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THE EVOLUTION OF LOW IMPACT DEVELOPMENT

WATER SENSITIVE URBAN DESIGN AND ITS EXTENSION TO CHINA AS "SPONGE CITIES"

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ABSTRACT

Since the 1980s urban planning and development has begun to take account of the natural water and nutrient cycles, seeking to manage water flows as would have occurred on the original greenfield site, emulating the original ecosystem. These approaches advanced in North America as *Low Impact Development* and later *Green Infrastructure* in response to the 1972 passage of the *Clean Water Act* (US).

Such developments can incorporate green roofs, rain gardens, swales, permeable pavements, wetlands, green spaces, and urban natural vegetation corridors. Britain adopted *Sustainable Urban Drainage Systems* techniques. In Europe, planners and local government respond to the EU *Water Management* and *Flooding Directives* on a river basin basis. In Australia, similar policy developments took place under the philosophy of *Water Sensitive Urban Design*.

The components and drivers vary between the states, each choosing emphases appropriate to their catchments, infrastructure, seasonal climate, local water cycle and community expectations.

Cities in East Asia have been undergoing rapid urbanisation over the past 40 years, often accompanied by increased flooding, especially in China. In 2013, China introduced new urban development policies which included the concept of *Sponge Cities* where "stormwater can be naturally conserved, infiltrated, and purified" for potential reuse, thereby reducing flood risks and increasing water availability.

Construction guidelines were issued. Thirty major cities are participating as pilot cities. Each is eligible for central government subsidies. Addressing technical integration problems, legislative constraints and community acceptance will be necessary for them to become *Water Sensitive Cities*.

INTRODUCTION

Since the 1980s, management of stormwater has undergone progressive change – in part driven by changes in the nature of cities, the increased proportion of the population living in them, and the frequency of flooding. However, the widespread creation of Environment Protection Authorities also had an impact.

Whilst these gave attention to the composition of waters from Waste Water Treatment Plants being added to receiving waters, attention also was directed to the composition of stormwaters and the non-point pollution attached to them. Progressively, understanding broadened to encompass the whole hydrological cycle bringing in concepts of Integrated Catchment Management (ICM) or Total Catchment Management (TCM).

As thinking progressed further, understanding led to a concept encompassing the entire development and evolution of cities. These developments resulted in a variety of technology descriptors such *as Low Impact Development, Green Infrastructure, Sustainable Urban Drainage Systems, Water Sensitive Urban Design, Low Impact Urban Design and Development* and *Water Sensitive Cities* being adopted in different countries (Fletcher *et al*., 2015).

However, there must be an integration of policies governing the growth of cities. There is no one definable problem and no one big solution.

There are many small, mutually dependent problems and solutions (Wong 2016). The solutions appropriate to each location will be dependent on the hydrological, infrastructural, planning and sociological circumstances, the need to protect urban watercourse ecosystem health and in likely consequence, the sought reduction in total suspended solids (TSS), total nitrogen (TN) and total phosphorus (TP).

Not the least of the considerations will be whether the city has a combined sewer system that also takes stormwater, a design common in many older cities such as London, as well as in Japan and in Eastern North America, even though new such installations have not been permitted since the mid-twentieth century.

Combined sewers are not used in any major Australian city with the exception of central Launceston (Jessup 2015) and consequently sewer overflows and contamination of urban watercourses are much less of a problem in Australia.

North America

Within the United States, the term *Low Impact Development* (LID) has come into widespread acceptance. The first use appears to have been by Barlow (1977) covering land use planning in Vermont following the introduction of the US Federal *Clean Water Act* in 1972 (USEPA 2016).

More widespread acceptance was strengthened by a seminal LID manual prepared for use in St George's County, Maryland, later reprinted for wider use (Coffman 1999), seeking to emulate the original "natural" hydrology extant before urban development had taken place.

The ill-defined expression Best Management Practice (BMP) came into use mainly to encompass pollution issues, but following a review of stormwater practice (National Research Council 2008), was replaced by Stormwater Source Control (SCM).

Bio-retention and bio-infiltration technologies have developed as principal control mechanisms at source (Davis *et al*., 2009), rather than relying on end of pipe solutions such as large sedimentation dams. However, the regulatory environment for implementing LID is managed by the states with great variability.

Over 770 US cities have combined sewer systems that lead to the discharge of overflows (including untreated sewage) into receiving waters during storm events (USEPA 2016a).

Image 1: Entering the Yanqi Lake Ecological Demonstration Park which is a 2100 hectare research project of the Sponge City Plan in Beijing.

A National Municipal Stormwater Alliance (NMSA) has been formed in the US to coordinate the activities of state and regional municipal stormwater organisations, with a vision to provide clean water for the nation (NMSA 2016).

