APPLICATION OF GREEN INFRASTRUCTURE FOR WATER MANAGEMENT IN BOGOR: A REVIEW

The Australia-Indonesia Centre

URBAN WATER RESEARCH CLUSTER

MONASH University

INSTITUT PERTANIAN BOGOR

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URBAN WATER CLUSTER PUBLICATIONS:

"Leapfrogging Pathways for a Water Sensitive Bogor".

B Rogers, D Ramirez-Lovering, DR Marthanty, HS Arifin, A Gunn, W Novalia, M Farrelly, H Fowdar, J Holden, R L Kaswanto, D McCarthy, R Marino, E Payne, R Suwarso, Y Syaukat, C Urich, A Wright, D Yuliantoro.

"Benchmarking Bogor's Water Sensitive Performance"

B Rogers, C Brodnik, A Gunn, DR Marthanty, HS Arifin, D Ramirez-Lovering, M Farrelly, R L Kaswanto, N Pandjaitan, Y Suharnoto, R Suwarso, Y Syaukat.

"Governance for a Water Sensitive Transition in Greater Bogor"

M Farrelly, A Gunn, R Suwarso, Y Syaukat, C Brodnik, YA Setyono, B Rogers, RA Velentina.

"Review of the application of green infrastructure for water management in Bogor"

E Payne, H Fowdar, DR Marthanty, H Pawitan, D Marsudiantoro D McCarthy.

"Guidance on developing infrastructure adaptation scenarios for Bogor's water sensitive transition"

A Wright, C Urich, DR Dwinanti, Y Purwanto, N Mulyana Arifjaya, F Zulkarnain

"Pulo Geulis Revitalisation 2045: Urban Design and Implementation Roadmap"

D Ramirez-Lovering, R Marino Zamudio, HS Arifin, RL Kaswanto, HA Simarmata, D R Marthanty, M Farrelly, H Fowler, A Gunn, J Holden, N Panjaitan, E Payne, B Rogers, Y Syaukat, Y Suharnoto, R Suwarso, I Sondang, C Urich, A Wright, L Desrainy, C Brodnik, D Yuliantoro

"Griya Katulampa: Lessons Learned Case Study Report"

D Ramirez-Lovering, R Marino Zamudio, HS Arifin, RL Kaswanto, HA Simarmata, DR Marthanty, , M Farrelly, H Fowler, A Gunn, J Holden, N Panjaitan, E Payne, B Rogers, Y Syaukat, Y Suharnoto, R Suwarso, I Sondang, C Urich, A Wright, C Brodnik, L Desrainy, D Yuliantoro,

"Situ Front City: Transition Strategy to WSC"

D Ramirez-Lovering, R Marino Zamudio, HS Arifin, RL Kaswanto, HA Simarmata, D R Marthanty, M Farrelly, H Fowler, A Gunn, J Holden, N Panjaitan, E Payne, B Rogers, Y Syaukat, Y Suharnoto, R Suwarso, I Sondang, C Urich, A Wright, L Desrainy, C Brodnik, D Yuliantoro

"Sentul City: Lessons Learned Case Study Report"

D Ramirez-Lovering, R Marino Zamudio, HS Arifin, RL Kaswanto, HA Simarmata, D R Marthanty, M Farrelly, H Fowler, A Gunn, J Holden, N Panjaitan, E Payne, B Rogers, Y Syaukat, Y Suharnoto, R Suwarso, I Sondang, C Urich, A Wright, L Desrainy, C Brodnik, D Yuliantoro

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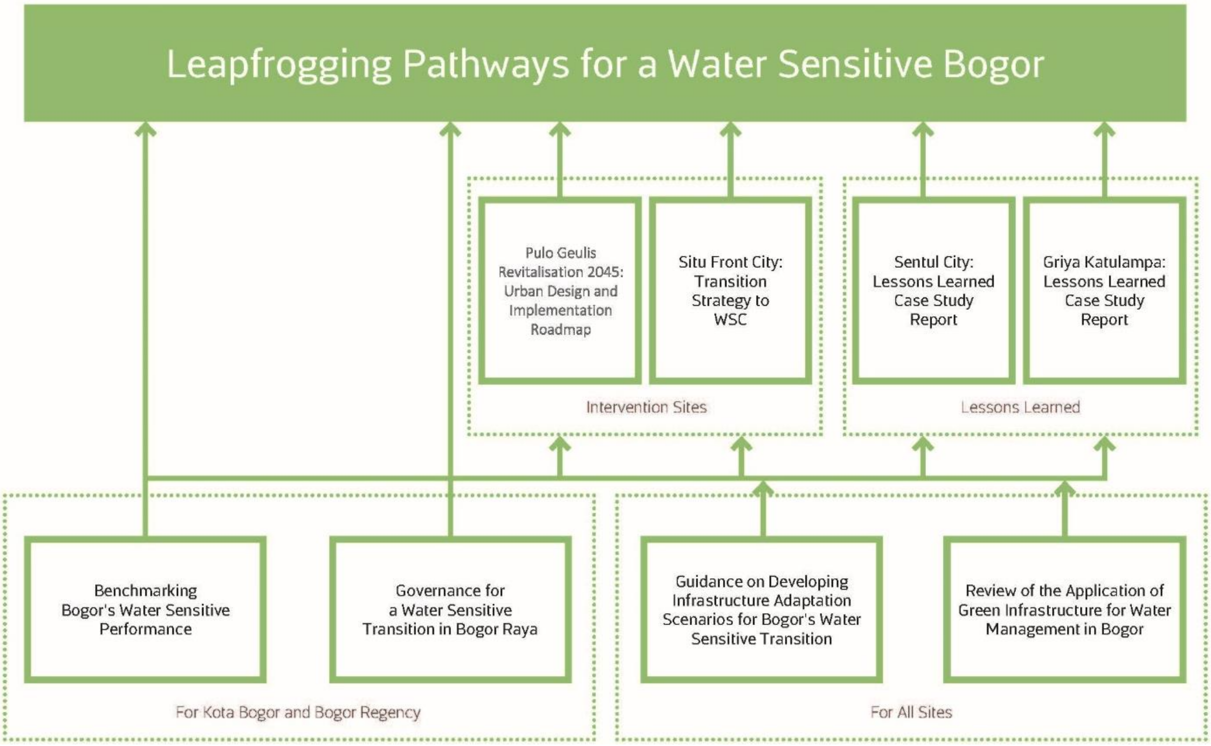
Preface

This work is part of the Australia Indonesia Centre Urban Water Cluster (AIC UWC), a research collaboration between Monash University, Universitas Indonesia and Institut Pertanian Bogor and funded by Australia's Department of Education and Training and Department of Foreign Affairs and Trade, with the support of Indonesia's Ministry for Research, Technology and Higher Education. The Urban Water Cluster was set–up to inform the development of social, political and technical pathways for Bogor city to leapfrog to a Water Sensitive City through different research activities (https://urbanwater.australiaindonesiacentre.org/). The main deliverables of these research activities are as shown in the diagram below. This document is an output of the green infrastructure deliverable.



This report aims to provide broad recommendations for the selection and application of green technologies or more commonly known as Green Infrastructure (GI) for the treatment and management of stormwater and greywater in Bogor city. The information presented in this document comes from a review of grey and academic literature, including technical reports and guidelines as well as a synthesis of numerous workshops and interviews held with local researchers and stakeholders.

The intended audience for the guidance manual is government agencies involved in water management and planning, engineers or other professionals involved in the design and maintenance of GI systems and practitioners involved in landscape design and researchers.

It is expected that the findings of the report will help inform future laboratory testing and development of pilot-scale systems aimed at refining the design and application of GI systems for the local context. This report thus aims to achieve a step in that direction.

Chapter 1

Introduction

Bogor is experiencing rapid urbanisation and population growth which is placing pressure on the environment and its water resources. Significant water pollution, declining groundwater, dry season water shortages, lack of potable water supply, shrinking green and blue open space, untreated wastewater discharges, and increased flood risk, are all critical challenges faced by the city. Many of these are significant challenges globally (IWA, 2015). Given that water is central to the economic productivity and liveability of a city, it is imperative that Bogor develops a new strategic action plan to address these challenges particularly at this critical time when it is on the verge of development. Many of the challenges faced by other urbanised cities in Indonesia can be avoided if a new approach for urban planning and design is incorporated.

The adoption of integrated water management and water sensitive urban design, including green and other treatment technologies, can help Bogor address many of these challenges as part of this strategic action plan. Indeed, many countries around the globe have recognised the importance of green infrastructure (embedded within the concept of urban water cycle) to transition a city to water sensitive status and help it achieve its sustainability and productivity goals.

Bogor's reputation as the 'city of rain' and 'city in the garden', suggests it is ideal for transformation to a Water Sensitive City. With its natural greenery, amenity and Botanic Gardens drawing people to the city, the importance of ornamental greenery is clear throughout the city. The government seeks to build upon this foundation to become a green city of the future. Positioned upstream of Jakarta on the banks of the Ciliwung and Cisadane Rivers, and alongside hundreds of natural lakes (situ), water is also a key feature of Bogor, and commonly believed to give you fortune (hoki) (Dr Herr Soeryantono, Green Technologies FGD, November 2017). Significantly, this upstream position means that Bogor's water management is of high significance to Jakarta, with a local saying that if it is raining in Bogor it is flooding in Jakarta.

This natural, social and political capital is a solid foundation for the application of green water treatment technologies or green infrastructure, which utilise the natural filtration processes of plants, microbes and soil to treat water and reduce flows of stormwater runoff.

1.1 Types of Green Infrastructure and their respective functions

There exists a suite of green-blue infrastructure or green technologies (referred to as Green Infrastructure, GI, in this document from now on) that have different functions in terms of providing essential water services such as water treatment, flow attenuation, storage for re-use, and other secondary benefits such as landscape value and urban cooling. They can be applied at a range of scales and used for a range of applications (notably urban farming, food production, etc).

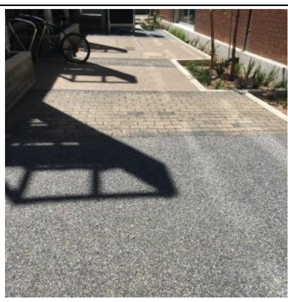
What the different types of green infrastructure have in common is the presence of vegetation and soil of adequate volume, nutrient content and drainage characteristics. Porous pavements and rainwater tanks are exceptions to this. They are considered water sensitive technologies and have relatively low environmental impact and are similar low-cost and low-energy systems and are thus regarded as part of the same group.

Green infrastructure elements looked into in this document, together with their respective functions in delivering sustainable water management outcomes, are presented in Table 1- 1.

Table 1- 1 Description and functions of Green Infrastructure measures

Green infrastructure	Description	Example	Function
Biofiltration/ bioretention/ raingardens	Biofiltration systems are vegetated filters, designed to capture, detain and infiltrate water for discharge to the surrounding soils or into the drainage/sewer system.		- Water quality treatment - Flow attenuation - Groundwater recharge - Storage - Landscape value - Urban cooling - Food production
Tree pits	Tree pits are a type of raingarden planted with trees. Trees can intercept additional rainfall in their canopy, direct runoff from roads and pavements to tree pits and percolate stormwater runoff through soil layers and root pores. Tree pits provide for passive irrigation of the trees. Additional benefits of trees include canopy shading, increasing urban cooling effects.		- Water quality treatment - Flow attenuation - Groundwater recharge - Landscape value - Urban cooling
Living walls	Living walls, also popularly known as green facades, are a type of vertical greening systems consisting of climbers growing directly onto a building façade or on an external structural supporting system adjacent to the wall. They are a type of biofiltration system with plants growing directly into the soil or in planter boxes at the base of the wall.		- Water quality treatment - Flow attenuation - Groundwater recharge - Storage - Landscape value - Urban cooling - Thermal buffer (low)

Green walls	Green walls are vertical gardens with plants grown in compartments or modules attached onto wall surfaces. They consist of plants with shallow root systems and lightweight growing substrate. Green walls need a substantial amount of water to remain lush and green and thus to maximise the benefits of providing thermal insulation and cooling properties to the surrounding environment. Greywater production in excess of the green wall's irrigation demands could be treated by these systems, providing an alternative water source for irrigation of surrounding landscapes.		- Water quality treatment - Flow attenuation - Landscape value - Urban cooling - Food production - Thermal buffer
Green roofs	Green roofs, also known as living roofs or roof gardens, consist of roofs covered with vegetation growing in a specifically designed growing medium and separated from roof structure via a waterproof membrane.	 Photo source: Fytogreen	- Flow attenuation - Landscape value - Urban cooling - Food production - Thermal buffer
Infiltration systems	Infiltration systems perform the same functions as a biofiltration system minus the vegetation. They are mainly used to promote infiltration of runoff into the surrounding soils.		- Water quality treatment - Flow attenuation - Groundwater recharge
Swales/buffer strips	Swales and buffer strips are grassed channels that convey rainwater to the drainage/sewer system. During the process, they help to slow down and partially infiltrate rainwater. They are usually used as a pre-treatment measure to downstream GI system such as bioretention systems.	 Photo source: www.salixrw.com	- Water quality treatment - Flow attenuation - Flow conveyance - Landscape value - Urban cooling

Constructed wetlands	Constructed wetlands are man-made shallow and densely-planted water bodies that retain and filter water for discharge into lakes and rivers or for re-use.		- Water quality treatment - Flow attenuation - Landscape value - Urban cooling
Sedimentation ponds/basins	Sedimentation ponds are water bodies that capture coarse sediments and litter washed off during storm events. They are usually employed as a pre-treatment measure to wetland systems.		- Water quality treatment - Flow attenuation - Landscape value
Retention ponds	Retention ponds are artificial water bodies or lakes that help retain water during a storm event to prevent downstream flooding and erosion. Vegetation grows around the perimeter of the ponds. They usually hold water permanently.	 Sentul City, Image: Raul Marino	- Water quality treatment (low) - Flow attenuation - Groundwater recharge - Storage - Landscape value -
Porous pavements	Porous pavements are alternative paving surfaces that allow water to percolate through a permeable sub-surface course. Water can either infiltrate into the surrounding soils or be discharged into the drainage/sewer system.		- Water quality treatment - Flow attenuation - Groundwater recharge - Storage
Rain barrels/tanks	Rainwater tanks are above or under-ground storage facilities, typically used in residential lots to retain rainwater from roofs on-site. The rainwater collected can be re-used around the building or discharged to the drainage/sewer system or infiltrated into the soils at a controlled rate.		- Flow attenuation - Storage - Harvesting

Riparian buffers	Riparian buffers are vegetated areas along the banks of rivers and lakes to protect the water quality of the water body. They help prevent erosion and are an important food source for fish populations. They include trees, grasses, groundcovers.		- Water quality treatment - Flow attenuation - Food production - Erosion control - Landscape value

1.2 Why implement Green Infrastructure?

Put simply, GI can help strengthen Bogor's economy and improve the health and quality of life of its residents. Several countries across the globe now recognise that GI is critical to the health, liveability and sustainability of urban environments. GI works towards strengthening the resilience of towns and cities to respond to the major current and future challenges of growth, health, climate change and biodiversity loss, as well as water, energy and food security (Ely and Pitman, 2013).

In highlights

How can GI benefit Bogor?

- GI could help reduce the infrastructure costs for managing runoff in a holistic and long-term way, particularly for greenfield developments
- GI could improve local residents' human physical and mental health and thus save on health costs in the long term
- GI could help improve the quality of Bogor's situs and rivers by promoting groundwater recharge and runoff and greywater purification
- GI plays an important role as a moderator for climate, hence can provide for cooler urban environments and improve air quality
- GI could help boost Bogor's tourism industry by increasing the general liveability and attractiveness of the Kota
- GI could provide for greater community engagement and collaboration by improving public open space for family gathering and group activities

1.3 Technology Adoption in Bogor

Selecting, locating and designing GI technological solutions in an effective manner will not only produce optimal hydrological and water treatment performance both in the short and long term but will also render the maximum benefits in terms of delivering the various co-benefits.

Error! Reference source not found. outlines the steps to follow for selection of the most appropriate technological solution. This would ideally start with a site investigation, followed by a definition of the design objectives, conceptual design (based on the principles of best practice water management) and lead into the detailed design stage. This whole process involves collaboration with multiple disciplines, e.g. local government, designers, engineers, landscape architects, planners and local community. For instance, with community involvement the benefits are maximised as sites are respected and become 'owned' by communities, vandalism and crime is reduced, and management costs are minimised. Without community support and 'buy-in' the risk of failure increases and the beneficial value is reduced. Creating and managing green infrastructure in this way comes at long-term financial and managerial costs.

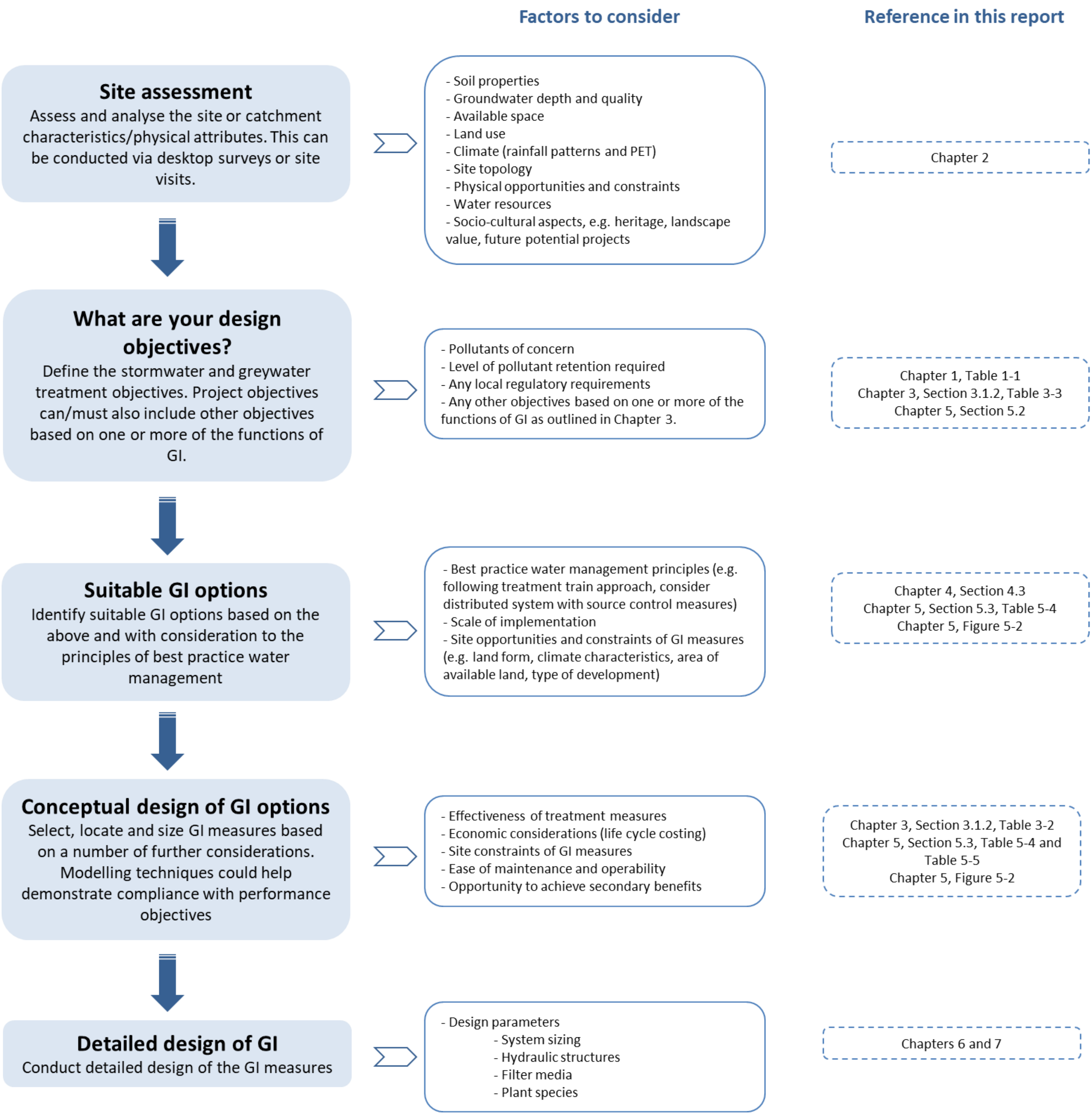


Figure 1- 1 Steps in Green Infrastructure selection and design for achieving the best outcomes

1.4 Report objective and scope

The key objective of this document is to conduct a review of the available information to provide broad recommendations for the selection and application of green infrastructure in Indonesia.

