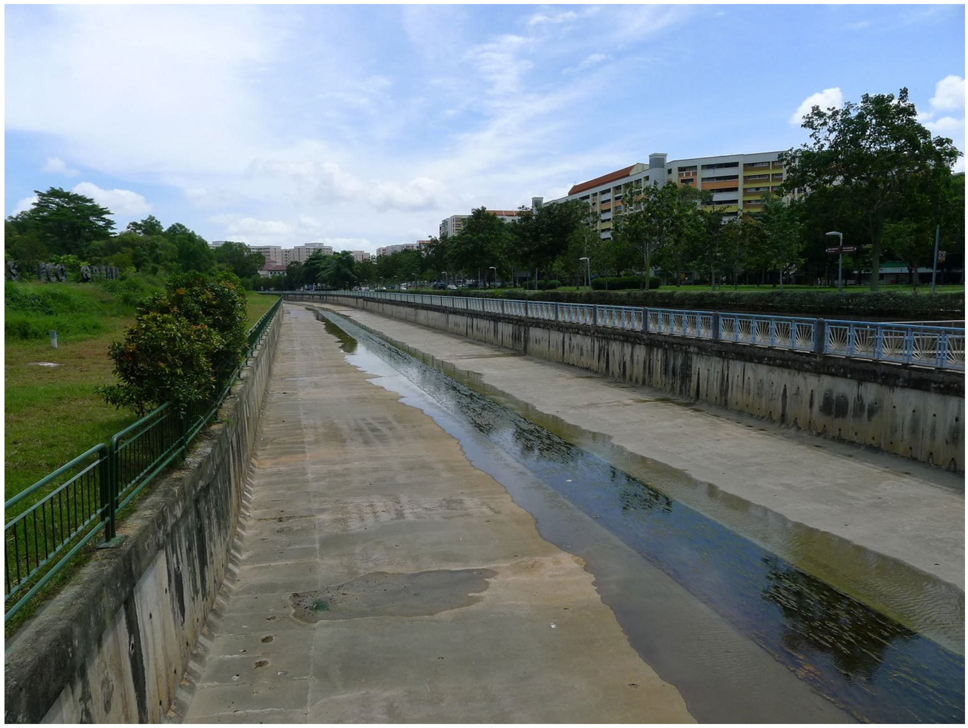

**Fig. 1** A typical channelized river in Singapore

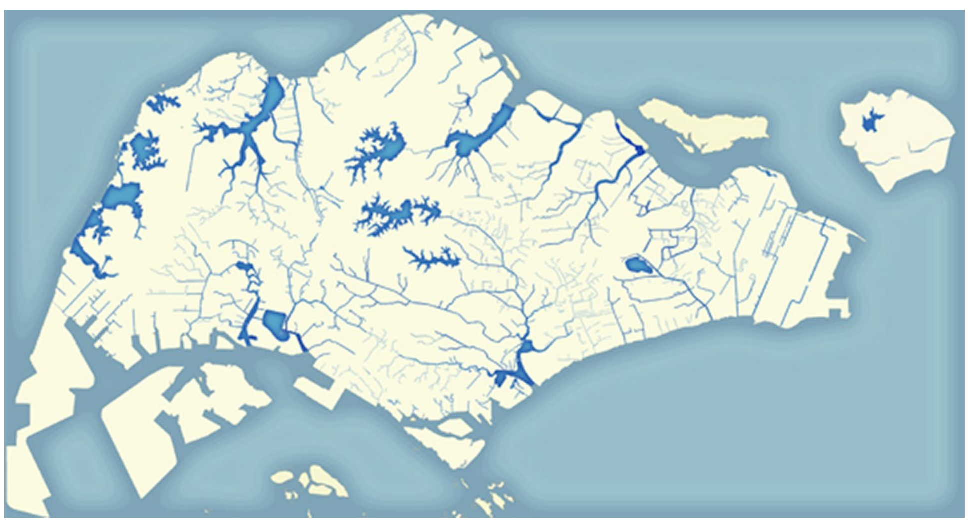

**Fig. 2** The water network of Singapore. There are 17 reservoirs, 32 major rivers, 990 km of drains and canals, and 7000 km of roadside drains in Singapore. (*Source and image credit*: PUB)

all rivers and streams in Singapore have been heavily channelized (Fig. 1), with several rivers dammed at the mouths to create reservoirs. Stormwater runoff is managed by a dense network of open and subsurface storm drains. Currently, Singapore has 17 reservoirs and more than 8000 km of concretized rivers, canals, and drains (Fig. 2). The ABC Waters Program emerged out of this backdrop of a highly utilitarian, tightly controlled, and aesthetically unappealing water network.

