Paper prepared for presentation at the annual meeting of the ICSD, 24-25 September 2019, New York

Low Impact Development and the Sponge City Model: Planning for the Sustainable Future of Urban Water

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Abstract

Water is the most important resource, and with the rapid spread of urbanization, human needs for water are increasing while urban water management is becoming increasingly difficult. Sustainable Development Goals 6.3 and 6A have prioritized clean water and sanitation and decreasing the negative human impacts on the environment. Low impact development (LID) is a practical means by which cities can bring back aspects of natural hydrology that have been lost through urban infrastructure development, on both small and large scales. By intensively introducing green infrastructure on a city-wide level, the recently emerging concept of the sponge city is one example of how LID can be applied on a mass-scale. This paper provides key information on LID and makes recommendations for successfully applying such processes to urban settings. It argues that LID is the right path forward for tackling urban water management towards SDGs 6.3 and 6.A, but that the sponge city model may be too ambitious for most municipalities to feasibly implement.

Keywords:

Low Impact Development, Green Infrastructure, Sponge Cities, China, urban development, stormwater management, Sustainable Development Goals, water security

Introduction

Water is the most important natural resource on Earth. Water is an irreplaceable and non-substitutable resource that is crucial to the quality of life and wellbeing of every individual on the planet. The importance of water has been recognized for centuries, and its importance and necessity has increased with the growth and development of global society. Today, this growth is exhibited on an international scale, evidenced by massive urban sprawl that has resulted in heavily populated urban centers reliant on adequate and potable water supply. There is a common misconception applied to perceptions of urban water, which is that many people across the globe are living with an insufficient supply of clean water. However, the real difficulty lies in the management of water resources rather than the water supply itself. The issue of water management is especially problematic in large cities, where widespread urban infrastructure has displaced key aspects of the natural system, and thus, disrupting the hydrological cycle.

The identification of clean water and sanitation as a Sustainable Development goal, first introduced at the United Nations Conference on Sustainable Development in 2012 (UNDP, n.d.), has emphasized their importance. Various technological and scientific advancements have been made to address water-related issues while simultaneously reintegrating displaced aspects of the natural system into urban environments. The introduction of green infrastructure (GI) as a form of integrated water resource management has begun to emerge as a solution for several specific targets within the sixth Sustainable Development Goal, “Ensuring availability and sustainable management of water and sanitation for all” (UNDP, n.d.). The development of green infrastructure has led to a concept now referred to as Sponge Cities, a large-scale, intensive form of green infrastructure strategy that equips entire cities to store and recycle rainwater (Huang, 2015). Sponge cities are becoming a popular focus of research, as they have the potential to mediate complications created by historically poor water management and heavy urban infrastructure which have destroyed natural systems. China is often cited as the birthplace of the sponge city concept, and has begun heavily implementing GI into a number of major urban centers as part of its wider “sponge city initiative”, the goal of which is to have 80% of Chinese cities capturing and reusing 70% of stormwater runoff by the year 2030 (Zevenbergen, Fu & Pathirana, 2018).

While these endeavours appear successful thus far, it is unlikely that other countries, particularly those in the global south, have the same resources, capacity, or societal buy-in to implement comprehensive sponge cities into pre-existing infrastructure. This paper will argue that the feasibility of sponge cities and large-scale implementations of green infrastructure in many regions of the world are not yet practical and that smaller-scale, forms of integrated water resources management must first be introduced before more advanced, comprehensive strategies can be viable. Rather than advocating for the adoption of the full-scale sponge cities model and comprehensive city-wide retrofits, low impact development should be incorporated into existing city models and future urban planning to establish best management practices and work towards the achievement of the sixth Sustainable Development Goal.

This paper will begin by defining water security to explain the importance of water storage, treatment, and reuse within urban centers. It will then identify key targets within the Sustainable Development Goal Number 6, explain their importance, and illustrate how these targets can be achieved through the use of green infrastructure. Following this, the paper will then shift its focus towards Low Impact Development, its opportunities and constraints, and recommendations for LID management approaches. Sponge cities will then be discussed as an intensive form of LID, using case studies from China to examine the effectiveness, cost and considerations associated with the sponge city model, as well as its limited potential to be applied elsewhere. The paper will conclude by discussing several management approaches for LID implementation and assess how an application of these approached could be best used as water management strategies in achieving certain targets within the sixth Sustainable Development Goal.