Importantly, it is not intended to provide local design guidelines; these require further research and field testing under local conditions.

Whilst it is accepted that sanitation represents one of the main water management priorities in Indonesia (see Chapter 2) and remains a key area of local research focus, grants and pilot schemes (Green Technologies FGD, November 2017), this document primarily focuses on the treatment and re-use of urban stormwater runoff and 'light' sources of domestic greywater (sourced from the bathroom sink, shower or bath) using green infrastructure. We believe that these relatively less polluted water sources present great opportunities for Bogor residents to solve many of the water-related issues in Bogor, including water scarcity and flooding associated challenges.

The structure and key components of the review have been outlined in below.

Chapter 1	Introduces the key Green Infrastructure elements and their corresponding functions and how their implementation can benefit Bogor. It also provides an outline of the scope and objectives of this document.
Chapter 2	Provides the context for the application of Green Infrastructure in Bogor. It presents information on the local bio-physical and climatic characteristics, reviews the current local water management paradigm and identifies some of the governing water-related issues in Bogor.
Chapter 3	Explains the potential benefits of Green Infrastructure implementation for Bogor from an environmental, societal and economic perspective. It also presents information on the expected treatment performance of systems as gathered from performance in similar socio-economic and climatic conditions.
Chapter 4	Seeks to provide some examples of design strategies in line with the principles of best practice stormwater and greywater management and in light of local opportunities for Green Infrastructure adoption in Bogor. It is hoped that these strategies will serve as a platform to create solutions that will help address the water-related challenges identified in Chapter 2 and transform Bogor into a more water sustainable city.
Chapter 5	Highlights the factors to consider and the process to follow for selection of the most appropriate technological solution. It also provides examples of potential conceptual solutions for retrofit applications.
Chapter 6	Provides technical information for the design and maintenance of the Green Infrastructure measures. It provides general guidance on how to design for local conditions. Readers are referred to available technical guidelines that need to be consulted in conjunction with the recommendations made herein.
Chapter 7	Provides guidance for the selection of suitable plant species for use in the different systems.
Chapter 8	Uses four case study sites in Bogor with different demographic profiles (Pulo Geulis, Cibinong, Sentul City and Griya Katulampa) to provide examples of potential green infrastructure solutions to improve water management in these regions.
Chapter 9	Reviews the key findings of the review and provides recommendations for future research directed at improving Green Infrastructure design in Bogor and Indonesia for more sustainable water management.

Appendix A Presents a list of plant species recommended for further testing and use in systems locally.

Key outputs from the review include:

- Evidence of system performance in tropical climates
- Business case for technology adoption, incorporating evidence of the multifunctional benefits provided by systems
- Selection guidance for which technology to use
- Technical guidance for capacity building
    - Key treatment concepts
    - Design considerations for each technology
    - Examples of solutions
- Local plant selection guidance for green infrastructure
- Guidance for selecting and designing green infrastructure for Bogor, with a focus on four case study sites, namely Pulo Geulis, Cibinong, Sentul City and Griya Katulampa.

Chapter 2

Local Context

This chapter provides the context for the application of green infrastructure in Bogor. It presents information on the local bio-physical and climatic characteristics, reviews the current local water management paradigm and identifies some of the governing water-related issues in Bogor.

2.1 Location and General Overview of Bogor

Bogor is a rapidly growing city located approximately 60 km from Jakarta. Comprising a population of over 1 million people across an area of approximately 120 km^2, Bogor's population is increasing at approximately 1.5% per year (BPS-Statistics of Bogor City, 2017). Bogor Regency, encompassing a wider area, is home to 5.7 million people, making it the most populated Regency in Indonesia (Dr Sharifah, Bappeda).

Positioned at the foothills to mountainous volcanoes, the city has grown from agricultural origins and transitioned to a city with 6 sub-districts and 68 villages (Figure 2- 1). The most obvious legacy from its colonial past is the open channel drainage system throughout the city; once agricultural irrigation channels they now serve a key role for the city's drainage of stormwater runoff. Politically, Bogor serves an important role as home to the Presidential Palace of the Indonesian President Joko Widodo. The city's position is also critical in the context of water management, as it is located upstream of Jakarta and can significantly impact upon flooding in the Capital.

Due to its location alongside mountainous forests and greenery throughout, Bogor has traditionally been known for its beauty. The city vision seeks to continue this with the objective to become a green city. Relative to other Indonesian cities, Bogor is blessed with a relatively high area of greenery in the form of street trees, vacant land and parklands. However, this is reported to be limited to only 320 hectares in area and many parks are currently fenced or open green areas are destined for development. This future development is a key issue threatening to compound existing challenges and further reduce greenery and the associated ecosystem services.

Blue open space is also naturally high with two major rivers; the Ciliwung and Cisadane Rivers, which continue downstream to Jakarta, hundreds of rivers and creeks, 95 small lakes (situs) and 6 catchment areas are in Bogor Regency (Dr Sharifah, Bappeda). The rivers and situs are a key local feature providing amenity, and new lake-front developments in Cibinong and Sentul City are recognising their value. However, these natural water assets have been significantly impacted by urbanisation, including the widespread loss and degradation of situs; a further challenge to be addressed hand-in-hand with managing future urban development.

Figure 2- 1 The city of Bogor

2.2 Bogor's Biophysical Characteristics

The topography of Bogor is uneven, steep in parts and ranges from 190 to 330 m above sea level. It is located in a basin between two volcanoes; Gunung Salak and Gunung Gede (Figure 2- 2).

The soils are predominantly volcanic sedimentary rocks comprising sandy clay, sands and sandy loam, but varying between areas. This contrasts with the clays that dominate Jakarta's soils. The soil thickness is variable, and in some places is not thick enough to safely allow dam construction (April FGD, 2018).

Importantly for the implementation of water sensitive design and green infrastructure, Bogor's soils are generally suitable for the promotion of infiltration, with relatively high infiltration capacity (April FGD, 2018). There are exception in some areas such as Sentul City where the soil is shale and has low absorption and poor structural stability.

Land uses in Bogor include areas of urban housing and settlements, and services. There still remains areas of vacant land, although possibly owned by developers for future development (April FGD, 2018). Military compounds, areas of green open space and forest are also relatively high compared to other Indonesian cities. Open space also includes the Presidential Palace, fields and rice fields. Blue open space includes the situ (lakes), rivers (sungai) and pools (Ulfah, 2018).

Figure 2- 2 Bogor's neighbouring volcanoes

2.3 Bogor's Climate

Bogor is known as 'the Rain City' due to its high rainfall, averaging 2,700 mm/year (Table 2-1). There is some variation across the city, with annual rainfall reported to range from 1,300 mm/year to 4,300 mm/year. Areas located higher on the mountain slopes, such as Sentul City, receive higher rainfall, exceeding 3,000 mm/year. The annual average rainfall as recorded at the Citeko meteorological station on a daily basis between 1985 to 2017, is 3117 mm/year (Figure 2- 3). Annual variation in total rainfall across this period ranged from 1568 mm in 1985 to 4563 mm in 2014.

The climate of Bogor is tropical, with seasons divided into 'wet' and 'dry'. While monthly rainfall totals decrease in the 'dry' season, rainfall continues to fall. January and February are generally the wettest months in Bogor, averaging 450-500 mm/month (Figure 2- 4). Monthly rainfall tends to be lowest in June, July and August, in the order of 100 mm/month or less. In some years a meteorological event known as the Borneo vortex occurs and interrupts the monsoon season, reducing rainfall in January (March researchers workshop, 2018). February is generally the month known for flooding in Jakarta, aligning with Chinese New Year, and flood problems occur with regularity almost every year (March researchers workshop, 2018) with major floods occurring approximately every 5 years (Resosudarmo, 2018). Locally it is said that 'if it is raining in Bogor it floods in Jakarta'. As such, the implementation of technologies that aim to control runoff flow in Bogor (see Chapters 3, 4) may help to alleviate the flooding problem in Jakarta. On a daily timescale, rainfall occurs on roughly 150 to 200 days of the year and it is common for two rainfall events to occur on the same day.

Table 2- 1 Summary of Bogor's climate

Average annual rainfall	2700 mm (1,300 – 4,300 mm) Sentul city: >3000 mm
Temperature	21 ^{O}C to 33 ^{O}C
Humidity	60-80%
Rainy seasons	High intensity rainfall December – February
Rainfall days	150 – 200 days per year
Rainfall patterns	Lower rainfall during dry seasons

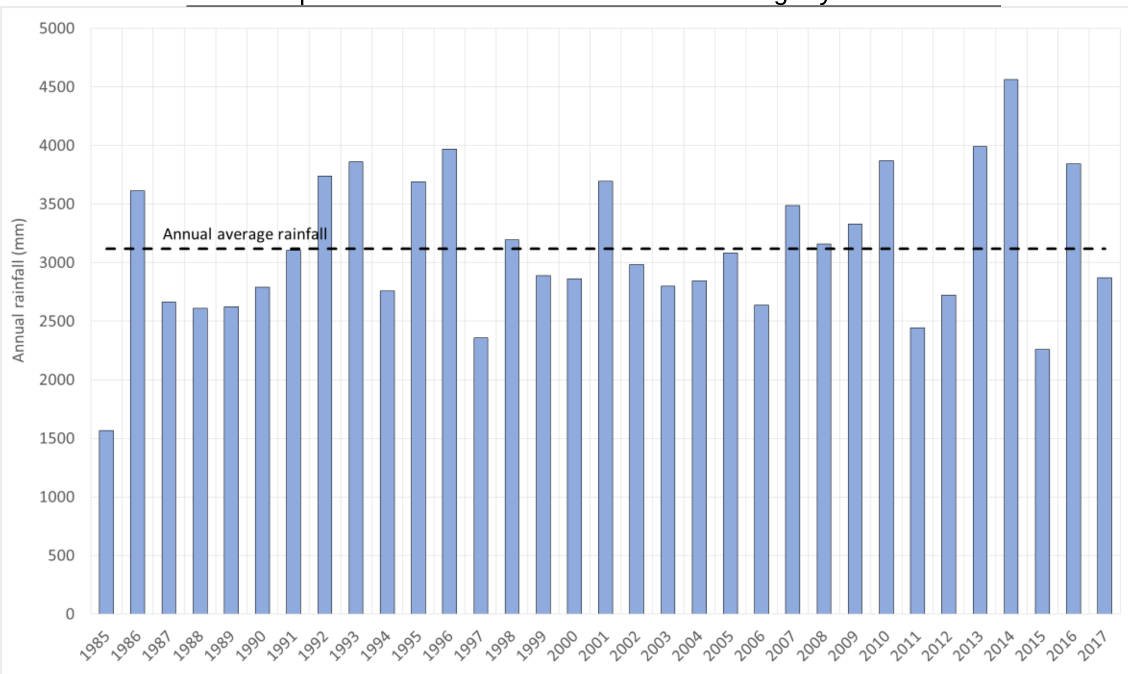


Figure 2- 3 Annual rainfall in Bogor from 1985 to 2017

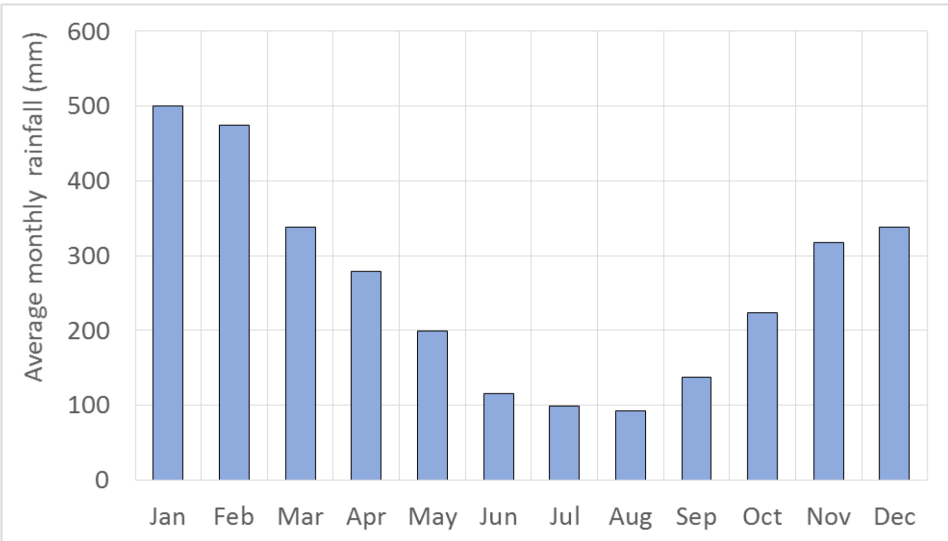


Figure 2- 4 Average monthly rainfall using daily rainfall (1985-2017)

Across the record 1985 to 2017, the average daily temperature in Bogor was 21.2°C, minimum was 11.6°C and maximum 33.3°C. Average daily temperatures in Bogor are relatively stable throughout the year around 21°C (Figure 2- 5). While there is some seasonal variation in the average daily minimum and maximum temperature, the range is not large, varying between 17-18°C and 24-27°C respectively.

Average humidity, also measured daily from 1985-2017, ranges from 37% to 100% and averages 85%. The average monthly humidity does vary seasonally, with highest humidity in the wettest months of January and February, but only ranges between 80 – 90% across the year (Figure 2- 6).

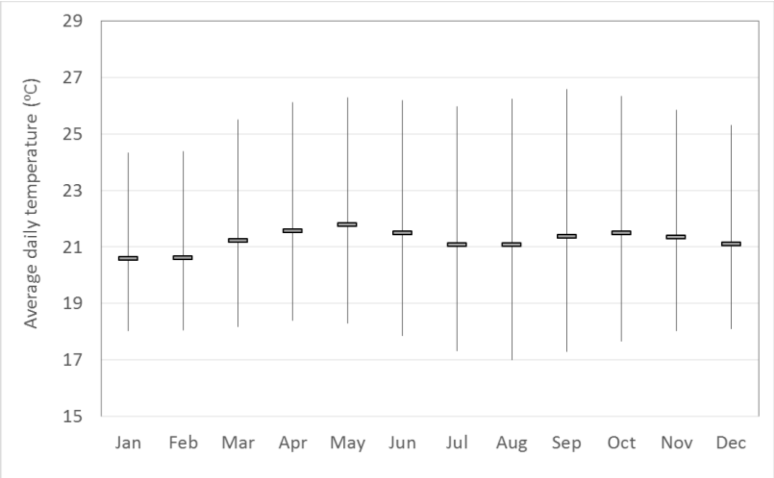


Figure 2- 5 Monthly variation in average daily minimum, average and maximum temperatures in Bogor (1985-2017)

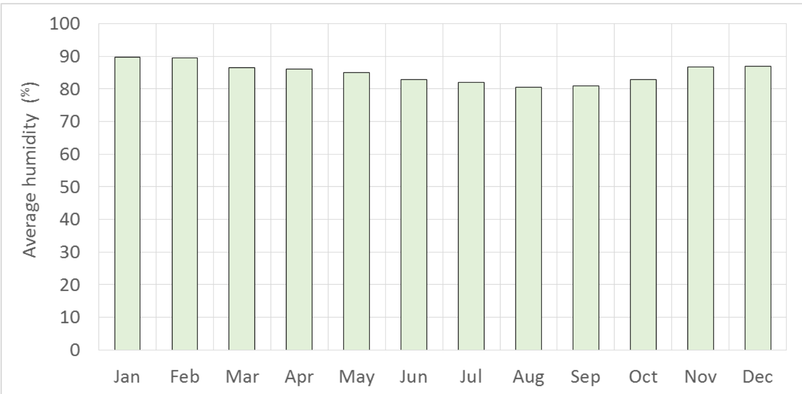


Figure 2- 6 Monthly variation in average daily humidity in Bogor (1985-2017).

Despite the high annual rainfall in Bogor, the dry season has a distinct impact upon the community due to dry season water shortages, driven by the over-extraction of groundwater and degraded quality of water resources. Climate change and population growth threaten to further exacerbate these water issues.

Anecdotally, the local climate of Bogor has changed in recent years. Locals report that as the population has increased and the city grown, temperatures have increased and it doesn't appear to get as cold as previously. In addition, the climate has reportedly become less predictable; such as the start and finish of the wet season (April FGDs 2018; ICLEI, 2016).

2.4 Bogor's Water Sources and Catchments

2.4.1 Water demand and sources

Bogor's surface water resources comprise two major rivers (Ciliwung and Cisadane), numerous creeks and hundreds of lakes (situs). The groundwater system includes a number of deep aquifers, shallow aquifers and various springs. However, pollution, over extraction or development, and poor water quality are significant issues for these water assets.

Domestic water demand was estimated at 28 m^3/cap/year over the period of 1997-2001. This equates to approximately 292 L/household/day if an average household size of 3.8 people is applied (reported for Jawa Barat Province, Statistical Yearbook of Indonesia, 2017). Other reports place water demand at 150 L/ household/ day in settlements such as Pulo Geulis (April researchers workshop, 2018) and the rule of thumb estimate for public housing works calculations is approximately 100 L/person/day (or 380 L/household/day for the average household size).

The water utility company Perusahaan Daerah Air Minum (PDAM) is responsible for supplying water to the community, sourcing water from the Ciliwung River and spring water in the upper catchment. PDAM services approximately 70-80% of the population in Bogor, and only 19% of the population within Bogor Regency (Dr Sharifa, Bappeda). Given the high availability of water in Bogor, it is debated why there is such a significant shortfall in servicing the entire community with this essential service. Private companies are also involved in water supply, helping to fill the need given the lack of coverage of PDAM service to the entire community. In particular, industry and hotels tend to use companies to supply them with water from deep wells (April FGDs, 2018).

Sources of drinking water, reported for the Jawa Barat Province, are as follows (Indonesia, 2017):

- Piped water (7%)
- Pumped water (19%)
- Bottled water (37%)
- Protected well (21%)
- Protected spring (7%)
- Unprotected spring (4%)
- Surface water (0.3%)
- Rainwater collection (0.1%)
- Other sources (0.06%)

These figures illustrate the heavy reliance on groundwater, river and spring water, and bottled water for drinking water supply. The very minimal use of rainwater is also noteworthy. Irrespective of the source (excluding bottled water), Bogor's residents are used to always boiling water before it is consumed for drinking (March and April researcher's workshops, 2018).

Hence, the drinking water supply is not reliable in either quality or quantity (November Green Technology FGD discussion, 2017). Sourcing clean water can also demand a large share of household income in Indonesia; in north Jakarta 50% of household income is reportedly allocated to clean water. Hence, the public have a strong interest in clean water supply projects (March researchers workshop, 2018).

Groundwater (and springs) are heavily utilised by the population as a key water source. Almost every house reportedly has a shallow groundwater well, where groundwater is available to supplement the PDAM supply. Given its proximity to the surface in some areas of Bogor, the community are reportedly reluctant to see the need for rainwater harvesting (April FGD, 2018). However, this depends upon the location, in some areas, such as Pulo Geulis and Sentul City, the groundwater is not accessible due to its depth.

Bottled water is used in areas where residents can afford this option. The reliance on bottled water also allows multinational corporations to own a critical share in the drinking water supply.

In many urban areas the community also still uses water directly from the rivers, particularly in low income neighbourhoods. This includes schools where river water is used for washing and other purposes (November Green Technologies FGD, 2017).

Government agencies are exploring the potential to use various situs (lakes) for water supply sources for the City of Bogor (FGD Bappeda Kota Bogor, April 2018). It is important that any new system can be gravity-fed. The current water supply system is largely gravity-fed, which reduces the energy demand, greenhouse gas emissions and is the most cost-effective.

2.4.2 Groundwater quality

Groundwater is a key water source for the daily lives of many of Bogor’s residents. There are two deep groundwater aquifers (classified as > 40 m below the surface), one in Bogor and another in Jakarta, with the boundary in Cibinong (April researchers workshop, 2018). There is also a system of shallow aquifers (categorised as less than 40 m below the surface) and in parts of Bogor the groundwater is reportedly as shallow as 2 m below the surface. It is important to note that in Indonesia shallow groundwater is categorised as ‘surface water’, while the term ‘groundwater’ refers to the deep groundwater only. However, for the purposes of this report, groundwater is classified as all water below the ground surface.

The groundwater reserve reportedly suffers from both poor quality and declining levels. In particular, *E. coli* and other pollutants from leaking septic tanks contaminate the groundwater. The common use of both septic tanks and groundwater wells in households leads to their very close proximity in dense neighbourhoods and contamination of the groundwater supply.

