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Veeriah Jegatheesan · Ashantha Goonetilleke
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Urban Stormwater and Flood Management

Enhancing the Liveability of Cities

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Preface

The liveability of our cities is being compromised more frequently by extreme weather events. The water environment is also being degraded significantly. Furthermore, cities are increasingly water stressed, resulting in costly and reactive strategies such as resorting to seawater and inland brackish water desalination. This is attributed to the growing urbanisation and escalating water demand which are compounded by changing climate conditions such as during strong El Niño and La Niña events that significantly impact on rainfall patterns. The consequences can include significant environmental degradation and increasing economic and social burden on the affected communities. Stormwater management and flood mitigation initiatives such as water-sensitive urban design (WUSD), sponge city and sustainable urban drainage systems (SuDS) are being increasingly implemented to overcome these growing challenges.

However, implementation of such strategies can be localised and may not be integrated with the wider geophysical and social characteristics of the broader surrounding region. There are highly varied approaches towards stormwater harvesting, ranging from advanced systems such as aquifer storage, transfer and recovery to simple rainfall capture from roofs, with technologies and new approaches in ongoing development. This book addresses some of the current and likely challenges in stormwater management that may occur in the future such as increased risks to water quality, environmental impacts and the use of stormwater as a resource for human and environmental needs. Stormwater management challenges are further intensified by emerging and recently identified problems such as transport of key synthetic organic pollutants, e.g. Per- and poly-fluoroalkyl substances (PFAS), antibiotic-resistant bacteria and genes, transport of nutrients and social acceptance and current regulations relating to stormwater capture and reuse. Future impacts of growing urbanisation on flood risks, also associated with changing climate and mitigation, need to be considered as well. The effective management of stormwater in our cities not only addresses many of these challenges but also can enhance the quality of life, local biodiversity and other environmental attributes, as well as the health and well-being of residents. This book explores how responses to all these considerations can be better integrated to enhance the liveability of our cities.

Now, how did this book idea come about? Meetings between Australian Technology Network (ATN) of universities (comprising of 5 universities in Australia) and the University Alliance of the UK (comprising of 19 universities in the UK) identified research areas and knowledge dissemination on stormwater harvesting and flood management and requested interested members to form a consortium to apply for an ATN Science and Research Priorities Seed Fund. Four out of five ATN Network of Universities (Queensland University of Technology, RMIT University, University of South Australia and University of Technology Sydney) met and agreed to conduct a review to identify current practices related to stormwater and flood management as well as to identify the research needs and industry imperatives in this field. The proposal was approved for funding in November 2016. The ATN partners of the project communicated with researchers from the University Alliance of the UK (University of Hertfordshire, Sheffield Hallam University, University of Portsmouth, Nottingham Trent University and Liverpool John Moores University), and the University of Hertfordshire and Sheffield Hallam University formed a consortium with the ATN partners of this project to contribute to a book. Thus, this book is a culmination of several meetings in Australia and a meeting in the UK and from subsequent discussions among the research partners.

This book comprises eight chapters, starting with an introductory chapter that discusses past and present stormwater practices around the globe. It discusses the various initiatives across the world such as WSUD, sponge city programme, SuDS and low impact development (LID). Stormwater governance in Australia, Baltic Sea Region, Canada and the USA, Latin America, the Republic of South Africa and Southeast Asia is also briefly addressed, including case studies.

The second, fourth and sixth chapters of this book deal with UK perspectives on stormwater harvesting and flood mitigation. These include an overview of the issues and barriers to potential solutions (Chap. 2) followed by an examination of WSUD (Chap. 4) and stormwater harvesting (Chap. 6) in detail. Reliance on centralised water supply systems and the lack of small-scale locally implementable techniques are discussed in Chap. 2. Appropriate WSUD systems for different landscapes and their design practice, field implementation and life cycle assessment are discussed in Chap. 4. Factors to be considered in stormwater harvesting such as pollution, treatment, constraints to wider adoption and environmental and economic considerations are included in Chap. 6. Chapter 5 deals with the Australian perspectives on recycling and treatment of stormwater under urban intensification. Several case studies are provided as exemplars of successful implementation of rainwater harvesting, treatment of stormwater through wetlands and managed aquifer storage and recharge. The use of treated wastewater is also included to show the potential of stormwater usage for similar purposes. It is important to know the types of pollutants present in stormwater and their fate before delving into WSUD and stormwater recycling. Accordingly, Chap. 3 provides a detailed overview of urban stormwater quality. Types of pollutants and their concentrations, transport processes as well as their variability and uncertainty, impacts and knowledge gaps are discussed in this chapter.