## 2.1 Objectives

Although Singapore's water network is part of the urban landscape, it is largely external to the everyday life of people. The ABC Waters Program is to "harness the full potential" of the existing water network to enhance urban livability (PUB 2018, p. 3). It aspires to bring people closer to the water by seamlessly integrating the water into the surrounding environment to "create new community spaces

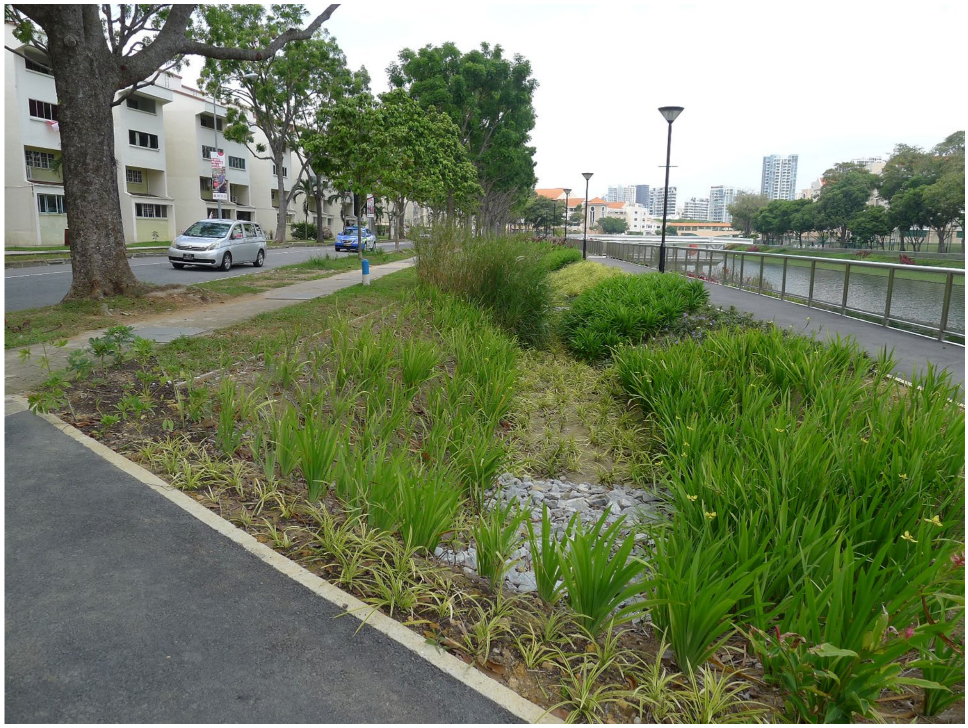

**Fig. 3** A bioretention swale near the Kallang River at Potong Pasir in Singapore

and to encourage lifestyle activities to flourish in and around the waters" (ibid., p. 4). It is expected that connecting people with the water would make the general public better appreciate the precious water resources and consequentially develop "a sense of stewardship toward water" (ibid.).

The name "Active, Beautiful, Clean" conveys the major objectives of the program. "Active" denotes the remaking of the existing waters into new community spaces for recreation; "beautiful" indicates the transformation of the concretized waterways into aesthetically pleasing features that are well integrated with greenery and the surrounding residential and commercial environment; and "clean" means the improvement in water quality (PUB 2018, pp. 66–68). In sum, the ABC Waters Program aims to improve the water quality of the rivers/canals and reservoirs, while also taking advantage of them to increase the livability of Singapore as a high-density city that still aspires to economic and population growth.

## 2.2 Technical components

The two targets—water quality and urban livability—of the program are addressed mainly by sustainable stormwater management and waterway enhancement.

### 2.2.1 Sustainable stormwater management

Drained directly into the receiving waterbodies, stormwater runoff is a major source of pollution in Singapore's water network. Following the sustainable stormwater management practices in the West, e.g., low-impact develop (LID) and sustainable urban drainage system (SUDS), and drawing particularly from Water Sensitive Urban Design (WSUD) in Australia, the ABC Waters Program deploys nature-based solutions to enhance the purification (sedimentation, filtration, and biological uptake), detention, retention, and infiltration functions of terrestrial green spaces to manage stormwater runoff at source before it reaches the rivers/canals and eventually the reservoirs. It is the first comprehensive sustainable stormwater management program in the tropics (Lim and Lu 2016, p. 842). Moreover, it precedes China's Sponge City initiative, launched in 2015, for almost a decade.

The nature-based stormwater facilities deployed in the program are called the ABC Waters design features, which are self-sustaining natural systems of plants and soils that require minimal maintenance (PUB 2018, p. 23, 32). Specifically promoted through the ABC Waters Design Guidelines (PUB 2018) are vegetated swales, bioretention swales (Fig. 3), bioretention basins (rain gardens), sedimentation basins (Fig. 4), constructed wetlands, and cleansing biotopes. Their functions are listed in Table 1. Floating wetlands and architectural elements (e.g., green roofs and green walls) are also used in the ABC Waters Program. A monitoring program that tracks the overall effectiveness of the program on water quality improvement does not exists, but some of the built ABC Waters design features were studied. They are in general effective in removing pollutants, and the removal efficiencies are consistent with those in the temperate region (Lim and Lu 2016, p. 856).