In addition, groundwater recharge is declining over time. Low groundwater levels in the dry season contribute to water shortages. Population growth and development continue to place high demand on groundwater. For example, there are many new hotels being constructed in Bogor and Cibinong, and each makes a new well. However, regulations by the Agency of Energy and Mining have recently been introduced to prevent this continual depletion, particularly for deep wells, and force new developments to seek alternative water sources. In addition, the destruction of situs for development reduces groundwater recharge rates (November Green Technologies FGD, 2017).

2.4.3 River water quality

The Cisadane and Ciliwung Rivers are the two major rivers in Bogor (Figure 2- 7). These lie within the Ciliwung Basin which has a catchment area of 337 km^2 and river length 110 km. The headwaters lie at Mount Pangrango, Bogor and flow via Jakarta to the Java Sea (presentation by Arif Wibowo, Green Technologies FGD, November 2017). Measured flow in the Ciliwung River is recorded as varying from 2.8 m^3/second to 256 m^3/second (Statistical Yearbook of Indonesia, 2017).

River water serves as an important water source for Bogor, distributed to parts of the community by PDAM and used directly by communities living alongside rivers for clothes washing, washing of domestic utensils, body washing or other uses. However, the river system is classified as heavily polluted (Statistical Yearbook of Indonesia, 2017) from sources such as direct sewage disposal, greywater and stormwater runoff, and river pollution is reportedly increasing in urban areas (S. Suprihatin presentation, November Green Technologies FGD, 2017). Bogor's drainage system tends to directly discharge into the Ciliwung and the Cisadane River and 84% of greywater enters the drainage system (March co-design workshop, 2018).

River water quality is categorised as class III or class IV; below the class I required by legislation for drinking (Government Regulation No. 82/2001 on Management of Water Quality and Water Pollution Control). In particular concentrations of sulphate, phosphate, nitrate and total coliforms exceed regulatory limits (presentation by Arif Wibowo, Green Technologies FGD, November 2017).

Livestock effluent is also commonly discharged into the river. Many dairy farms are located along the river banks, with the unregulated river disposal of effluent common due to a lack of waste management systems, convenience of disposal and limited understanding of the environmental impacts (November Green Technologies FGD, 2017). The livestock effluent contributes to very high Biological Oxygen Demand (BOD), reportedly approximately 45 kg BOD/day in the upper Citarum River (Puslitbang SDA, 2016) (Mirshra et al. 2014), which can contribute to toxic algal blooms. The effluent also carries high concentrations of pathogens including *Salmonella*, *E. coli* and *Cryptosporidium*. The effluent can also contribute salts, heavy metals, antibiotics, pesticides and hormones (Bambang Priadie & Syamsul Bahri presentation, November Green Technologies FGD, 2017). In addition, organic matter in water reacts with disinfectants, such as chlorine, producing disinfection by-products (DBPs) which are potential carcinogens and include trihalomethanes (THMs) (S. Suprihatin, Green Technologies FGD, November 2017).

River water quality for the Ciliwung River at Katulampa, measured monthly during the drier months of April to November, is presented in Table 2- 2. The data illustrates the wide range of river water pollutants, and particularly high concentrations of pathogens, solids, nitrate and sulphate. It should be noted that this discrete sampling is unlikely to capture peak pollutant loads that may be transported during storm events.

Table 2- 2 River water quality summary statistics for the Ciliwung River at Katulampa from 2010 – 2016. The statistics summarise monthly data, collected over varying 4-6 month periods between April and November.

Parameter	**Units**	**Median**	**Standard deviation**	**Range**
Water temperature	ºC	26	2.8	14.4 - 30
pH	-	7.61	0.68	5.93 – 8.90

Total Dissolved Solids (TDS)	mg/L	103.0	111.0	30.8 - 696
Total Suspended Solids (TSS)	mg/L	16.7	16.6	1 - 71
Ammonia (NH_3)	mg/L	0.06	0.60	0.01 – 2.61
Nitrate (NO_3^-)	mg/L	1.4	13.0	0.18 – 76.5
Nitrite (NO_2^-)	mg/L	0.02	0.21	0.00 – 1.02
Phosphate (PO_4^{3-})	mg/L	0.05	0.14	0.01 – 0.62
Sulphate (SO_4^{2-})	mg/L	7.0	26.2	0.4 – 103.8
Dissolved oxygen (DO)	mg/L	5.2	1.32	3.0 – 7.5
Biological Oxygen Demand (BOD)	mg/L	7.0	7.1	0.4 - 30
Chemical Oxygen Demand (COD)	mg/L	26.3	23.8	5.1 – 114.0
Cyanide (Cn)	mg/L	0.01	0.03	0 – 0.11
Chlorine (Cl_2)	mg/L	0.06	0.09	0.01 – 0.4
Iron (Fe)	mg/L	0.06	0.26	0.0 – 1.0
Cadmium (Cd)	mg/L	0.0	0.0	0.0 – 0.01
Chromium (Cr)	mg/L	0.02	0.04	0 – 0.16
Manganese (Mn)	mg/L	0.07	0.14	0 – 0.56
Nickel (Ni)	mg/L	*Note - only sampled on four occasions in 2015, all readings 0.197		
Zinc (Zn)	mg/L	0.01	0.01	0 – 0.05
Copper (Cu)	mg/L	0.04	0.06	0 – 0.18
Lead (Pb)	mg/L	0.00	0.06	0.00 – 0.22
Mercury (Hg)	mg/L	0.00	0.00	0.00 – 0.0002
Arsenic (As)	mg/L	0.00	0.00	0.00 – 0.001
Hydrogen sulphide (H_2S)	mg/L	0.01	0.02	0.00 – 0.06
Faecal coliforms	Jml./100 mL	31,500	1,884,604	90 – 11,000,000
Total coliforms	Jml./100 mL	73,500	7,542,864	300 – 42,000,000
Phenol	µg/L	4.0	16.9	0.001 - 70
Detergent (MBAS assay)	µg/L	30.0	74.6	0 - 360
Oils/fats	µg/L	1000	1140.8	1 - 4290
Sodium Adsorption Ratio (SAR)	-	5.15	0.48	4.3 – 5.4

Figure 2- 7 Images of Bogor's rivers, including the Ciliwung River at Pulo Geulis

2.4.4 Lake water quality

Bogor and its surrounding area has a rich abundance of natural lakes (situs) (Figure 2- 6). The Depok area has approximately 250 situs and these variously serve irrigation, retention and recreational purposes. Together, the hundreds of situs contribute significantly to the rate of water infiltration and groundwater recharge (Herr Soeryantono presentation, November Green Technologies FGD 2017).

However, poor water quality and pollution of these resources is a significant challenge. High levels of faecal coliforms (ranging from 13,000 – 110,000 CFU/100 mL), phosphorus (2.47 – 13.45 mg/L P), nitrogen (only nitrate reported; 0.2 – 1.6 mg/L NO_3^{-}–N), turbidity (15 - 50 NTU) and biological oxygen demand (10.08 – 55.21 mg/L) are reported in by Dr Herr Soeryantono in his study of six lakes (Danau Kenanga, Aghatis, Mahoni, Puspa, Ulin and Salam) (UI, November Green Technologies FGD, 2017). The work includes calculation of a water quality index, with all six lakes scoring a 'Bad' rating. Most situs also have a problem with algal blooms at various times, including toxic cyanobacterial blooms (Dr Cynthia Henny, LIPI, Interview 2018).

Similarly to the rivers, the situs receive inflows of urban stormwater, greywater and in some cases blackwater. The dumping of solid waste, or its transport with inflows, leads to accumulations of gross pollutants. A study of three lake inlets, under various flow conditions, identified the composition of gross pollutants to be 16% organic, 84% non-organic (Anti's Laporan Akhir Pekerjaan Penataan Pengelolaan Limbah Debris dan Sedimen report). The pollution of situs with industrial effluent is also reported (FGD Bappeda Kota Bogor, April 2018).

Water pollution can degrade water quality to the extent of preventing use of the situ for storage or reuse purposes (FGD Bappeda Kota Bogor, April 2018). **Water pollution is compounded by limited community awareness regarding water quality and pollution prevention**, and this makes it challenging to manage the systems for water supply (FGD Bappeda Kota Bogor, April 2018). However, research at LIPI has focused upon studying and improving lake water quality. Henny (2015) found that urban lakes with a high degree of riparian vegetation cover have significantly better water quality than lakes with concrete shorelines. Pilot projects have also been implemented to regenerate lake shoreline plant communities.

Figure 2- 8 Situ in Cibinong

2.5 Local Water Management and Issues

2.5.1 Urban stormwater runoff

Stormwater runoff is drained from the city via a network of channels, largely open rectangular concrete drains of various sizes (Figure 2- 9). It carries untreated urban stormwater runoff and household greywater discharges. The drainage network also suffers from a high sediment and litter load. Currently there are effectively no measures in place to treat runoff in the drainage network.

The drainage channels were originally constructed in colonial times to serve as irrigation distribution networks. Thus, they were not constructed for the purpose of drainage, leading to present day issues of poor connectivity within the network, inefficiency (in terms of stormwater drainage) and a non-ideal drainage configuration. At small scales, people often construct their own drainage infrastructure and manage it themselves.

Figure 2- 9 Open drainage channels throughout Bogor, many adapted from the former irrigation system

2.5.2 Greywater discharges and recycling

Greywater is typically discharged into drains and flows out into receiving water bodies with stormwater runoff. It is estimated that approximately 80% of water use becomes wastewater, and of this approximately 80% is greywater (March researchers workshop, 2018).

Currently there are at least eight examples of commercial buildings with greywater recycling systems in Jakarta. They comprise a dual-pipe system with microbiological treatment of the greywater prior to reuse for non-drinking and relatively low contact purposes, such as irrigation of fields, gardens, toilet flushing, cooling towers, boilers, car washing and cleaning. In this case the recycled water meets more than 50% of the demand and the price is competitive relative to the price of the water supply. This saving on water bills provided the economic motivation for reuse. These greywater recycling systems require building users to be educated in the appropriate uses of the recycled water according to Priadi et al. 2017 (*Water Recycling Opportunity in the business sectors of Greater Jakarta, Indonesia*; November Green Technologies FGD, 2017).

2.5.3 Wastewater treatment and disposal

In Indonesia it is a requirement to treat wastewater to Class 3 prior to discharge into the environment. Yet, across Indonesia, it is estimated that less than 2% of the population are serviced by centralised sewage and wastewater treatment. Instead, approximately 73% of the urban population use toilets connected to basic soak pits or septic tanks (which can be open at their base) and approximately 14% of blackwater is directly released to the environment via open defecation or direct toilet discharge into waterways (Eales et al., 2013). In Bogor there is a centralised wastewater treatment system operated by the government near the botanic gardens in the oldest part of the city. However, it only services a small number of people in Bogor. Manufacturing industries and new housing developments are required to provide their own blackwater and greywater treatment system (FGD Bappeda Kota Bogor, 2018). While some affluent communities such as Sentul City can afford to pay for a private centralised system, even in this case only a small fraction of the community is serviced, far from 100% coverage.

Instead, many households have individual septic tanks. In high density urban areas, septic tanks are often located near to groundwater supply wells, and frequently not cleaned out resulting in seepage into and contamination of the groundwater (March researchers workshop, 2018). In the case of poor communities living alongside rivers, blackwater is mostly discharged directly into the river via small pipes.

Some actions are being taken towards improved wastewater treatment. There are projects planning for the construction of communal septic systems for the treatment of both black and greywater. Such a system has been proposed for Pulo Geulis to service 100-200 households. There are also current plans to construct a communal wastewater management system to service approximately 30% of the domestic wastewater in the City of Bogor, with the cost justified against the cost of annual health care for poor families (FGD Bappeda Kota Bogor, April 2018). In addition there is government funding for awards, such as the sanitation awards, which encourages innovative solutions (FGD Bappeda Kota Bogor FGD, April 2018). However, a lack of space or limited funding can be significant hurdles that prevent projects going ahead. Problems have also been reported for constructed systems which have failed in their first few years due to a lack of proper and ongoing maintenance, and tanks not being cleaned out regularly (April researchers workshop, 2018).

There is also a significant amount of local research focused on decentralised wastewater treatment solutions including grease traps, anaerobic tanks and wetlands (November Green Technologies FGD, 2017). These systems offer passive, relatively low cost treatment. As the conveyance of wastewater is expensive, passive and near-source, decentralised solutions offer significant advantages (Dr Cindy Priadi presentation, Green Technologies FGD, November 2017). There is also potential for energy recovery from the wastewater using methane generation from human waste, fat, oil and grease, and nutrient recovery based upon microalgae and bacterial digestion of waste (paper in preparation Dr Cindy Priadi) (Dr Cindy Priadi, Green Technologies FGD, November 2017).

A large amount of local research and technology adoption is also focused on the treatment of highly contaminated agricultural or industrial waste streams (such as animal waste or tannery waste). In particular, the treatment of dairy effluent is a key focus. More effective on-site management systems, such as the separation of liquid and solid cow waste have been recommended. In addition, pilot treatment systems such as an Anaerobic Upflow Filter (AUF), constructed wetland and sludge drying bed has been implemented at a dairy farm along the Cikapundung River (Bambang Priadie and Syamsul Bahri, Green Technologies FGD, November 2017).

2.5.4 Solid waste management

Gross solid waste disposed directly into the environment causes blockage and reduced capacity of flow channels, pipes, inlets and outlets. This leads to degradation of water quality, increased human disease risk, damage to ecological communities and biodiversity, poor amenity and increased flooding risk. In Bogor, ineffective management of gross solids waste is posing a critical health and environmental issue, and despite regulations preventing illegal garbage disposal, the dumping of waste into rivers, channels or other areas is common with regulations not being enforced (Figure 2- 10). Solid waste management issues are growing with the increasing population, resulting in the President mandating River Clean Up working groups to address this challenge for Ciliwung, Cisadane and Citarum Rivers in West Java. This problem is recognised as a priority for national, provincial and local governments.

Where collection systems are in place, often there is no sorting of the waste into different streams, and it is all destined for landfill. Some separation can occur at the tip from people manually searching for items with some value. An example of separate waste collection system is given in Figure 2- 11.

Gross solids also pose a key risk to the function of any future green infrastructure implemented, as they can cause clogging of inlets, outlets, smothering of vegetation and leaching of pollutants. **Hence it is important to protect both natural water bodies and green infrastructure systems from gross solids through capture (via screens, Gross Pollutant Traps, nets etc.) and regular maintenance to remove the accumulated solids.**

Figure 2- 10 Dumped and accumulated gross solids alongside and within a situ in Cibinong

There is already some use of systems to capture gross solids within Bogor, but high rates of waste accumulation and a high cleaning frequency has been reported. Further details of these programs are provided in Chapter 3, Section 3.4.3.

Figure 2- 11 Bins at the UI campus for the sorting of gross solids

2.5.5 Community connection to water and the environment

Water and greenery are traditionally very important within local culture, and this is reflected by ornamental features throughout Bogor. Green features and the local skills and resources that could be harnessed to support green infrastructure are discussed in the following text box.

However, there is a perception that the community's connection with water and the environment has reduced over time (April researchers workshop, 2018). There is little appreciation of the multiple benefits associated with water management on human health, wellbeing and the environment. For example, health issues are not generally considered linked to a clean environment (April researchers workshop, 2018). While there are some high-end waterfront developments underway, it is most often poor communities that live alongside water bodies, such as rivers. The rivers and lakes (situs) are generally fairly accessible to the community, which allows people to interact and connect with water. However, this also leaves them vulnerable to damage, such as the dumping of solid waste (April researchers workshop, 2018). The destruction of lakes (situs) for development further demonstrates the generally poor appreciation of natural water features, and **it is vital to indicate to developers and the community the value that natural water features can provide to them** (November Green Technologies FGD, 2018).

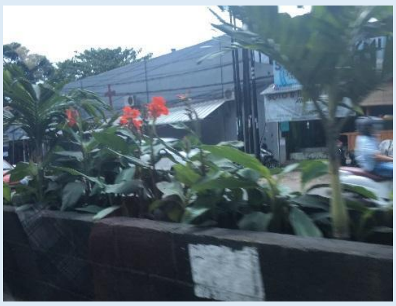
Urban greening within Bogor

There are multiple examples of ornamental greenery in public spaces throughout Bogor, particularly along roadsides and in median strips. There are also numerous strips of roadside plant nursery stalls. This clearly demonstrates the value of greenery to the community for its aesthetic benefits, and the local availability of landscaping and horticultural skills.

Many roadside systems were installed as part of the Mayor's program of Greening the City. Some vertical gardens were installed using drip irrigation, but mechanised systems reportedly suffer from theft or breakage of the pump equipment. Maintenance is also problematic with a high cost from issues such as dead plants or dirty irrigation water. In the case of high-end developments such as Sentul City, private landscaping companies are involved in some roadside greening projects, such as the roadside traffic islands. Maintenance teams can be seen working to maintain the condition of the vegetation.








The roadside nursery stalls sell a wide diversity of plants, are readily available, and willing to take orders. Some features such as waterfalls or landscape design services can be offered (March FGD 2018). **Most importantly, the stalls highlight the high availability of plants. This provides a positive foundation for the adoption of green water treatment technologies.**



There is significant potential for systems to become multifunctional and watered using stormwater runoff or greywater discharges. In particular, roadside systems designed to be watered passively by runoff can reduce flooding and reduce or eliminate the need for mechanised watering systems. These may include biofiltration systems and tree pits, or more simple designs of sunken gardens beds. However, it is critical that designs must ensure road drainage is maintained and flood risk is not increased.

2.6 Summary of critical water supply and management issues

The water issues faced across Bogor City are diverse and include aspects related to use and management of water resources, governance and regulations, and social and cultural aspects. These are summarised below:

- **Lack of access to reliable and potable water –** PDAM do not service the entire population. Residents utilise multiple water sources to combat the lack of a safe and reliable supply. Most commonly groundwater wells, and in some cases rainwater. Many water sources are not safe for drinking and residents generally boil water prior to drinking.
- **Water scarcity during the dry season –** the demand for groundwater in particular exceeds the sustainable limit of extraction
- **Pollution of surface water resources –** the rivers and situs receive significant quantities of gross solid waste dumped or washed into them as a result of widespread littering. Water quality also suffers from a lack of sanitation and wastewater treatment facilities, with untreated stormwater runoff and household greywater and in some cases blackwater, directly into water bodies. In addition, the discharge of untreated industrial (such as tannery waste) and agricultural wastewaters is also a widespread problem.
- **Polluted groundwater utilised heavily by the population as a water source –** pollution of the shallow groundwater aquifers is particularly problematic. Given the dense population, one households groundwater extraction well often lies within close proximity to a septic tank. The groundwater also receives the percolation of leachate from poorly sealed landfills.
- **Over-extraction of groundwater resources –** this is leading to decreasing capacity at a time of increasing demand from a growing population.
- **Excess stormwater runoff in the wet season and flooding –** in contrast to the lack of reliable water sources in the dry season, the wet season
- **Limited land availability to provide essential water infrastructure –** this provides a critical barrier to the implementation of green infrastructure and other government infrastructure programs. Land acquisition for essential services is a large problem throughout Indonesia. In some cases residents have donated their own private land to allow government water supply pipes to be constructed, demonstrating the critical need for access to clean water.
- **Limited funding –** this is a critical factor for the delivery of infrastructure in Indonesia. Environmental issues are often viewed as lower priority for funding, relative to the delivery of transport or other essential services. As a result it is critical to demonstrate the multifunctional performance of green infrastructure and include the avoided costs (of not implementing these solutions) when considering their cost-benefit ratio. In particular, long term funding for operation or maintenance is limited, and hence designs that are passive and low maintenance are vital.
- **Inefficient and polluted drainage system –** not designed for its current purpose, the drainage system suffers from insufficient capacity, poor connectivity, blockage by sediment accumulation, household waste, disposal of greywater and a smaller contribution from blackwater. In addition, despite the existence of drainage Masterplans, some newly developed areas of Bogor are not connected to the drainage system, or have no drainage system in place (April researchers workshop, 2018).