Defining Water Security

When addressing any water-related issues, the first question often posed is whether or not the region or community in question is water secure. Although there is already significant research to support the fact that there is more than enough water to sustain all life on Earth, some regions are still more water secure than others sometimes simply because of geographical location and sometimes due to poor water policy and management. While there are numerous accepted definitions of water security, one of the most applicable definitions comes from the Global Water Partnership Technical Advisory Committee. This definition states that: 'water security at any level means that every person has access to enough safe water at an affordable cost to lead a clean, healthy and productive life while ensuring that the natural environment is protected and enhanced' (Global Water Partnership, 2000). Multiple definitions of water security identify the need for water to be affordable and clean to result in an improved quality of life. While these are all correct aspects of water security, the Global Water Partnership definition specifically identifies the importance of considering the natural environment and argues the belief that a region cannot be water secure if its endeavours to do so negatively impact the natural environment.

This definition of water security aligns itself with the components of integrated water resource management and more specifically, green infrastructure. One of the main goals of green infrastructure is to replace some of the natural systems that may have been displaced through the introduction of gray infrastructure. While many large urban centers may believe they are water secure because all residents have access to a clean water supply, this may come at the cost of environmental degradation. Finding a balance between affordable clean water for all those living within a community, especially highly populous urban centers, and ensuring the natural environment is both protected and enhanced are all necessary qualifications of adequate water security. Furthermore, water security plays a vital role in the achievement of several targets outlined in the clean water and sanitation Sustainable Development Goal.

Examining Key SDG Targets

When observing the goal of clean water and sanitation, it can be seen that there are multiple targets and indicators within the goal since this large goal cannot be achieved without addressing multiple different facets associated with the current challenges. However, the overall achievement of the goal can only succeed if initiatives and strategies are developed that each address certain targets and eventually come together as a collective. 6.3 and 6.A are two targets in particular that have a strong relation to the implementation of green infrastructure. 6.3 states: ‘By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing the release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally’ while 6.A states ‘By 2030, expand international cooperation and capacity-building support to developing countries in water-and-sanitation-related activities and programmes, including water harvesting, desalination, water efficiency, wastewater treatment, recycling and reuse technologies’ (UNDP, n.d.). Indicators for these targets involve proportions of wastewater safely treated, increasing the proportion of water bodies with suitable water quality and increasing the amount of water and sanitation related development assistance as part of a government-coordinated spending plan (UNDP, n.d.).

While there are many other targets and indicators associated with the goal of clean water and sanitation, targets 6.3 and 6.A share heavy focuses on water reuse and recycle, the improvement of water quality and water-use efficiency, and a call for capacity building that not only addresses issues of water management but also takes into consideration the wellbeing and preservation of the natural environment. These key components of the respective targets are synonymous with the objectives of green infrastructure. These objectives are heightened when examining large urban centers, as populous regions consequently use more water and damage the natural environment whether it be through pre-existing infrastructure or new gray infrastructure. These issues, along with the need for low impact development and a widespread increase in green infrastructure as a form of integrated water resource management will be discussed in further detail in the sections below.

Low Impact Development

Low impact development (LID) is a newly popular alternative to conventional methods for urban water management that has been found to function effectively in a variety of climates and soil conditions (Zimmer et al., 2007; Dietz 2007). LID practices mimic the natural hydrologic cycle to store and treat stormwater runoff on-site, and have been shown to improve urban water quality, increase infiltration and evapotranspiration, decrease runoff, and revive and enhance ecosystems within urban centers (Shah & Antuma, 2016; Zimmer et al., 2007). The strategy uses small- scale, distributed, and lot-level best management practices that fit with localized conditions and infrastructure to help restore natural hydrologic processes of urban watersheds (Zimmer et al., 2007; Dietz, 2007). LID includes various forms of green infrastructure to infiltrate, store, treat, and reuse runoff, as well as proactive urban planning, such as building narrower roads and shared driveways and avoiding the construction of cul-de-sacs in order to preserve as much permeable natural surface as possible (Zimmer at al., 2007). Also, non-structural LID changes can be made, such as redirecting roof downspouts to sloped areas that contain permeable topsoil to infiltrate and evaporate runoff during periods of high rainfall (Toronto & Region Conservation Authority, 2013). These solutions not only have great potential to mitigate the hydrological damages of urbanization but also positively impact people, the economy, and the environment LID can enhance quality of life in urban areas by enhancing aesthetic qualities of the landscape, drawing people outside and providing increased recreational and community-building opportunities for citizens (Zimmer & James 2010; Dhalla & Zimmer 2010). Research shows that outdoor activities, such as walking and jogging, increase in communities after implementing LID (Credit Valley Conservation 2010).