**Fig. 4** A sedimentation basin in Clementi, Singapore

**Table 1** The functions of the ABC Waters design features (PUB 2018, pp. 34–46)

| Design features | Functions |
|---|---|
| Vegetated swales | Similar to concrete drains, vegetated swales function to convey stormwater runoff. However, the flow velocity is lower in the vegetated swale, which can help prevent erosion of the downstream ABC Waters design features and the receiving waterbody. While water treatment is not its main function, a vegetated swale could still remove coarse sediment and act as a pretreatment mechanism for the downstream ABC Waters design features |
| Bioretention swales | Different from vegetated swales, bioretention swales are designed mainly to encourage biological uptake of nutrients by plants for water quality treatment |
| Bioretention basins (rain gardens) | Bioretention basins are to detain and treat stormwater runoff. They are similar to bioretention swales in that they filter stormwater runoff through the densely-planted surface. Bioretention basins are not designed to convey stormwater runoff |
| Sedimentation basins | Sedimentation basins function to temporarily retain stormwater runoff to facilitate sedimentation. They are designed to capture 70–90% of coarse to medium-sized sediment, also functioning as a pretreatment mechanism |
| Constructed wetlands | Constructed wetlands are used primarily to remove fine to colloidal particles and dissolved contaminants |
| Cleansing biotopes | Cleansing biotopes are a form of constructed wetlands. They consist of nutrient-poor substrates and are often designed to allow the treated water to circulate back to the biotope for further treatment |

To a lesser degree, the ABC Waters Program also addresses flood mitigation to cope with the increasing stormwater runoff associated increasing urban development and climate change through the "source-pathway-receptor" approach (PUB 2018, p. 9). It involves reducing stormwater runoff where it is generated (source); expanding the capacity of the rivers/canals and drains that convey stormwater runoff (pathway); and strengthening flood protection where stormwater runoff is collected and where it poses flood risk (receptor). Modeling studies show that integrating the ABC Waters design features into the existing green spaces and buildings could help achieve optimal hydrological improvements and restore predevelopment hydrology in Singapore (Lim and Lu 2016, p. 856).

### 2.2.2 Waterway enhancement

Waterway enhancement focuses on improving the aesthetics of and public access to Singapore's rivers and canals, which are largely considered a danger and fenced out. The most common measures include greening of the embankment and the waterfront area; adding amenities such as benches and look-put decks along the waterfront; building weirs to form a permanent pool of water; and using gabions or other soil bioengineering techniques to naturalize the embankment (Fig. 5; PUB 2018, pp. 49–50). The approach to waterway enhancement is arguably less progressive than stormwater management. While space

**Fig. 5** A waterway enhancement project at the Kallang River at Potong Pasir in Singapore. Several lookout decks were installed at the river bank to allow people to be closer to water. The river bank was made greener with lush and diversified vegetation to improve aesthetics

**Fig. 6** The Bishan-Ang Mo Kio Park, where the naturalized Kallang River is integrated with its surrounding terrestrial green space

limitation is a constraint, it is also because waterways are seen merely as "elements for stormwater conveyance and storage" (see PUB 2018, p. 47), not ecosystems. To be clear, the purpose of the ABC Waters Program is to transform the waters into "postcard-pretty community spaces" (PUB 2018, p. 3), not ecological restoration of the aquatic ecosystems.

The Bishan-Ang Mo Kio Park—the landmark project of the ABC Waters Program—is a major exception. It involves redesigning an existing park and naturalizing the section

**Fig. 7** The cleansing biotope at the Bishan-Ang Mo Kio Park

of the Kallang River along the park. The original 2.7-km concretized, straight channel has been transformed into a 3.2-km naturalized, meandering river, integrated with the surrounding terrestrial green space (Fig. 6). The heterogeneous geomorphology of the naturalized Kallang River—meander bends, varying channel width, rock beds, and vegetated banks—is an attempt to generate diverse flow patterns and provide a variety of wildlife habitats (Baur et al. 2012, p. 103). To assess the effect on biodiversity, an ecological survey (Tan 2013) was carried out to collect data on bird, butterfly, dragonfly, damselfly, and wildflower species before and after construction. It was also to prevent disturbance to areas with relatively rich biodiversity. It is claimed that biodiversity has increased in the park by 30% (Baur et al. 2012, p. 103).

The Bishan-Ang Mo Kio Park now resembles a natural river corridor, which entails not only the channel but also the closely interacting floodplain and riparian zone. It is also multifunctional: during low flows, people can enjoy the entire park and even step into the water; during high flows, most of the park functions to convey the flow downstream. Allowing the channel to spill onto the adjacent terrestrial green space significantly enlarges the flood carrying capacity of the Kallang River, and now the naturalized river corridor can safely convey a 1-in-25-year storm. The Bishan-Ang Mo Kio Park manifests a shift in flood mitigation from the conventional approach, which struggles to confine flows within the channel, to the new approach of "making more space for the river" (see Warner et al. 2013). The park also incorporates several ABC Waters design features, including the first cleansing biotope in Singapore (Fig. 7).

## 2.3 The 3P partnership approach

The ABC Waters Program does not merely concern the physical waters. PUB recognizes that achieving the most important objective of clean waters requires the public to share the responsibility of water resources protection. Nurturing a sense of stewardship among the public is also an aspiration of the program. PUB takes the "3P—people, public, private—partnership approach" to foster such stewardship by working with schools, grassroots organizations, community groups, and private companies to design educational programs about the ABC Waters concept (PUB 2018, pp. 60–63). For example, schools are encouraged to develop educational learning trails in and around the ABC Waters sites. Individuals and organizations are also encouraged to adopt and help mantain the ABC Waters sites.