- **Development, loss and degradation of situs –** Threats to the situs include reclamation of land from situs to construct apartments, degradation of the riparian vegetation, polluted inflows of stormwater and greywater, and littering within the lake and along the shoreline. In addition, there are some negative community perceptions of lakes as unhealthy, attractive to rodents and breeding mosquitoes, and the belief they provide no benefit to individuals (Dr Herr Soeryantono, Green Technologies FGD, November 2017).
- **Lack of solid waste management and community education –** disposal of solid waste is a huge challenge. Only approximately 70% of litter in Bogor is managed (FGD Bappeda Kota Bogor, April 2018). Community attitudes to littering are also problematic. Littering often occurs directly into drainage channels, rivers and situs. In particular, for people living along the river bank it is far easier to throw waste into the river than carry it up the river bank and to a disposal area. This is magnified by a lack of transportation for many. In addition, landfills may be leaching contaminants into groundwater. Solid waste also magnifies flooding due to blockage of channels, inlets and outlets (Researchers workshop, April 2018).
- **Aging infrastructure and reactive maintenance –** current pipe networks reportedly aged and rusted, and the available funding cannot replace the entire network. The renewal requirements of infrastructure are a critical issue in Kota Bogor, but can be used to demonstrate the cost-benefits of green infrastructure.
- **Lack of green and blue open space –** while Bogor incorporates significant green and blue spaces currently, there are some densely populated neighbourhoods with a distinct lack of these natural features. In addition, the number of green and blue open spaces that are government-owned, publically accessible, conducive to recreational activities and protected from future development, are limited.
- **Lack of green corridors and low biodiversity in the urban environment –** there are some biodiversity hotspots (such as the botanic gardens, Forest Fiorda CIFOR) and the city has higher biodiversity relative to other Indonesian cities. However, there is a lack of connectivity and this threatens their capacity to remain diverse. Rivers and canals provide natural corridors.
- **Erosion and land subsidence –** heavy rainfall leads to landslides and erosion, and this was particularly problematic earlier in 2018 in Bogor.
- **Climate change and climate uncertainty -** Climate change, either driven by global shifts or local effects from land use change, is a critical factor to that may compound many of these listed challenges. Locals already report changes to the climate. For example, there is less certainty about when the wet season will start or finish (FGD Bappeda Kota Bogor, April 2018), and the local climate is reported by some locals to be warmer in recent years since the population of Bogor has increased (personal correspondence, November 2018).
- **Unplanned development, lacking essential services –** in these cases essential services need to be retrofitted. However, land is not kept aside for the purpose of providing sanitation or other essential services. Most of the available land has already been acquired by housing settlements and development agencies for future development, prior to government legislation being enacted to protect the conversion of agricultural to residential land uses (FGD Bappeda Kota Bogor, April 2018).
- **Preferential focus on hard infrastructure with lower priority for environmental programs –** within some levels of government, water is not always seen as an essential

issue, and the budget and priority is allocated to hard assets such as concrete drains or transportation infrastructure (FGD Bappeda Kota Bogor, April 2018). Environmental programs are given lower priority, and Environmental impact assessments ineffective in fully establishing the future implications for climate change adaptation and community and ecological health. This highlights the need to demonstrate the essential and multiple functions provided by green water treatment infrastructure. However, some government agencies such as Bappeda are transforming the provision of environmental services to essential services infrastructure, and putting forward the business case in light of the cost of not acting.

- **Limited government resources to oversee the implementation of regulations –** some government agencies have very limited human resources. For example, the Environment Agency has only three people to oversee works and projects within the Bogor area (with a population of some 5 million people). Most new settlements in Bogor are being developed by the private sector and there is a lack of supervision of implementation of regulations (such as the need for efficient drainage and an absorption well) (FGD Bappeda, April 2018).
- **Political agenda and limited terms of government –** this hinders the capacity for long-term programs or change. For example, the Mayor of Bogor city has a fixed term and predecessors do not always share the same priorities and agenda.
- **Limited environmental and water management knowledge within communities -** Despite the celebration of water in some cultural festivities, the popularity of water parks and pools, and the connection of some communities to their local water assets, there is a paradox in community behaviour towards water, given widespread littering of waterways. In addition, Bogor has a large population of transient residents, known as contractors or renters. Without long-term ties to the area it is speculated that they feel a reduced sense of ownership or responsibility towards the environment (FGD Bappeda Kota Bogor, April 2018). The local wisdom of older citizens regarding water and its management is well respected, particularly the experience of those who have lived outside urban areas. However, this is at risk of becoming lost and the traditional community rules related to water use (such as only washing downstream) are also lessened by mobile populations and urbanisation. It is therefore evident that the connection between people and water resources is diminishing.
- **Limited local expertise in Water Sensitive Cities concepts –** there is a critical need for capacity building within government agencies regarding Water Sensitive Cities and how to affect the transformation of Greater Bogor towards a more livable and resilient future through integration of GI into city and regency urban development strategies (FGD Bappeda Kota Bogor).

Examples of solutions or strategies that could help alleviate some of these issues and advance Greater Bogor towards achieving water sensitive status are discussed in the following sections of this report. While sanitation management is a key area for action, this document focuses mostly on the application of green treatment technologies (or Green Infrastructure) for urban stormwater runoff and greywater management.

Chapter 3

Benefits and Performance of Green Infrastructure

As discussed in the previous chapter, some of the major water related problems faced by Bogor City and Bogor Regency include flooding, degradation in lake and river water quality due to wastewater and runoff discharges, low storage capacity of its water reservoirs, high dependence and overexploitation of its groundwater resources leading to water scarcity during dry seasons, erosion and land subsidence.

The incorporation of green-blue infrastructure or green infrastructure has the potential to mitigate these issues and improve the resilience of cities and neighbourhoods of Greater Bogor to respond to future urban and climatic challenges arising from future development. Indeed, this approach is being increasingly adopted in several cities across the globe in an attempt to fight the deleterious impacts of population growth and climate change. It should be noted that while the application of green infrastructure will not likely solve all the water-related issues outlined in Chapter 2 in Greater Bogor, it will make a significant contribution towards transforming Bogor into a more water friendly city. Indeed, as briefly discussed in the following chapter (Chapter 4), ***a combination of green and "grey" infrastructure is likely recommended in the journey to achieving more sustainable water management in Bogor.***

GI represents "**a significant tool for designing resilient regions and improving the flexibility and adaptability of urban infrastructure"**. It serves to achieve this through the incorporation of a network of natural systems. These techniques include low-cost, low-energy technological solutions for effective management of stormwater and greywater while providing various other ecological and societal benefits associated with urban greening. Green Infrastructure differs from its 'grey' counterparts in two key aspects, notably their multi-functionality and connectivity. Importantly, GI can deliver multiple benefits from the valuable urban space it occupies, compared with single purpose engineering infrastructure.

There now exist multiple evidence of the beneficial effects of implementing GI solutions within growing cities not only from a water management perspective but also from societal and economic perspectives. This chapter explains the potential benefits of GI for Greater Bogor. It also presents information on the expected treatment performance of systems as gathered from performance in similar socio-economic and climatic conditions.

3.1 Benefits of Green Infrastructure

"Green Infrastructure is based on the concept/realisation that natural systems can deliver a range of engineering and human services to the city, known as 'ecosystem services'." Potential benefits span the socio-cultural, economic and environment spheres.

ENVIRONMENTAL ADVANTAGES

- River and lake health resulting from water quality improvement (Section 3.1.1, Table 3-1)
- Flow control/ flood reduction (Section 3.1.1, Table 3-1)
- Erosion control (Section 3.1.1, Table 3-1)
- Water supply and security (Section 3.1.1, Table 3-1)
- Greywater management (Section 3.1.2, Table 3-2)
- Climate change mitigation (Section 3.1.3, Table 3-3)
- Urban cooling (Section 3.1.3, Table 3-3)
- Air quality improvement (Section 3.1.3, Table 3-3)
- Ecosystem health/biodiversity (Section 3.1.3, Table 3-3)

SOCIO-CULTURAL ADVANTAGES

- Human health & well-being (Section 3.1.3, Table 3-3)
- Community engagement and inclusion (Section 3.1.3, Table 3-3)
- Visual & aesthetics (Section 3.1.3, Table 3-3)

ECONOMIC ADVANTAGES

- Economic growth and investment (incl. commercial vitality, increased property value, local economic productivity) (Section 3.1.3, Table 3-3)
(Section 3.1.4)
- Reduces future cost of grey infrastructure
- Thermal benefits to buildings (reduces energy consumption cost) (Section 3.1.3, Table 3-3)

3.1.1 Water-related benefits of GI

Table 3- 1 Green infrastructure water-related benefits and their governing processes

Water-related benefits	Process
Water quality improvement	Achieved through treatment of a range of pollutants, including sediments, suspended solids, nutrients, heavy metals, oil and grease, micropollutants and other dissolved substances. This occurs through a range of physical, chemical and biological processes as the water is in contact with the filter media, plant roots and associated microbial assemblage. Primary treatment techniques include: physical screening, rapid sedimentation (targeted contaminants: gross pollutants and coarse sediments) Secondary treatment techniques include: fine particle sedimentation filtration techniques (targeted contaminants: fine sediment, attached pollutants) Tertiary treatment techniques include: enhanced sedimentation and filtration, biological uptake and absorption onto sediments (targeted contaminants: nutrients, dissolved heavy metals) See Table 5 for expected pollutant treatment performance of the different GI measures.
Hydrological – flow control and flood reduction	Mechanisms include: Canopy interception (works best during small rain events; with large rainfalls that continue beyond a certain threshold, vegetation begins to lose its ability to intercept water); infiltration into surrounding soils; Retention and storage of stormwater; Slowing down of flow. A benefit of trees and other vegetation is their ability to enhance the storage capacity of the soil. Some water loss also occurs via evapotranspiration. In Bogor, with the high intensity rainfall devices that detain, store or slow down rainwater such as rainwater tanks, raingardens (with storage) and retention ponds will be of most benefit to achieve this function. See Table 5 for expected hydrological performance of the different GI measures.
Erosion control	Vegetation acts as barriers, slowing down runoff and capturing and preventing sediment from flowing downstream (Kika de la Garza Plant Materials Center). They are able to achieve this because of their dense concentration of thick stems which slows and ponds water and cause sediment to deposit (Kika de la Garza Plant Materials Center). Roots help reinforce the soil by increasing soil shear strength and cohesion during saturated conditions while the fine feeder roots of trees, shrubs and groundcovers bind soil particles at the ground surface, thus helping reduce soil erosion during saturated conditions (Menashe, 2004). Large trees can arrest, retard, or reduce the severity and extent of failures by buttressing a slope, similar to retaining walls – however, note that this occurs only in fully-developed, mature tree systems, so planted trees need some time before becoming effective in stabilising slopes (Menashe, 2004). As such, the effectiveness of using vegetation for erosion control will increase over time as plants are more established and mature.

Water supply and security	Harvesting of rainwater and re-using of greywater will provide for an alternative source of water supply, thereby reducing the demand on PDAM water and ensuring water security during all times of the year. A study conducted in Southern Italy found that re-using light greywater (from washing basins) for toilet flushing could lead to water savings of ~10-30% of domestic water demand (Campisano and Modica, 2010). See Chapter 4, Section 4.3.4 for rainwater harvesting and greywater re-use solutions/opportunities.

3.1.2 Treatment performance of GI elements

Table 3- 2 provides an account of the performance of the green infrastructure based on studies from similar climatic conditions unless otherwise specified. This table can be used as a guidance to gauge the expected performance of the different systems. It should be noted that performance will likely vary depending on the design and operating conditions and maintenance regimes of site-specific system.

Table 3- 2 Hydrological and pollutant treatment performance of Green Infrastructure measures

Green infrastructure	Hydrological performance	Pollutant removal efficiency	Comments
Biofiltration systems		Stormwater Pollutant removal range: TSS: 53% (-12% up to 92%) TP: 46% (-7% up to 75%) PO_4: 45% (4% up to 75%) TN: 25% (-24% up to 68%) (Wang et al., 2017)	Location: Singapore Water source: stormwater from a residential catchment The system was found to be undersized; hence a significant proportion of the flow was bypassing the system, untreated (and included in the removal efficiency). Biofilter size and storage capacity, and filter media composition are key design parameters.
		Light greywater BOD: Over 90% TOC: Over 70% TP and TN: 20 – 80% of TP and TN (depending on plant selection) Pathogen: 2-3 log reduction (Fowdar et al., 2017)	Location: Melbourne, Australia Note: study on treatment performance of light greywater was conducted in the temperate climate of Melbourne.
Living walls	Similar to bioretention systems		
Green walls		Mean COD and BOD: approx. 50% (Masi et al., 2016)	Water source: light greywater (from hand washing basins from an office building)

			Influent concentrations ranged between 6-47 mg/L (mean of 25 mg/L) for BOD and 20-100 mg/L (mean of 60 mg/L) for COD. Effluent from the green wall system complied with local regulations for irrigation. Pre-treatment recommended to avoid premature clogging
Green roofs	• Delay in runoff (peak to peak) by approx. 10 mins • <10 mm rain events were fully absorbed by the green roofs • For 12 mm rain event, retention ranged from 88% to 26% • For 28 mm event, retention ranged from 43% to 8% • For 49mm rain event, retention ranged from 44% to 13% (Simmons et al., 2008) • Retention by the vegetated roofs varied between 39 – 45% depending on designs (mean of all events) • Mean retention was 73-84% for light events (<2 mm) • Mean retention was 36-47% for medium events (2-10 mm)	Quality of runoff from green roof OK for use for irrigation purposes if correct substrate and minimal fertilisers are used. (Simmons et al., 2008)	Water source: roof runoff Hydrological performance depends on rainfall magnitude, duration and frequency. Key design parameters are growing substrate selection, type of green roof (extensive vs intensive), plant species and drainage layer depth. Retention volumes decrease with rainfall intensity while rain events of variable intensity will have higher retention volumes compared with those of constant intensity (Villarreal, 2007). Peak reduction can be expected to be lower compared to temperate climate as a result of higher rainfall intensity.

	• Mean retention was 16-19% for heavy events (>10 mm) • Peak delay was between 25 – 35 mins (for >10mm rainfall depth) (Wong and Jim 2014)		
Constructed wetlands		<u>Free water surface constructed wetlands (FW CWs)</u> TSS, COD and BOD: 70-80% TN: 60 – 75% TP: 13-75% <u>Subsurface flow constructed wetlands (SSF CWs)</u> TSS: -80% BOD : 78-88% COD: 64 – 71% NH4: 60-70% NO3: 40% (Horizontal flow) – 70% (Vertical flow) TN: 50% TP: 60-70% <u>Hybrid systems</u> TSS: 97% COD: 84% NH4: 80% TP: 85% (Zhang et al., 2015) Fecal coliform: 75% (Tanaka, et al., 2011) Water source: secondary treated municipal wastewater Location: tropical city; Varanasi, India Mesocosm free-water surface wetland study. Aquatic macrophytes removed heavy metals effectively from wastewater. Averaging up to 71% Fe, 69% Cr, 68% Cu, 66% Cd, 65% Zn and 55% Ni removal. - Removal highest for Fe>Cr> Cu>Cd>Zn>Ni. Plants require Fe in highest amount, also Cu, Zn and Ni essential nutrients. (Upadhyay et al., 2007)	Water source: wastewater 14 studies on FWS CWs 13 studies on HSSF 11 studies on VSSF 11 studies on hybrid systems 9 studies on FTWs Studies in Kenya, El Salvador, Taiwan (Zhang et al., 2015) Difference in performance across different studies may be due to different operating conditions (incl. design, hydraulic loading rate, pollutant concentrations) Treatment performance is generally higher than temperate countries due to higher biological activity and productivity under high temperatures (Katsenovich et al., 2009). However, humidity and high intensity rainfall in the tropics can promote faecal coliform survival and inflow concentrations respectively. Oxygen solubility is also reduced under high temperatures (Katsenovich et al., 2009). Wetlands in Indonesia may be able to sustain a rich diversity of biota for wastewater treatment because of the warm and tropical climate (Kivaisi, 2001) This will also depend on the nature and quality of the wastewater.

		Location: El Salvador Wetland types vary in their performance across different pollutants; combinations of wetland sub-surface flow and surface flow can be more effective. Surface flow wetlands planted with *Typha*, treating wastewater first treated in a facultative lagoon treatment: BOD_5: 81% (± 9.4%) COD: 65% (± 19.6%) TN: 59% (± 19.3%) TDP: 66.5% (± 20.7%) Oil & grease: 78% (± 10.6%) Faecal coliform removal correlated positively with TSS and BOD_5 removal. P removal requires a longer retention time than C or N. Performance in the wet season was only slightly higher than in the dry season, but this was exacerbated by dilution (and evapotranspiration in the dry season). Sub-surface flow wetlands can clog due to sediment or algal blooms. Plant species differ in pollutant removal performance, including their ability to remove pollutant spikes in either the wet or dry season. Wetlands can buffer against increased pH due to algal photosynthesis. (Katsenovich et al., 2009).	Vertical flow constructed wetlands have been found to have a high capacity to treat high-strength wastewater in tropical climates (Kantawanichkul et al., 2013). Wetland performance in the tropics can be skewed by the effect of high evapotranspiration in the dry season and high rainfall in the wet season, which concentrate and dilute pollutant concentrations significantly. Hence, water balance calculations are important to determine performance using pollutant loads (Katsenovich et al., 2009).
Swales		Location: Singapore Significant sediment removal possible if slope is low (1-4%) and flow is well distributed across the swale width. Important form of pre-treatment, but on its own performance does not meet Singapore's stormwater treatment objectives. (PUB, 2018b)	Most suited to catchments of 1 ha or less. Higher flow velocities and volumes from larger catchments are difficult to treat. (PUB, 2018b)
Porous pavements	Porous pavements can provide effective peak flow reductions of up to 42% and longer	Coarse sediment: 50-80% Medium sediment: 30-50% Fine sediment: 30-50% Free oil and grease: 10-50% TN: 40-80% TP: 50-80% Metals: 10-50%	Brattebo et al., 2003 report that their permeable pavement systems infiltrated almost all precipitation (highest rainfall intensity was 7.4 mm/h) but are of the view that performance might

	discharging times (Scholz et al., 2006).	(Department of Planning and Local Government, 2010) See Scholz et al., 2006 for more statistics on other pollutants	decrease under higher rainfall intensity conditions. Note: Performance will also depend on the quality of runoff. High sediment levels will require more frequent brushing of the pavement surface.
Retention ponds		Source: Chapter 5, Auckland Regional Council, Technical publication #10. Source: WMI, 1997 TSS: 20-60% (Dry; D) 50-90% (Wet; W) TP: 10-30% (D) 30-80% (W) TN: 10-20% (D) 30-60% (W) COD: 20-40% (D) 30-70% (W) Pb: 20-60% (D) 30-90% (W) Zn: 10-50% (D) 30-90% (W) Cu: 10-40% (D) 20-80% (W) Bacteria: 20-40% 20-80% (W)	Water quality improvement occurs through settling, and moderate to high rates of pollutant removal are achieved if the permanent water volume in the reservoir is between approximately 30 and 60 mm of runoff per hectare of stormwater flows of impervious surfaces (generally, as has been found in temperate climates). Note that wetlands provide better filtration of contaminants, including dissolved ones due to densities of wetland plants, incorporation of pollutants in soils, adsorption, plant uptake and biological microbial decomposition.
Rainwater tanks			Key pollutants: turbidity, suspended solids, lead. Shorter travel distances from roof to tank tend to lead to higher water quality. Challenge if high water demand occurs during low rainfall periods. Tank volume and design are key performance drivers. Use modelling to optimise tank volume given catchment area, patterns of rainfall and water demand. To maximise water quality: - First flush diverter - Calm input (minimise resuspension) - Inlet barrier & drainpipe (to concentrate & drain sludge) - Floating suction device (draw water below surface to avoid scum & sludge) - Siphonic discharge (allows surface scum to drain away)

			- Solar disinfection in polyethylene terephthalate bottles for 4-8 hrs + lemon + vinegar removes pathogens - Regular tank cleaning & maintenance by tank owner (IWA, 2015)
Sedimentation basins		Designed to capture 70-90% of coarse to medium-sized sediments	

