POTENTIAL OF STORMWATER SOURCE CONTROL MEASURES FOR URBAN DEVELOPMENT: A REVIEW FOR A HIGH-DENSITY AREA

"Chayanun MANEEWAN[1] and Dr Marjorie VAN ROON[2]"

[1]PhD candidate, [2]Senior Lecturer, School of Architecture and Planning, University of Auckland, New Zealand

ABSTRACT

The sustainability of conventional stormwater management systems has long been considered impractical. However, many cities around the world still use combined sewers to deal with both waste and stormwater. As those cities continue to grow and their population densities increase, combined sewer overflows (CSOs) may cause adverse effects on receiving waters.

Sanitation infrastructure and stormwater management in urbanized areas have made different advances in recent decades. A wide range of source control measures have been gradually implemented in new developments and redevelopment to reduce contaminants and the rate and volume of water runoff through increasing infiltration or storage, and thus reducing the impact of stormwater loads entering the sewers. However, the implementation of these practices in older and higher-density metropolitan areas is still limited.

In Bangkok, the implementation of sewerage systems to service the whole population has become the main water quality objective over the last few decades. Pollutants generated from anthropogenic activities are often washed out to downstream catchments and water bodies during storm events. Domestic sewage is considered as a significant source of organic and nitrogenous pollution in Bangkok (Buathong et al., 2013; ADB, 2012). The implementation of open stormwater systems may provide an ability to reduce CSOs and handle runoff volumes locally.

The aim of this study was to review the potential of source control measures to reduce stormwater pollution and lower stormwater runoff in a high-density area by drawing from peer-reviewed articles on the various practices. An overview of source control techniques and key research findings highlighted the potential of green roofs, bioretention devices, permeable pavements, swales, detention ponds, and constructed wetlands. Finally, the results of their potential were synthesized and parallels were drawn with areas in Bangkok where environmental quality improvement might be promoted.

KEYWORDS

"Source control measures, Stormwater management, Water pollution, Bangkok"

1 INTRODUCTION

The traditional approach to urban stormwater management addresses urban stormwater as a nuisance rather than as a resource and treats it as a risk by collecting and conveying it via pipes or hidden infrastructure to mitigate flood events, with little regard for receiving waterways (van Roon, 2007). This results in degraded water quality, and loss of biodiversity in urban streams and coastlines (Raja Segaran et al., 2014).

Combined sewers linked to traditional stormwater management systems have been applied in many urban areas to convey household sewage and stormwater runoff generated on impervious surfaces to water pollution control facilities for treatment. However, when stormwater runoff exceeds the capacity of these available systems, combined sewer overflows (CSOs) can occur resulting in discharge to receiving waters.

As older cities such as those in Europe and North America continue to grow and their population densities increase, they still use combined sewers to deal with both waste and storm water (Gasperi et al., 2010). In the U.S.A., combined sewer systems discharge roughly 3.2 million m^3 of untreated sewage from CSOs each year, and this is a primary cause of pollution in rivers, lakes, and estuaries (USEPA, 2002). CSOs are common and can occur even during small (i.e. <30 mm) rainfall events (Olness, 1995).

In Bangkok, stormwater is usually either discharged directly into rivers, or drained via combine sewers into sewage treatment plants for purification. However, rapid drainage of stormwater from urban built-up areas to wastewater treatment plants, instead of its infiltration, has led to combined sewer overflows (CSOs) and the intensification of river pollution.

At present, the combination of wastewater and stormwater discharge in Bangkok represents approximately 2.9 million cubic metres per day (Leerasiri, 2010). Up to 75% of this effluent is generated from domestic sources and roughly 25% from manufacturing and commercial uses (Leerasiri, 2010; BMA, 2011; ADB, 2012; Suriyachan et al., 2012). The growth of urbanization associated with an inadequate water management system has resulted in the release of untreated water into receiving rivers.

Central wastewater treatment plants are still inadequate in Bangkok. Although seven central wastewater treatment facilities have been constructed, they do not cover the whole urban area and still have limitations. Currently, central wastewater treatment plants cover only 20% of the Bangkok area, serving around 3 million people or approximately 54% of the residents (ADB, 2012). Insufficient wastewater treatment facilities have led to high organic pollutant loads and lower dissolved oxygen than the water quality standards set for the lower Chao Phraya River (Suriyachan et al., 2012).

Significantly, exceedance of the capacity of the system during heavy rainfall events results in discharges from the wastewater treatment system during the rainy season that are at least 25 times that of the average Dry Weather Flow (DWF) (Leerasiri, 2010). In this case, combined sewer overflows (CSOs) in Bangkok may impact on aquatic ecosystems of receiving waters.

As Bangkok has experienced rapid economic and population growth during recent decades, this has brought a vast inflow of migrants, rapid loss of farmland and a quick deterioration of the urban environment. Evidence suggests that the growth of urbanization and industrialization since the mid-twentieth century has resulted in the conversion to urban use of concentrated paddy cultivation in the floodplain of the lower delta (Emde, 2012). These anthropogenic land-use changes along with coastal erosion of the delta also caused overflow and flood in Bangkok floodplain areas (Emde, 2012; Prajamwong & Suppataratarn, 2009). Hence, a more sustainable approach is considered necessary in combination with the use of drainage pipelines, to solve flooding and water quality problems and to restore degraded landscapes in Bangkok.

In this paper, the potential of source control measures to minimise stormwater pollution and runoff in a high-density area was addressed by making deductions from a review of selected articles and journals on the several practices. An overview of source control practices emphasised the implementation of green roofs, bioretention devices, permeable pavements, swales, detention ponds, and constructed wetlands. The potential of these practices to promote environmental quality improvement was assessed for areas in Bangkok.

2 AN OVERVIEW OF SOURCE CONTROL MEASURES

Recognition of sustainable approaches to urban stormwater management has grown globally over the last few decades. The shift in recognition of stormwater as a nuisance to being a resource resulted from the rising environmental awareness.

Source control measures are being implemented in different parts of the world, from North America and Europe to Australia, New Zealand and Asia. This approach has potential for improving stormwater quality through the integrated performance of stormwater treatment devices. These Best Management Practices (BMPs) are considered as an alternative and/or supplement to conventional piped stormwater systems to minimise the negative impacts of urbanization on water systems.

As greening urban development has become ever more prominent and urgent in recent decades, managing water pollution through source control to reduce the amount of stormwater discharged into rivers has become more prevalent (Barbosa et al., 2012). These common practices are a part of concepts such as Low Impact Development (LID), U.S.A.; Low Impact Urban Design and Development (LIUDD), New Zealand; Water Sensitive Urban Design (WSUD), Australia; and Sustainable Urban Drainage Systems (SUDS), the United Kingdom (U.K.).

Source control measures are regarded as the approaches of retention, treatment and infiltration of stormwater that are implemented at the source, primarily applicable for land uses such as individual building lots, parks, and highways (Li, 2012). The methods adopted by countries vary in a number of design procedures. Burkhard et al. (2000) believe that the main requirement is the establishment of sufficient detention storage to reduce runoff volumes during a storm event within upstream areas of the specified location. This provides control over the quantity but not necessarily over the quality of stormwater.

Systems may consist of an array of devices constructed to treat stormwater at the source or close to the discharge into the sewer system, or into the receiving rivers (Barbosa et al., 2012). Common practices within these systems include green roofs, bioretention devices, permeable pavements, swales, detention ponds, and constructed wetlands.

2.1 GREEN ROOFS

Green roofs are one of several techniques of source control measures. The techniques aim to reduce runoff volumes and the risk of urban flooding and minimise water and contaminant loads to sewer systems and receiving rivers.