LID designs usually comprise multiple, overlapping techniques towards integrated management of runoff at a given site. For example, when planning for a new subdivision, a bioretention area might be included on each property, downspouts could be redirected from the impervious pavement, and grass swales could be added to common outdoor areas (Dhalla & Zimmer 2010, 2). Some of the most common applications of LID come in the form of green roofs, bioretention systems, bio swales, and permeable pavement incorporated into the urban landscape. All of these methods can be designed to operate under a variety of seasonal conditions efficiently and can be applied in both public and private spaces (Ahiablame, Engel, & Chaubey 2012).

A green roof is a rooftop with partial or complete vegetation cover, where rainwater is captured both through synthetic material structures and evapotranspiration in plants ((Ahiablame, Engel, & Chaubey 2012; Dietz 2007). Research across various locations finds that between 60% and 70% of rainwater is retained through green roofs, reducing flooding and providing water for household use (Dietz 2007; Ahiablame, Engel, & Chaubey 2012). Green roofs also provide convenient spaces for urban agriculture (Zimmer & James 2010). Bioretention systems, or rain gardens, are depressed areas designed to reduce and treat runoff, using media such as sand or soil and vegetation such as grasses, rushes, and shrubs (Ahiablame, Engel, & Chaubey 2012; du Toit, 2018). The reduction of runoff volumes and rates depends on the magnitude of rainfall, but many studies have found they can reduce up to 99 % of sediment (Ahiablame, Engel, & Chaubey 2012). Bio swales are shallow channels with gentle side slopes, filled with vegetation which is resistant to erosion and flooding (Ahiablame, Engel, & Chaubey 2012 s). Swales are used to replace traditional curbs and gutters and maintain natural flow paths through open drainage to slow runoff and ameliorate water quality (Dhalla & Zimmer 2010; Ahiablame, Engel, & Chaubey 2012).

Permeable pavements are an alternative to traditional pavement temporarily store runoff, slowing infiltration into the subsoil (Ahiablame, Engel, & Chaubey 2012). These include porous asphalt, as well as concrete or plastic grids with open voids filled with gravel or topsoil for infiltration (Dietz 2007; Ahiablame, Engel, & Chaubey 2012). These can be applied in any location where conventional pavement, concrete, or tarmac are utilized, such as parking lots, sidewalks, roads, and driveways.

The Wider Benefits of LID

The potential of LID extends beyond its ability to improve stormwater management in cities; it can have far-reaching benefits to society, the economy, and the environment.

LID has been shown to enhance the quality of life in urban areas by enhancing aesthetics, drawing people outside and providing increased recreational and community-building opportunities for citizens (Zimmer & James 2010; Dhalla & Zimmer, 2010). It provides a model for brownfields, such as polluted post-industrial sites and empty lots, to be transformed into healthy, aesthetically pleasing green areas for public use (Kramer, 2014). Research shows that outdoor physical activity, such as walking, jogging and sports increase in communities after implementing LID, and that citizens identify spaces like parks and sports fields as important sources of both recreation and relaxation (Credit Valley Conservation, 2010; du Toit et al., 2018). LID is also able to provide sources of food and income for citizens who engage in urban agriculture, whether in the form of community gardens or green roofs (du Toit et al., 2018). Moreover, LID creates educational opportunities for the public through greater proximity and exposure to nature, and an ability to participate directly in sustainable practices.

The benefits of educational opportunities provided by LID may be enhanced for urban youth who have grown up with the “extinction of experience” of nature (Zimmer & James 2010; du Toit 2018, 257). When citizens have access to natural settings close to where they reside, interact with one another in welcoming public spaces, and take collective ownership over sustainable water resource management, societal cohesion and quality of life increases (Mansor & Mohamad, 2012). In addition to the aforementioned environmental benefits of better stormwater management, LID can help reduce urban heat stress, improve air quality, prevent erosion, and enhance groundwater recharge (Dhalla & Zimmer 2010, 4). These systems also serve to revive and protect ecosystems, making cities more hospitable for native plants and wildlife and enhancing biodiversity (Credit Valley Conservation 2010, 15). Moreover, utilizing LID can create opportunities for more sustainable consumption patterns via stormwater reuse at the household level (i.e. rain catchment systems) and urban agriculture (i.e. green roofs) (Zimmer & James 2010, 50).