Both the Australian and UK perspectives on urban stormwater and flood management are further analysed in Chaps. 7 and 8. While Chap. 7 focusses on the challenges, the governance and the knowledge gaps and barriers in implementing urban stormwater and flood management, Chap. 8 considers the relationship between biodiversity and ecosystem services and urban stormwater and flood management.

We hope that this book provides a valuable compilation and consolidation of information that facilitates improved understanding of stormwater management and flood mitigation based on Australian and UK perspectives. A primary aim in producing this book was that it would form the basis for the development of a framework for implementation of integrated and optimised stormwater management strategies in order to mitigate the adverse impacts of an expanding urban water footprint.

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Contents

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Baden Myers is a Research Engineer at the University of South Australia. Baden graduated from the University of Technology, Sydney, with a Bachelor of Engineering (Civil and Environmental) in 2005. He completed his PhD based on a study of the physical, chemical and biological processes affecting stormwater quality in permeable pavement structures. His current research interests include stormwater harvesting, urban hydrology, green infrastructure, stormwater drainage and water-sensitive urban design (WSUD).

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Kevin Spence is a Senior Lecturer at Sheffield Hallam University. Kevin's teaching interests include domestic house construction (historic and modern), building conservation, land surveying, structures, geotechnics, water engineering, flood estimation and statistics. His research interests focus on solute and sediment transport and its impact on water quality in urban drainage and river systems during steady flows and rainfall events using laboratory and field investigative techniques, traditional building construction and land evaluation in a Mediterranean climate.

Geoffrey Parker is a Senior Lecturer in Water Engineering at Liverpool John Moores University. He is currently the Principle of BioFlume which specialises in the development of novel and disruptive solutions for the optimisation/protection of infrastructure and natural resource assets. He is also a contributor and named researcher on several major grants, including the successful 2014 (~ £4.5M) award for the Centre for Doctoral Training (CDT) in Future Infrastructure and the Built Environment (FIBE) funded by the UK EPSRC.

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Chapter 1
Introduction to Urban Stormwater: A Global Perspective

John van Leeuwen, John Awad, Baden Myers, and David Pezzaniti

Abstract Stormwater is seen as a water resource that needs to be captured, stored and utilised in meeting current and future water supply demands. However, increase in impervious surfaces due to expansion of urbanisation has led to increase in pollutants being transported through stormwater runoff and an increased risk of flooding. The world's urban population continues to steadily grow, and the absolute increases in urban populations remain very high and are expected to reach 66% of total world population by 2050. Consequently, ongoing development on managing water resources and water sustainability in urban environments is needed to address risks from increased stormwater flows arising from further development of impervious areas, due to expanded human populations and urban growth. This introductory chapter gives an overview of past and current management of stormwater for flood mitigation, for improved stormwater quality and sustainable practices such as SuDS, LID and WSUD. Existing governance for stormwater management and flood mitigation in selected cities is also included to identify future needs for improving liveability.