Two different types of green roofs include intensive green roofs and extensive green roofs. Intensive green roofs typically have moderate slopes and soil covers with a thickness of more than 15 cm. These roofs require regular watering for large plants. In contrast, extensive green roofs require little soil cover of a few centimetres and can be placed on slopes up to 40–45%. For existing buildings where the weight of the green roof is limited, extensive green roofs can usually be placed without structural reinforcement as the soil layer is thin (Locatelli et al., 2014).

Since the 1990s, green roofs have become increasingly popular in several countries such as in the United States and European countries particularly Germany. Moreover, several countries such as the U.K., the U.S.A., Germany, Australia, and New Zealand have also been publishing guidelines for the implementation of green roofs for a few decades (Locatelli et al., 2014).

The hydrological performance of green roofs may vary among geographic regions due to different climates, a wide range of precipitation patterns, building practices and plant materials. Locatelli et al. (2014) stated that the most influential hydrological performance functions of green roofs during rainfall events are the interception capacity of the vegetation layer, infiltration in the soil substrate, and retention/detention in the soil substrate and drainage layer.

Green roofs minimise stormwater runoff compared to traditional roofs due to the capacity of water infiltration, retention, and evapotranspiration. The amount of water stored on a green roof is lost through evapotranspiration. Rainwater in excess of the storage capacity will be carried into an outlet by main drains, which receive water from the laterals. Volume retention mainly depends on hydrologic characteristics of the rainfall events such as the rainfall intensity, rainfall duration, the initial moisture conditions; and green roof characteristics such as layer thickness, slope, and materials of the green roof (Locatelli et al., 2014).

2.2 BIORETENTION SYSTEMS

Bioretention systems, also referred to as biofilters or rain gardens, are the most commonly used source control measure in several countries. The systems use physical and biological processes to remove pollutants, slow down stormwater flows, absorb and filter contaminants before stormwater flows to streams and rivers. The main elements of a rain garden typically include: soil mix; ponding area; plants; overflow system; mulch, pebble and rock layer; sand layer; underdrain system and; grass buffer strip (Auckland Council, 2014).

Some studies have reported on factors influencing treatment performance of biofilter devices. For instance, Hathaway et al. (2014) reported that a wide variation of bioretention performance to reduce runoff volumes depends on system size, underdrain systems, and soil type. Henderson et al. (2007) found that a fine sand or sandy loam filter media for biofiltration provides a substantial nutrient removal as they support plant growth as well as show little leaching. Davis et al. (2001) demonstrated that increased depth in biofilters also provides support for total phosphorus removal.

In Melbourne, Australia, Bratieres et al. (2008) reported the effectiveness of stormwater biofilters for sediment, nitrogen and phosphorus removal, using 125 large-scale biofilter columns. Different factors were compared to offer guidance on the optimal design elements for an effective biofilter in terms of treatment performance. The results indicated that the optimally designed biofilter should be sized to at least 2% of its catchment area. Additionally, biofilters planted with *Carex appressa* and *Melaleuca ericifolia* using a sandy loam filter media provided a significant nutrient removal when compared with those using other plant species. Biofilters constructed according to these optimal factors offer consistently very high removal in both nutrients and suspended solids, which accounted for around 70% for nitrogen, 85% for phosphorus, and up to 95% for suspended solids removal. However, the addition of organic matter to the biofilter soil media can reduce the phosphorus treatment efficiency.

2.3 PERMEABLE PAVEMENTS

Permeable pavements have been demonstrated as effective devices in reducing surface runoff volumes and delaying peak flows due to their high surface infiltration capabilities (Hunt & Collins, 2008). Moreover, permeable pavement has been used to protect water quality by filtering out urban contaminants.

Five types of permeable pavements include Porous asphalt (PA), Pervious concrete (PC), Permeable interlocking concrete pavers (PICP), Concrete grid pavers (CGP), and Plastic grid pavers (PG). However, it is evident that different types of permeable pavement provide a minor difference in reducing runoff. A study of performance of PICP, and CGP in North Carolina showed that no substantial difference in runoff reduction could be detected among these permeable pavement types (Collins et al., 2008; Hunt & Collins, 2008).

Permeable pavements have performed effectively for surfaces on pedestrian walkways, sidewalks, courtyards, parking lots, residential driveways, and low-traffic roads (Burkhard et al., 2000). In North Carolina, more than 20% of a parking space was required by law in 2007 to be either made of permeable pavement or used to implement other environmentally friendly stormwater techniques (Hunt & Collins, 2008).

The author points out that sandy soils provide good infiltration. However, providing enough infiltration is the major concern for low permeability soils such as clay, therefore, the underdrain is needed in place to slowly drain the base layer of the permeable pavement (Hunt & Collins, 2008).

2.4 SWALES

Swales are biofiltration and bioretention practices in source control measure designed to convey urban stormwater and capture pollutants from runoff. The devices contain a drainage course with moderate sloped sides and typically lined with grass that receive flow laterally over the vegetated surface (NRDC, 2001).

Swales are commonly used for treating stormwater runoff in several countries. In Portland, Oregon, a large scale 2,330 foot (710 metres) swale was installed in Willamette River Park since 1996 to detain and capture stormwater contaminants entering the Willamette River. These swales provided a high performance with a 50 percent reduction of all suspended solids entering the river (France, 2002). In Sonoma County, California, a large scale two mile swale was designed in 1997 to reduce and capture pollutants in urban runoff entering Sonoma Creek (Hogan, 1998).

Grass swales also provide primary treatment for road runoff, and are increasingly popular for installation alongside highways in several cities (Yu et al., 2001; Deletic, 2005; Zanders, 2005; Davis et al., 2012; Stagge et al., 2012). In Taiwan, Yu et al. (2001) monitored a grass swale along a highway with the length of 30 m and slope of 1% using standardised runoff event simulation procedure. The percentage of contaminant removed ranged from 30 to 97% for TSS, 29 to 99% for total phosphorus, and 14 to 24% for total nitrogen. In Maryland, the U.S.A., Davis et al. (2012) investigated the hydraulic performance of two grass swales with pre-treatment grass filter strips and vegetated check dams to reduce highway runoff near a Maryland highway. Results showed that during 4.5 years swales greatly reduced total runoff volume and overflows with a rainfall event less than 3 cm, while functioning as stormwater conveyance with no runoff reduction during a large storm event. Additionally, it was found that pre-treatment grass filter strips and check dams increases swale effectiveness in runoff reduction.

The swales provide the principal process for removing high influent concentrations in the first flush through infiltration process, following this contamination is reduced by sedimentation and filtration processes. However, it was noted that a sedimentation process along grass swales is the most significant mechanism in removing runoff pollutants (Deletic, 2005; Stagge et al., 2012).

2.5 DETENTION PONDS

Ponds have been popular and particularly well represented in sustainable drainage literature across different fields of source control measures. As the main factor governing the efficiency for reducing peak storm flows is the storage volume of facilities, ponds can play an important role in attenuating peak flows due to the retention and detention capacity of the systems, especially for the low frequency storms or high intensity rainfall events. This system can reduce the total flow volume through maximising the storage capacity between storm events. Rapid removal of stormwater from developed areas by ponds was observed even during a once in 10-year storm event with wet conditions in upstream areas (Villarreal et al., 2004).