From a fiscal perspective, implementing LID practices has the potential to stimulate economic development through the creation of green jobs and green investment opportunities, as well as higher property values (USEPA 2017; Dhalla & Zimmer 2010). Enhancing aesthetic and recreational value to cities also has the power to attract tourism to the area, injecting funds into the local economy (Finlayson, D'Cruz & Davidson, 2005). For cities who rely on industries like agriculture and fishing, which depend heavily on the availability and quality of water, LID has the potential to enhance these economic sectors (Finlayson, D'Cruz & Davidson, 2005). Lastly, LID has been shown to have lower upfront construction costs compared to those of grey infrastructure, but long term lifecycle cost comparisons need more research at this time (USEPA, 2017). By limiting hard, dark surfaces and expanding and protecting green space and tree cover, LID can reduce urban heat stress, improve air quality, prevent erosion, and enhance groundwater recharge (Dhalla & Zimmer 2010). These systems also serve to revive and protect ecosystems, making cities more hospitable for native plants and wildlife and enhancing biodiversity (Credit Valley Conservation 2010). Moreover, utilizing LID can create opportunities for more sustainable consumption patterns via stormwater reuse at the household level (i.e. rain catchment systems) and urban agriculture (i.e. green roofs) (Zimmer & James 2010).

Overcoming Challenges to Adoption of LID

As a relatively new way of thinking about urban water management, a large-scale shift in thinking is a requirement for the LID is to be widely accepted and implemented. There may be hesitancy in some cases for administrators, developers, and even "water experts" to move away from what has "always been done" (Chocat et al., 2007). Especially in parts of the world where the phenomenon of rapid urbanization has occurred more recently, there is a tendency to see urban development decisions as a trade-off between grey and green infrastructure; urbanization is often perceived to have higher economic value than green space, sometimes referred to as the “green value gap” (du Toit et al., 2018). Moreover, the incentive to change the status quo in water management is low when it appears that no major problems or crises are occurring within the existing system. Many cities' urban water services function without major failures and thus do not receive significant public or political attention (Chocat et al., 2007). However, there is an overall knowledge gap when it comes to the negative impact of "grey" urban growth on stormwater management and water quality (Godwin et al., 2008). To those for whom this connection is unclear, the need for a change in direction is not self- evident, and LID remains largely under- promoted (Ahiablame, Engel, & Chaubey 2012). Further research and monitoring towards the evaluation of LID projects across different scales and climatic conditions are needed to prove the effectiveness of the approach (Ahiablame, Engel, & Chaubey 2012). Also, more research is needed to estimate and compare life-cycle costs of LID designs versus conventional designs for stormwater management, including the costs of long-term operation, and maintenance. (Dhalla & Zimmer 2010).

Incentivizing municipalities, developers, and landowners can promote the application of LID. Incentives include stormwater fee discounts, development incentives, installation subsidies, rebates and installation financing, and awards and recognition programs (USEPA, 2012; Ahiablame, Engel, & Chaubey 2012). To encourage local innovation and participation in LID processes, local design contests can be held, and community champions of LID can be highlighted by local news and media sources (USEPA, 2012).

Education is imperative to the uptake and success of LID. Governments, local leaders, developers, and the public must see a clear, empirical link between LID strategies and their wide-reaching benefits before they give their support (USEPA, 2017). The information must be made accessible to build community awareness of urbanization impacts on water security, and an understanding of the importance of sustainable water resource management where they live (Zimmer & James 210, 5; Godwin 2008). Perhaps the greatest key to sustainable LID systems is ensuring that projects are designed and carried out in partnership with all relevant local stakeholders (Center for Neighborhood Technology 2010; USEPA, 2014). It is integral that development addresses public safety and health, as well as other concerns or desires from community members and local leadership (Godwin 2008; USEPA 2017; du Toit, 2018). Designs should fit with climatic and environmental contexts, as well as objectives and targets relevant to the site (Dhalla & Zimmer, 2010; USEPA, 2017). Given that the adoption and upkeep of LID require increased public engagement and responsibility, local citizens and decision-makers must be empowered as informed participants in the process from start to finish (Center for Neighborhood Technology 2010, 5). Du Toit et al. highlight the importance of giving special attention to the needs of the urban poor and those living in informal settlements, whose voices are often left out of urban planning processes (2018). Another main challenge in the adoption of LID comes in the form of rapid urbanization in large urban centers and the problems faced when a heavy amount of stormwater are prevalent within such regions.