Keywords Governance · Harvesting · International · Management · Reuse · Urban · Stormwater

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1.1 Background

Stormwater is an important issue considered by governments at various levels, the building and construction industries, university and other tertiary institutes and the general community. Stormwater has impacts on human living spaces, infrastructure and natural environments and also has value as a water resource. It may be assumed that its meaning is generally understood and agreed on by practitioners and stakeholders. However, definitions of stormwater vary and should be considered in the context of the definition of "runoff" more generally. For example, the Oxford Dictionary defines stormwater as "surface water in abnormal quantity resulting from heavy falls of rain or snow" (Oxford Dictionaries 2017). The National Research Council (2008) in the USA describes stormwater as "that portion of precipitation that does not naturally percolate into the ground or evaporate, but flows via overland flow, interflow, channels, or pipes into a defined surface water channel or a constructed infiltration facility". The Victorian Building Authority (2014) in Australia gives a definition as "rainwater that falls on the ground, paving, driveways or other hard surfaces within a property. It also includes overflows from tanks and roof guttering". Urban stormwater has been defined as "runoff from urban areas, including the major flows during and following rain, as well as dry-weather flows" (Agriculture and Resource Management Council of Australia and New Zealand 1996).

Stormwater generally refers to waters that could impact detrimentally on urban infrastructure and communities including physical damage such as erosion from flows and floods of different scales, increased health risks to communities and ecosystems and transport of chemical and biological pollutants that lower the water qualities of receiving environments (Barbosa et al. 2012; United States Environmental Protection Agency 2012a). It can comprise of materials and constituents accumulated on surfaces including litter, dust and soil, fertilisers, pesticides, micro-organisms, metals, oils and grease (Department of Environment and Heritage 2002) but also constituents less noted for their presence in stormwater, such as per- and poly-fluorinated alkyl substances (Australian Government Department of Defence 2016; City of Salisbury 2016). Through mixing with sewerage effluents in some situations (see Sect. 1.2), higher loads of pathogenic organisms can be collected, in addition to other wastewater-derived pollutants including antibiotic-resistant genes (Garner et al. 2017), endocrine disrupting compounds (EDCs) (Kalmykova et al. 2013) and pharmaceutical compounds (Birch et al. 2015; Zhang et al. 2016).

Increase in impervious surfaces due to expansion of urbanisation leads to the increase in stormwater runoff flow rates, volumes and pollutant loads being transported, which has subsequent impacts on receiving aquatic environments (Aryal et al. 2010; Smith and Fairweather 2016). Increased runoff peak flow and volume physically degrades natural waterways (Walsh et al. 2012). Transport of stream-derived sediment, in addition to pollution from human activity, is a significant source of nearshore pollution including faecal indicator bacteria and viruses (Ahn et al. 2005; Schiff and Bay 2003), nutrients (Fabricius 2005) and suspended solids (Fox et al. 2007). Pollutants from stormwater runoff can also lead to the degradation of a range of coastal habitats i.e. reefs, estuaries and rocky shores (Smith and Fairweather 2016; Cox and Foster 2013; Kinsella and Crowe 2015).

The quality of stormwater in urban and city environments is a function of the contributing catchment characteristics. These include local climate and seasonal variations, land use and degree of imperviousness, existing infrastructure and management, the distance of stormwater from source to receiving environments and current and historic stormwater management practices. Stormwater management is essential for the control of flooding in urban areas and ongoing development is needed to address the impacts from climate change, increasing urban growth and human population expansion.

The world's urban population continues to steadily grow. From 1960 to 2016, the proportion of the global population living in urban areas increased from 33.6% to 52.3% (The World Bank 2017). In China alone, large-scale urbanisation started in the 1980s and increased rapidly from 36.2% in 2000 to 54.8% in 2014 (Li et al. 2017). In Africa, overall urbanisation is expected to increase from about one-third of the population in 2015 to about half the population by 2050 (African Progress Panel 2015). Globally, urban population is expected to reach six billion by 2045 with much of this growth in developing nations. The number of megacities (cities with populations > 10 million) has increased from 10 in 1990 to 28 in 2014, and it can be expected that this expansion will continue (United Nations 2014). Growth in urban population requires urban environments to expand or become more densely populated. In either case, the increased level of built infrastructure and accompanying impervious areas will cause hydrological and ecological changes to receiving waters (Burns et al. 2012) if stormwater management is undertaken in the conventional manner of rapid disposal, as described in Sect. 1.2.