In Beijing, it was suggested that the combined use of source control devices through the retention pond and the Living Water Park provided great potential for enhancing river water quality and reducing runoff pollutant loads or CSOs in the city. In these systems, ponds were designed to receive inflows of polluted water from the park and finally purify water for local water supply and river discharges. To enhance the potential of these facilities, Li (2012) suggested that the water in the retention pond should be emptied shortly before a coming rainstorm event to enhance the storage capacity for runoff reduction during the flood season. The combination of ponds and parks not only reduces both runoff volume and pollutant loads through retention of stormwater by ponds, and infiltration and purification runoff by plants, but also increases biodiversity and provides an aesthetic purpose (Li, 2012). There is, however, evidence that some off-line ponds produce adverse downstream aquatic ecosystem effects (van Roon, 2013).

2.6 CONSTRUCTED WETLANDS

Constructed wetlands are artificial wetlands consisting of saturated or unsaturated substrates; emergent, floating or submergent plant species; and a number of microbial communities for purifying wastewater and stormwater runoff. Polluted water can be treated by sedimentation, filtration, oxidation, and precipitation processes (Vymazal, 2013).

Constructed wetlands are an effective stormwater treatment measure to achieve removal of soluble contaminants such as some nutrients. The systems apply a combination of physical, biological and chemical processes in removing stormwater contaminants. Plant uptake is also the main process for nutrient removal from wastewater. Nitrogen and phosphorus are removed by plant uptake, while ammonia is removed by volatilization, nitrification, and denitrification processes (Vymazal, 2013). In Thailand, the most commonly used of emergent plants in CWs are cattail (*Typha latifilia*), bulrush (*Scirpus lacustris*) and reed (*Phragmites australis*) (Brix, 1993). Water hyacinth has also been used to purify wastewater in the several tropical regions where climatic conditions are suitable for plant growing for the whole year. Its extensive root system increases the ability for the attachment of microorganisms and decomposing organic matter (Kivaisi, 2001).

Sewage treatment plants were recommended to combine with constructed wetlands in order to enhance the potential of water purification and reduce pollutants from sewage overflows (Zalewski 2002; Li, 2012).

3 THE IMPLEMENTATION OF SOURCE CONTROL MEASURES IN EXISTING HIGH-DENSITY URBAN AREAS

Many articles in the literature on source control measures have focused primarily on the treatment efficiency of different facilities under a variety of conditions and climates. However, these practices have increasingly been implemented in the construction of new developments, while their use has been less widespread in existing high-density urban areas, partly due to spatial and economic constraints. The following case studies are based on literature focusing on source control facilities within high-density urban areas in Europe, North America, Asia, and Oceania.

3.1 EUROPE

3.1.1 SWEDEN

In Sweden, the popularity of Sustainable Drainage Systems (SuDS) has gradually increased in cities due to the concern of increased precipitation and climate change. SuDS for stormwater management are becoming prevalent in newer housing developments in Sweden for lowering flood risk and treating stormwater. The common practices include swales, porous pavements, rain gardens and detention ponds (Semadeni-Davies et al., 2008).

The use of detention ponds is very popular in Sweden and a typical practice in the centre of a small park. Ponds are normally incorporated into parks to provide habitats for urban wildlife, enhance leisure activities in greenspace, and cool urban environments. Recently, there were roughly 1,000 urban stormwater ponds and an additional 400 ponds for treating highway runoff in Sweden. These so-called SuDS are multi-purpose in increasing water quality, minimising stormwater runoff, and also providing urban blue–green spaces (Semadeni-Davies et al., 2008).

In Malmo, southern Sweden, an array of source control practices in series has been implemented to solve inner-city drainage problems in the old inner-city suburb of Augustenborg— a high density housing area since 1997. The disconnection of stormwater from the existing combined sewer and drainage by means of an open system aimed to eliminate CSOs and reduce flooding by up to 70% in Augustenborg. The results show a substantial decrease in the total runoff volume and the amount of stormwater reaching the piped systems (Villarreal et al., 2004).

3.1.2 THE UNITED KINGDOM

In the U.K., the use of Sustainable Drainage Systems (SuDS) for the management of stormwater runoff has been promoted by the Environment Agency and the Scottish Environment Protection Agency. These SuDS typically consist of green roofs, rain gardens, infiltration basins, soakaways, swales, and ponds (Stovin et al., 2013).

In London, the development of green roofs has been introduced in the London Plan since 2004. The green roofs agenda has been fully supported through the incorporation of the city and the role of local authorities, and the Homes and Communities Agency (HCA). In 2012, the city facilitated the installation of 100,000m² green roofs. Currently, London City has also required all main new developments located within London's Central Activities Zone policy area to green their rooftops in order to meet London's Climate Change Adaptation Strategy (Greenroofs.com, 2014).

3.1.3 GERMANY

Berlin has become one of the greenest large cities in the world. Urban green spaces in Berlin city have increased over the last decade from 9,087 ha in 2000 to 9,677 ha in 2011. In 2013, it was observed that public green spaces represented more than 30% of the city area (Petrucci et al., 2013).

The use of green roofs is relatively widespread in the country. In 2001, it was evident that 13.5 million square metres of green roofs had been installed in Germany, of which 80% of the greenroofs in Germany are extensive. It was evident that incentives and subsidies have been provided to building owners for the installation of greenroofs over 80 cities in the country. In Munich, the requirement of green roofs in building ordinance has been introduced since 1984. By 2000, around 4.2 million square feet (390,600m^2) of rooftops have been installed in the city (Greenroofs.com, 2014).

3.1.4 DENMARK

In Denmark, the City of Copenhagen has set up requirements for green roofs for new private and public buildings which contain flat roofs at less than a 30 degree-pitch. Additionally, it also applies to old roofs, and public financial support will be provided to the building owner if aged roofs have to be retrofitted. Recently, green roofs for new buildings in the city are expected to increase around 5,000 m^2 per year. This target has been set in order to meet the goal of becoming the world's first carbon neutral capital by 2025 (Nusca, 2010).

3.2 NORTH AMERICA

3.2.1 CANADA

In Montreal, Canada, it was observed that an increase in the annual rainfall had lead to a high volume of CSO for a catchment. Moreover, continued urbanization has also contributed to the increase of the impervious surfaces, accelerating the volume of stormwater in urban catchments (Autixier et al., 2014). To deal with these issues, rain gardens have been installed to reduce the impact of sewer overflows in a residential and commercial area of Montreal, with a drainage area of 345 ha. Results showed that rain gardens provide a good performance in reducing volumes of stormwater entering a drainage system for the total catchment ranging from 12.7% to 19.4%. In terms of the CSOs reduction, it was found that the decrease of discharged volume ranged from 13% to 62% and the decrease of peak flow rate ranged from 7% to 56% during 2009-2010 (Autixier et al., 2014).

In Toronto, Ontario, the City Council released a mandatory greenroof requirement in 2009 to install greenroofs for all new buildings made after January 2010, including commercial and industrial buildings, schools, and residential housing over six stories. This greenroof by-law required for green roofs on all new buildings over 2,000 m² of Gross Floor Area with a coverage requirement ranging from 20-60% of the roof area. Toronto became the first City in North America to have a greenroof bylaw provided on new development. Eco roof incentive program was also introduced in 2009 to encourage the creation of green roofs on new and existing buildings. Under the incentive program, owners of industrial and commercial buildings who install green roofs may receive incentives up to $50 per square metre or up to $100,000 on a one-year basis (Greenroofs.com, 2014).

3.2.2 THE UNITED STATES OF AMERICA

In the US, the stormwater management practices were first adopted in the State of Maryland in 1984 by the United States Environmental Protection Agency (USEPA) (Petrucci et al., 2013). The Clean Water Act requires states to reduce pollution and remediate an impaired waterbody through defining total maximum daily load (TMDL) in the water body and developing an implementation plan, also known as best management practices (BMPs) (Wang et al., 2014).