This is based on meeting stormwater quality runoff standards for stormwater separately transported through ***M****unicipal* ***S****eparate* (not combined) ***S****torm* ***S****ewer* ***S****ystems* (MS4s), which often discharge untreated stormwater into local water bodies.

The US uses a concept of *Total Daily Maximum Load*, required under section 303(d) of the *Clean Water Act* (US), for discharges from pollution sources to waterways. It is a calculation of the maximum amount of a pollutant that a water body can receive, and still meet water quality standards based on its beneficial users, and an allocation of that amount to the source of pollutants causing the impairment (USEPA 2016b).

There have also been concerns that Low Impact Developments may be less effective in cold climates where the ground can be frozen, and poor substrate permeability and low biological growth rates coincide with high flows from subsequent snow melts.

However, Roseen *et al*., (2009) concluded that while impacts due to cold climate were observed, they were not substantial with regard to changes in hydraulic efficiency.

Meanwhile, the concept of *Green Infrastructure* (GI) has been developed, linking landscape architecture and urban ecosystem services with water cycle management. Planning may incorporate green roofs, rain gardens, swales, permeable pavements, improved infiltration, wetlands, green spaces, and urban natural vegetation corridors to improve urban amenity as well as reducing flood and pollution risks.

The initiative is supported by the Environment and Water Resources Institute of the American Society of Civil Engineers, which strives to lead the integration of public policy and technical expertise into the planning, design, construction, operation, management, and regulation of environmentally sound and sustainable infrastructure. (ASCE-EWRI 2016).

Britain and Europe

Sustainable Urban Drainage Systems (SUDS) was developed in Britain, and resulted in the publication in 2000 of definitive guidance documents for Scotland and Northern Ireland and separately for England and Wales, since progressively revised as The SUDS Manual (Woods Ballard *et al*., 2016). SUDS is a key part of water sensitive urban design (WSUD), integrating the management of surface water run-off into the urban form, but WSUD has a broader consideration of the whole water cycle including wastewater and water supply and the wider integration of water courses and flood pathways within urban planning and design.

Image 2: Observing the performance of a weir at the Yanqi Lake Park during rainfall.

Image 3: Red crucian carp (*Carassius auratus* red var.) Beijing Botanical Gardens

The four primary benefits of SUDS are oriented to water quantity, water quality, amenity and biodiversity. The philosophy is to try to mimic natural hydrology that may be impacted by urban development. Orientation is primarily towards water quantity rather than quality through mitigating peak flow rates and run-off volumes. Reducing potential pollution impacts and bank erosion risks are also important.

Many strategies are described in detail such as rainwater collection as a resource, green roofs, pervious pavements, bio-retention systems such as rain gardens that allow temporary ponding and soil infiltration, increasing evapotranspiration from revegetation such as tree planting, and the use of swales, detention basins, ponds and wetlands to encourage water quality remediation and to slow run-off rates.

Most encourage infiltration and recharge to groundwater. Run-off events are to be controlled to ensure that peak flows do not affect the morphology or ecology of receiving waters. For previously established drainage systems, capacity structures will have been designed to accommodate a 1:100 year flood event.

There should be no run-off from small frequent (5mm) rainfall events – these should be intercepted on site, especially as they may contain the "first flush" of non-point pollution, thereby minimising impact on downstream ecosystem health.

The SUDS manual provides methods to estimate various run-off characteristics, referring to earlier Flood Estimation Handbooks and the regional variations that can be adopted in Britain and Ireland to estimate peak flow frequency curves.

Design should provide that there is no flooding on site for up to 1:30 year events unless there is community acceptance of temporary overflow facilities, such as car parks that have other community functions.

Within the European Union, a revised Water Directive (2000), which was transposed into United Kingdom legislation in 2003, sought to expand the scope of water protection to all surface and ground waters; achieving "good status" for all waters by a set deadline; developing water management based on river basins; establishing a "combined approach" of emission limit values and quality standards; getting the prices right; getting the citizen involved more closely, and streamlining legislation.

Objectives are set for each river basin encompassing ecological status, quantitative status, chemical status and protected area objectives (EU 2016a). Flood Risk management plans were to be developed by 2015, but no specific technologies have been outlined.

However, the Director-General, Environment, of the European Commission has identified preferred options for the flood risk management through working with nature, rather than against it. Building up green infrastructure – which requires investing in ecosystems – offers triple-win measures: (1) contribution to the protection and restoration of floodplain and coastal ecosystems, (2) mitigation of climate change impacts by conserving or enhancing carbon stocks or by reducing emissions caused by wetland and river ecosystem degradation and loss and, (3) provision of cost-effective protection against some of the threats that result from climate change such as increased floods. Key services of floodplain ecosystems are defined as water retention, clearance of water and prevention of soil erosion – services which can considerably contribute to flood prevention and mitigation if the delivering ecosystems are in good health (D-G Environment 2011).