Urbanization and Storm Water Management Issues

With the rapid expansion of cities, impervious (non-absorbent) surfaces have increasingly covered up grass and topsoil, and “grey infrastructure” development has resulted in the removal of green space and the burial of streams (Martin-Mikle et al., 2015; Zimmer et al., 2007). This destruction of the natural environment negatively impacts existing ecosystems and wildlife habitats, while simultaneously interrupting natural flow regimes that infiltrate, store and productively use rainfall (Burns et a.l, 2012). The result is that rain is pooled on hard urban surfaces, such as concrete, and is not absorbed into local land. Instead, stormwater is wasted as it becomes runoff, and in incidences of intense rainfall, there is an increase in frequency and volume of flooding (Burns et al., 2012). The increase in rainfall causes contaminants such as nitrate, pesticides, and other chemicals from anthropogenic activity to leach into groundwater, and to flow downstream to key water sources such as rivers, lakes and reservoirs, and eventually coastal waters (Mahler, n.d; Barbosa, Fernandes & David, 2012). Harm is done not only to water quality, but also biological communities, industries such as fishing and tourism, and existing infrastructure through erosion and flood damages (Mahler, n.d.).

Attempts to mitigate the damages of urban development towards better stormwater management have come in several forms since the 1970s, mostly with the goal of flood control; drainage systems were engineered which could efficiently route runoff to receiving bodies of water (TRCA, 2019; Burns et al., 2012). In the 1990s, in addition to quick removal of stormwater and controlling peak flow rates, aims shifted to include water quality improvement and the reduction of contaminant flow to water sources (TRCA, 2019). Since that time, the key focus has been end-of-pipe stormwater treatment, methods to remove contaminants as the last stage before water is either disposed of or delivered for use (GreenFacts, 2019). Unfortunately, conventional means of managing urban stormwater are increasingly unable to keep up with the speed and growth of development and associated water and ecology-based issues (Zimmer et al., 2007). Much of the existing sewers, detention ponds and other stormwater infrastructure were not designed to account for the high level of stormwater runoff cities are experiencing today, and are reaching capacity in the face of heavy rainfall and failing to protect upstream water quality (Shah & Antuma, 2016; Burns et a.l, 2012).

Moreover, conventional stormwater management techniques use construction methods and materials which add to the core of the problem: the disruption of the natural hydrological cycle via loss of vegetative cover and evapotranspiration (Shah & Antuma, 2016; Burns et al., 2012). There is also a failure to address other urban water issues within these conventional systems. For example, growing urban populations have increased consumption needs, both at the household level and in terms of virtual water; residents rely on imported mass-produced food with high water demands, rather than growing and harvesting rain-fed food close to home (Astee & Kishnani, 2010). There is a need to move towards more holistic approaches in managing urban stormwater, where aims go beyond dealing with runoff to include intentional ecology restoration and reclamation of the pre-development flow regime (Burns et al., 2012).

Sponge Cities: An Intensive Form of Low Impact Development

While low impact development is often introduced on a small-scale, site-specific level, the sponge city concept takes an intensive approach to apply LID, which has emerged over the past few years as a way to comprehensively address water-related issues in large urban centers. Sponge cities utilize green infrastructure, planned and managed semi-natural or natural systems designed to fulfill a specific need by enhancing or replacing the functionality that is typically provided by human-made structures (Hawkins & Prickett, 2014). The presence of green infrastructure is of dire importance as it attempts to replicate the hydrological cycle that is disrupted by the development of grey infrastructure which comes with urbanization, as demonstrated in the previous section.

Sponge cities aim to retrofit existing infrastructure on a grand scale, incorporating unique LID components such as green roofs, pervious surfaces and redesigned water systems that absorb, restore and reuse rainwater efficiently throughout an urban center (Huang, 2015). Although the sponge city method is set apart by its city-wide, full-cover approach, it is inspired by the emergence of more modest LID practices and technologies (Li, Li, Fang, Gong & Wang, 2016). The difference is that sponge cities attempt to redesign the entire urban center so that these green components can be integrated to their maximum potential in attempts to mimic the hydrological cycle wherever possible. However, an implementation of these projects on such a grand scale is no simple task; sponge cities require a great deal of capacity, time, money, cooperation and resources to succeed.

China is often considered as the originator of sponge cities, as this intensive form of low impact development has taken off throughout the nation over the past few years. With an astounding population, China is home to some of the largest urban centers in the world, and these densely populated areas require a tremendous amount of water. The urban population sits at about 705 million people and represents 54% of the country's total population (Zevenbergen, Fu & Pathirana, 2018). The call to introduce sponge cities in China began due to the vast water issues that have plagued the country over the past number of years. The rapid progress of urbanization and industrialization in China combined with extreme weather events have resulted in major urban water problems, often in the form of water scarcity, heavy flooding and poor water quality (Zevenbergen et al., 2018).