3.1.3 Co-benefits of Green Infrastructure

Table 3- 3 Evidence-based co-benefits of Green Infrastructure

Co-benefits	Explanation	Evidence
Human health and well-being	GI provides multiple ecosystem services which benefit human health and well-being such as reduced urban temperatures, amelioration of air quality and a more diverse human microbiome, likely associated with better health and reduced allergies such as asthma. Importantly, the presence of green space is associated with a variety of psychological, emotional and mental health benefits. For instance, being amidst natural environments and greenery can help rejuvenate mental health commensurate with a decline in depression and anxiety of a city's residents. Moreover, proximity to green space influences the likelihood of undertaking physical activity which then results in an improvement in physical health. The cooling effect of urban greenery also reduces the health impacts of extreme heat (see further below in table for more detail).	Lee and Maheswaran (2010) and Shanahan et al. (2015) have reviewed a number of studies that provide evidence of the multiple health benefits of urban green spaces. Some studies have shown that green space may indirectly reduce stress levels by serving as a buffer against the adverse health impacts of stressful life events (e.g. Van Den Berg et al., 2010; Ottosson et al., 2008; Nutsford et al., 2013; Beyer et al., 2014). Studies have found multiple links between urban biodiversity, human microbiota and human health. The health impacts include a healthy immune system and less inflammatory disease. Evidence also suggests a reduction in infectious disease transmission may occur (Hanski et al., 2012; Sandifer et al., 2015).
Air quality improvement	Trees and other vegetation can reduce air pollutants such as nitrogen oxide (NO_2), ozone (O_3), sulphur dioxide (SO_2) and particulate matter through direct up-take and absorption. Particulate matter are deposited onto leaf surfaces.	The structure of large trees and their rough surfaces caused interception of particulate matter of less than 10 microns in diameter (PM_{10}) by disrupting the flow of air; trees can provide a surface area for capture that can be between 2 and 12 times the area of land they cover (Tiwary et al., 2009 in Forest Research, 2010) Trees can intercept particle-bound PAHs by accumulating particles of

		less than 2.5 microns ($PM_{2.5}$) on the surface of leaves and bark. Some species of tree, such as those with needles, are more successful at intercepting $PM_{2.5}$ due to high surface area (Jouraeva et al., 2002 in Forest Research, 2010).
Contribution to urban cooling	GI can cool down cities via the processes of tree shading, evapotranspiration and wind speed modification. Coutts et al. (2013) found that the area of shade produced by a tree canopy can drastically reduce the surface temperature of the ground surface. Through evapotranspiration, large amounts of solar radiation can be converted into latent heat which does not cause temperature to rise (Wong et al., 2010). Usually, the hotter the climate, the greaterreduction in surface temperature can be expected. Passively irrigated green open space such as trees, grasses and swales among others have higher moisture levels, leading to reduced surface temperature and in turn produce lower air temperatures. The levels of temperature reduction observed will depend on the strategic placement of trees and vegetation around buildings.	Under hot, sunny daytime conditions during an Extreme Heat Event (EHE), tree shading lowered potential evapotranspiration rates (PET) by around 12-14 °C altering HTC from "extreme heat stress" to "strong heat stress" (Coutts et al., 2013). Coutts et al. (2013) also found that for a 10% increase in total vegetation cover, in general there was around a 1°C reduction in land surface temperature during the day. A large oak tree, for example, can transpire 40,000 gallons of water per year; an acre of corn can transpire 3,000 to 4,000 gallons a day (http://ga.water.usgs.gov/edu/watercycleevapotranspiration.html)
Ecosystem health and biodiversity	Biodiversity is one of the most important indicators of ecosystem health. By increasing the overall vegetative cover within a city, GI helps to preserve and enhance diversity within ecosystems in terms of habitats, species and genes. Species-rich ecosystems have higher productivity, or vigour and tend to be more resistant to invasion. In this way, GI positively influences ecosystem health by contributing to ecosystem resilience, organisation and vigour (Tzoulas et al., 2007). For instance, green roofs are used by birds and a wide range of invertebrates, including beetles, ants, bugs, flies, bees, spiders and leafhoppers, as well as large numbers of collembolans, which is an important group of invertebrates for soil carbon cycling (Schrader and Bonning, 2006)	A study measuring bird abundance on 27 green walls found that bird species abundance was 4 times greater on the green walls as compared to a bare wall (Chiquet et al., 2012). These results were found to be very relevant to areas suffering from a general decline in the number of bird species.
Visual and aesthetics	Improving the aesthetics of the local landscape attracts business, e.g. tourism industry can benefit. Improvement in the aesthetics quality of a region tends to be accompanied by increases in land and	The placement of streetscape raingardens in Sydney, Australia have caused increasing property values by around 6% for houses

	property prices which might attract more investors to the area.	within 50 m and 4% up to 100 m away (Payne et al., 2015). Similar results were found for a Philadelphia-based study where properties close to new tree plantings increased in price by about 10% (Wachter and Gillen, 2006).
Thermal benefits to buildings	Vertical greenery systems such as green walls can help to reduce the surface temperatures of building facades, and improve the energy efficiency of buildings, subsequently reducing the cooling load and energy cost. A range of factors will affect the thermal performance of the vertical greening system, including substrate type, insulation from the system structure, substrate moisture content as well as shade and insulation from greenery coverage (Wong et al., 2010). A building façade fully covered by greenery can reflect or absorb in its leaf cover between 40% and 80% of the received radiation, depending on the amount and type of greenery (Department of Stuttgart, 2008).	In Hong Kong, coverage of a concrete wall with modular vegetated panels reduced exterior wall temperatures by up to 16°C in summer (Cheng et al. 2010). In terms of internal wall temperatures, a difference of more than 2°C was maintained even late at night, indicating that green walls can significantly reduce energy use for building cooling. At HortPark in Singapore, a number of green wall systems were assessed for their thermal performance (Wong et al. 2010). The researchers reported differences in external wall temperatures of up to 10°C between vegetated and bare concrete walls.
Climate change mitigation	Climate change is recognised as one of the most serious environmental, societal and economic challenges (IPCC 2007). Urban greenery can reduce the amount of atmospheric CO_2 through direct carbon sequestration, reductions in water and wastewater pumping and treatment and the associated energy demands and reductions in building energy use.	A study found that increasing the urban canopy of New York city by 10% could lower ground-level ozone by about 3% (Luley and Bond 2002).
Economic growth and investment	Green space can make positive impacts on local economy regeneration, especially for job creation, increased land values (as per above), food production by supporting urban farming (see next section), and fish farming practices. This in turn could lead to higher levels of employment and tourism and to lower levels of crime.	Proximity to at least 20% woodland cover was found to have the potential to raise the value of an average house by 7.1% (Garrod, 2002 in Forest Research, 2010)
Community engagement and inclusion	Green spaces can bring people together, creating community cohesion as different social groupings engage with each other. Community gardens can bring people together. Green space could be aligned to create open space where people can gather for lunch or for conducting a range of social activities.	

GI can support wildlife

GI helps rejuvenate mental health and encourages participation in physical activity

Sentul City – Image: Raul Marino

3.1.4 Urban farming

Key opportunities exist to integrate urban farming practices and stormwater or greywater management infrastructure. For instance, rooftop vegetable gardens (a form of green roofs) and food crops planted in green walls and biofilters, can serve as urban community vegetable gardens. Food production can be combined with other services to urban citizens, such as agro-tourism or parks. Urban food production can take place over a range of scales from backyard or balcony vegetable gardens to productive gardens on building walls and rooftops and large scale orchards and city farms. Systems must be multi-functional – food production, re-use of composted urban wastes, stormwater storage, recreation and biodiversity. Types of practices, in addition to food production, include horticulture and floriculture. As such, urban farming practices have a number of socio-economic advantages (see below).

Benefits of urban farming:

- ***Source of income, creation of jobs both directly and indirectly***

A study investigating the net income generated in small-scale periurban open space vegetable production in a number of African cities found that monthly net income figures for such peri-urban producers usually range between US$30 and US$70 per month, but can increase to US$200 or more. In the same countries, the minimum monthly wage is in the range of US$20– 40, indicating that urban vegetable production is a profitable business compared to other urban jobs (Van Veenhuizen & Danso, 2007 in DeZeeuw et al., 2011).

Urban agriculture can in turn generate income for other households by producing certain agricultural inputs – e.g. producing compost and worms from agricultural waste. For instance,
26,000 people in Havana are involved in jobs indirectly related to urban agriculture in addition to the 117,000 people involved in urban agriculture production directly (Gonzalez Novo & Murphy, 2000 in DeZeeuw et al., 2011).

It is pertinent to note that the use of urban farming for food production pose a number of health and environmental risks (similar to rural agriculture), namely inappropriate use of contaminated irrigation water and inadequate use of agrochemicals (fertilisers, pesticides and fungicides) (DeZeeuw et al., 2011). See the later references for more information and guidelines to follow to minimise the associated health risks.

We do not recommend the use of untreated greywater for production of food crops (except for irrigation of non-food crops such as horticultural and floricultural crops) due to associated health risks as a result of pathogenic contamination until there are more research to prove otherwise. Nor do we recommend the use of stormwater runoff other than roof runoff for food crop irrigation. Tom et al. (2014) found that when vegetables are irrigated with stormwater runoff metal accumulation occurs within the soil and the plant, increasing with crop age but differing between crop types. Hence, there are health risks that need to be carefully managed.

In contrast, using roof runoff to irrigate vegetables is a much safer practice. In a study using rainwater collected in a tank, Tom et al. (2013) found no increased risk in terms of chemical or microbial contamination of vegetables, relative to a vegetable garden irrigated with potable water.

Another potential solution, the feasibility of which is yet to be tested for the local context of Bogor cities, is diluting untreated stormwater with freshwater before irrigation of food crops.

Urban agriculture in Bogor

As a rapidly growing city with agricultural origins, parts of Bogor still incorporate small plots of farm land. However this land is likely destined for future development, making the adoption of urban agriculture, particularly important. Practised on a smaller scale within the relatively dense urban environment, urban agriculture is already practiced in Bogor and gaining some momentum with a number of recent pilot systems, government initiatives and grants (http://bogor.tribunnews.com/2017/07/13/guru-besar-ipb-usulkan-penataan-kota-dengan-cara-urban-farming). There is scope for business opportunities and for private sector involvement in projects (April FGD 2018). Urban agriculture can be combined with green water treatment technologies when roof runoff is collected and used to water the plants. This reduces the demand on the potable water supply and reduces runoff and local flooding risk. Studies in Australia have demonstrated that roof runoff is suitable for the watering of food crops (Richards et al., 2015; Tom et al., 2013).

However, it is important to note that other urban stormwater runoff sources contain a higher pollutant load (particularly heavy metals), and can accumulate within food crops and the soils with time exceeding WHO/FAO guidelines (Ng et al., 2016; Tom et al., 2014). Hence, **it is only recommended to utilise roof runoff for the watering of urban agriculture**.

The current examples of urban agriculture in Bogor are all relatively small-scale and may comprise community gardens in public spaces, or part of private residences. In Pulo Geulis passionfruit and butternut squash vines have been planted and the community enjoy picking the fruit. A vertical system has been proposed as a community garden. Given the community desire to develop as a culinary destination, urban agriculture offers economic opportunity.

Rats eating plants has been problematic for the pilot biofiltration systems in Pulo Geulis, but this could be potentially combated by planting species that repel pests such as peppermint, garlic and herbs. Griya Katulampa also includes small-scale plots of vegetables within the community and aquaculture with fish grown in the spring-fed ponds. Some businesses are also using urban agriculture for commercial purposes, such as the Aston Hotel's growth of lettuce using a pilot-scale hydroponic system, with future plans to expand production (Interview with Aston Hotel manager, 2nd May 2018).

The primary purpose of urban agriculture is for nutrition, amenity, economy and greenery. In dense environments vegetables or fruits, including climbing species, can be used in vertical potted systems or narrow containers. Small gardens can be created in small spaces, and recycled containers can be used as pots. These functional systems can enhance public spaces and community resilience via enhanced nutrition and economic benefits. Popular vegetable crops in Indonesia include shallot (bawang merah), chilli (cabai), potato (kentang), cabbage (kubis), Chinese Cabbage (petsai), tomato (tomat), while popular fruits include mango (Mangga), Durian (Durian), Orange (Jeruk), Banana (Pisang), Papaya (Pepaya), Salacca (Salak). Popular medicinal plants include ginger (Jahe), Galanga (Laos/Lengkuas), East Indian Galangal (Kencur) and Tumeric (Kunyit) (Statistical Yearbook of Indonesia, 2017). More details on plant species that can be grown in urban agricultural systems, including further popular vegetable, fruit, medicinal and ornamental plants grown and harvested in Indonesia is given in the plant selection guidance within Section 6.

Examples of a roof top garden, small-scale gardening and compact gardens in Pulo Geulis

Examples of food production and small vertical systems in a community vegetable garden in Pulo Geulis. Images: Raul Marino

Floriculture in Bogor. Image: Raul Marino

Urban agriculture growing lettuce for use at the Aston Hotel, Sentul City. Image: Raul Marino

Fish pond in Griya Katulampa. Image: Raul Marino

Chapter 4

Key Strategies for Green Infrastructure Implementation in Bogor

As seen in the previous chapter, the implementation of green infrastructure is expected to result in more effective stormwater and greywater management (and hence less situ and river water pollution, diversity in water supply sources and better water security), climate adaption, increased biodiversity and potential economic boost from urban farming, in addition to the other advantages of urban greening. In fact, GI interventions comprise a valuable and viable opportunity for creating multifunctional landscapes as well.

In order to achieve this, the correct type and mix of GI measures should be used and these should be complemented with non-structural measures (e.g. solid waste management, community education, development of technical guidelines; Section 4.3.3). Importantly, systems need to be applied in accordance with the principles of best practice water management (Section 4.3). Doing so will help identify the best technologies for implementation and help to maximise the opportunities and benefits of the different GI measures for water treatment and management in Bogor.

In response to the water management challenges identified in Chapter 2, this chapter seeks to provide some examples of design strategies in line with the principles of best practice stormwater and greywater management and in light of local opportunities; it is hoped that these strategies will serve as a platform to create solutions that will help address Bogor's water-related challenges and turn Bogor into a more water sustainable city. When planning and designing water systems in Bogor, it is, thus, recommended that the following principles are followed as much as possible.

4.1 How GI systems work?

GI for water management includes a set of site design strategies that achieve the aforementioned objectives via the action of infiltration, evapotranspiration, harvesting, filtration, detention and storage of stormwater and treatment and recycling of greywater (Figure 4- 1). These strategies strongly advocate the use of source control measures for water management, that is, the management of water sources as close as possible to where they are produced in order to minimise the catchment effects; yet, they also include catchment scale (end-of-pipe) solutions (Table 4- 1).

The systems can either be connected to the drainage system or in some cases be unlined to promote exfiltration into the surrounding soils - this helps provide passive irrigation for deep-rooted trees but also help to recharge the groundwater table.

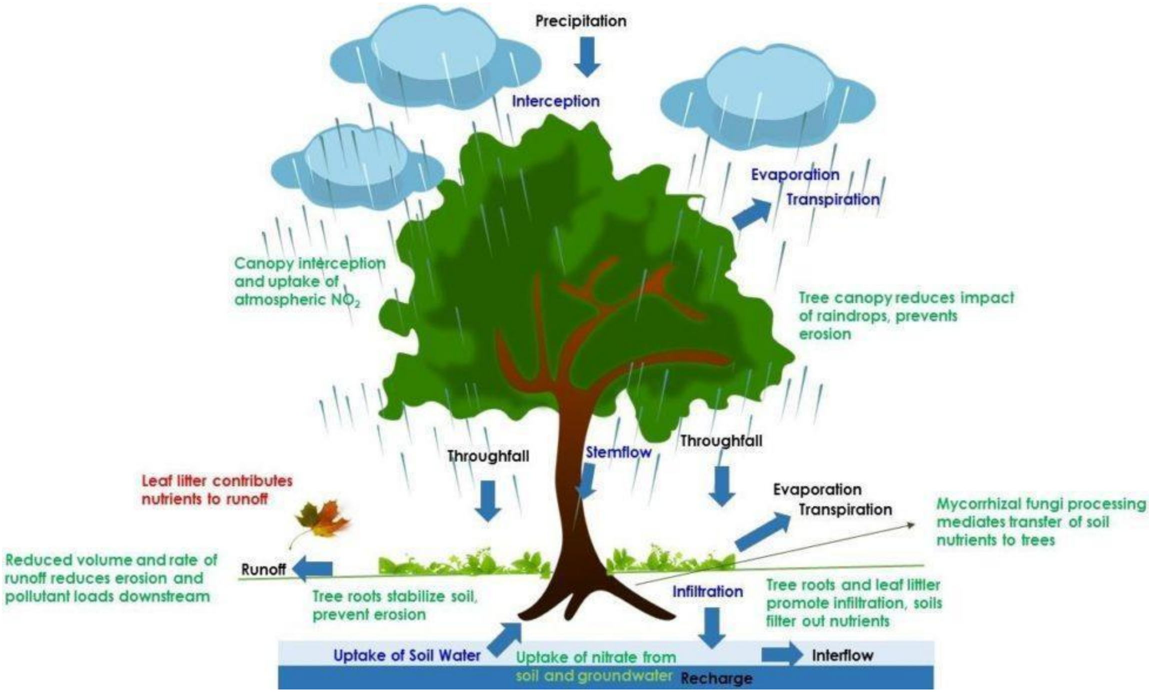


Figure 4- 1 The diverse processes via which green infrastructure mediate water treatment. Image source: Centre for Watershed Protection

4.2 Key principles for best practice water management

It is recommended that the application of GI in Bogor be integral to the principles underpinned by the concept of Water Sensitive Urban Design (WSUD) in Australia, Low Impact Development (LID) in the United States and Sustainable Urban Drainage Systems (SUDS) in Europe and Active Beautiful Clean Waters (ABC) in Singapore. These represent best management practices that combine urban planning and design with the management, protection and conservation of the whole of water cycle.

The key principles of these best practices strategies are to:

- Protect natural systems
- Protect water quality
- Integrate stormwater/greywater treatment into the landscape
- Reduce runoff and peak flows
- Add value while minimising development costs
- Reduce potable water demand
- Minimise wastewater generation
- Reduce pollutant and contaminant sources

4.3 Examples of (best practice) strategies for addressing Bogor's water issues

Table 4- 1 provides some examples of different strategies that can help mitigate some of the water issues in Bogor and transform the region into a more water sensitive one. More details around these strategies are provided in the following sub-sections with specific recommendations for application in Bogor. Please note that these strategies form part of best management practices that sit within the proven concepts of WSUD, LID, SuDs and ABC outlined above.

Table 4- 1 Examples of strategies for addressing Bogor's water issues and transforming the Regency into a more water sensitive one

Strategies	Targeted/Expected outcome(s)
Source control measures Maximise ● Infiltration ● Evapotranspiration ● Detention and storage ● Vegetative uptake on-site	● Groundwater recharge depending on site conditions ● Reduced flooding as a result of decrease in runoff volume ● Elimination of stormwater pollutants at-source ● Prevent crop damage due to over-saturation and waterlogging of soil due to frequent, high intensity rainfall – through storage of rainwater and subsequent slow release into the environment
Rainwater harvesting – rainwater capture and storage	● Prevention of localised flooding through reduction in runoff volume ● Provision of an alternative water source to local community. ● Better water security during dry seasons; Rainwater stored during rainy seasons can be used to supplement water demand during dry seasons ● Reduced reliance on groundwater for water supply and irrigation
Greywater treatment and re-use	● Reduction in wastewater generation – reduce the discharge of wastewater into rivers, canals and reduce their pollution ● Reduced situ and river pollution ● Provision of an alternative water source to local community. ● Improved water security during dry seasons – adapt to risk of drought during dry seasons ● Reduced reliance on groundwater resources for water supply and irrigation
End-of-pipe (catchment scale) water treatment	● Reduced situ and river pollution, improved waterway health and human health
Vegetating riparian zones	● Reduced situ (lake) bank erosion and siltation
Non-structural measures ● Regulations enforcement ● Policy ● Technical guidelines ● Education and training of staff ● Community education	● Greater community awareness of water and environmental issues, leading to more conscientious decisions regarding dumping of waste in lakes and rivers and on roads ● Greater technical capacity in designing and maintaining green water infrastructure ● Inclusion of green infrastructure solutions into new urban development and in general urban planning

	• A standardised method (technical guidelines) for designing and implementing green infrastructure into developments in Bogor

Note: While this document focuses largely on the structural measures relating to water management, a brief account of relevant non-structural tools is given in this chapter (Section 4.3.3).

Local case examples

Sentul city – the presence of emergency lakes which function as a recreational, amenity water feature and provide for water security during low rainfall seasons – see Chapter 8 Section 8.3.

Griya Katulampa – one sub-division in Griya Katulampa makes use of two water sources, including PDAM water and spring water to meet their domestic water demand. No major water shortage is thus reported for this locality in contrast to their neighbours. This is a potential success story learning for other regions of Bogor in that providing an additional reliable water source can help mitigate water shortage issues – see also Chapter 8, Section 8.4.