Due to the nature of flooding, much flexibility in objectives and measures is being left to the Member States in line with "subsidiarity", a principle that directs attention to the levels of government where policy objectives can best be formulated and implemented (EU 2016b). Thirty-four guideline documents are available. Those responsible are being expected to review plans and maps every six years.

Where real risks of flood damage exist, flood hazard maps and flood risk maps were to be developed by 2013 for such areas. These maps identify areas with a medium likelihood of flooding (at least a 1 in 100 year event) and extreme events or low likelihood events, in which expected water depths should be indicated in the areas identified as being at risk.

Image 4: Some Chinese lakes and wetlands have earlier origins. The Lotus Pond in Baoding (Hebei Province) was established by the Dowager Empress Cixi who effectively ruled China in the late Qing Dynasty from 1861 to 1908.

The number of inhabitants and economic activity potentially at risk and the environmental damage potential must be indicated. By 2015 flood risk management plans must have been drawn up for these zones, and almost all EU countries have done so (EU 2016b).

Australia

Following an initial use of the term *Water Sensitive Urban Design* (WSUD) by Mouritz (1992), the first formal guidance to it appears to be by Whelans and Halpern Glick Maunsell (1994), and was soon summarised as formulating development plans that incorporate multiple stormwater management objectives, and involve a pro-active process which recognises the opportunities for urban design, landscape architecture and stormwater management infrastructure to be intrinsically linked (Wong 2000).

From 1994, various Ministerial Councils developed the National Water Quality Management Strategy (ARMCANZ & ANZECC 1994) which now encompasses 24 guidelines covering water quality, groundwater, diffuse and point pollution, sewerage systems, effluent management and water recycling.

In consequence of the commitment in the Intergovernmental Agreement on the National Water Initiative, guidelines were issued for Water Sensitive Urban Design (Joint Steering Committee for Water Sensitive Cities, 2009). These guidelines encompass the integrated design of components of the urban water cycle, incorporating water supply, wastewater, stormwater and groundwater management, urban design and environmental protection.

The guidelines suggest that operations should be aiming for 80% reduction in total suspended solids, 60% reduction in total phosphorus, 45% reduction in total nitrogen and a 90% reduction in gross pollutants when compared to untreated stormwater run-off.

By using a variety of WSUD techniques, the post-development peak one-year Average Recurrence Interval (ARI) event discharge to the receiving waterway should not exceed the pre-development condition.

Image 5: LID 2016 Conference delegates inspect a wetland established as part of the Yanqi Lake Ecological Demonstration Park.

MUSIC (Model for Urban Stormwater Improvement Conceptualisation) is a software program originally developed by the Cooperative Research Centre for Catchment Hydrology and since upgraded to model a wide range of treatment devices to identify the best way to capture and innovatively manage and/or reuse stormwater, reduce its contaminants load, and reduce the frequency of runoff.

It supports WSUD principles and evaluates alternative treatment devices until the best combination of cost, hydrology and water quality improvement is achieved (eWater 2016).

Australian thinking has also developed the concept of *Water Sensitive Cities* in which the cumulative socio-political drivers for a set of evolutionary steps in the development of a city have been articulated (Brown, Keath and Wong 2008).

Six progressive achievement levels of the urban water system are recognised as a city develops. The first three stages describe the evolution of the water system to provide essential services such as secure access to potable water ("Water Supply City"), public health protection ("Sewered City") and flood protection ("Drained City"). These are followed by the "Waterways City", "Water Cycle City" and ultimately a "Water Sensitive City".

The latter provides a palette of services including social amenity (for example - green spaces and ameliorating city heat island effects) and environmental protection, reliable water services under constrained resources (including accessing non-climate dependant sources), intergenerational equity and resilience to climate change.

The Cooperative Research Centre for Water Sensitive Cities, established in 2012, has since been developing an index for benchmarking water sensitive cities (Chesterfield *et al.,* 2016).

Most States have implemented policies based on the principles of WSUD, though emphases vary with local priorities. Queensland (2016) has a comprehensive approach within its State Planning Policy regulatory instrument with especial emphasis on environmental values, stormwater management and acid sulfate soils.