1.2 Past and Present Stormwater Management Practice

The management of stormwater has historically been driven by the need to protect the community from the adverse (sanitary and flood) impacts created by rainfall and runoff. This has led to the development of hydraulically efficient systems for the collection and conveyance of runoff to a receiving location, typically a stream, lake or ocean outfall. Across many jurisdictions, the primary objective for stormwater management that continues to exist is to provide protection to the community. Authorities at several levels are charged with ensuring a standard of flood protection is provided to the public. In many instances, these authorities have developed guidelines and standards for setting minimum requirements for flood management, and multiple guidelines can exist even in a single country. For example, in Australia, there are guidelines at the national level, namely the Australian Rainfall and Runoff

Guidelines (Ball et al. 2016) and specific to some state governments such as Queensland (Institute of Public Works Engineering Australia 2013). For flood protection, these guidelines use the magnitude and frequency of runoff events as a means to provide a level of protection. Typically, there are two standards of flood protection proposed by these guidelines (Ball et al. 2016):

1. Higher-frequency, lower-magnitude runoff events – events expected to occur with a shorter average recurrence interval, e.g. 2–10 years – to enable safe pedestrian and vehicle passage in urban areas
2. Lower-frequency, higher-magnitude events – events expected to occur with a longer average recurrence interval, e.g. greater than 50 years – that should be managed to protect life and infrastructure

In Australia, stormwater runoff has been managed using a network of pipework systems separate from sewer systems (Department of Environment and Heritage 2002), while in other countries such as the USA (Southeast Michigan Council of Governments 2008), China (Che et al. 2011; Wu et al. 2016; Li et al. 2014), the UK (Southern Water, accessed 2017; Dwr Cymur Welsh Water, accessed 2017) and some European countries (Ashley et al. 2007), there are many cities where stormwater management includes the use of combined sewer systems where stormwater and wastewater are conveyed together via a single pipe drainage system.

1.2.1 Drainage System Approaches

Mixed storm and sewer waters and combined sewer overflow can present a wide range of risks from contaminants such as EDCs, pharmaceuticals, personal care compounds (Ryu et al. 2014) and pesticides (Park et al. 2017). Combined sewer waters present challenges in terms of treatment requirements, especially during high flow events. Management for this includes temporary storage of excessive water flows (e.g. Wu et al. 2016) until these can be treated at a wastewater treatment plant or diverted without treatment to receiving environments (e.g. Southeast Michigan Council of Governments 2008).

Due to the benefits of separation, recent and ongoing infrastructure developments globally are generally implementing separate stormwater and sewer systems (Southeast Michigan Council of Governments 2008). However, despite the separation of stormwater from sewer systems, wet weather conditions can still lead to overflows from sewerage systems, which impact on waterways and cause significant problems (Department of Environment and Energy 2002).

According to one Australian source (Victorian Builders Authority 2014), stormwater can pose the same risks as sewage effluent and should always be treated before any reuse. Li et al. (2014) reported a study on the performances of separate sewer systems (SSS) and combined sewer systems (CSS) of Shanghai and Hefei, finding that serious illicit connections occurred for some SSS. Their results showed that for the systems investigated, there was no obvious advantage of having SSS over CSS in terms of pollutant control, suggesting that the mix of stormwater and sewer waters presented the same risks as sewer wastewaters alone. Park et al. (2017) reported that many studies have focussed on organic wastewater contaminants such as EDCs and pharmaceuticals and personal care products (PPCPs), with the underlying assumption that the chemicals of concern come from point source municipal wastewater treatment facilities. However, they reported that significant EDCs and PPCPs may also come from nonpoint sources such as agriculture and urban/suburban runoff and hence are potential contaminants in stormwater.