4.3.1 Use of source controls

Source controls involves minimising the generation of excessive runoff and/or pollutants from runoff and greywater (including nutrients, oil and grease, sediment, toxic material including trace metals, bacteria and litter) at or near its source. Techniques can be both structural (techniques that aim to improve the quantity and quality of stormwater/greywater at or near its source by using infrastructure or natural physical resources – see Section 4.3.2) and non-structural (i.e. for pollution prevention – e.g. litter or solid waste management on roads – see Section 4.3.3).

Some of the advantages of implementing source control measures include:

- A cost-effective way of managing urban runoff – prevention practices are usually cheaper than remediation (via deployment of physical infrastructure) practices
- Can mostly be implemented quickly in comparison to end of pipe management practices.
- Is predominantly concerned with prevention and thus minimises the ongoing mitigation (operation and maintenance) costs that are inherent in end-of-pipe solutions.

Examples of source control measures include (Lewis et al., 2015):

- Urban planning and development – aim to develop interventions that limit site disturbance, retain existing natural systems and minimise impervious surfaces (e.g. via shared driveways, shared road surfaces for low traffic environments, replacing impervious surfaces with pervious paving, living roofs),
- Sediment and erosion controls, such as diversion devices, sediment barriers, secure stockpiles that help to reduce pollutants generation,
- Isolation of hazardous material sites
- Minimising the use of construction materials that leach contaminants and,
- Appropriate applications of land management practices (e.g. fertilisers and pesticides).

4.3.2 At-source water management

At-source water management strategies aim to manage the quantity and quality of stormwater and greywater at or near its source; they include techniques that promote infiltration, evapotranspiration, detention and storage of runoff and treatment and re-use of greywater where it is produced. A suite of GI techniques can be used to achieve this (see Table 1- 1). Devices such as soakage trenches and gross pollution traps can also provide benefits when used close to source.

Infiltration

Measures that promote the infiltration of runoff into the underlying soils can assist in returning the post-development catchment hydrology closer to pre-development levels and hence subdue rising river levels. Infiltration can also be an effective technique to recharge the groundwater table under suitable site conditions, for instance, presence of deeper water tables at the site has a lower risk of contaminating groundwater due to improved water purification as the water infiltrates through multiple soil layers as opposed to shallow groundwater tables. The quality of the runoff generated (which is in turn dependent on the land use) will also drive the suitability of infiltration measures as a water management strategy. Note that there exists a risk of infiltration systems being compromised due to sediment clogging if appropriate measures to reduce sediments inflow into these systems are lacking.

Annual runoff volume and soil type are also factors influencing soil infiltration capacity (and hence effectiveness of infiltration measures). Implementing infiltration measures under well-drained soils with high infiltration capacity, such as sandy soils, is therefore one possible flood mitigation strategy among a range of others.

Due to the intensity and frequency of rainfall events in Bogor, the infiltration capacity of soils can be expected to be limited compared to temperate climates. In this instance, adequate storage or other means to direct rainfall into rivers and lakes – e.g. use of swales to slow down flow or use of retention ponds - should be provided.

GI systems that perform a singular infiltration function are potentially not recommended due to soil saturation from high intensity rainfall events experienced in Bogor (see Chapter 2). Infiltration measures should be coupled with storage techniques.

Infiltration systems in Bogor – Ecodrains, Biopiori, Absorption wells (somurasokan) and the concept of Zero runoff

The importance of managing, retaining and infiltrating stormwater runoff on-site or close to source is well established in Indonesia and Bogor (known as the 'Zero Runoff' concept). Several technologies have been locally developed or adopted to promote infiltration and reduce runoff, including:

- **Ecodrains –** These are simple drains constructed alongside road in Bogor to promote the retention, storage of and infiltration of stormwater runoff, and minimisation of discharge. The technology bears similarity to a buried rainwater tank or an infiltration trench. The concept arose from an elder of the community who heads the Healthy City Communications Forum. The project is in its early days, but Bappeda Kota Bogor intends to install these along most major roads in 2018 and encourages their incorporation into development projects by other agencies. However, there are reports that the existing old drainage system is not compatible with the ecodrainage system, and this can pose risks to the area (FGD Bappeda Kota Bogor, April 2018). The name ecodrainage can also be applied more broadly to emcompass ponds, infiltration wells (sumur resapan), polders alongside rivers and green areas used to infiltrate runoff (https://www.bangkoor.com/2014/11/mengendalikan-dan-menanggulangi-banjir.html).

- **Absorption/ recharge/ infiltration wells (somurasokan) –** It is a requirement to have either a retention pond or absorption well in the community, and these are commonly constructed with many households having infiltration wells. Local companies are constructing groundwater recharge wells.

- **Small backyard garden compost and recharge holes (biopori) –** These comprise a small (approximately 10 cm hole) receiving runoff from the garden and organic waste. They are simple and popular, with a movement towards adoption of these systems in many Indonesian cities. The waste becomes compost and can be collected several months later for use or sold. However, the compost must be removed to allow ongoing infiltration. In addition, the small volume and surface area of biopori will limit their capacity and effectiveness from an infiltration purpose.

The effectiveness of these infiltration systems will depend upon their capacity and the infiltration rate of surrounding soils. While many parts of Jakarta are clay, the soils underlying much of Bogor are sandy loam with relatively high infiltration rates.

On-site detention and storage

Detention involves the capture, attenuation and controlled release of stormwater volumes before they discharge to receiving environments. This moderates peak flows, reduces runoff velocities allowing contaminants to settle, and increases contact time between vegetation, soil and water.

As a result of the limited infiltration rate of local soils during intense rain events, it is recommended to provide for site detention of runoff and subsequent slow release of the water into the soil over time. The stored runoff can be disposed of through infiltration, evaporation or various applications such as landscape irrigation. A combination of these measures will likely provide the most water related benefits.

Note that because of large volumes of rainfall in Bogor, the capacity of storage devices may be lower than that in temperate climates. This implies that local storage facilities will need to be larger in size.

Vegetation

Vegetation reduces stormwater runoff in catchments through the interception of rainfall in the canopy, infiltration through root systems, and transpiration. Vegetated systems can also reduce contaminant levels through direct plant uptake or other influences on the soil and associated microbial communities. Additionally, vegetation provides a range of environmental services within a catchment, including enhancing biodiversity and ecosystem values, landscape amenity, dust interception, and temperature moderation (see Chapter 3, Table 3-3).

4.3.3 Use of non-structural tools

Non-structural tools for water management include normative, regulatory and educational guidelines for land use planning. These tools can be used to limit the generation of pollutants and surface runoff within a catchment, and can be a particularly successful mitigation strategy for new developments when applied at the initial planning stage (Lyold et al., 2002).

The additional advantages of using non-structural source controls are long term sustainability and effective use of all resources – including the community (Lyold et al., 2002). Table 4- 2 lists some examples of non-structural solutions that can be applied for both retrofit and greenfield developments in Bogor.

It has traditionally been difficult to predict the beneficial effects of non-structural solutions from a purely technical perspective. Lyold et al (2002) recommend the adoption of a qualitative and intuitive approach for assigning beneficial effects to these options and evaluating their ability to deliver on the values, objectives and issues identified in the management plan. Some suggested criteria for evaluating source control options include (1) effectiveness of pollutant removal; (2) number of pollutants targeted; (3) percentage of catchment targeted; (4) community acceptance; (5) ease of implementation and (6) longevity of impact (Lyold et al., 2002).

Table 4- 2 Examples of non-structural solutions for best practice water management

Non-structural solutions	Comments
Environmental and urban development policy	Required to encourage widespread adoption of water sensitive technologies, including the incorporation of GI into the urban planning process. The establishment of water quality and flow targets can pose as stormwater/greywater management objectives to strive for during project development.
Solid waste management programs	Provide economic incentives to encourage solid waste management initiatives among local residents, e.g. explore opportunities relating to the use of waste for compost and biogas. There are currently a number of community programs in place in Bogor – these should be propagated on a larger scale.
Regulations and law enforcement programs	Penalties can potentially act as a deterrent to reduce activities that result in the pollution of rivers and situs.
Community education programs	Community education programs addressing stormwater and wastewater management issues encourage change in social “norms” and behaviours. Individual changes in behaviour may collectively contribute to reducing water pollution through the determent of waste dumping into rivers. Education of local residents regarding the impact of

Non-structural solutions	Comments
	litter and trash in the environment, empowering local community in sustainable waste management practices.
Education and staff training - Local government - Industry - Business	Education programs including staff training should be directed to all staff levels to instigate effective changes in practice. Training should provide the necessary tools/techniques to help with the planning, implementation, operation and maintenance of GI practices.
Environmental considerations on construction sites	Poor planning and management of construction/building sites can severely deteriorate the quality of runoff. Site management plans are a useful strategy to minimise the generation of pollutants from land development and building activities.

Source: Adapted from Lyold et al., 2002

Solid Waste Management Programs currently in place in Bogor

There are community programs organised by the City of Bogor and other government sponsored programs for waste collection points, garbage banks, waste separation and recycling programs that exchange certain types of waste for money. This provides incentive for the collection of garbage, which is otherwise readily thrown into rivers, drainage channels or situs given the lack of transportation, collection systems and community education. Local landfills are also unlikely to meet environmental standards that prevent leachate reaching groundwater.

Programs have also developed systems for waste separation and the production of compost, fertiliser and biogas from organic waste, valuable by-products that provide economic incentive for waste collection and management. There are a number of examples across Bogor of successful implementation at the RT RW scale, including in Griya Katulampa. At a residential scale, backyard holes where organic waste is deposited and allowed to turn into compost (which can be potentially sold) are encouraged and known as 'biopori'. These holes also receive stormwater runoff, promoting infiltration. At neighbourhood scales, there has been some implementation of trash traps, but these are quickly overwhelmed by the high load, filling after only 2 or 3 rains. The filled trash trap can then contribute to drainage problems if flows are unable to bypass (Dr Herr Soeryantono, Green Technologies FGD, November 2017).

Other programs include a government sponsored program cleaning waterways (using brigades of people wearing orange suits), provision of garbage bags and public education campaigns and fines against littering (March and April researchers workshops, 2018).

Local research has also investigated more effective solid waste management options. The treatment of manure using vermiculture principles (i.e. worms and composting) has been studied as a way to prevent fly reproduction and the spread of disease (Bambang Priadie and Syamsul Bahri, November Green Technology FGD 2017).

Bins at the UI campus for the sorting of gross solids

4.3.4 Opportunities for rainwater harvesting and greywater treatment and re-use

The high intensity of rainfall experienced in Bogor (approximately 3000 mm/yr) implies that there is a massive opportunity to tap into this water resource to solve some of its water related challenges. To illustrate the potential and scale of rainwater harvesting in Bogor, Melbourne is taken as an example. The annual average rainfall in Melbourne is comparatively much lower than Greater Bogor at approximately 665 mm/yr. The corresponding volume of stormwater generated on an annual basis amounts to approximately 175 KL/hh/y while its reticulated water supply is around 150 KL/hh/y. This suggests that if all stormwater were harvested (although 100% harvest is not recommended to allow for environmental flows to balance the city's hydrology), this could satisfy the city's household water demand. Taking into consideration that the amount of runoff produced depends on the catchment's effective imperviousness, this example illustrates that there exists much potential in harvesting rainwater, treating it and re-using it for non-potable purposes, hence ensuring a more secure water supply to the inhabitants of Bogor. The use of rainwater that falls on Bogor's urban areas can also be optimised by designing for appropriate storage. Table 4- 3 provides some examples of suitable rainwater harvesting technologies that could be employed both at the micro- and macro- scale.

Harvest rainwater for use during dry seasons for a number of end-applications

Stormwater from rooftops can be captured for use in buildings and landscape areas, reducing the requirements for mains water supply. Roof runoff is typically least contaminated, and can be easily used for landscape irrigation and potentially for food production. There are reports of the presence of pathogenic contaminants from house roofs due to cats and rats occupying roofs in certain areas (Co-design Researcher workshops, March 2018). In this case, caution should be exerted. To reduce any potential health risk, the first flush of the captured water should be diverted into the drainage channels as per normal while the remaining roof water can be used for irrigation of non-food crops.

Runoff from ground level surfaces can also be captured; they often contain entrained nutrients which can be beneficial for irrigation of landscape areas. Research efforts invested in this arena could help match runoff source with end-use applications. In fact, use of GI measures for pre-treatment of the roof runoff can potentially help to reduce pathogen loads from roofs. Readers are referred to the NHRMC guidelines in Australia for more information on managing the health and environmental risk for effective rainwater and stormwater harvesting practices (NHMRC, 2008).

Some other opportunities include capturing stormwater via GI for use to recharge groundwater and that water can be used for urban agriculture (i.e. to irrigate vegetable gardens) and fish farming.

Greywater treatment and re-use for toilet flushing and irrigation

Opportunities for greywater recycling include capturing wastewater from washing basins and bathrooms, treated through GI and re-used for irrigation. Doing so helps in fertilisation of horticultural crops, floriculture and food crops. This is particularly pertinent in commercial or large apartment buildings where greywater generation is sufficiently high to meet demand as well as more cost-effective.

Table 4- 3 Examples of rainwater harvesting technologies for implementation at the micro- and macro-scale

Implementation scale	**Examples of rainwater harvesting technologies**	
Micro-scale	- Rainwater tanks *Installed at the lot scale to capture and store roof runoff* *(Note: If roof runoff is known to be contaminated, stored water should be used for irrigation of non-food crops only).*	 *Image: Rainharvest.co.za*
	- Backyard or street-scape raingarden with storage *Rainwater runoff captured from surrounding impervious surfaces, including roof surfaces, can be treated using biofiltration and stored for subsequent re-use*	 *Image: EPA.gov*
	- Tree-pits *Rainwater runoff from surrounding concrete surfaces directed into tree-pits can help provide passive tree irrigation and maintain urban greenery*	

	- Green roofs with storage *The effluent from green roofs receiving rainwater can be directed into a below-ground storage tank for re-use*	
Macro-scale	- Bioretention systems followed by storage in situs *Bioretention systems installed downstream of a catchment can be used to treat stormwater runoff and greywater before storage into the connecting, adjacent situ. The stored water can be used to supplement non-potable water demand during dry seasons.*	
	- Retention ponds preceded by some form of pre-treatment of runoff *Mainly used for flood control, retention ponds could also provide some water quality improvement and function as a storage facility for irrigation of surrounding landscape.*	
	- Centralised underground rainwater tanks *In catchments with limited space, runoff can be directed into a centralised tank. Another application could be installation of an infiltration device alongside roads (such as porous pavements) to capture road runoff and subsequent storage into underground tanks.*	

4.4 Other design strategies

To maximise benefits of stormwater and greywater management, design strategies should also consider how GI systems are planned and integrated into the surrounding landscape.

4.4.1 Distributed, decentralised systems versus centralised systems

The distributed approach involves installing a number of smaller and potentially different treatments throughout a catchment. Distributed measures are advantageous in that they are small systems so that they can be fitted even in dense areas with limited space and are usually used at locations near the source of stormwater runoff or greywater production.

The centralised approach involves installing a larger treatment system at the end of the catchment to meet the catchment quality and quantity objectives; this approach is often termed the end-of-pipe approach.

Distributed, decentralised systems that are connected to each other (to eventually form a treatment train – see Section 4.4.2) are often preferred for a number of reasons. According to Melbourne Water (www.melbournewater.com.au, 2018), some of the merits of the distributed approach are:

- Improved protection
- Localised treatment
- Distributed risk – risk of overall system failure is lower
- Improved removal efficiencies
- Staged implementation
- Urban greening – that could help address other objectives

Studies have found that centralised in-pipe or end-of-pipe structures can also be used to meet the same receiving quality protection objectives (e.g. Freni et al., 2010, Hatt et al., 2007). The choice of either approach will, most importantly, depend on the site constraints and project objectives.

For example, a simulation study found that a centralised stormwater tank had better mitigation efficiencies (in terms of volume and pollutant load reduction) compared with infiltration measures with loamy soils (soils with average infiltration capacity) (Freni et al., 2010). In another study conducted in Singapore, improved hydrological response was obtained by combining bioretention basins with green roofs and/or porous pavements (Trinh and Chui, 2013; Chui et al., 2014 in Lim and Lu, 2016).

Water managers may also find that a combination of both to obtain hybrid solutions is the best management strategy for a specific catchment as they are able to harness the advantages of the two types of mitigation measures.

In conclusion, all sites will be different; while distributed and decentralised systems are preferred (as they are able to address other competing objectives), the best approach will reflect the site opportunities and constraints as well as the project objectives. For effective flood control and flow management, it is best to implement GI measures at every scale.

4.4.2 Use of stormwater treatment trains

A stormwater treatment train consists of a sequence of management responses that collectively deliver stormwater quality and quantity objectives for a site (Figure 4- 2). It follows the flow of stormwater through the catchment, starting with source control measures (rainwater capture, re-use, on-site detention and storage), followed by the conveyance and treatment of runoff before discharge into rivers and lakes. As such, the treatment train approach involves deployment of multiple GI systems and is concerned with GI application at a number of scales from lot scale (e.g. rain gardens, permeable pavement, green roofs. etc) to regional scale (e.g. constructed wetlands, retention ponds, etc). Pollution prevention measures (e.g. through regulations, public education, solid waste management programs) can also be part of the treatment train approach (Lewis et al., 2015).

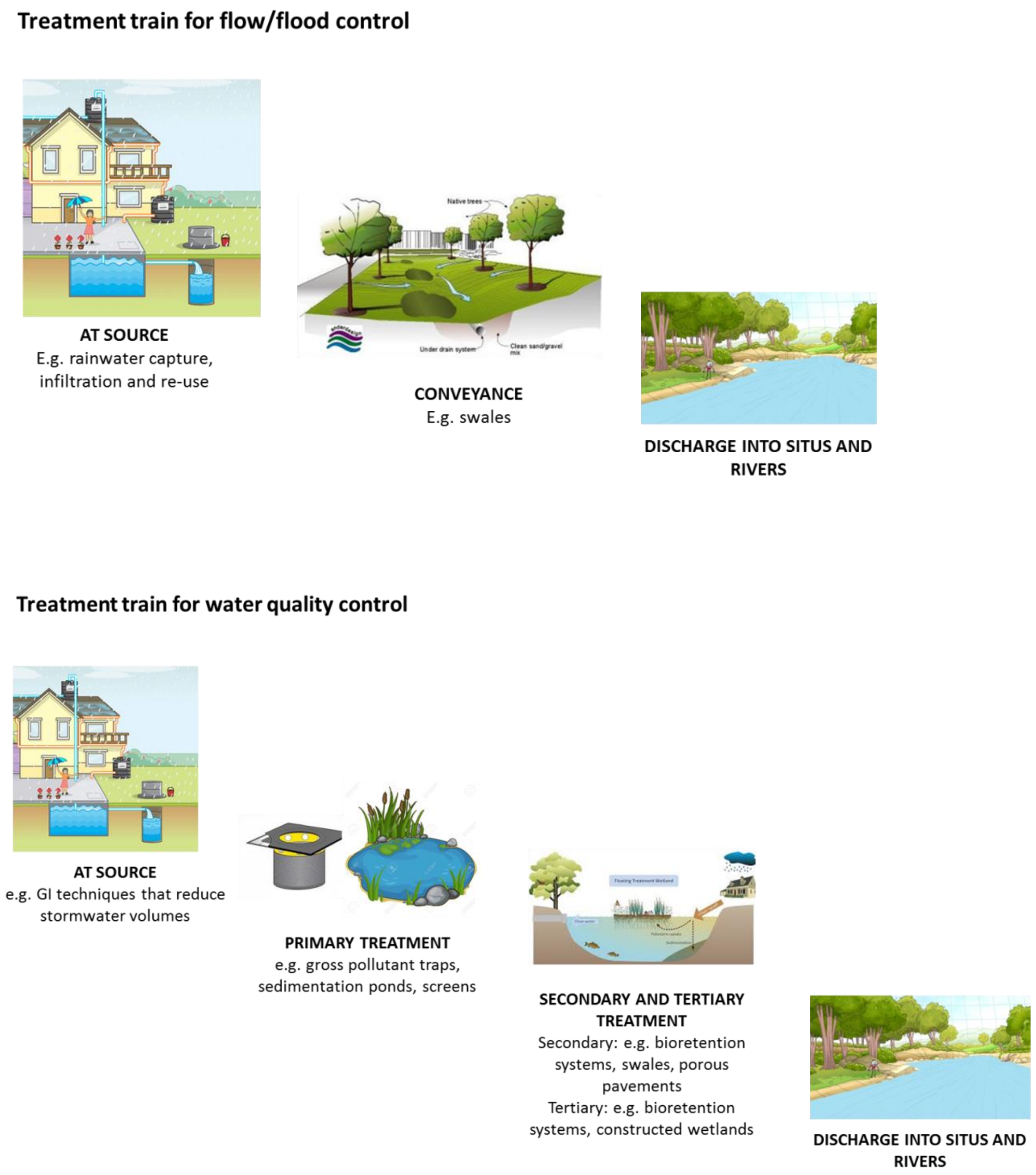


Figure 4- 2 Example of a treatment train for flood and water quality control

A treatment train should be selected from a suite of potential stormwater management responses in order to target specific land use contaminants (different GI techniques remove different contaminants based on particle size and hydraulic loading; Figure 4- 3). Hydraulic and physical processes remove larger solids and associated pollutants during storm events, while biological and chemical processes treat finer solids and dissolved pollutants.