## 2.4 The master planning approach

As an urban water management program, the ABC Waters Program is unusual because it involves a master planning approach. The ABC Waters Masterplan (PUB 2008) was developed to identify project sites and to guide project design. The master planning approach was to ensure that projects are not ad hoc, and that each project would integrate with the surrounding landscape to be multifunctional and readily accessible (Author's personal communication with PUB officials in 2013). In the masterplan, Singapore is divided into three planning units—the Central, Eastern, and Western Catchments. While each catchment has an individual plan with a different planning concept because of different social and physical traits, sustainable stormwater management is the overarching design principle across the board (Malone-Lee and Kushwaha 2009, p. 31).

The selection of project sites was a process of suitability assessment based on several criteria (Author's personal communication with PUB officials in 2013). The first is the potential for water quality improvement, concerning suitable site characteristics, e.g., topography, for installing the ABC Waters design features. The second is the potential for incorporating educational activities, concerning whether the site could be designed to showcase the ABC Waters design features to the public and whether the site can serve as an outdoor classroom for schools. The third is the potential for benefiting the community, concerning whether the site would be frequented by more people so as to benefit from the project. The fourth is ease of implementation, concerning the physical constraints of the site, e.g., existence of service pipelines, availability of space, and accessibility by public transit. The fifth is the potential for integrating with an existing park or a development project. A site is highly preferable, if it had been slated by PUB for upgrading its hydraulic capacity, of which the Bishan-Ang Mo Kio Park was the case; or if it involved a land development project, which provides an opportunity to better integrate the ABC Waters concept into it. The sixth is the potential for uniqueness, concerning whether the preexisting site characteristics could provide a unique identity for the future ABC Waters project; for example, if there existed a cultural heritage, the project could incorporate it to become more unique.

More than 100 projects throughout Singapore are identified in the ABC Waters Masterplan for implementation in phases through 2030. As of March 2018, more than 30 of them were completed (PUB 2018, p. 4). In addition, 75 projects—not identified in the masterplan—have received the ABC Waters Certification, which is awarded to projects that voluntarily incorporate the ABC Waters design features by other public agencies or private developers. In sum, there are already more than 100 projects that materialized the ABC Waters concept throughout Singapore.

## 2.5 Drivers of the program

Regardless of the effectiveness of the ABC Waters program on water quality improvement, the fact that it has entered the 13th year with more than 100 completed projects reflects sustained political will and public support behind it. To better appreciate the program's success in implementation, it is necessary to understand its two important drivers.

### 2.5.1 The quest for water security

The foremost important driver is Singapore's tenacious endeavor for water security. Water security has been a top priority in Singapore, dominating almost every facet of national development (Tan et al. 2009, p. xxiii). It began with the painful experiences of droughts between 1963 and 1964, after which Singapore started to invest heavily in water resource development (ibid., pp. 125–126). Singapore's reluctant independence from Malaysia in 1965 further underlined the importance of water security because Singapore had depended heavily on the water supply from Malaysia, which and this water supply could be terminated by Malaysia any time (Ong 2010, p. 67). It was recognized that diversifying the water sources is key to water security, hence the policy of "Four National Taps", which represents four different water sources (Khoo 2009, p. 239)—local reservoirs, imported water from Malaysia, reclaimed water or NEWater, and desalinated water. The Four National Taps policy links together water supply, stormwater management, and sewage treatment, making PUB responsible for the entire urban water management cycle of collection, production, distribution, treatment, and reclamation. Despite the rather successful water resource development, water security remains an issue because of Singapore's insatiate water demand associated with further economic and population growth (ibid., p. 246).

The most important national tap is the local reservoirs. Singapore's ~8000 km of concretized water network is essentially a water collection system to eventually deliver rainwater to the nation's 17 local reservoirs. The total water catchment area accounts for two-thirds of Singapore's land. It is possible for PUB to carry out such a large-scale water harvesting scheme because all streams of wastewater are treated, combined sewer overflow is not an issue because of separate sewers, treating urban stormwater for portable use is technically feasible, and PUB has the authority over the entire urban water management cycle (ibid., p. 75). However, stormwater runoff poses a major threat to the urban reservoirs in heavily populated areas, and increasing land development would worsen the problem (Yap et al. 2010, p. 4). For example, the Marina Reservoir is an urban reservoir located in the central business district and is also a world-famous tourist destination, but its catchment of 100 $km^2$ is the largest in Singapore. Water quality protection for and improvement in the local reservoirs is a daunting task, and hence, sustainable stormwater management is a major component in the ABC Waters Program.