3.2.2.1 LOS ANGELES, CALIFORNIA

Due to urbanization, stormwater runoff from urbanized areas causes significant water quality problems in the Los Angeles River. The city created an interconnected network of separate storm sewers to convey discharge runoff from urban impervious areas to local waterways. However, this untreated stormwater has resulted in contamination by metals, nutrients, and pesticides in rivers (Garrison et al., 2011).

Since 2004, many green infrastructure projects have been constructed including Wetland Park in South Los Angeles and Green Streets L.A. in the Sun Valley neighbourhood north of downtown. The Wetland Park Project in South Los Angeles was converted from a former bus yard to create green space for lower-income housing and the treatment of stormwater runoff from urban areas. Two large ponds with storage capacity of 1 million gallons were also installed inside the park to receive polluted runoff from adjacent canals, allowing infiltration into the ground and replenishment of groundwater, or even irrigating the park during dry seasons (Garrison et al., 2011).

The Green Streets L.A. Project was launched for Elmer Avenue in the Sun Valley neighborhood north of downtown through the installation of a series of green infrastructure including an infiltration device along with curb cuts, grass swales, and porous pavement. During the last decades, the area was previously damaged by flooding when the rate of rainfall exceeded the capacity of drainage systems. By the introduction of green infrastructure, the runoff from the street has been greatly reduced and pollutants, and stormwater is retained for a 2-inch (5 cm) storm event within developed areas (Garrison et al., 2011).

3.2.2.2 WASHINGTON D.C.

In urban areas of Columbia District, Washington, DC, urban runoff contaminated by stormwater pollutants becomes a serious environmental issue. Impervious surfaces, covering around 65 percent of the District's area, have created large quantities of surface runoff and caused severe environmental and river degradation. Additionally, combined sewer overflows (CSOs) and urban runoff discharging through separate stormwater sewer systems are the main sources of pollutants in urban rivers, representing roughly 70 percent of contaminant sources in the district. It was evident that the dissolved oxygen levels in the Anacostia River were too low and the river was too polluted for swimming (NRDC, 2014).

In response to environmental concerns, a number of LID retrofits including bioretention and detention cells have been applied across the Washington Navy Yard in order to reduce peak discharge and to protect and restore the Anacostia and Potomac Rivers and Chesapeake Bay. These source control projects are in place to treat runoff at the Navy

Yard from about 3 acres (1.2 ha) of the 60 acres (24.3 ha) of impervious surfaces, while conventional treatment systems are also applied to treat runoff from a further 10 acres (4.05 ha). At Willard parking areas, several bioretention and detention cells were applied to capture and treat stormwater runoff from parking lots, roadways, rooftops, and landscaped areas. To maximize parking spaces, bioretention strips were also installed throughout Willard Park. Rain barrels are also used to capture and store runoff from rooftops for landscape irrigation (NRDC, 2014).

3.2.2.3 NEW YORK

To reduce discharges of untreated sewage including from CSOs in New York City, a Sustainable Stormwater Management Plan was adopted in 2008, aiming to increase the implementation of source control techniques, for both public and private projects (Greenroofs.com, 2014). In 2012, the New York City Department of Environmental Protection (DEP) and New York State also finalized an administrative consent order to achieve CSO volume reductions in New York city. According to the order, some planned grey infrastructure projects such as two costly CSO detention tunnels were eliminated or deferred, and new green infrastructure projects were substituted and developed. These green alternative practices include reducing CSOs through capturing or detaining the first inch (2.5 cm) of rainfall on 10% of the impervious surfaces area over the next 15 years (Garrison et al., 2011).

The green infrastructure projects were rapidly constructed over the last few years, including 135 right-of-way bioswales installed in 2013, increase to 2,000 bioswales in 2014, and projected to rapidly increase to 6,000 bioswales in 2015. Additionally, dozens of bioswales were also installed in three Neighborhood Demonstration Areas to reduce runoff flowing into the combined sewer system, and they were projected to capture more than 7 million gallons (31,500 m^3) of runoff per year (Garrison et al., 2011).

In terms of financial incentives for green roof implementation, under the bill passed by the New York legislature in 2008, building owners will receive a maximum annual property tax credit of up to $100,000, when installing green roof covering more than 50% of rooftop space. This credit is equivalent to $4.50 per square-foot of (0.093 m^2) roof area, or approximately 25 percent of the operating costs (Greenroofs.com, 2014).

3.2.2.4 CHICAGO ILLINOIS

In Chicago, Illinois, CSO discharges have become the main environmental issue, which often reduce dissolved oxygen levels in receiving rivers. To enhance river water quality and localise street flooding, the city government adopted the Green Stormwater Infrastructure Strategy and allocated $50 million in 2013 to integrate green stormwater infrastructure under a five-year plan. In response to the green infrastructure plan, a set of data layers for areas where green stormwater infrastructure could be operative was analysed in 2013. These identify areas, including the areas most vulnerable to flooding; areas reached by small service pipes; and vacant public land, to implement green stormwater infrastructure, particularly community gardens and rain gardens in order to reach the goal of managing 10 million gallons (45,000 m^3) of stormwater runoff with green infrastructure by 2015 (Garrison et al., 2011).

3.2.2.5 PORTLAND, OREGON

The implementation of green infrastructure to manage stormwater runoff and resolve combined sewer issues was launched in Portland in 2008, with a $55 million investment in green infrastructure systems. During 2008 to 2013, the city planted 32,200 native shrubs and street trees, re-vegetated 4,400 acres of natural areas, and constructed 867 green street facilities. Additionally, 398 green roofs have currently been installed in Portland (Garrison et al., 2011). With a number of green facilities implemented in the city, Portland reduced the quantity of CSOs entering the Willamette River by 94 percent and the Columbia Slough by up to 99 percent in 2011 (Environmental Services, 2014).

Financial incentive had been promoted to reduce urban runoff from individual land parcels. In 1993, the Portland Downspout Disconnect Program offered inhabitants a US $53 incentive to redirect stormwater runoff from roofs to gardens and lawns. As a result, more than 47,000 households have responded to this strategy in 2005, resulting in the reduction of stormwater drained into combined sewer systems at approximately 4.2 million m^3per year (PBES, 2006). Furthermore, to accelerate the installation of green roofs in Portland, the city allocated the eco roof incentive grants of up to $5 per square foot in 2010 for new green roof projects for all residential, commercial, industrial, and mixed-use projects. With the City of Portland's Grey to Green effort, more than 90 buildings have installed green roofs in 2010 (Greenroofs.com, 2014).

3.2.2.6 SEATTLE, WASHINGTON

In 2013, the Seattle Department of Planning and Development and Seattle Public Utilities (SPU) implemented a Director’s Rule and required single-family residential and parcel-based projects to install and optimise the use of best management practices (BMPs) including bioretention, permeable paving, green roofs, and rainwater harvesting. In 2014, Seattle’s Office of Sustainability and Environment implemented green stormwater infrastructure (GSI) plan to establish green stormwater infrastructure under the goal of increasing the retention capacity of 700 million gallons (3.15 million m^3) of stormwater runoff yearly by 2025 (Garrison et al., 2011).

3.2.2.7 PHILADELPHIA, PENNSYLVANIA

In Philadelphia, the Clean Waters program was introduced in 2011 under the 25-year Green City Project, which primarily aims to reduce CSOs through creating green infrastructure of 744 acres in area within a five-year target. In response to this target, the strategies rely primarily on installing green infrastructure on both private property and public space (Garrison et al., 2011).