The treatment train design should be aimed at identifying the most effective sequence, in particular when pre-treatment is required to remove pollutants which can affect the system's performances.

How to design for a treatment train?

The catchment area is divided into sub-catchments. Each sub-area is characterised by different drainage strategies, drainage capacity and land uses. Dividing catchments into smaller sections is important to control the whole catchment, facilitate a normal hydrological cycle and develop better open and green spaces in cities.

The treatment train rests on the concept that the best combination of practices is identified to manage the pollutants.

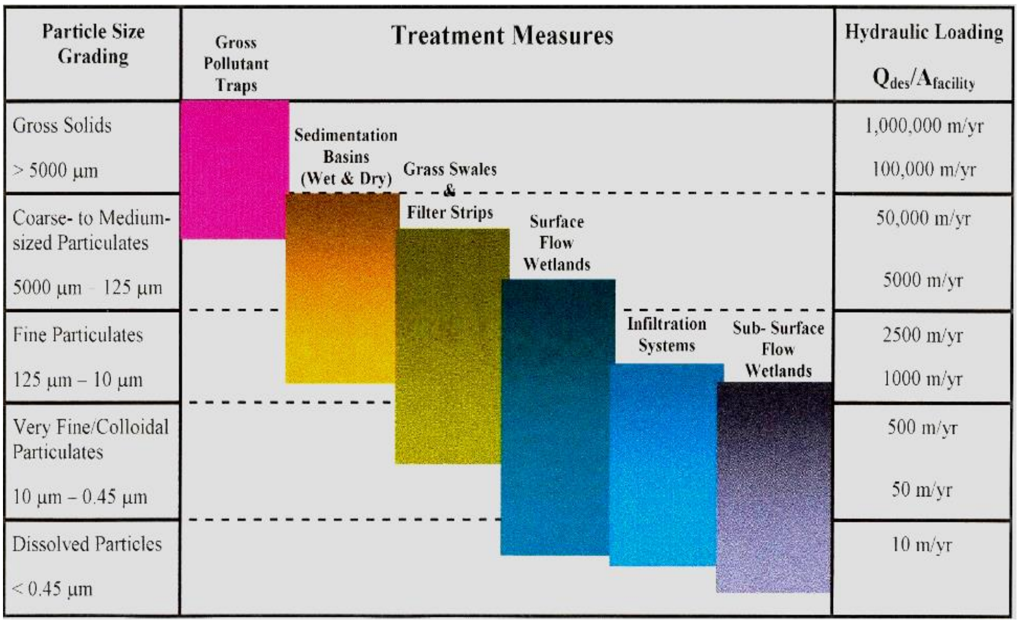


Figure 4- 3 GI technologies matched to particle size and hydraulic loading as part of the treatment train; source Wong, 2000

4.4.3 Integrate stormwater and greywater treatment into the landscape

The individual design of stormwater and greywater solutions should be adapted to the surrounding area (buildings, urban structures, landscapes). Green-blue infrastructure solutions should ideally engage the city, respond to the environment and invite use and attention (Department of Environment, Land, Water and Planning, 2017). One way to achieving this is by making the most of nature's drainage – for instance, strive to retain natural channels and incorporate into public open space, retain and restore riparian vegetation to improve water quality through biofiltration and protect river banks, minimise the use of artificial drainage systems (particularly relevant for greenfield developments). Design elements for the GI solutions should blend with the surrounding landscape – for instance, plant species employed in these systems should match the surrounding area.

4.4.4 Design so as to maximise the benefits of these systems

Planning for multi-functional systems will help optimise the cost-benefit ratio of GI implementation projects. This will lead to cities enjoying efficient infrastructure, greater collaboration and heightened benefits (Department of Environment, Land, Water and Planning, 2017). GI must be designed and implemented in such a way so that it achieves multifunctional urban landscapes on a holistic catchment scale.

4.4.5 Add value while minimising development costs

While designing, the objective should always be how to add value (that is, create pleasant multi-functional landscapes) while minimising the development costs. This will involve working efficiently across disciplines (landscape design, urban planning, engineering, etc) and making the best use of already available assets on-site.

4.4.6 Use of both green and grey infrastructure to tackle water problems

Use of GI for water management will not be able to solve all of Bogor's water challenges. Instead, it is proposed to incorporate a combination of both green and grey (traditionally engineered concrete infrastructure) infrastructure to create a synergy that will help Bogor attain its sustainability goals where water management is concerned.

Chapter 5

Technology Selection

Selecting, locating and designing GI technological solutions in an effective manner will not only produce optimal hydrological and water treatment performance both in the short and long term but will also render the maximum benefits in terms of delivering the various co-benefits mentioned in Section 3.1.3. Selection of appropriate GI measures will also help avoid unexpected surprises during the construction phase. Having in place a logical procedure to follow will help towards selection of the most appropriate GI measures (e.g. see Chapter 1)

This whole process involves collaboration with multiple disciplines, e.g. local government, designers, engineers, landscape architects, planners and local community. For instance, with community involvement the benefits are maximised as sites are respected and become ‘owned’ by communities, vandalism and crime is reduced, and management costs are minimised. Without community support and ‘buy-in’ the risk of failure increases and the beneficial value is reduced. Creating and managing green infrastructure in this way comes at long-term financial and managerial costs.

5.1 Factors to consider when selecting technologies

Table 5- 1 provides some examples of key factors to consider during the technology selection phase (**Error! Reference source not found.**). Please note that this is not an exhaustive list.

Table 5- 1 Key factors to consider when selecting technologies

Factors to consider during the technology selection phase	Where can I find this information?
Water use *Water uses for the different end-use applications if either stormwater or greywater were to be used for harvesting purposes*	
Water quality and quantity *The volume and characteristics of runoff and greywater (incl. type and concentrations of pollutants present) will help match with the best technological option to pollutants.*	Chapter 5, Table 5-4
Available space *Land available for implementing the various interventions – noting that some technologies are more flexible while others require large land areas to function effectively*	Chapter 5, Table 5-4
Economic considerations *Implementation, operation and maintenance costs of the different technological interventions. It will repose on the allocated budget during the planning stage.* *Need to take into account both capital and on-going maintenance costs*	
Climatic conditions *The choice of technology and corresponding design parameters will depend on the climate, including rainfall patterns, wind speed, humidity, etc. It may also be useful to consider future climate change scenarios.*	
Operation and maintenance *Some technologies involve a higher degree of expertise for their operation and maintenance while others can be effectively maintained by the local community. The same goes for the costs involved in these processes. These should be taken into consideration in the planning stage as allocating sufficient budget for these activities is important as the successful performance of the technological interventions depend on it.*	Chapter 6
Other environmental objectives *It is recommended that GI solutions are implemented in such a way so as to take advantage of their expected co-benefits, including cooling effects, landscape value, food production potential which would justify for a higher return on investment.* *Positive cost-benefit ratio – design so as to optimise the multi-functional benefits of the GI*	Chapter 3, Table 3-3

5.2 Objectives for the application of green infrastructure

In selecting and adopting green water treatment technologies it is essential to first define the key objectives for their application (**Error! Reference source not found.**). The design of GI systems can be varied depending upon the objective of the GI intervention/strategy and the local environmental characteristics (such as local climate, soils, pollutant sources, plant species, nearby infrastructure etc.). Hence, it is important to establish what the priority benefits a planned green infrastructure intervention aims to achieve and how the performance of the GI system applied can be measured and evaluated for these priority outcomes. Figure 5- 1 details some of the multiple objectives that green infrastructure can provide.

Our research has found that the objectives for GI interventions aligns well with and would support a number of current regulations, programs and future goals for Bogor including:

- Bogor's Strategic Direction plan of 30% open space,
- Inauguration of Bogor Regency as a National Geopark, and aim to raise the standing of Bogor's Botanical Garden to UNESCO level (Head Bappeda Kabupaten Bogor, Dec 2018)
- the National Healthy Cities Program,
- Indonesia's Green Building Code, Law No. 11 1974 relating to the provision of drinking water to the entire community,
- Rainwater harvesting code for new buildings (Law No. 11 2004), and
- the requirements for retention ponds or absorption wells within the RT RW Masterplan, and
- the Environmentally friendly village program (Kapubaten Bogor Green).
- Future Blue vision for development of Kabupaten Bogor's including preservation of 8 rivers (7900kms), 98 Situ and 50 waterfalls (Head Bappeda, UWC Showcase Dec 2018)

Also see Chapter 3, Section 3.1.3 for information about the multi-functional benefits of green infrastructure.

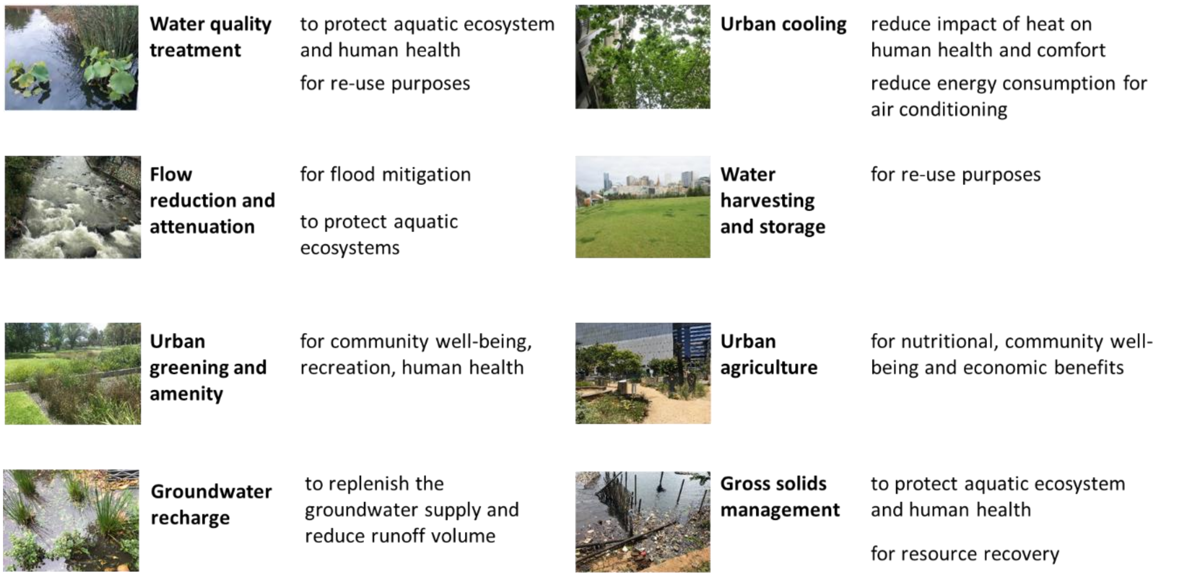


Figure 5- 1 Potential objectives for the application of green infrastructure in Bogor

Water quality treatment and flow reduction and attenuation are generally key objectives for the use of green infrastructure. Specific targets are often set by local authorities to enforce the adoption of these technologies and ensure systems are designed to meet measurable objectives. Table 5- 2 details specific objectives set in other tropical regions for the treatment of runoff discharged by developments that could be used as a guide for the design of green infrastructure in Bogor until local guidelines are established.

Table 5- 2 Water quality and flow objectives for runoff discharged from developments in other tropical regions

Location / Climate	**Total suspended solids (TSS)**	**Total phosphorus (TP)**	**Total nitrogen (TN)**	**Gross pollutants**	**Flow**	**Source**
Townsville – Coastal Dry Tropics	80% (mean annual pollutant load)	65%	40%	90%		Darwin – dry tropics, *Water Sensitive Urban Design Planning Guide* (McAuley, 2009)
Singapore – Tropical 2,400 mm rainfall	80% (or <10 ppm)	45% (or <0.08 ppm)	45% (or <1.2 ppm)			Singapore *ABC Waters Design Guidelines*

Table 5- 3 provides some examples of different considerations needed for different design goals and design situations. This is not a complete list and is intended only to illustrate that different goals require different techniques and solutions.

Table 5- 3 Examples of considerations needed for different design goals and situations

Key goals	**Considerations**
Improve local economic productivity	- Local community can use harvested rainwater and/or treated greywater as a potential water source for urban farming, hydroponics and fish farming (rainwater preferred) practices e.g. through installation of a treatment measure upstream of lake to

	protect lake water quality for use for fish farming or irrigation. This could be a good source of revenue for local communities. - Consider harvesting biomass for economic uses such as fish food, fertiliser, weaving materials - Use greywater for irrigation/fertilisation of horticultural crops, e.g. flowers. - Use innovative designs to blend green water infrastructure into urban planning to create aesthetically pleasing environments with amenity and recreation facilities that can help boost local tourism as well as local community productivity^ - Riparian vegetation on river banks can include food crops such as Cassava.
Low cost	- Aim to maximise the benefit-cost ratio of GI during the project objectives definition stage, i.e. design for multi-functional systems (**Error! Reference source not found.**) - Small scale, distributed systems may be more cost-effective solutions depending on the site - Consider use of non-structural tools (as a preventive approach) which tend to be cheaper alternatives to technological solutions (as a corrective approach) to tackle water problems, e.g. through the establishment of an adequate solid waste management program and effective land-use planning
Sustainable	- Proper maintenance is key for system longevity - Use pre-treatment systems (such as sediment traps, screening devices) to reduce ingress of sediments into the GI systems. Have an adequate solid waste disposal program in place for litter and sediment control - Community education around the purpose and benefits of the GI interventions will empower residents and facilitate protection and maintenance of GI systems - Design GI systems to perform well under local climate conditions. ieensuring systems are structurally stable to withstand high rainfall intensity in Bogor (e.g. through use of a well-functioning high flow bypass structure in the case of bioretention systems and the ability to withstand higher loads owing to soil saturation in the case of vertical structures such as green walls and roofs) - Use locally available plant species adapted to the local climate
Designing for retrofit interventions in urban settlements	- Solutions will depend on the available space and physical water infrastructure within the catchment ● Select solutions that minimise the footprint of the technological interventions, e.g. use a combination of small scale, distributed systems (distributed underground rainwater tanks can be used where applicable) rather than one large system to achieve the same objectives ● If land area is available at the end of the catchment and depending on the physical infrastructure, consider installation of a wetland treatment system or bioretention system upstream of the receiving situ or river - Select technologies that do not require additional functional space such as porous pavements
Designing for new developments	- Ensure good planning/regulations to put aside land for GI systems early in the development process - Consider both structural and non-structural solutions at the planning stage

^ Research shows that the incorporation of urban greening has a positive effect of human health and well-being and can boost productivity. See Chapter 3, Section 3.1.3 for more details on the benefits of GI

5.3 Insights into the characteristics of the different GI elements

How successful will each green infrastructure element be in achieving the defined project objectives or water management target(s) will depend on appropriate selection, siting and design of the technologies deployed. This section provides the reader with useful insights into some of the characteristics of the different GI elements that will aid the selection process following an understanding of the catchment bio-physical properties (**Error! Reference source not found.**).

As mentioned briefly in the previous sections, each technology differs in terms of their scale of application, type of pollutants treated, suitable locations and other characteristics.

The treatment measures selected can cover a range of scales and land uses, including:

- lot scale – residential, commercial and industrial,
- neighbourhood or street scale and public open space and
- regional or precinct or catchment scale.

Green infrastructure planning will likely need to consider possible interventions at all scales, to form a treatment train (see Chapter 4, Section 4.4.2). Some technologies can be sized up or down to suit the individual site, from a standard house block through to a whole catchment; an example is bioretention systems (Table 5- 4) while for others they are most effective if applied at a specific scale, for example, retention ponds are likely to be most cost-effective if applied at the regional scale.

Some technologies may be more appropriate (have larger benefits) for integration in greenfield applications while others may have more flexible design attributes that might facilitate retrofitting in existing developments, particularly in locations where space is limited and valuable.

As discussed in previous chapters, a combination of inter-connected technologies will likely bring the most benefits and is recommended when the site conditions permit.

Proper selection of technologies at the planning, conceptual design stage may help save un-programmed expenses in the later project stage – for e.g. siting an unlined bioretention system near contaminated or shallow groundwater tables may increase project costs to line the system when an alternative technology (or site) may have been more appropriate. Therefore, it is pertinent to match site conditions with the recommended sites for application of the technology.

Table 5- 4 provides useful information on the different technologies that will guide selection of appropriate technologies for use for a particular development project. This table should ideally be consulted after an understanding of the site bio-physical characteristics (e.g. by undertaking a site survey) and establishing the project objectives.

Some of the limitations mentioned in the table should not deter implementation; if no suitable technology can be found and no other site is available, then there are possible remedial solutions that should be considered depending on the project budget and technical expertise of the construction and maintenance personnel involved.

Table 5- 4 Useful information on the different types of GI that will guide GI technology selection

Biofiltration/ bioretention/ raingardens/ treepits	
Scale of application	• Lot – household, commercial • Streetscape • Neighbourhood • City • Regional
Target pollutant size	• Medium particles (< 200 µm) • Fine particles (125 µm – 10 µm) • Very fine/colloidal particulates (10 µm – 0.45 µm) • Dissolved particles (<0.45 µm)

Advantages	• Flexible in shape, size
	  ○ Use in small and constrained spaces
	  ○ Can be integrated into relatively steep topography
	  ○ On flat topography – can be located at-source
	• Can be used at a range of scales from at-source treatment to management of runoff from large catchments (end-of-pipe system)
	• Can be sited within flood detention infrastructure**

Limitations/ Considerations	• Ability to delay peak timing for large events small • Ability to store and hold up runoff poor
Where to use	• Within allotments (raingardens on individual residential lots or small bioretention basins on commercial, industrial and multi-unit developments) • In the streetscape (integrated into road reserve verges or traffic calming 'build-outs' from the kerb) • Within civic space (combined with stormwater harvesting for landscape irrigation, topping up water features or within buildings for flushing toilets) • Within and adjacent to parkland (promote green space, engage community with water cycle, provide opportunities to reuse stormwater; typically end-of-pipe systems* but can also be designed as at-source systems; can be sited within flood detention infrastructure)
Where not recommended	• Steep sites • Sites with underlying high groundwater table • Sites with tidal influence (coastal areas) • Sites with continuous flow • Sites subject to toxic runoff

Living walls	
Scale of application	• Lot – household, commercial, government buildings
Target pollutant size	• Medium particles (< 200 µm) • Fine particles (125 µm – 10 µm) • Very fine/colloidal particulates (10 µm – 0.45 µm) • Dissolved particles (<0.45 µm)
Advantages	• A good application of biofiltration in areas with limited space • Contribute to urban greenery in urban centres • Contribute to building energy efficiency
Limitations/Considerations	• Ability to delay peak timing for large events small

	• Ability to store and hold up runoff poor
Where to use	• Dense urban areas
Where not recommended	• Steep sites • Sites underlying high groundwater table • Sites with continuous flow • Sites subject to toxic runoff

Green walls

Scale of application	• Lot – household, commercial, government buildings
Target pollutant size	• Medium particles (< 200 µm) • Fine particles (125 µm – 10 µm) • Very fine/colloidal particulates (10 µm – 0.45 µm) • Dissolved particles (<0.45 µm)
Advantages	• Contribute to urban greenery in urban centres • Contribute to building energy efficiency • Significant opportunity to improve aesthetics of urban centres through creative wall designs
Limitations/Considerations	• Clogging can be an issue depending on greywater load; pot replacement may be required from time to time
Where to use	• Dense urban areas • Sites where an adequate source (and volume) of water (e.g. rainwater, greywater) can be provided to irrigate the wall. • Sites where maintenance can be ensured
Where not recommended	• Sites with harsh environmental conditions (strong winds, direct rainfall, high sun exposure). Green walls should be sited on building walls which are 'protected' from these harsh environmental conditions; yet receive enough sunlight and rain for plant health.