Many specific parameters are included in its stormwater planning including controlling the rate and volume of run-off to approximate pre-development values, including for the one in one year average flood recurrence interval (ARI) frequency, impervious area first flush systems, infiltration techniques and stream rehabilitation. (Queensland 2010). Within South-east Queensland, following the Moreton Bay study (Dennison and Abal 1999) there has been a strong thrust of conserving the ecological quality of Moreton Bay by controlling wastewater treatment plant nitrogen plumes. This has been followed by an unique program to protect and improve waterways with a collaborative model involving strong community, industry, government and research partnerships (Healthy Waterways and Catchments 2016).

A WSUD Program, part of the Greater Sydney Local Land Services, seeks to identify and address capacity needs within the Sydney Metropolitan region, assisting Sydney's transition to a Water Sensitive City (New South Wales 2014).

The adoption of WSUD in NSW is not enacted by any State legislation or policies but has a strong thrust of increasing urban water use efficiency in new developments and managing stormwater. The *Environmental Planning and Assessment Act, 1979 (NSW)* and the *Local Government Act 1993 (NSW)*, established a planning framework using State Environment Protection Policies (SEPPs) and Regional Environmental Plans (REPs) to set objectives, policies and requirements for developments having state or regional significance.

The main WSUD-related SEPP is the Building and Sustainability Index (BASIX) scheme, driven through the Environmental Planning and Assessment Regulation 2000 (EP&A Regulation) and 2004 State Environmental Planning Policy: BASIX which, among other attributes, requires a 40% reduction in potable mains water use for all new residential developments and redevelopments. Stormwater management includes strong orientation to erosion and sediment control (New South Wales 2015).

The Victorian State Environment Protection Policy (Waters of Victoria) identifies a number of beneficial uses of Victoria's waterways including natural aquatic ecosystems and associated wildlife; water-based recreation; agricultural water supply; potable water supply; production of molluscs for human consumption; commercial and recreational use of edible fish and crustaceans; and industrial water use.

There had been concern that stormwater and industrial pollution issues could be effecting the Port Phillip Bay catchment, which receives runoff from one of Australia's most densely populated catchments of nearly 10,000 square kilometres. The seminal Port Phillip Bay Environmental Study of 1996, which was an important contribution to policy development, established that the Bay was remarkably resilient, principally because the entering toxicants (heavy metals, pesticides and petrochemicals) were being largely "locked up" in the sediments.

Nitrogen had a rapid turnover in the populations of aquatic micro-organisms and seafloor organisms (Harris *et al*., 1996) leading to substantial denitrification rather than eutrophication. WSUD is now recognised as an alternative to the traditional conveyance approach to stormwater management (Melbourne Water 2016a).

It seeks to minimise the extent of impervious surfaces and mitigate changes to the natural water balance, through on-site reuse of the water as well as through temporary storage. Specific Victorian guidelines for stormwater management cover 80% retention of the typical urban annual load for Total Suspended Solids (TSS), 45% retention of the typical urban annual load for Total Phosphorus (TP), 45% retention of the typical urban annual load for Total Nitrogen (TN) and 70% retention of the typical urban annual load for gross pollutants (litter).

The guidelines prescribe that discharges for 1.5yr average recurrence interval (ARI) be maintained at pre-development levels for stormwater treatments (Victorian Stormwater Committee 1999). Melbourne Water operates a stormwater offset service which involved in 2016 a financial contribution by residential developers of $6,645 per kilogram of annual total nitrogen load for stormwater management works to be undertaken in another location.

Image 6: The Shijiazhuang (Hebei) Botanical Gardens were completed in 1998 but extended to 157 ha in 2003 as a green infrastructure project for the north side of the city and to protect against sand storms. This landscape feature actually serves as the observation site for conservation of fish species.

These works 'offset' stormwater impacts not treated within the development (Melbourne Water 2016b).

South Australia has produced its own Technical Manual (South Australia 2010), with the objective of minimising demand on the reticulated water supply system; protecting and restoring aquatic and riparian ecosystems and habitats; protecting the scenic, landscape and recreational values of streams; minimising treated wastewater discharges to the natural environment and integrating water into the landscape to enhance visual, social, cultural, biodiversity and ecological values.

It seeks to reduce greenhouse gas emissions by reducing water consumption, increasing rainwater harvesting and "natural" treatment alternatives. The Manual recognises all water sources in the total water cycle as valuable resources including rainwater (collected from the roof); runoff (including stormwater collected from all impervious surfaces); potable mains water (drinking water); groundwater; greywater (from bathroom taps, showers and laundries); and blackwater (from kitchen sinks and toilets).