For private property, owners are required to install green infrastructure to capture the first inch (2.5 cm) of runoff on-site for new development and redevelopment projects. In 2011, it was evident that 146 greened acres have been created in the CSO drainage area. For public works projects, 61 greened acres on vacant lots, public squares, and along roadsides, were completed in 2011 under the corporation of the city, state, federal agencies, and nonprofit organisations. These practices include the installation of rain gardens, pervious pavements, infiltration trenches, city tree planting and swales (Garrison et al., 2011).

To increase the implementation of green infrastructure retrofits, the Philadelphia Water Department (PWD) and the Philadelphia Industrial Development Corporation provided grants to private land owners in the CSO drainage area under the Stormwater Management Incentive Program (SMIP) in 2012. During 2012 - 2013, this program granted approximately $9.6 million, projected to create green areas accounting for 154 acres in the CSO drainage area and adjacent part by 2013 (Garrison et al., 2011).

3.3 ASIA

3.3.1 CHINA

In Asia, China is embarking on a project of building green facilities in several cities. Such a project is proposed not just for the mega cities like Beijing, Shanghai and Tianjin but also for the small town of Jiangsu. It is apparent that the most advanced developments in source control measures in China are in Tianjin, where the project was initiated in 2007 covering the city of 30 sq km with 350,000 residents (Li, 2012).

3.3.1.1 BEIJING

In Beijing, China, with rapid urbanization, severe stormwater overflows have been a common problem in urban areas after every short-term intense rainstorm, mainly under overpasses or low-lying areas. Li (2012) reports that this resulted from climate change, increasing impervious surfaces, inadequate green areas and an inadequate stormwater drainage system.

To cope with the urban stormwater issues, Good Urban Design (GUD) policy has been proposed for water purification and retention in Beijing. The policy issued in 2012 required BMP facilities for stormwater control and reuse during the construction of new development or expanded facilities of all buildings and neighbourhood developments in Beijing (Li, 2012).

Existing source control facilities implemented in the City of Beijing consist of infiltration trenches and well, pervious pipe, road water inlet, roof water container, rain tank, underground tank, wetland detention, green roof, and rainwater treatment techniques. However, green roof technology has recently been applied to less than 1% of the roof areas in Beijing (Li, 2012).

The permeable surfaces such as pervious brick, pervious concrete and asphalt ground have also been constructed for pavements, yards, parks, and low-volume roadways in residential areas in Beijing to enhance rainwater infiltration, reduce runoff, recharge groundwater, and prevent overflows. It was noted that during a one-hour rainfall of 107.17 mm, the permeable pavements reduced runoff peak flow by up to 82.29% compared to the impermeable ground surface (Li, 2012).

3.3.1.2 JIANGSU, SUZHOU

In Suzhou, Southern China, a combination of several source control measures has been constructed to reduce runoff volume entering into rivers. Suzhou is a highly developed historical city in Jiangsu Province, which has faced serious urban water problems particularly water pollution and flooding in the wet season. Moreover, it has been suggested that the encroachment on the river channel is manifest. Rivers have been cut-off or truncated, and, as a result of rapid urbanization, the numbers of enclosed water systems have enlarged (Jia et al., 2014).

Recently, the Suzhou municipal government has introduced a river revitalization project and worked on water pollution control to restore the urban rivers and historical landscapes. In response to river revitalization and pollution control policies, source control practices for stormwater treatment for urban river systems in the Taohuawu Cultural District have been implemented, including 52% constructed wetlands, 10% bioretention cells, 9% permeable pavements, 13% grassed swales, 9% infiltration pits, and 7% buffer strips. However, a conventional stormwater drainage system has also been implemented to convey excess stormwater runoff (Jia et al., 2014).

The projects showed promising results for the practicability of source control devices. Stormwater runoff from most parts of the Taohuawu cultural areas (covering 3,303 m^2, which represents 4.8% of the total urbanized area) has been captured and treated by these devices for use as the main water source for the local residents. These facilities were considered as a solution to reduce runoff volume entering into the conventional stormwater drainage system by up to 39.8% and the infiltration quantity increased by 42.7% compared to a conventional drainage system without source control practices (Jia et al., 2014).

3.3.2 SINGAPORE

Singapore has become a highly urbanized city-state, where water is a limited resource in this island environment. As with many other coastal cities, Singapore will likely face several potential impacts including rising sea levels and storm surges, urban heat stress, extreme precipitation, inland and coastal flooding, water resource scarcity, and increased energy demand. Moreover, the loss of coastal land to flooding will be forthcoming if the sea levels rise up to 5 metres (Yuen, 2013).

With regard to water pollution, the major heavy metals found in urban runoff include Copper (Cu), Zinc (Zn), Cadmium (Cd) and Lead (Pb), which are generated in Singapore primarily from roads, vehicles, and industrial activities. These metals are crucial pollutants in Singapore as they can lead to poisoning at low concentrations and tend to accumulate in living things (Lim et al., 2015).

In response to environmental concerns, there has recently been an increase of awareness on source control measures arising from the need to improve water quality of stormwater runoff for environmental protection, particularly using rainwater harvesting techniques to treat stormwater and re-use for drinking water (Lim et al., 2015). The government of Singapore also promotes sustainable design, construction and operation practices in green and sustainable buildings through energy savings, water savings, and greenery indoor environments (Yuen, 2013).

Marina Barrage, is the most well-known of catchment area which harvests stormwater across Marina Channel which then forms Marina Reservoir. It is primarily used as a source of city water supply, flood control and a lifestyle attraction in the city centre of Singapore.

There has also been an effort to accelerate the implementation of green roofs in the country. The Green Roof Incentive Scheme has been launched by Singapore National Parks (NParks) to heighten the retrofit with extensive green roofs by owners of existing buildings. Under the incentive project, the building owners will be subsidised up to 50 percent of installation costs of green roofs in Singapore’s downtown and adjacent areas (Greenroofs.com, 2014).

3.3.3 TAIWAN

In Taiwan, the National Sustainable Campus Program for encouraging sustainable development through implementing source control stormwater management systems was launched in 2002. This national policy aims to improve environments surrounding the campus through source control stormwater management systems including permeable pavements, constructed wetlands, green roofs, stormwater ponds, and other source control devices. The strategies for developing sustainable campuses also include the use of green roofs under standardized regulations following the German guidelines to reduce urban runoff in cities (Chen, 2013).

In 2008, a LID approach following the USEPA' guidelines was also launched in Taiwan to mitigate flooding problems. Additionally, the Taiwanese Building Act also requires building owners to construct onsite water management, permeable pavements, green roofs, and detention ponds (Chen, 2013).

In New Taipei City, the implementation of green roofs on buildings and campuses has recently increased as the city government has made an effort to direct the city towards a low-carbon city and more a sustainable city. In 2011, Taipei City released a regulation to increase stormwater retention capacity through the use of retaining and detaining stormwater facilities to increase green space surrounding building areas (Chen, 2013).

3.4 OCEANIA

3.4.1 AUSTRALIA

The awareness of Water Sensitive Urban Design (WSUD) in Australia has taken place as a result of drought, water restriction legislation, urban population growth and environmental concerns (Raja Segaran et al., 2014). Due to climate change and uncertainties, Australia experienced a severe drought, followed by severe floods resulting from extreme ‘La Nina’ situation during 1997 and 2009 (Floyd et al., 2014). WSUD addresses the restoration of stormwater for local use, which then prevents the deterioration of receiving waters resulting from the contamination by sediment and pollutants from roads and urbanized areas (Wong & Brown, 2011; Floyd et al., 2014).