### 2.5.2 The pursuit of higher quality of life

Another driver behind the ABC Waters Program is Singapore's continuous pursuit of higher quality of life in the small island to remain globally competitive. Singapore has long been taking advantage of ecosystem services to improve livability (Friess 2016, pp. 279–280). Its reputation as a green city can be attributed to a belief—promoted by Lee Kuan Yew, the nation's founding father—that such an environment would increase Singapore's competiveness to attract foreign investments to fuel economic growth. To increase the livability of the tropical city that is hot and humid throughout the year, Lee Kuan Yew introduced the vision of "Garden City" in 1963, which has led to lush greenery and ample green spaces throughout the city, functioning for esthetics, recreation, and microclimate regulation. Garden City, along with the more recent "City in a Garden" vision, concerns mainly terrestrial green spaces. The ABC Waters Program extends it by including the aquatic green spaces with the vision of "City of Gardens and Water".

In fact, the notion that clean waters can increase livability has already emerged before the ABC Waters Program, after the cleanup of the Singapore River (Malone-Lee and Kushwaha 2009, p. 20). With a goal of bringing aquatic life back to the heavily polluted river, the cleanup project began in 1977 and took 10 years to complete (Chou 1998, p. 134). The much cleaner Singapore River prompted intensive business and residential redevelopment along the waterfront, which is now a major tourist attraction in Singapore. The cleanup of the Singapore River was the start of the separation of drainage and sewer systems, subsequently enabling Singapore to carry out the large-scale water harvesting scheme mentioned earlier (Khoo 2009, p. 238). Furthermore, it led Singaporeans to strat to appreciate the environmental, social, and economic benefits of a clean waterway and inspired the notion that water can play an important role in urban livability (Malone-Lee and Kushwaha 2009, p. 20). In the following decades, several waterway enhancement projects were implemented to harness the recreational potentials of other waterways in Singapore (Malone-Lee and Kushwaha 2009, p. 20). The ABC Waters Program subsequently puts these otherwise isolated actions under a strategic umbrella (Yap et al. 2010, p. 4).

## 2.6 Overcoming the challenges

The ABC Waters Program has been a journey of learning by doing, involving various challenges ranging from the technical to the perceptional. For example, although sustainable stormwater management has been practiced in the West for some time, in 2006 it was still new to Singapore. There was a lack of technical knowledge and an industry of sustainable stormwater management. Developing the nature-based stormwater facilities that work in Singapore requires trial and error. Several pilot projects of different ABC Waters design features were implemented to experiment with the design parameters. To nurture knowledge and build a local industry, PUB launched the ABC Waters Professional Program in 2011 to provide courses for practitioners to learn how to design, construct, and maintain the ABC Waters design features. Later in 2013, PUB launched the ABC Waters Professional Registry, where qualified ABC Waters Professionals are listed (PUB 2018, pp. 71–72).

Like any new policy that involves new concepts and measures, the ABC Waters Program also met with public skepticism. For example, the nearby residents were worried that naturalizing the Kallang River would increase flood risk and mosquito population. It was also a concern that the ABC Waters design features would become mosquito breeding grounds. Mosquitos are a huge concern because dengue fever outbreak occurs in Singapore periodically. To overcome public skepticism, stakeholders were involved during the planning stage of the ABC Waters projects to address community concerns and needs. For example, it was communicated to the public that mosquito population could be controlled by providing habitats for species that pray on mosquito larvae such as dragon flies and by making the water flow constantly. While Singapore is not known for a culture of civic participation, PUB well understands that the ABC Waters Program will not succeed without public support (Author's personal communication with PUB officials in 2013).

## 2.7 Building BGI for Singapore

Unlike LID, SUDS, and WSUD, the ABC Waters Program does not merely concern sustainable stormwater management. It addresses all surface waters within the city to build BGI for Singapore. PUB communicated to the public that the ABC Waters design is not just "good to have" but is a "vital public good" (PUB 2018, p. 5). This notion resonates with the concept of BGI. According to Hansen and Pauleit (2014, p. 517), the ABC Waters Program can be considered a BGI program, albeit not a perfect one (Table 2). Under the program, waterways are no longer managed just for flood control and water supply, but also for recreation and aesthetics to enhance livability; stormwater runoff is no longer managed solely by concrete drains but also by natural processes. By so doing, the ABC Waters Program practically taps into ecosystem services, and it is to enhace ecosytem services of the existing green spaces, despite not mentioning the term. The ABC Waters design features enhance the ecosystem services of the terrestrial green spaces by introducing the regulating services of water quality treatment and to a lesser degree, flood mitigation; and the ABC Waters design features are argued to also enhance the aesthetics and biodiversity of the urban landscape (PUB 2018, p. 10). The waterway enhancement projects add the cultural ecosystem services of recreation and aesthetics to aquatic green spaces. The Bishan-Ang Mo Kio Park is particularly a good example of BGI, which delivers a wide range of ecosystem services, including recreation, aesthetics, flood mitigation, wildlife habitats, environmental education, etc. The ABC