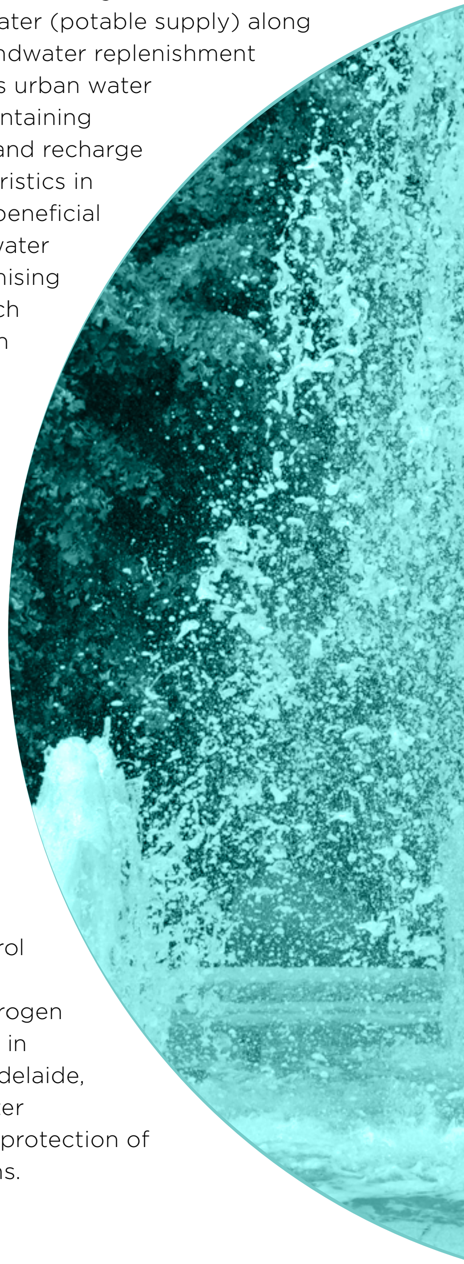
The South Australian Manual reflects the dry Mediterranean climate, limited catchment water harvesting opportunities and the importance of groundwater for high value agriculture. It includes an emphasis on waste water and the associated need to meet discharge standards to receiving waters, especially to St Vincent Gulf adjacent to which Adelaide is built.

During the period 1949 to 1995, some 4000 ha of seagrass was lost between Aldinga and Largs Bay. Seagrass along the Adelaide coastline continued to decrease with 720 hectares lost between 1995 and 2002 (South Australia 2003). Mangroves also decreased, but pollutant loads from treated waste water discharged into Gulf St Vincent were also reduced.

An Adelaide Coastal Waters Study was initiated in 2002. This showed that there was no evidence that toxicants or nutrients other than nitrogen played a key role in the ecosystem degradation. However, sediment movement inshore of the seagrass beds was sufficient to prevent regrowth of seagrasses (Fox *et al*. 2007). Results were similar to other studies such the Port Phillip Bay and Moreton Bay studies. The results were drivers to address issues through an all-encompassing interpretation of WSUD.

Western Australia similarly accepts WSUD as it strives to have Perth become a "waterwise city", encompassing management of catchments to maintain or improve water resources; managing risks to human life and property including adequate flood clearance from 100 year average recurrence interval flooding, and surface or groundwater inundation/waterlogging; ensuring the efficient use of water resources, and recognising and maintaining economic, social and cultural values.

An extensive set of policies and guidelines links water and state planning processes (New WAter Ways 2016a, 2016b). With South-west Western Australia's drying climate and Perth's dependence on groundwater for about 45% of its scheme water (potable supply) along with desalination and groundwater replenishment from recycled water, Perth's urban water management strives to maintaining appropriate aquifer levels, and recharge and surface water characteristics in accordance with assigned beneficial uses by managing groundwater recharge sustainably; minimising the export of pollutants such as phosphorus and nitrogen to surface or groundwater; and preventing groundwater acidification processes (Western Australia 2008).



It can be concluded that whilst WSUD is widely recognised across Australia, the emphasis varies in response to local circumstances, as it should. Brisbane is particularly oriented to protecting urban creek ecosystem health and consequently the riparian environment.

Erosion and sediment control are important in Brisbane, Sydney and Melbourne. Nitrogen management is highlighted in Brisbane, Melbourne and Adelaide, particularly from waste water treatment plants to ensure protection of in-shore riparian ecosystems.

Perth is particularly keen to minimise use of its potable water resources and achieve effective management of groundwater resources on which those potable resources depend. Most capitals have invested in non-climate dependent supplemental drinking water sources.

New Zealand

The concept of sustainability was embodied in the New Zealand *Resource Management Act 1991.* New Zealand has been progressing the concept of *Low Impact Urban Design and Development* (LIUDD) since early in the current century with a nation-wide LIUDD research and implementation program.