Water legislation has been introduced by state governments in support of WSUD principles in several states such as Queensland and Victoria (Raja Segaran et al., 2014). However, existing stormwater management policies and plans in Australia are likely to focus on the mitigation of stormwater quality for new developments rather than on an established urban catchment and the awareness of the impervious surface areas impacts on urban catchments. This is attributed by Raja Segaran et al. (2014) to legislation that generally requires municipalities to formalise plans for stormwater quantity and quality management to ensure water savings targets for new urban developments.

In Adelaide, South Australia, the potential has been demonstrated for existing public parks to significantly improve urban stormwater quality. Existing parks in an established urban catchment are reserved for stormwater filtration by networks of bioretention devices and an explicit treatment train covering 16% of park areas. The potential role of retrofitting source control measures into existing parks and networks of land has shown the improvement of stormwater quality particularly nitrogen removal in an urbanised catchment. The results indicate that the efficient combinations of parks and stormwater devices including the use of vegetated swales, detention ponds and constructed wetlands play significant roles in stormwater pollutant reduction. The potential for nitrogen removal from stormwater was demonstrated by a decrease of up to 62% or 7.8 tonnes per year (Raja Segaran et al., 2014).

3.4.2 NEW ZEALAND

In New Zealand, there has been a growing interest in implementing source control stormwater management since 1991 to reduce the quantity of runoff and mitigate environmental effects and protect its natural resources under the Resource Management Act 1991 (Zanders, 2005). Low Impact Urban Design and Development (LIUDD) is an urban design concept initiated in New Zealand primarily aimed at reducing the generation of stormwater, through sensitive urban layout treating residual stormwater at source and protecting aquatic ecosystems from the effect of stormwater. It emphasises sustainable urban practices including Low Impact Development (LID) and Integrated Catchment

Management (ICM) to promote alternative urban development by sustaining natural processes to provide flood protection and enhance resilience of the city (van Roon & van Roon, 2009).

According to WWF, (2012) the successful practice of green corridors in New Zealand not only provides walkways and cycle route for inhabitants, but also accelerates flood protection by containing stormwater even for a 100-year flood, as well as enhancing stream quality. Other benefits of LIUDD are also to create natural systems through water flows, minimise energy uses by reducing surface temperatures in summer, and keeping buildings dry during the rainy season (Mortimer, 2010).

4 POTENTIAL FOR SOURCE CONTROL MEASURE IMPLEMENTATION IN BANGKOK

In Bangkok, the application of stormwater management source control approaches is relatively new; however, detention ponds for storing and treating stormwater as well as flood protection are relatively widespread under the operation of Royal Projects (World Bank, 2011). The Monkey Cheeks Project (Kaem Ling Project) was launched in 1995 to provide stormwater detention systems for minimising stormwater issues of Bangkok and other cities (Suksawang, 2012). Additionally, the Makkasan Pond Royal Project and the Rama IX Pond Royal Project have also been implemented to treat polluted water and resolve water quality issues in Bangkok, with the overall capability of efficient collecting by and treating around 288,000 cubic metres per day of wastewater in Bangkok (BMA, 2011).

It is apparent that the application of source control measures by private and public sectors is not widespread in Bangkok. In 2009, The National Housing Authority funded King Mongkut's Institute of Technology, LatKrabang, Bangkok to study and initiate the Low Impact Development practices with a view to the reduction of long-term flooding in a housing project of the National Housing Authority. The focus of this Low Impact Development is on flood protection and sustainable water management in consideration of the environmental aesthetics for this housing pilot project (National Housing Authority, 2009).

Stormwater management source control measures seem to be promising approaches to apply in Bangkok and other high density cities as they provide high performance in urban runoff reduction, pollutant removals, and display a good efficiency for improving water quality in several countries. These practices also offer reclamation of urban runoff through converting the "waste" of the urban nuisance into a valuable water resource, through techniques such as rainwater harvesting. Treated stormwater also allows for the minimisation of demand for water supply as it can be used for various non-potable purposes such as landscape, agricultural irrigation, and toilet flushing.

Insufficient land area for source control facilities is a major concern in high-density areas where a large area is required to store and infiltrate stormwater runoff. As land may be limited in Bangkok, the use of public parks and public spaces in Bangkok should be considered in order to reduce space constraints in private land. It is apparent that public parks provide opportunities for integrating source control measures for medium to high-density residential developments. As the constraint of high prices of competing urban land uses poses threats to and resistance against the adoption and implementation of stormwater quality management strategies, introducing source control strategies within parks may mitigate public resistance due to lower public costs of storm water management.

To increase public implementation of source control technologies, financial incentive can be used to create a public subsidy program for property owners for installing the technologies. Public subsidies are also a main influence on the probability of source control systems adoption. In several cities, financial incentives and subsidies of source control device installations have been introduced such as Germany, Toronto, New York, Singapore (Greenroofs.com, 2014), Portland (PBES, 2006), Philadelphia (Garrison et al., 2011). As the subsidy amount would be regressive in time, and properties would potentially be valuable when they change hands (Montalto et al., 2007), financial incentives might be the most cost-effective way to encourage individual property owners to replace conventional facilities.

The applicability of source control systems may primarily depends on climate and geographic conditions. Most studies have been considered out in temperate or semi-arid zones of western countries and the performance of source control technologies may be significantly different in tropical and temperate climate zones. The lowest temperature in winter in Bangkok is generally more than 20 ◦C and the highest temperature in summer can exceed to 35-40 ◦C. Moreover, there is intensive rainfall during the rainy season and no snowmelt in Bangkok, making the pattern unlike that of many Western countries. These climatic variations may result in differences in the performance of source control facilities in stormwater quality and quantity improvement.

Green roofs as the examples described in many countries show great opportunities for application in Bangkok to achieve multiple benefits of substantially reducing stormwater runoff and minimising urban water pollution problems. Additionally, green roofs are appropriate for highly urbanised cities like Bangkok as they require existing space with no additional land area. However, reduced energy consumption and thermal reduction may offer significant benefits in Bangkok. Without additional maintenance, sediment and nutrient concentration on runoff from green roofs may be high especially during wet seasons due to high rainfall associated with mass loading. Thus, to sustain green roof performance, the systems may require more maintenance effort in hot climatic regions than that required in temperate climate regions, particularly additional irrigation to maintain water level.

Rain gardens are the most commonly used stormwater control devices in several countries. They provide substantial results in detaining stormwater flows, absorbing and filtering pollutants before stormwater flows into rivers. It was found that a fine sand or sandy loam filter media for bioretention provides a substantial nutrient removal (Henderson et al., 2007). However, as the soil in Bangkok consists mostly of low permeability soils such as clay (Surarak et al., 2012), the underdrain is needed in place to slowly drain the base layer of the rain gardens. Rain gardens could also be constructed using media or suitable soils from other locations.

The installation of permeable pavements instead of impervious surfaces on pedestrian walkways, courtyards, parking lots, and low-traffic roads would be effective in reducing surface runoff volumes as well as urban contaminants in Bangkok. However, as Bangkok clay soils may not provide a good infiltration rate, underdrain systems may be important to enhance the performance of the systems.

Stormwater ponds can play an important role in storage runoff volume and attenuating peak flows due to the retention and detention capacity of the systems. Moreover, the combined use of a retention pond and park may result in great potential for enhancing river water quality through retention of stormwater by ponds, and infiltration and purification runoff by plants as well as reducing runoff pollutant loads or CSOs in the city.