**Table 2** Evaluation of the ABC Waters Program against BGI planning principles

| BGI planning principles (adapted from Hansen and Pauleit 2014, Table 1) | | ABC Water Program |
|---|---|---|
| Integration | Consider green spaces as a kind of infrastructure | *Yes* Aquatic green spaces have been functioning as part of the water supply system in Singapore |
| | Integrate and coordinate green spaces with other infrastructures in terms of physical and functional relations | *Yes* Waterways and nature-based stormwater facilities are to be integrated with the surrounding environment and existing infrastructure |
| Multifunctionality | Combine ecological, social, and economic functions of green spaces | *Yes and No* The ABC Waters design features are multi-functional<br>However, most waterway enhancement projects do not consider ecosystem functions |
| Connectivity | Include physical and functional connections between green spaces at different scales and from different perspectives | *Yes* But it is not done through the program but through Singapore's green space planning in general and more specifically the Park Connector Network[a] |
| Multi-scale approach | Consider functions at multiple scales | *Not mentioned* |
| Multi-object approach | Include all kinds of green and blue spaces | *Yes* It involves aquatic and terrestrial green spaces |
| Strategic approach | Aim for long-term benefits but remains flexible for change over time | *Yes and No* The long-term benefits, water security and higher quality of life, are basically the drivers of the program, but flexibility is not mentioned |
| Social inclusion | Stand for communicative and socially inclusive planning and management | *Yes* Community engagement is committed |
| Transdisciplinarity | Base on knowledge from different disciplines | *Yes* The implementation of the ABC Waters projects involved not only hydraulic engineers and water managers, but also landscape architects and ecologists |
| | Develop partnership with different local authorities and stakeholders | *Yes* It is done by the 3P (People, Public, Private) partnership. PUB also collaborates with other government agencies |

[a]Urban Redevelopment Authority of Singapore. https://www.ura.gov.sg/Corporate/Planning/Master-Plan/Key-Focuses/Recreation/Providing-Green-Spaces. Accessed January 11, 2019

Waters Program therefore exemplifies how a city can build BGI through enhancing the water-related ecosystem services within the existing urban fabric.

## 3 Lessons for other high-density cities

As a city, Singapore is unique because its governance structure and decision-making framework operate as a nation. As a high-density city, Singapore is also unique because its high-rise spatial arrangement leaves rooms for ample green spaces, and this is because of its long-term planning efforts, supportive legal framework, and effective governance (Tan et al. 2013, p. 25). Furthermore, Singapore is one of the wealthiest nations in the world, and the important driver of water security behind the ABC Waters Program may not exist in other cities. While it is important to note Singapore's idiosyncrasy, how it contributes to the successful implementation of the ABC Waters Program is beyond the scope of this article. Nevertheless, even if the context of the program is rather unique, the program still provides valuable lessons on BGI planning and design for other high-density cities, especially in Asia. For example, China recently rolled out the Sponge City initiative to address urban water problems, and while the government has invested heavily in it, many challenges lie ahead (see Xia et al. 2017, pp. 655–656). Chinese cities could learn from the strategies of the ABC Waters Program that contribute to its success. These include a master planning approach at the scales of the city and the catchment, a relatively long timeframe from 2006 to 2030, and a focus on both aquatic and terrestrial green spaces and on both the tangible design of the green spaces and the intangible public education, community engagement, and capacity building. This section, however, focuses on another two strategies that are more important for the high-density context. While land availability seems like a constraint, Singapore has demonstrated that a high-density city can still build BGI by optimizing the existing green spaces and leveraging cultural ecosystem services to gain public support. As a high-ranking Singapore Government official commented, "high density is a possibility rather than an obstacle" (Author's personal communication in 2013).

### 3.1 Optimizing the existing green spaces

Although high-density cities have relatively limited green spaces, there still exist some green spaces, on which BGI can be built. Building BGI means creating green spaces that deliver multiple water-related ecosystem services. Although urban green spaces might have already provided some ecosystem services, the qualities of the existing ecosystem services and the degree to which the urban green spaces are multifunctional can vary. Some green spaces, such as lawns and fully concretized waterways, provide poor, if any, ecosystem services. Building BGI requires explicit efforts to integrate ecosystem services into green space planning and design. It can be done by adding new green spaces that provide water-related ecosystem services to the city and by adding water-related ecosystem services to the existing green spaces in the city. Since the former is difficult for high-density cities because of land scarcity, the latter—which is to optimize the existing green spaces—is the key (see Jim 2004, p. 312). Since it is possible to maximize the ecological performance of green spaces for any given density (Tratalos et al. 2007, pp. 313–314; Richards et al. 2017, p. 558), high-density cities can optimize the functionality of the available green spaces, making them as multifunctional as optimal to go beyond recreation and esthetics to provide more ecosystem services.

The ABC Waters Program demonstrates such an effort with its aim to "realize the full potential" of the existing water network of Singapore (PUB 2018, p. 3). The potential could be understood as the capacity to provide multiple ecosystem services. The Bishan-Ang Mo Kio Park exemplifies how an existing green space, previously designed only for recreation, can be retrofitted to provide more ecosystem services. The naturalized Kallang River also enriches the park's recreational function by providing Singaporeans with a rare opportunity to step into the river to play and observe aquatic organisms. Other waterway enhancement projects—despite not as radical—have turned the utilitarian waterways into accessible and beautiful spaces to enhance their social functions. While the degree to which these projects "realize the full potential" of the waterways is debatable, the once lifeless concrete waterways have gone beyond the single function of drainage. The ABC Waters Program also optimizes the existing terrestrial green spaces by adding stormwater-related ecosystem services with the ABC Waters design features, which may come with other ecosystem services as by-products, such wildlife habitats.