The six-year programme from 2003 was funded by the New Zealand Foundation of Research, Science and Technology and led by Landcare New Zealand and the University of Auckland (Puddephatt and Heslop, 2008). Van Roon and van Roon (2009) described LIUDD as operating within a hierarchy of principles, firstly to work on a catchment basis to maintain the integrity of mauri (the unique personality of all things animate and inanimate) in ecosystems, then ensure selection of sites that minimise impact and adverse effects, use ecosystem services and infrastructure efficiently, maximise local resource use and minimise waste and then promote and support alternative development forms that create space for nature, restore, enhance, protect biodiversity; reduce and contain contaminants; recognise natural soil, water and nutrient cycles and ensure energy efficiency. LIUDD also recognises and provides for aspirations by Maori groups for biodiversity protection and enhancement. Criteria for design and construction of land development and subdivision infrastructure for use by local government and developers include LID and LIUDD principles. They are covered in New Zealand Standard NZ4404 (2010). The Standard encourages sustainable development and is applicable to greenfield sites, infill development, and brownfield redevelopment projects. NZS4404 has been in part or more generally embedded in many of the Infrastructure Development Standards or Codes of Practice for local authorities in New Zealand, albeit they are not legally binding.

East Asia

The cities of Eastern Asia are evolving and urbanising at a far greater rate than those of the developed world. For example, South Korea was 36% urbanised in the 1960s, but by 2005, was 86% urbanised. The percentage of impervious surfaces in Seoul had increased from 8% in 1962 to 48% in 2010. With more than 90% of the downtown area impervious, major flooding occurred in 2011 from the heaviest rain in 100 years (Yoon 2014). Despite that outcome, Korea has been a leader in the philosophy of “Green Growth”, responding to environmental degradation brought about by rapid economic growth. Green growth recognises the interdependency between economic and environmental systems, and the risks posed by increased water scarcity, resource bottlenecks, air and water pollution, soil degradation, climate change and biodiversity loss. Green Growth philosophies have been supported through South-east Asia by the OECD and UNEP. (Spies & Dandy, 2012).

China

China presents an even more dramatic situation. The urban population increased from 29% in 1995 to 46% in 2010, and is anticipated to reach 70% by 2020 (Shi *et al.,* 2016). Shortage of water resources and pollution of the water environment have become constraining factors in the sustainable development of China. About 80% of water resources are in the southern area of the Yangtze River where there is 36% of the cultivated land, while 19% of water resources are in the northern area of the Huaihe River which has 64% of the cultivated land (Figure 1). The rainfall in the northern area is concentrated in the three months of summer with a major risk of floods (Qian 2007). The demand for water is increasing fast with population growth and industrial demand. However, water use efficiency is low, with the leakage rate of urban piping systems higher than 20%. Half of the 600 largest cities are suffering from inadequate water supply. Forty cities suffer from acute water shortage in that only 60-70% of peak demand supply can be met. Ensuring water availability to cities is of primary importance whilst managing run-off quality and peak discharge is of secondary, but still major importance. Note that this priority tends to be reversed in Australian cities.

China’s water resource management system involves policies and laws being set centrally, but administered though national, provincial, prefectural and county levels of administration. Urban water management represents the most challenging component of water resource management. Chinese public policy has a continuing history of establishing independent management systems with limited coordination of their related functions, and often with limited communication between agencies responsible for complementary management functions (Cosier & Shen 2009).

In December 2013, Chinese President Xi Jinping spoke at the Central Working Conference of Urbanization where he highlighted the significance of "building *Sponge Cities* where stormwater can be naturally conserved, infiltrated, and purified" for potential reuse. Since this announcement, "Sponge City" planning and construction has been pursued throughout the country (Tu and Tian 2015). In October 2014, a "Sponge City" pilot program was initiated.

To implement the plan, the Ministry of Housing and Urban Rural Development (MOHURD), and Ministries of Finance and Water released the "Guideline to promote building sponge cities" (State Council 2015). Under the guideline, cities in China are to collect and utilize 70 percent of the rainwater, with 20 percent of urban areas meeting the target by 2020, and the proportion will increase to 80 percent by 2030.

As a consequence, sixteen cities (Baicheng, Qian'an, Jinan, Hebi, Changde, Wuhan, Pingxiang, Guian New Area, Zhengjiang, Jiaxing, Chizhou, Xiamen, Nanning, Chongqing, Suining and Xixian New Area) were designated as pilot cities in 2015 with a further fourteen cities (Beijing, Dalian, Guyuan, Qingyuan, Qingdao, Xining,, Yuxi, Yuncheng, Ningbo, Shanghai, Fuzhou, Sanya, Shenzhen and Zhuhai) added in 2016 (NL 2016).