The Chinese government introduced the Sponge City Initiative in 2013 with aims to enhance infiltration, evapotranspiration and reuse of stormwater (Zevenbergen et al., 2018). Stormwater is especially valuable as a means of alternative non-potable water supply as it can be used for a variety of domestic and industrial usages, and with the use of LID systems, the quality of drinking water has the potential to improve as well via the slowing and treatment of runoff (Wong, 2006; Barbosa, Fernandes & David, 2012). An important target laid out by the Chinese government is that, by 2030, 80% of urban areas should absorb, retain and reuse 70% of rainwater (Zevenbergen et al., 2018). Coincidentally, this target also coincides with the 2030 targets set out by the Sustainable Development Goals.

In terms of determining participatory cities, the pilot program outlined 16 cities in 2015 for project implementation, with an additional 14 cities identified in 2016 (Li, Ding, Ren, Li & Wang, 2017). The government allocated between 400 and 600 million Chinese Yuan (around 59-89 million US dollars) each year for three years for each pilot city, with a heavy focus placed on garnering additional funding through public-private-partnerships (Li et al., 2017).

As sponge cities are still relatively new in China, there is still limited information available to effectively evaluate their success and long-term feasibility on a nation-wide scale. However, the research made available since the years of the initiative's inception paint a picture of their successes thus far, the challenges ahead and what the future might hold for sponge city implementation throughout additional urban centers in China. One clear observation is that sponge city implementation is an expensive operation. China has one of the strongest economies in the world and can commit to allocating large amounts of capital to such an all-encompassing project. However, the initial amount of money invested by China in the sponge city project seems highly unreasonable for many other countries with weaker economies. Since the launch of the project in 2014, Chinese researchers have determined that the initial implementation has already been too ambitious and have recommended that the government slow down the expansion of the program to allow Chinese society and the private sector catch up and participate effectively (Zevenbergen et al., 2018). The success of a sponge city is highly determinant on proper implementation throughout the entire urban center, therefore including the general public and the private sector in the participation of green infrastructure is key moving forward. This need for capacity building is discussed directly within SDG target 6.

The implementation of sponge cities in multiple pilot cities also allowed China to see whether or not particular forms of GI can be successful in every region. In certain instances, such as in the city of Jinan, geographical settings have created barriers to successfully introducing sponge city construction (Li et al., 2016). A combination of uneven rainfall throughout different seasons along with a combination of sloped and flat landscapes has resulted in flash flooding that limits the opportunity for sponge city construction (Li et al., 2016). Furthermore, Jinan and its main discharge river, known as the Xiaoqing River, have encountered issues with improving water quality due to heavy runoff and a combined sewer overflow (Li et al., 2016). Despite the best efforts of sponge city construction, green infrastructure cannot always adequately manage issues in certain regions, depending on their unique climatic and geographic conditions.

Baicheng is another pilot city that has encountered problems associated with sponge city construction, mainly due to old pre-existing infrastructure that cannot handle complex adaptation towards better stormwater management (Li et al., 2016). Water quality is highly problematic in Baicheng due to untreated wastewater pipes that discharge into stormwater pipes, as well as directly into groundwater through septic tanks that pollute water source wells (Li et al., 2016). Moreover, Baicheng is home to a great deal of alkaline land that must be taken into consideration during sponge city construction to promote soil restoration and avoid leaching (Li et al., 2016). As seen in Jinan, geography and climate affect Baicheng as well. Baicheng experiences relatively low temperatures and is accustomed to using high volumes of de-icing salt, another main pollutant to the groundwater in the region (Li et al., 2016). Barriers such as these are not always of when introducing sponge city construction and must not be taken lightly if sponge cities are to succeed. Sponge cities can be successful if implemented properly, but they must be able to overcome the physical, financial and legal challenges along with challenges of public acceptance and inter-agency cooperation (Li et al., 2017). Any issues or limitations associated with sponge city construction must be discussed in order to avoid such problems in cities that would like to introduce the sponge city approach.

Despite the problems that China has faced in a number of its pilot cities, there has also been great progress made in terms of improving water management, water reuse and water quality. The success of sponge cities in China has not only improved water management within the nation, but it has also encouraged partnerships and capacity building on an international level. This type of innovation has resulted in the Chinese European Water Partnership (CEWP) which aims to increase international research and introduce new water-related technology (Zevenbergen et al., 2018). In China, the Ministry of Housing and Urban-Rural Development (MOHRUD) have since published a number of evaluations to assess the progress of sponge cities in China, with these reports highlighting a great deal of technical information that identifies the good progress the sponge city program has made since its launch (Li et al., 2016). Overall, it can be concluded that the introduction of sponge cities in China has resulted in improved water management and water quality.