Other high-density cities could also enhance the ecosystem services of their existing green spaces to "upgrade" them to BGI by waterway enhancement and even river restoration, as well as by nature-based stormwater facilities. The latter is particularly the low-hanging fruit because nature-based stormwater facilities are spatially efficient. The existing planting strips, for example, can be easily retrofitted to become bioretention swales without taking extra space (PUB 2018, p. 28). Where underground utilities do not pose a concern, nature-based stormwater facilities should be incorporated into any green space—even the smallest ones.

### 3.2 Leveraging cultural ecosystem services

Given that limited green spaces in high-density cities are inevitably expected to fulfill multiple social needs, cultural ecosystem services play an important role in the optimization of the existing green spaces to ensure a successful BGI program that requires public support. The utilitarian perspective in conventional urban water management has resulted in a focus on efficiency and engineering measures, excluding not only the ecological, but also social values of urban waterways (Buurman and Padawangi 2017, p. 2). Cultural ecosystem services of urban waterways have been largely ignored in the process of urban development. Singapore's network of lifeless waterways is just an epitome of urban waterscapes around the world. But circumstances have begun to change. Cultural ecosystem services of urban waterways, such as waterfront recreation, aesthetic river views, recreational fishing, and even swimming, are paid increasing attention in urbanism, particularly in the wealthier cities. Cultural ecosystem services have been argued to be a gateway for addressing and managing nature in cities through civic engagement and public support (Andersson et al. 2015, p. 165). The ABC Waters Program demonstrates how to leverage cultural ecosystem services to gain public support.

The program appeals to the ecosystem services that can easily be appreciated in Singapore with its name: "Active" for recreation, "Beautiful" for aesthetics, and "Clean" for water security. The first two are cultural ecosystem services, while the last is a provisioning ecosystem service. Unlike Singapore, most high-density cities do not depend on local water resources and hence may not appreciate the need for clean waterways in the city. However, the importance of recreation and aesthetics can easily be appreciated in any city that pursues a higher quality of life. The vision of the ABC Waters Program—"beautiful and clean streams, rivers and lakes with postcard-pretty community spaces for all to enjoy"—is made clear to the public.[2] While such a vision may sound superficial from an ecological perspective, it may be a necessary first step toward ecological restoration of urban waterways to turn them into BGI to provide multiple ecosystem services. It is argued that focusing on recreational benefits is necessary to make urban river restoration projects feasible (Booth 2005, p. 731). This is because such projects are often costly compared to rural projects due to high land value and competing land uses in the urban area; moreover, drastically altered watershed conditions in the urban area have made it an impractical goal to restore an urban river to a predevelopment state anyway (Bernhardt and Palmer 2007, p. 746). Furthermore, where ecological awareness is low, which Singapore is still the case,

[2] The website of the ABC Waters Program: https://www.pub.gov.sg/abcwaters/about. Accessed September 30, 2018.

it may be necessary to first focus on easily understood cultural ecosystem services. The less understandable, hence less appreciated, supporting and regulating ecosystem services can be embedded within and communicated under cultural ecosystem services because they are often interdependent (ibid., pp. 165–166). For example, since enhancing a river's recreational and aesthetic functions requires cleaner water, the significance of water purification can be simultaneously communicated to gain public support for nature-based stormwater facilities and for the restoration of the riparian zone and aquatic species key to nutrient cycling. Focusing on cultural ecosystem services could help promote the awareness of other types of ecosystem services that only a healthy river can deliver.

Making sure that people actually utilize the cultural ecosystem services provided is also important to gain public support. Efforts were made to ensure that the ABC Waters sites are enjoyed by as many people as possible through the aforementioned site selection process in master planning. A site was chosen based not only on the technical feasibility, but also on whether it would be visited frequently; therefore, factors such as accessibility, population of the nearby neighborhoods, and the number of schools in the vicinity were also taken into account. Making the first BGI projects well known and highly appreciated would help gain public support to sustain the BGI program.

While cultural ecosystem services play an important role in BGI in high-density cities, the provision of them should not compromise other ecosystem services. For example, if there is still some intact riparian zone, which contributes to water purification, the enhancement of a river's recreational function should not result in the removal of the riparian zone. It is possible for a green space to simultaneously provide multiple ecosystem services through careful design; however, it should be noted that there are still inevitable trade-offs between ecosystem services (Rodriguez et al. 2006). Maximizing or prioritizing some ecosystem services might compromise the capacity of the green space to provide certain others. In high-density cities, where cultural ecosystem services tend to be prioritized, the optimization of green spaces requires special attention to the trade-offs between cultural and other three types of ecosystem services.

## 4 A research gap in BGI planning and design as a socio-ecological practice

While the ABC Waters Program has been discussed as a BGI program in this article, it is not easy to answer the question: Does the program turn Singapore's green spaces into BGI? This is because a fundamental question has yet to be answered in the literature: What qualifies as BGI? This question is not about a precise definition but pertains to the extent to which ecosystem functions should be incorporated in green spaces, as ecosystem services depend on ecosystem functions (de Groot et al. 2002, p. 394). Exploring the question would help advance BGI planning and design as a socio-ecological practice.