Most areas in Bangkok are impervious surfaces, including several commercial offices, apartment buildings, houses, roads, impervious pavements, and car-parking areas. The disconnection of stormwater from the combined sewer and drainage through an array of open systems within private and public properties may contribute to a substantial reduction in the amount of stormwater reaching the piped systems and CSOs in Bangkok.

5 CONCLUSIONS

Urban water quantity and quality issues are closely related to the city's development. In Bangkok, population growth and urban development have caused several environmental impacts, and resulted in increased stormwater runoff and non-point source pollution by nutrients, metals, and other pollutants. The examples from other countries clearly illustrate remarkable advantages in runoff reduction and contaminant removal achieved by source control technologies. Source control measures also promote the use of urban stormwater as a valuable resource rather than an urban nuisance.

The reform of stormwater management through source control measures for the restoration and protection of pre-development flow regimes in Bangkok could be promising if some efforts were made. For instance, financial incentives should be encouraged for increasing the implementation by building owners. The institutional capacity to design and manage stormwater source control systems should be enhanced. Moreover, the use of public parks and public spaces in Bangkok should be taken into account. As a result, the application of source control measures and reclaimed water may significantly mitigate the stormwater pollutants and runoff in Bangkok.

REFERENCES

Asian Development Bank [ADB]. (2012). *Good Practices in Urban Water Management: Decoding Good Practices for a Successful Future.* National University of Singapore. Retrieved 25-05-2013 from http://reliefweb.int/sites/reliefweb.int/files/resources/good-practices-urban-water-management.pdf

Auckland Council (2014). Rain garden construction guide: Stormwater device information series. Retrieved 21-08-14 from http://www.aucklandcouncil.govt.nz/EN/environmentwaste/stormwater/Documents/raingardenconstructionguide.pdf

Autixier, L., Mailhot, A., Bolduc, S., Madoux-Humery, A. S., Galarneau, M., Prévost, M., & Dorner, S. (2014). Evaluating rain gardens as a method to reduce the impact of sewer overflows in sources of drinking water. *Science of The Total Environment*, *499*, 238-247.

Bangkok Metropolitan Administration [BMA]. (2011). *A Royally-Initiated Path Towards a Heavenly Bangkok*. Bangkok Metropolitan Administration. Retrieved 14-04-2014 from www.bangkok.go.th

Barbosa, A. E., Fernandes, J. N., & David, L. M. (2012). Key issues for sustainable urban stormwater management. *Water research*, *46*(20), 6787-6798.

Bratieres, K., Fletcher, T. D., Deletic, A., & Zinger, Y. A. R. O. N. (2008). Nutrient and sediment removal by stormwater biofilters: A large-scale design optimisation study. *Water Research*, *42*(14), 3930-3940.

Brix, H. (1993). Wastewater treatment in constructed wetlands: system design, removal processes, and treatment performance. *Constructed wetlands for water quality improvement*, 9-22.

Buathong, T., Boontanon, S. K., Boontanon, N., Surinkul, N., Harada, H., & Fujii, S. (2013). Nitrogen Flow Analysis in Bangkok City, Thailand: Area Zoning and Questionnaire Investigation Approach. *Procedia Environmental Sciences*,*17*, 586-595.

Burkhard, R., Deletic, A., & Craig, A. (2000). Techniques for water and wastewater management: a review of techniques and their integration in planning. *Urban Water*, *2*(3), 197-221.

Chen, C. F. (2013). Performance evaluation and development strategies for green roofs in Taiwan: A review. *Ecological Engineering*, *52*, 51-58.

Collins, K. A., Hunt, W. F., & Hathaway, J. M. (2008). Hydrologic comparison of four types of permeable pavement and standard asphalt in eastern North Carolina. *Journal of Hydrologic Engineering*, *13*(12), 1146-1157.

Davis, A. P., Shokouhian, M., Sharma, H., & Minami, C. (2001). Laboratory study of biological retention for urban stormwater management. *Water Environment Research*, 5-14.

Davis, A. P., Stagge, J. H., Jamil, E., & Kim, H. (2012). Hydraulic performance of grass swales for managing highway runoff. *Water research*, *46*(20), 6775-6786.

Deletic, A. (2005). Sediment transport in urban runoff over grassed areas.*Journal of hydrology*, *301*(1), 108-122.

Emde, G. (2012). *Flooding in Thailand's Chao Phraya River Basin*. Retrieved 20-08-13 from http://mysite.du.edu/~gemde/pdfs/Fundamentals_ChaoPhrayaRiverBasinFlooding.pdf

Environmental Services. (2014). *Combined Sewer Overflows (CSOs)*, City of Portland. Retrieved 11-12-2014 from http://www.portlandoregon.gov/bes/article/316721

Floyd, J., Iaquinto, B. L., Ison, R., & Collins, K. (2014). Managing complexity in Australian urban water governance: transitioning Sydney to a water sensitive city. *Futures*.

France, R. L. (Ed.). (2002). *Handbook of water sensitive planning and design*. Boca Raton, FL: CRC Press.

Garrison, N., Hobbs, K., Resouces, N., & Council, D. (2011). Rooftops to Rivers II: Green strategies for controlling stormwater and combined sewer overflows. *Natural Resources Defense Council, New York, NY*, 1-134.

Gasperi, J., Gromaire, M. C., Kafi, M., Moilleron, R., & Chebbo, G. (2010). Contributions of wastewater, runoff and sewer deposit erosion to wet weather pollutant loads in combined sewer systems. *Water research*, *44*(20), 5875-5886.

Greenroofs.com. (2014). *Industry Support.* Retrieved 30-11-2014 from http://www.greenroofs.com/Greenroofs101/industry_support.htm

Hathaway, J. M., Brown, R. A., Fu, J. S., & Hunt, W. F. (2014). Bioretention function under climate change scenarios in North Carolina, USA. *Journal of Hydrology*, *519*, 503-511.

Henderson, C., Greenway, M., & Phillips, I. (2007). Removal of dissolved nitrogen, phosphorus and carbon from stormwater by biofiltration mesocosms. *Water Science & Technology*, *55*(4), 183-191.

Hogan, C. M. (1998). Hydrology and biology studies for Carneros Business Park, prepared for the William A. Saks Company pursuant to requirements of the County of Sonoma.

Hunt, W. F., & Collins, K. A. (2008). Permeable pavement: Research update and design implications. *North Carolina Cooperative Extension Service. Raleigh, NC*.

Jia, H., Ma, H., Sun, Z., Yu, S., Ding, Y., & Liang, Y. (2014). A closed urban scenic river system using stormwater treated with LID-BMP technology in a revitalized historical district in China. *Ecological Engineering*, *71*, 448-457.

Kivaisi, A. K. (2001). The potential for constructed wetlands for wastewater treatment and reuse in developing countries: a review. *Ecological Engineering*, *16*(4), 545-560.

Leerasiri, S. (2010). *Wastewater Management in Bangkok.* Department of Drainage and Sewerage Bangkok Metropolitan Administration. Retrieved 14-05-2014 from http://office.bangkok.go.th/training/training/data/pst/know/15-06-6.pdf

Li, C. (2012). Ecohydrology and good urban design for urban storm water-logging in Beijing, China. *Ecohydrology & Hydrobiology*, *12*(4), 287-300.

Lim, H. S., Lim, W., Hu, J. Y., Ziegler, A., & Ong, S. L. (2015). Comparison of filter media materials for heavy metal removal from urban stormwater runoff using biofiltration systems. *Journal of environmental management*, *147*, 24-33.