While it is evident that sponge cities are a successful form of green infrastructure in China, the numerous challenges and barriers encountered during the first few years of construction highlight the fact that such as the large-scale approach of LID cannot succeed everywhere. China is unique in both its geographical positioning and its strong presence in the global economy. LID on a smaller scale is a better alternative to sponge cities in many places of the world due to the lower number of risks and fewer challenges, highlighted by the financial burden associated with sponge cities that is not present in smaller scale LID. While sponge cities are one example of successful urban water management that countries may strive towards, it should not be the lone solution. Instead, solutions with the gradual integration of smaller-scale projects into the urban water system are most feasible. An increase in innovation, accessible technology, and technical knowledge, are also needed to reinforce the success of the sponge city approach.

Management Approaches for Implementation of LID

As seen through the case study of China, a number of the barriers to LID implementation arise from challenges surrounding public perception and normative practices (Brown et al., 2009). One of the first steps to carrying out LID plans is changing paradigms of the populous in order to instill a knowledge and acceptance of LID as a desirable change. This step of change involves including all relevant stakeholders in the planning process. It is imperative that parties included a range from the general population, marginalized communities, political leaders, infrastructure developers, engineers and all interested parties (Center for Neighborhood Technology 2010; USEPA, 2014; du Toit, 2018). Community acceptance is key in ensuring that the low impact infrastructure, once developed, is maintained and utilized correctly When the importance of LID and sustainable water management is understood, changes in normative behaviours and daily practices of all stakeholders can occur. Improved normative behaviours involve water conservation and protection practices, such as proper disposal of wastes ranging from household pharmaceuticals to agriculture chemicals. The final change that must occur is on the regulative level. Once it the prioritization of water is an accepted norm, rules and regulations must be established by local leaders. Rules and regulations will ensure that a better-defined framework will be created involving the proper procedures in water protection and conservation. The prioritization of water will also ensure the continued implementation of best practices in water conservation. Overall, it is clear that both perceptions and behavioural practices surrounding urban water are crucial for the successful implementation of low impact development for sustainable water resources. There are two approaches outlined for the implementation of low impact development. The two approaches outlined involves the systems approach and the adaptive management approach.

The Systems Approach

The systems approach involves identifying alternate water sources and separating the different needs for water supply (Coombes & Kuczera, 2002). The urban water cycle currently treats the various cycle components in separate treatment stages. Novel solutions must consider using what was previously thought of as wastewater as a potential water source. For example, rainwater is currently thought of as a challenge that needs immediate removal. Rainwater should, however, be considered as a source of productive water that can be stored and treated to be used for various purposes (Coombes & Kuczera, 2002).

Steps involved in the systems approach are outlined in Figure 1. When creating an integrated water resource management system for LID, it is imperative that clear objectives are defined and maintained as the key drivers of every project. In following the Sustainable Development Goals, expected outcomes should be effective wastewater management, and ensuring safe drinking water is available to all urban citizens. The feasible solution space in urban water management involves consideration of all potential water sources, and the alternative uses of wastewater. The Pareto-optimal solutions, solutions that involve the compromise of distribution of water from one individual to share the resource among a group, is typically unavoidable. The optimization of water sources does not mean limitless water supply for all stakeholders; rather it ensures the distribution of water to all stakeholders according to their respective water needs. Because there are multiple ways in which these objectives can be addressed, all relevant stakeholders must be consulted, and have the opportunity to voice their needs and perspectives towards consensus on a preferred strategy. Lastly, the optimal and well-managed practice involves a continuous monitoring and review cycle. The review cycle must ensure that, at each stage, the process is working towards the core objectives of the project. It also involves continuous research and ongoing consultation to ensure that projects are still meeting the needs and expectations of stakeholders and are in line with current best practices, standards, and codes. The review process can use the adaptive management approach, which is outlined hereafter.