Multifunctionality is an important concept in BGI (see Wright 2011, p. 1007). It implies the explicit consideration of multiple ecological, social, and economic functions, and these functions can be understood as ecosystem services (Hansen and Pauleit 2014, pp. 518, 520). Since green spaces should provide multiple water-related ecosystem services to be BGI, it would be a lack of rigor to call any urban green space or any preexisting collection of green spaces of a city BGI before its multifunctionality, in terms of ecosystem services, is assessed. Furthermore, because ecosystem services are provided through ecosystem functions, BGI planning and design require explicit consideration of ecosystem functions. The social and economic functions of a BGI element (i.e., an individual green space) and BGI as a whole (i.e., the green space network) should be derived from ecosystem functions. At least, they should not compromise ecosystem functions.

The ABC Waters Program increases the functions of the existing green spaces. The functions of water quality treatment and flood mitigation are added to the existing terrestrial green spaces. The functions of recreation, aesthetic appreciation, and/or environmental education are added to the existing waterways. However, do these new functions turn the terrestrial and aquatic green spaces into BGI just because they now provide more functions? Nature-based stormwater facilities, such as rain gardens and constructed wetlands, are widely and unambiguously called BGI (e.g., Liao et al. 2017; Thorne et al. 2018). However, to what degree can an urban waterway be called BGI is rarely discussed.

As mentioned earlier, river restoration is not an objective of the ABC Waters Program. Except for the naturalization of the Kallang River, most other waterway enhancement projects did not change the heavily channelized nature of the waterways. Because ecosystem functions are irrelevant in waterway enhancement, an early project at the Alexandra Canal involved decking over a section of the canal to create community space (Fig. 8). Even though the canal is already heavily concretized, such an enhancement project ignores its ecological impacts on the canal as an ecosystem. To be sure, some manmade structures are often necessary to enhance the recreational function of a natural stream or river, but to what extent can a river be modified and still qualify as BGI? In a highly urbanized context, such as Singapore, where most streams and rivers have been heavily channelized, this question becomes more complex. Is a fully concretized river BGI? If not, would that same river become BGI after it is beautified cosmetically and added with recreational function, despite its species-poor and highly degraded ecological and altered hydrological conditions? To what degree should the ecosystem functions of a degraded river be restored for it to

**Fig. 8** The community space at the Alexandra Canal in Singapore, as a waterway enhancement project in the ABC Waters Program, was created through decking over a section of the canal

qualify as BGI? These questions fundamentally pertain to what can be considered urban ecosystem services. The notion that ecosystem services are underlined by ecosystem functions has become increasingly diluted in the urban context. However, not all functions provided by an urban green space are ecosystem services. Certain functions may not be provided through natural processes or ecosystem functions, but mainly through manmade structures or engineering work. As the case of the aforementioned Alexandra Canal reveals, social functions are particularly ambiguous because they often require some modification of the original ecosystem, e.g., installation of trails and clearance of vegetation to create gathering space. When a certain social function of an urban waterway is largely provided by engineering work, should they be considered ecosystem services?

The research gap raised here needs to be addressed in socio-ecological practice research because urban waterways are likely to remain heavily channelized in high-density cities. As BGI gains increasing attention in practice, the term is also prone to misuse and even abuse. Calling any waterway BGI, regardless of the quality of its provision of ecosystem services, would do little to promote urban sustainability and resilience. The question of what exactly qualifies as BGI is far from trivial. It affects the outcome of BGI planning and design. Filling the research gap would generate actionable socio-ecological knowledge for practitioners tasked with planning and designing urban green spaces as BGI.

## 5 Conclusions

In the Anthropocene, where urbanization is a major driver of global environmental change (Biermann et al. 2016, p. 345), the quest for urban sustainability and resilience demands socio-ecological practice and its research. This article examines the ABC Waters Program with a lens of BGI. As a BGI-building program, the ABC Waters Program is not perfect, but Singapore is learning by doing. The program tells us that a high-density city could systematically build BGI through optimizing the existing aquatic and terrestrial green spaces and leveraging cultural ecosystem services to gain public support. This case study contributes to socio-ecological practice research as “action research on knowledge implementation”, as defined by Xiang (2018, p. 2). This article also enriches the literature on BGI planning and design by providing a case in high-density city in Asia, a context that is rather different from USA and Europe where most of the literature focus (Lennon 2014, p. 4). Along with Africa, Asia will host 90% of the global urban population growth by 2050 (United Nations 2018). Rapid urbanization in Asia will continue to give rise to more “mega-conurbations”, an urban form that is characterized by rapid population growth and high population densities (Friedmann and Sorensen 2019, p. 1). Against this backdrop, BGI planning and design will play an important role to move toward urban livability, resilience, and sustainability through the preservation, restoration, and creation of urban ecosystem services. The utilization of ecosystem services is still a new subject in urban governance. Much more socio-ecological practice research on BGI is needed to better promote its planning and design for a high-density urban future in Asia.

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