Locatelli, L., Mark, O., Mikkelsen, P. S., Arnbjerg-Nielsen, K., Jensen, M. B., & Binning, P. J. (2014). Modelling of green roof hydrological performance for urban drainage applications. *Journal of Hydrology*, *519*, 3237-3248.

Montalto, F., Behr, C., Alfredo, K., Wolf, M., Arye, M., & Walsh, M. (2007). Rapid assessment of the cost-effectiveness of low impact development for CSO control. *Landscape and Urban Planning*, *82*(3), 117-131.

Mortimer, C. (2010), *Our Future: What on Earth is LIUDD?,* Landcare Research. Retrieved 23-08-2013 from http://www.ourfuture.net.nz/Stories/21

National Housing Authority. (2009, January). National Housing Authority: Reducing flood problems in housing community with natural methods. *House and City, p.*22. Retrieved from http://dindang.nha.co.th/download/warasarn_bannmung/Bannmung%20VOL%201.pdf

Natural Resource Defence Council [NRDC]. (2001). *Stormwater Strategies: Community Responses to Runoff Pollution*. Retrieved 05-12-2014 from http://www.nrdc.org/water/pollution/storm/chap5.asp

Natural Resource Defence Council [NRDC]. (2014). *Stormwater Strategies: Community Responses to Runoff Pollution, Chapter 12 Low Impact Development.* Retrieved 09-12-2014 from http://www.nrdc.org/water/pollution/storm/chap12.asp

Nusca, A. (2010). *In an attempt to be the world's first carbon-neutral capital, Copenhagen, Denmark will enact a new policy mandating green roofs*. Retrieved 12-01-2014 from http://www.smartplanet.com/blog/smart-takes/striving-to-be-worlds-first-carbon-neutral-capital-copenhagen-enacts-mandatory-green-roof-policy/

Olness, A. (1995). Water quality: prevention, identification and management of diffuse pollution. *Journal of Environmental Quality*, *24*(2), 383-383.

Petrucci, G., Rioust, E., Deroubaix, J. F., & Tassin, B. (2013). Do stormwater source control policies deliver the right hydrologic outcomes?. *Journal of Hydrology*, *485*, 188-200.

Portland Bureau of Environmental Services (PBES). (2006). Combined Sewer Overflow Program Progress Report. *In*: Montalto, F., Behr, C., Alfredo, K., Wolf, M., Arye, M., & Walsh, M. (2007). Rapid assessment of the cost-effectiveness of low impact development for CSO control. *Landscape and Urban Planning*, *82*(3), 117-131.

Prajamwong, S., & Suppataratarn, P. (2009). Integrated Flood Mitigation Management in the Lower Chao Phraya River Basin. In *Expert Group Meeting on Innovative Strategies Towards Flood Resilient Cities in Asia-Pacific 2009 MEETING DOCUMENTS*. Retrieved 19-06-2013 from http://203.150.225.233/archives/download/idrc/2007_Integrated%20Flood%20Mitigation%20Management%20in%20the%20Lower%20Chao%20Phraya%20River%20Basin.pdf

Raja Segaran, R., Lewis, M., &Ostendorf, B. (2014). Stormwater quality improvement potential of an urbanised catchment using water sensitive retrofits into public parks. *Urban Forestry & Urban Greening*, *13*(2), 315-324.

Semadeni-Davies, A., Hernebring, C., Svensson, G., & Gustafsson, L. G. (2008). The impacts of climate change and urbanisation on drainage in Helsingborg, Sweden: Suburban stormwater. *Journal of hydrology*, *350*(1), 114-125.

Stagge, J. H., Davis, A. P., Jamil, E., & Kim, H. (2012). Performance of grass swales for improving water quality from highway runoff. *Water research*, *46*(20), 6731-6742.

Stovin, V., Poë, S., & Berretta, C. (2013). A modelling study of long term green roof retention performance. *Journal of environmental management*, *131*, 206-215.

Suksawang, W. (2012). Holistic Approach for Water Management Planning of Nong Chok District in Bangkok, Thailand. Retrieved 10-04-2014 from http://escholarship.org/uc/item/3mf6k4d5.pdf

Surarak, C., Likitlersuang, S., Wanatowski, D., Balasubramaniam, A., Oh, E., & Guan, H. (2012). Stiffness and strength parameters for hardening soil model of soft and stiff Bangkok clays. *Soils and Foundations*, *52*(4), 682-697.

Suriyachan, C., Nitivattananon, V., & Amin, A. T. M. (2012). Potential of decentralized wastewater management for urban development: Case of Bangkok. *Habitat International*, *36*(1), 85-92.

USEPA. (2002). Wastewater Management. Controlling and Abating Combined Sewer Overflows. *In*: Montalto, F., Behr, C., Alfredo, K., Wolf, M., Arye, M., & Walsh, M. (2007). Rapid assessment of the cost-effectiveness of low impact development for CSO control. *Landscape and Urban Planning*, *82*(3), 117-131.

van Roon, M. (2007). Water localisation and reclamation: Steps towards low impact urban design and development. *Journal of environmental management*,*83*(4), 437-447.

van Roon, M., & Van Roon, H. (2009). *Low Impact Urban Design and Development the big picture: an introduction to LIUDD principles and methods framework* [online]. Landcare Research Science Series No. 37. Manaaki Whenua Press.

Van Roon, M. R. (2013). *Paired catchment research reveals WSUD influences on stream ecosystem condition at average and low residential densities*. 8th International Water Sensitive Urban Design Conference, Gold Coast City, Australia, 24 - 29 Nov 2013.

Villarreal, E. L., Semadeni-Davies, A., & Bengtsson, L. (2004). Inner city stormwater control using a combination of best management practices. *Ecological Engineering*, *22*(4), 279-298.

Vymazal, J. (2013). The use of hybrid constructed wetlands for wastewater treatment with special attention to nitrogen removal: A review of a recent development. *Water research*, *47*(14), 4795-4811.

Wang, C. Y., Sample, D. J., & Bell, C. (2014). Vegetation effects on floating treatment wetland nutrient removal and harvesting strategies in urban stormwater ponds. *Science of the Total Environment*, *499*, 384-393.

Wong, T. H. F., & Brown, R. R. (2011). Water sensitive urban design, in: Floyd, J., Iaquinto, B. L., Ison, R., & Collins, K. (2014). Managing complexity in Australian urban water governance: transitioning Sydney to a water sensitive city. *Futures*.

World Bank. 2011. *Thailand environment monitor: integrated water resources management - a way forward*. Washington, DC: World Bank. Retrieved 23-07-2013 from http://documents.worldbank.org

World Wide Fund for Nature [WWF]. (2012). *Low Impact Urban Design and Development*. Retrieved 23-9-2013 from http://wwf.panda.org/?204377/Auckland

Yu, S. L., Kuo, J. T., Fassman, E. A., & Pan, H. (2001). Field test of grassed-swale performance in removing runoff pollution. *Journal of Water Resources Planning and Management*, *127*(3), 168-171.

Yuen, B. (2013). 49th ISOCARP Congress 2013. 1. *Eco-city Planning*: *Pure Hype or Achievable Concept*. Belinda YUEN. Singapore University of Design and Technology Singapore Retrieved 01-11-2014 from http://www.isocarp.net/Data/case_studies/2334.pdf

Zalewski, M. (2002). Ecohydrology—the use of ecological and hydrological processes for sustainable management of water resources. *Hydrological Sciences Journal*, *47*(5), 823-832.

Zanders, J. M. (2005). Road sediment: characterization and implications for the performance of vegetated strips for treating road run-off. *Science of the Total Environment*, *339*(1), 41-47.