These cities are shown in Figure 1. The government will oversee the construction of sponge cities and let the market play a decisive role in allocating resources. Various fund-raising methods, including public private partnership and franchising, are to be promoted according to the guideline. The Chinese central government will allocate each sponge city between 400 and 600 million RMB (approximately A$85 million to A$128 million) towards developing ponds, filtration basins and wetlands; and to build permeable roads and public spaces that enable stormwater to be infiltrated and reused.

Ultimately, the plan is to manage 60 per cent of rainwater (presumably including stormwater) in these cities (Austrade 2016). The philosophy is expected to be applied to older as well as new land use developments. It must be recognising that in many cases, runoff will also enter cities from catchments beyond city boundaries and broader land-use management will be required.

In June 2016, the Low Impact Development Conference (LID2016) was held for the first time outside the USA, generating a "Beijing Consensus" with a commitment "to manage urban stormwater in such a way to create a living environment in which humanity and nature co-exist harmoniously and a sustainable condition is maintained" (LID 2016). The Conference allowed many Chinese researchers and planners to discuss the scope for applying LID technologies to China in response to President Xi Jinping's direction.

The wide variability of environments in which investments were to be made, and the varying constrains thus imposed were highlighted by many speakers. In a keynote address, Qian (2016) summarised that water shortage was restricting economic development, and along with pollution, were harmful to human health, while flooding and waterlogging were disasters for human settlement.

The presentation was based on an LID strategy of prioritising and controlling water demand and encouraging water saving; controlling pollution at source; increasing investment in waste water treatment; developing non-traditional water resources including rainwater harvesting, reclaiming wastewater and desalinating sea water; preventing or reducing the impacts of major floods and water logging; and reframing rainwater and wastewater as resources, including as a source of energy.

Whilst the initial impression may be that the "Sponge Cities" philosophy is primarily about floods, it is evident that the aspirations for the program go far beyond that, and deal with the whole water cycle, especially supply and run-off quality.

But implementation is not without difficulties. Su and Luo (2016) outlined the problems of meeting Shanghai's requirement that all new or reconstructed rooftop terraces on buildings lower than 50 m should include 30% green roofs. This has proven much more technically difficult for the old buildings, and limits the opportunity to cut peak flows of stormwater, improve water quality, and reduce the energy use for cooling and heating buildings and the urban heat island effect.

Li *et al.* (2016) noted how the diversity of climate and rainfall in China, particularly the storm characteristics (depth / intensity/frequency) are the main factors that influence the performances of individual and combined LID devices.

The 2-year and 50-year design rainfalls (for a 200 minute duration) for Hong Kong are 122 mm and 260 mm, respectively, whereas for Seattle, the similar standards are only 20 mm and 37 mm, respectively.

Figure 1 – Pilot "sponge cities" identified in 2015 and 2016 for investment.

In China, the main problem is that large intense storms will cause urban floods. In general, the annual average rainfall depth in the south-east cities in China is much larger than that in the north-west cities. For example, a short rainfall intensity of 30 mm/hour is sufficient to cause flash floods in steep terrain cities such as Jinan, Chongqing and Qingdao (Figure 1).

A similar intensity would need to have a duration of over ten hours in Shanghai to cause floods because the river density is high and the terrain is flat. The performance under heavy storms of LIDs, which might mitigate urban floods in China, are usually modelled rather than measured. More local research is recommended by the Chinese LID practitioners, particularly where LID technologies are combined with traditional stormwater infrastructure such as deep tunnels required for heavy storms.

Although Chinese water resources and urban planners are still coming to grips with what will be required to implement the "Sponge City" philosophy, it is evident that modelling skills will be important. As well as using well-known models such as SWAT (soil and water assessment tool), and SWIM (soil and water integrated model), there has been considerable interest in developing a distributed hydrological model, named Hydro-Informatic Modelling System (HIMS), now widely tested in China, and subsequently extending it to encompass ecosystems and nutrients (Liu *et al.,* 2009).

As well as adopting the "sponge cities" philosophy to new developments, China also faces the retrofitting of this concept to brown field developments. China has many sites of great historical significance where surrounding subsequent activities may have disrupted the original hydrology.

Further adaptation will be required. An example of accommodating to these changes can be found in Suzhou, a very old city, but now one of the fastest-growing cities in China. An integrated solution combining knowledge of urban planning, landscape ecology, environmental science, and hydrology was used to overcome problems arising from urban expansion surrounding the Taohuawu Cultural District which was developed during the Ming Dynasty.

Consideration took account of the location of planned developments, soil conditions, the groundwater level and variation, terrain and drainage areas and the space requirements to put in place Low Impact Development (LID) installations. Runoff control for quantity and quality was provided, along with an evaluation of the economics of construction and maintenance costs, and the cost uncertainty associated with adopting LID practices.