Figure 1

The Systems Approach

1. Identify system and its important linkages with subsystems
2. Define objectives and how to measure performance
3. Identify the feasible solution space
4. Search for the Pareto-optimal solutions
5. Evaluate Pareto-optimal solutions to identify the preferred solution
6. Can we do better? Review

(Coombes & Kuczera, 2002)

Adaptive Management Approach

An additional approach is the Adaptive Management approach, which is an iterative cycle of critical processes that begin with data and information collection, analysis, plan development, and finally, monitoring and evaluation (Pearson, Coggan, Proctor, & Smith, 2010). This management style greatly depends on stakeholder engagement to ensure the acceptance, ownership, uptake and success of the planning process. There are three main requirements for the success of adaptive management: the transfer of knowledge for transformation, monitoring and evaluation, and stakeholder engagement (Pearson, Coggan, Proctor, & Smith, 2010)

The systems and adaptive management approaches are strong models which could be used to implement LID in urban communities effectively. Using the strongest elements from each approach can help the systems approach will be used in the first stages of water management, and adaptive management practices are best applied in the review stage of the systems approach. The key concepts of stakeholder engagement and optimal resource allocation are to be considered in all stages of resource management.

Successful implementation also involves learning from previous mistakes. Previous implementation studies always result in a 'lessons learned' section. The lessons learned in past implementations, such as the case studies in the Sponge City developments in China, should be understood to avoid repetition of history. There are some barriers to the incorporation of integrated water resources management that have already been identified by (Pearson, Coggan, Proctor, & Smith, 2010) and are:

- Methods of engaging stakeholders are largely unsuitable for target communities and must consider a top-down engagement (Rauch et al., 2005).
- Professional norms and practices of urban water management are based on engineering methods and rationale and generally not appropriate for public consultation processes including timing (McManus and Brown, 2002).
- Organizational structures and norms provide barriers to the implementation of outcomes and ownership of consultation processes (McManus and Brown, 2002)
- Capacities of communities to participate are not catered for or understood (McManus and Brown, 2002).
- Willingness and desire of communities to participate may not be apparent (Blomquist and Schlager, 2005).

It is crucial that a proper level of background research is done before an implementation plan is determined. A successful water management system must be holistic, considering all components of the system, and involve water conservation practices with diverse fit-for-purpose water supplies. It also must work at a range of scales, both centralized and decentralized to ensure that all stakeholders are supplied with the appropriate water needs. Finally, the water management cycle must allow for the establishment of other environmental cycles, such as energy and nutrition (Bach, Rauch, Mikkelsen, McCarthy, & Deletic, 2014) For example, brown and yellow wastewater from sewage waste contain potential nutrients for agricultural fertilizer (Lofrano and Brown 2010).

Conclusion

In conclusion, low impact development is a highly feasible solution to achieve integrated water management to achieve the sustainable development goals outlined by the United Nations. However, there is not a one size fits all solution. Understanding the current landscape of development and the requirements of that community is crucial for a successful sustainable implementation. For example, a large city with a centralized population, and already existing infrastructure has vastly different needs from a developing area with little to no existing water infrastructure and a decentralized population. The low impact development projects are smaller in scale but may be applied to in highly populated cities. Successful LID projects involve the application of point-of-use water supply systems such as collecting the rainwater into storage for non-potable applications. These de-centralized, low impact developments can be used in any existing infrastructure. In China, Sponge Cities were created. The sponge city development is a large overhaul project with high capital costs. The successes in China have been relatively great, but this type of implementation plan is not feasible in other cities or regions. For one, the Chinese government was the sole provider of the funds, and China has the resources to implement and complete large-scale development projects over a short period. Therefore, sponge cities are a high-intensity form of low impact development. The ideologies between low impact development are to create an equitable water supply system without negatively impacting the environment.

One solution is not better than another. However, small scale development projects are easier to implement. Depending on the resources available, it is likely that the best solution is to divide the project into small sub-projects that will eventually resolve into a sustainable water city. When deciding on an implementation plan, it is also important to use all resources available and speak with key stakeholders. The need for integration of new solutions with local knowledge and resources is crucial to ensuring that the new sustainable infrastructure is maintained. Consideration factors include the existing local infrastructure, available resources, social and political factors, funding, hydrological and environmental features, and any other local circumstances. However, it is important to recall that the current ideological sustainable water city may change with new research and information.

It is therefore advisable that a water sensitive city undergoes the adaptive management approach after the systems approach was used to implement the initial infrastructure. The adaptive management ideologies refer to the need to undergo a continuous monitoring and review cycle. With changing technologies and priorities, the ideas for an ideological city may change. By using a low impact development approach to implement sustainable water management solutions, we are ensuring the fulfillment of SDGs 6.3 and 6.A. These feasible and creative solutions will prioritize protecting ecosystems and enhancing the quality and quantity of water available to all stakeholders within the hydrological cycle.

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