Despite the infrastructural separation of this water resource from sewerage networks, significant challenges still exist in this form of water supply. These include high variability in flows from extreme rainfall events, prolonged droughts and costly infrastructure for stormwater utilisation that includes capture, treatment (for traditionally recognised pollutants) and separate pipelines for distribution to users. There are further risks from pollutants derived from catchment-specific human activities that have gone unrecognised until these are subsequently detected in downstream stormwater, as demonstrated by contamination by Per- and poly-fluoroalkyl substances (PFAS) derived from past use as a fire retardant. For example, at a military defence base in South Australia (Australian Government Department of Defence 2016) within a stormwater catchment of the City of Salisbury, low levels of PFAS have been detected in drains, wetlands and aquifers near to that base (City of Salisbury 2016), which subsequently affect stormwater harvesting operations.

1.2.2 New Approaches to Stormwater Management

In Australia, with much traditional stormwater management being focussed on rapid transport from urban areas to receiving waters, stormwater had received little, if any, treatment (Department of Environment and Energy 2002). In many instances, the rapid collection and transport of runoff has led to flooding in downstream reaches, requiring peak flow mitigation typically in the form of runoff volume detention, where stormwater is temporarily stored and released at a controlled flow rate without treatment (Argue and Pezzaniti 2005). Other practices for ameliorating flooding involve retention practices where runoff is captured and either allowed to infiltrate into soil on site or be used as an alternative water resource. In some instances, stormwater systems can provide multiple benefits for flood control through stormwater detention and retention.

Historically, the management of stormwater has focussed attention at the point of discharge. However, it is now recognised that better outcomes (e.g. stormwater quality) can be achieved if efforts are directed throughout the catchment to minimise treatment needs (Environment Protection Authority South Australia 2007). This emulates a Hazard Analysis and Critical Control Point (HACCP) approach that is well established in the food and beverage industries (Bradsher et al. 2015) and for management of drinking water quality and supply in Australia (Australian Drinking Water Guidelines 2011).

According to the Australian Department of the Environment and Energy (2002), a well-designed, integrated stormwater system can provide a range of community benefits including minimisation of flood risk, protection of downstream water bodies, preserving aesthetic values, recreational facilities, natural habitat conservation and water reuse. The Department of Environment and Energy (2002) details that this can be achieved by management of source control, contaminant interception and receiving waters.

More recent stormwater management approaches globally include enhanced stormwater retention and rainwater infiltration as part of programmes such as water-sensitive urban design (WSUD) in Australia, the “Sponge City” initiative in China (Li et al. 2017; Austrade 2016), sustainable urban drainage systems (SuDS) in the UK (NetRegs, accessed 2017) and low impact development (LID) in the USA (United States Environmental Protection Agency 2012b). Dhakal and Chevalier (2016) referred to such approaches alternatively as green infrastructure (GI). The background and definition of these and other similar approaches has been well documented by Fletcher et al. (2015). For these, the focus is on managing water resources in urban environments that includes addressing risks from increased stormwater flows arising from further development of impervious areas from expanded human populations and urban growth (Li et al. 2017; United States Environmental Protection Agency 2012b; Chandana et al. 2010). Stormwater management strategies are formulated on the basis of increasingly recognising the need to emulate predevelopment flow regimes in addition to reducing pollutants and their loadings (Hamel and Fletcher 2013).

Current advances in stormwater management such as LID, WSUD, SuDS and Sponge Cities involve a shift in approach from a reactive response through engineered actions to more interactive and collaborative water management styles (Yang 2016). For instance, in the Netherlands, the “Space for Rivers, 2007” and the “Building with Nature” programmes under the Climate-Proof City initiative involve taking approaches to stormwater management as working or building within the scope of naturally occurring variances, i.e. “a paradigm shift from building in nature to building with nature” (Yang 2016; de Vriend and van Koningsveld 2012).

1.2.2.1 Water-Sensitive Urban Design

The ongoing and increasing application of WSUD principles in Australia has enabled the control and better management of stormwater runoff, minimisation of pollution and for storage and reuse to occur in urban, commercial and industrial settings (Department of Environment and Energy 2002). The peak professional body in Australia (Engineers Australia) for stormwater management has recognised the need to provide guidance on broader management of stormwater, including integrated water management approaches such as WSUD (e.g. Wong 2006 and Ball et al. 2016). Local jurisdictions have also taken a broader approach to managing