It was shown that a closed water system would be able to maintain water quantity and quality. Although the conventional stormwater pipe system in the district met only met the 2-year ARI storm standard, there would be no local flooding in a 5-year ARI storm if LID practices were adopted. The developed scheme was implemented (Jia *et al.* 2014).

In addition, China faces the problem of retrofitting the 'Sponge City" philosophy to areas developed in the boom construction years of the 1990s onwards where *hutongs* (alleys formed by lines of traditional single-storey residences) were replaced by high-rise apartments. Even recently constructed facilities can be improved.

Jia *et al.* (2014) reworked the design of the 36 ha Beijing Olympic Village comprising 42 high rise residential buildings which were converted after the games to residential apartments. The village was originally built with some LID characteristics including porous pavements, roof gardens, infiltration trenches, green spaces and rainwater tanks.

By using the SWMM model (USEPA 2016c), the authors showed that with further LID improvements, including re-routing roof run-off through green spaces, increasing detention times in storage facilities, and properly designed bio-retention cells, total run-off volume could be reduced by 27% and the peak flow rate reduced by 21% compared with that which occurred in the original construction.

It is apparent that China is developing its expertise to respond to the specific characteristics of its cities in pursuit of the "Sponge City" initiative. Its aspirations are very high. It has access to a world-wide wealth of experience upon which to develop. Geiger (2015) has identified evidence of LID techniques being adopted long-ago in the Jin Dynasty, 1115-1234 A. D. in the Circular City of Beihai Park in Beijing.

The infiltration facilities included inverted trapezoidal cyan paving bricks with high infiltration capacity, providing more space at their lower part so that that rainwater could easily flow towards the sub-layer. At some places inlets were located to drain surplus water from the surface. They led to underground culverts, serving a double purpose: when the groundwater table was low, rain water infiltrated into the ground, recharging groundwater; when the groundwater table was high, the system worked like a drain, thus forming a complex (LID) drainage system.

It is estimated that with the average depth of a culvert of 1.46 m, the maximum soil water storage capacity is 4,037 m^3 which is greater than the average annual precipitation volume (3,427 m^3).

But Geiger also observed that a major obstacle for planning can be seen in inadequate regulations and control. Discrepancies exist between different laws and regulations, administration procedures and tools are lacking to control compliance with existing regulations and to safeguard that each on-site LID design fits into the overall Sponge City concept.

Hu and Li (2015) observed that China has been using single project definitions to define future practices, quoting for example, that the water departments work on water projects, park departments work on park projects, the transportation specialists work on road constructions, and the environmental specialists work on pollution control.

These specialisations need to be better linked, and China needs to establish policies that help promote integration.

There are also legislation barriers. The Planning Division is a Government department, which has to work "according to the law", because in China, the remit and competence of government departments are statutory. If it is "unauthorized by law, then it cannot be exercised". Since technical indicators like "runoff coefficient" are not in the scope of legislation, they cannot be approved or regulated by the Planning Division.

China recognises that it will still need some traditional "grey infrastructure" for managing extreme storm events.

Although it has started the LID/WSUD journey a little later that developed countries, it is likely to soon overcome its initial constraints. It has the potential to adopt a 'leapfrogging' pathway for its developing cities that are not yet 'locked-in' to traditional mono-functional, single-purpose infrastructure and institutions (Wong 2016).

It has the potential to become the most authoritative proponent of what are otherwise evolving as Low Impact Development, Sustainable Urban Drainage Systems, Green Infrastructure and Water Sensitive Urban Design as it embarks on the path to achieve its "Sponge Cities" as Water Sensitive Cities.

CONCLUSION

The commonality of principles encompassed within LID, SUDS, Green Infrastructure, WSUD, LIUDD and now Sponge City are increasingly recognised. The emphases appropriate to each location will be dependent on the hydrological, infrastructural, planning and sociological circumstances in each case. Sewer overflow protection and flood management together with access to green space are important in Europe.

Water quality protection and green space aesthetics as well as flood mitigation are significant in USA. Waterway ecosystem protection and littoral zone conservation have been drivers in coastal Brisbane, Melbourne and Adelaide while groundwater protection is a dominant consideration in Perth. Flood mitigation is a major consideration in much of Asia, while China is also picking up the importance of stormwater harvesting and environmental protection as well as addressing floods.

Image 7: The Shijiazhuang Botanical Gardens as well as greening the city, provides a cultural opportunity where visitors can watch, listen, and smell the traditional sacred lotus (*Nelumbo nucifera*).

Most of these communities will also be seeking to interpret possible changes due to the scope for climate change. All will seek an improved understanding for accommodating the water cycle within their urban planning and development.

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