Green roofs

Scale of application	• Lot – household, commercial, government buildings
Target pollutant size	• Medium particles (< 200 µm) • Fine particles (125 µm – 10 µm) • Very fine/colloidal particulates (10 µm – 0.45 µm) • Dissolved particles (<0.45 µm)
Advantages	• Effective for delaying runoff peak during small to medium rain events • Opportunity for food production in dense city centres

Limitations/Considerations	• Poor performance during high rainfall events
	  ○ Ability to delay peak timing for large events small
	  ○ Ability to store and hold up runoff poor during large events

Where to use	• Densely populated metropolitan areas where roofs take up a significant proportion of the impervious urban surfaces • Use in densely populated areas to reduce and delay peak runoff. • Sites where maintenance can be ensured
Where not recommended	• Sites with harsh environmental conditions (intense rain, high sun exposure, strong winds) • Building roofs with inadequate structural/loading capacity

Constructed treatment wetlands	
Scale of application	• Local and regional
Target pollutant size	• Medium particles (< 200 µm) • Fine particles (125 µm – 10 µm) • Very fine/colloidal particulates (10 µm – 0.45 µm) • Dissolved particles (<0.45 µm)
Advantages	• Can be used to treat a range of water types, from domestic wastewater to industry wastewater to stormwater^ • Used as secondary treatment – usually with high pollutant removal efficiency • Relatively easy operation and maintenance (relatively low and only periodic rather than continuous, on-site labour) • Good value investment, i.e. low cost for high treatment capacity (with potential for water reuse) • Tolerance to high variability in influent loads (considerable buffering capacity)
Limitations/Considerations	• Need for large land areas • Potential for mosquito breeding and odours (can be avoided) • If not designed and maintained, system can get clogged over time
Where to use	• Upstream of rivers
Where not recommended	• Sites with space constraints • Sites with permeable soils (a liner may need to be installed at an additional cost) • Sites with high groundwater table • Steep sites

Swales/buffer strips	
Scale of application	• Neighbourhood • Streetscape
Target pollutant size	• Medium particles (< 200 µm) • Fine particles (125 µm – 10 µm) • Very fine/colloidal particulates (10 µm – 0.45 µm) • Dissolved particles (<0.45 µm)
Advantages	• Effective for delaying runoff and thus reduce downstream flooding • Retain pollutants close to source
Limitations/Considerations	• If not sited, sized or designed properly, they can be vulnerable to large storms with potential erosion. When designing, ensure that water will not pond for large periods of time after a large storm event.
Where to use	• Residential lots replacing conventional canalised sewerage • Streets and roadways (with impermeable contributing catchment areas ranging between 2 ha and 4 ha).
Where not recommended	• Sites with slopes > 4% • Sites with high groundwater table

Porous pavements	
Scale of application	• Lot – household, commercial, government buildings • Streetscape
Target pollutant size	• Medium particles (< 200 µm) • Fine particles (125 µm – 10 µm)
Advantages	• Reduce the area of land dedicated solely to stormwater management • Retain pollutants close to source • Have increased infiltration rate compared to biofiltration systems
Limitations/Considerations	• Can only support light traffic loads • Are prone to pavement clogging, especially in sites with high sediment load • Carry a risk of possible groundwater contamination
Where to use	• Pathways and shopping centre parking areas (basically low trafficked areas) • Any other places where maintenance can be easily ensured, hence reducing the danger of clogging
Where not recommended	• Sites with high sediment/waste generation • Steep sites (slopes > 4%) • Protection needed when near a construction site to avoid post-construction movement of sediment from landscape areas • Sites with underlying soils of low permeability (unless an underdrain connected to the drainage system is installed)

Retention ponds	
Scale of application	• Regional • Tertiary treatment, storage following secondary treatment
Target pollutant size	• Coarse - medium particles (5000 µm – 125 µm) • Fine particles (125 µm – 10 µm)
Advantages	• Can be used as a fish pond. • Can be used as a storage for irrigation or other reuse options • Provides a habitat for wildlife • Research show that stormwater ponds can increase property values (Adams et al., 1984; Tourbier and Westmacott, 1992; USEPA, 1995) • Retention pond: simple design if space is available
Limitations/Considerations	• Possible proliferation of mosquitoes* • Space requirement • Foul smell if inflow is contaminated by sediments and sewage
Where to use	• Near low lying areas • Where land is available • Use liner when used in sites above vulnerable groundwater
Where not recommended	• Sites with flat topography

Rainwater tanks	
Scale of application	• Lot – household, commercial, government buildings • Neighbourhood
Advantages	• Retain water close to source • Can be a valuable alternative water source for non-drinking purposes, hence reducing the demand on groundwater • Reduce runoff volume and can help reduce downstream flooding
Limitations/Considerations	• Following the dry season during which time the tank may not have been utilised, the tank may need to be cleaned before use (mostly applicable to small rainwater tanks installed at the lot level) • Rainwater tanks may need to be installed with a first flush diverter to divert the first few mms of the runoff into the traditional drainage channels that may contain a higher pollutant load. • Maintenance is required to maintain good water quality from the tank
Where to use	• In a retrofit situation, where space is limited • Ability to connect roof runoff to tank
Where not recommended	• Contaminated sites (including roofs) where runoff is not safe to use.

Sedimentation basins	
Scale of application	• Regional
Target pollutant size	• Coarse - medium particles (5000 µm – 125 µm) • Fine particles (125 µm – 10 µm)
Advantages	• Cost-effective for treating coarse sediments from catchments ranging between 2 – 40 ha with soil textures of predominantly sand, or medium to large silt (MDEQ NPS BMP Manual, 2014 - https://www.michigan.gov/documents/deq/nps-sediment-basin_332133_7.pdf)
Limitations/Considerations	• Need for available space • Potential for mosquito breeding and odours (can be avoided)
Where to use	• Use as part of a treatment train, e.g. use as part of inlet zone to constructed wetland, or pre-treatment to bioretention systems in medium to large sized industrial or mixed use developments. • Sites with maintenance access
Where not recommended	• Sites with space constraints • Sites with permeable soils (a liner may need to be installed at an additional cost) • Sites with high groundwater table • Steep sites

**Systems would be larger in size than if it were used simply as bioretention system
^: Design of stormwater wetlands will differ from wastewater wetlands
[ß]: use for small catchment areas because of high rainfall
[#]: Permeability of porous pavements is dependent on many factors (including age of pavement) and is expected to decrease over time.

Table 5- 5 provides a basic summary of the relative effectiveness of each technology in terms of the water quality improvement and flow attenuation potential. See the previous section for more detailed information on the expected pollutant and hydrological treatment efficiencies.

Table 5- 5 Relative effectiveness of GI for runoff quality and water quality management

GI technology	WQ treatment	Peak flow attenuation
Biofilter/ bioretention/ raingarden/ tree pits	H	M
Living walls	H	M
Green walls	M	L
Green roofs	L	M
Constructed wetlands	H	H
Swales and buffer strips	M	L
Porous pavements	M	H
Retention ponds	M	H
Rainwater tanks	L	H
Sedimentation basins	M	M

Source: adapted from WSUD Technical; Design Guidelines for South Est Queensland, Version 1 June 2006
H – high; M – medium and L - low

Sentul City -- Integration of swales with landscape design for runoff conveyance. Swales constructed along the road edge can assist in defining the boundary of road or street corridors as well as enhancing landscape character.

Green walls vs Living walls

The selection of the most adequate system will depend on building characteristics (e.g. orientation,
(e.g. sun, shade, wind, rainfall). Table 5- 6 distinguishes between green and living walls.

Table 5- 6 Comparison of green versus living walls

	Green walls	Living walls
Cost		More economical
Benefits	Thermal benefits higher – contribute to thermal resistance of the wall, leading to a reduction on energy demand for heating and cooling.	Smaller environmental burden considering that they have no materials involved
Design	A wider variety of plant species can be used – more visual creativity Light weight media used	Limitation in plant diversity
Installation	More complex implementation	Slow surface coverage
Water consumption	High water and nutrient consumption – making this GI system an opportunity for greywater treatment and re-use.	
Maintenance		Difficulties in ensuring vegetation continuity in the event of plant replacement. Climbing plants require guidance to ensure that they cover the entire surface. Lower maintenance needs

Source: Manso et al., 2015 among others

5.4 Matching treatment of water sources with design objectives and technologies

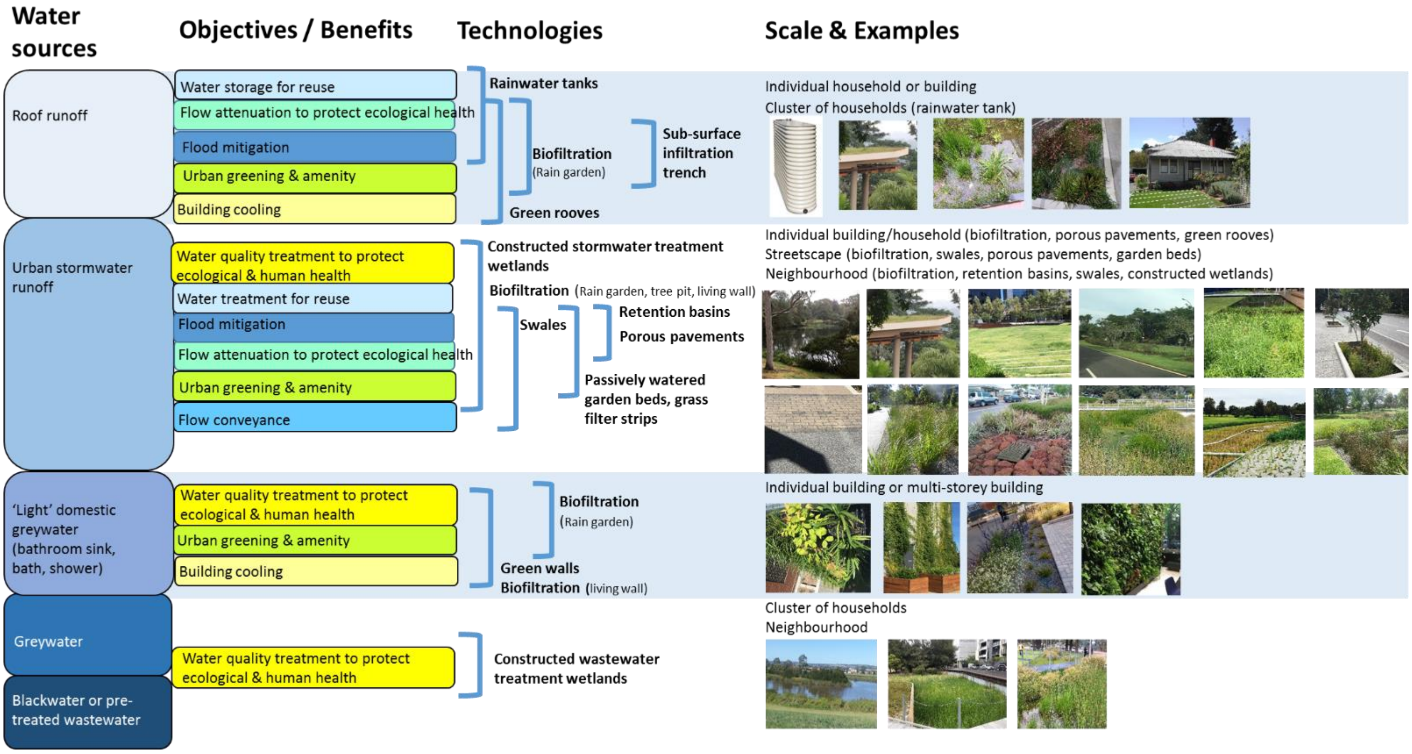
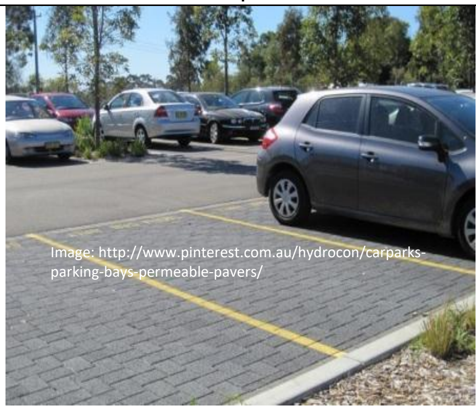


Figure 5- 2 Matching the treatment of various water sources with the different objectives or benefits that can be achieved, and with technologies to achieve these targe

5.5 Examples of conceptual solutions for retrofit applications

Table 5- 7 Examples of conceptual solutions for retrofitting green infrastructure

Before – existing condition	**After - opportunity**
	 Wetland
	 Biofilter with food crops for local food production (urban farming)
	 Street trees along roads

Before – existing condition	After - opportunity
	 Permeable pavement - use for retention and infiltration of road runoff and collection into underground drain
	 Swales, tree pits along roads
	 Street scape biofilter
	 Car park - porous pavement

Before – existing condition	After - opportunity
	 Streetscape biofilter
	 Swale along road side
	 Raingarden

Before – existing condition	After - opportunity
	 Converted into a swale
 Footpath along lake in Cibinong	 Footpath along lake in Sentul City. Image: Raul Marino

Chapter 6

Technical Design and Maintenance of Green Infrastructure

This chapter provides an overview of the key GI design parameters. It also provides guidance on how to design for local conditions. Readers are referred to available technical guidelines that should be consulted in conjunction with the recommendations made herein. An overview of the maintenance requirements of each GI element has also been provided to ensure the long term performance of these systems. Some systems are relatively simple to operate and maintain and can thus be the responsibility of the local community, while for others, a higher level of technical expertise is required to maintain the systems. These are important considerations when selecting and designing technologies for a particular development project.

6.1 Overview of Key Design Parameters

It is important to select a suitable filter media and plants species for the successful operation of the various GI systems over its designed life-span. Key design parameters include the filter media, vegetation, hydraulic structures (including inflow, outflow, over-flow bypass), ponding zone (for stormwater systems), underdrain collection pipe, system liner. In this section, we highlight the important role of the filter media and vegetation in flow control and water quality improvement in addition to the general functioning of GI systems (Table 6- 1). Further guidance for the selection of plant species for different green infrastructure in Bogor, and more broadly Indonesia, can be found in Chapter 7.

Table 6- 1 Roles and characteristics of filter media and vegetation in GI systems

Design variable	Role	Properties
Filter media	- Provides physical filtration of particulates - Provides physicochemical pollutant removal processes such as adsorption, fixation, precipitation - Supports vegetation and the associated microbial assemblages - Enables infiltration of stormwater/greywater at an adequate rate - Retains stormwater in its intra-pores, will help reduce the magnitude of the outflow hydrograph for small to medium events	- Low in nutrient and organic matter (to limit leaching into the effluent) - Must have enough fines to support plant growth (e.g. for moisture retention) - Adequate hydraulic conductivity (for unsaturated treatment systems) to ensure satisfactory infiltration and prevent flow by-pass in excess of design flow. - Adequate water holding capacity for green roofs and green walls - Minimum depth for plant growth (deeper systems generally seen to have higher treatment capacity than shallower systems - Lightweight substrates for green roofs and green walls.
Vegetation	- Direct uptake of nitrogen, phosphorus and some heavy metals - Supports and influences microbial processes responsible for pollutant	- Please refer to Chapter 7 for more detailed plant species

	transformation and degradation (e.g. nitrification, denitrification, decomposition and mineralisation) - Maintain media porosity and hence helps alleviate the clogging phenomenon - Helps to slow down flow rate and stabilise soil, hence preventing soil erosion - Reduces outflow volume and the exported pollutant loads via evapotranspiration loss - Assists in urban cooling via the processes of evapotranspiration and shading. - Provide biodiversity, habitat and amenity which contribute to multiple human health, environmental and economic benefits	selection guidance for Bogor and Indonesia - Select native plant species to enhance biodiversity and ensure plants are suited to local conditions - Species with the characteristics to survive in the environment (e.g. shallow substrate, drying and heat exposure on green roofs; sandy media, intermittent inundation and drying in biofiltration systems; potentially shaded conditions). - Plants with appropriate size for the system, particularly substrate depth or container size (i.e. not too large) - For effective plant nitrogen uptake select species with the following morphological traits: • Extensive and fine roots • Moderate to high growth rate • High total plant mass - Avoid species with weed potential or known weeds - Avoid N-fixing plant species - Use a mixture of different plant species - Relatively dense planting is recommended to optimise the benefits provided by the plants in pollutant removal and the other ecosystem services provided.

6.2 General information for the design of GI systems in Bogor

The successful application and performance of GI systems in Bogor will necessitate that design normally developed and applied in developed countries with mostly temperate climates be modified to suit the local climatic and socio-economic conditions. Figure 6- 1 provides an overview of the prevailing local characteristics and the corresponding opportunities and challenges that they present. Some general considerations are also provided for water engineers designing GI systems for application in Bogor.

LOCAL CHARACTERISTICS	OPPORTUNITIES	CHALLENGES
Warm and humid climate	- Higher evapotranspiration rates and biodegradation rates = higher pollutant retention - Plant growth throughout the year - Heightened biological activity year-round	- Favourable conditions for proliferation of mosquitoes - Humidity can enhance faecal coliform survival[1] - Reduced oxygen solubility at high temperatures[1] can impact on microbial processes
High rainfall intensity/ flooding	- Ample rainwater available for harvesting	- Greater generation of runoff = larger peak flows - Greater sediment production[2] - Greater solid transport capacity[2] - Higher faecal coliform inflows[1] - Greater erosive capacity
Litter disposed to the environment (incl. roads and waterways)		- More contaminated runoff - Elevated incidence of system clogging - More contaminated river and situ water quality - Ugliness
Wastewater ingress into drainage systems		- Poorer water quality accompanied by higher levels of nutrients and organics in runoff - More variable influent over the year - Risks to humans contacting the surface of the media - Clogging due to sediment loads

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DESIGN CONSIDERATIONS

System sizing
- Larger treatment systems for both hydrological and treatment purposes (i.e. to meet 80% of treated runoff)

Pre-treatment
- Installation of pre-treatment measures such as gross pollution traps, sedimentation tanks upstream of GI measure critical
- Inclusion of sedimentation basin upstream of bioretention system or constructed wetlands recommended

High-flow bypass
- A well-functioning high-flow or overflow bypass highly recommended to divert excess flows and protect plant from damage during rainfall events

Plant species
- Species used should be adapted to the local climate
- Use dense vegetation to control erosion

Design to prevent mosquito breeding
- Minimise surface flow systems where possible
- Promote continuous flow through wetlands and avoid promotion of stagnant ponds[3]
- Avoid plant species that can pond water in their leaves or flowers[3]

Storage capacity
- Design with a high storage capacity where possible

Figure 6- 1 Design opportunities, challenges and general recommendations for the application of GI in Bogor

[1]Katsenovich et al., 2009; [2]Rivard et al., 2006; [3]ABC Design Guidelines, 2014

Tropical regions are characterised by a relatively steady solar energy flux, as well as high humidity and warm temperatures throughout the whole year. This translates into year-round plant growth and heightened micro-biological activity, which in general have a positive effect on treatment efficiency (e.g. biodegradation of organic matter and nitrification/denitrification) (Zhang et al., 2015). As such, systems in tropical climates will typically experience higher biological activity and productivity, thereby resulting in higher treatment efficiencies as compared to temperate climates (Katsenovich et al., 2009) (Zhang et al., 2015). This can be particularly advantageous for greywater treatment using nature based systems.

At the same time, due to the higher rainfall intensities, stormwater management systems will need to be larger to incorporate the whole hydrograph. This will influence design parameters. For e.g., the rainfall intensity corresponding to a 1 in 2 year return period for a 2h duration event is 39 mm/h in Malaysia compared to 10 mm/h in Paris (Rivard et al., 2006). The differences in rainfall characteristics between temperate and tropical climatic conditions will mean the design guidelines for a 10-year rainfall event in Paris will be inadequate to treat a 10-year rainfall event in Malaysia. Recommendations for design sizing, based on studies or guidelines from tropical climates, are given in the sections below for different technologies.

Higher air temperatures and greater plant biomass in tropical areas should increase evapotranspiration losses (Lim and Lu, 2016) which can increase rainfall retention and reduce the exported pollutant load. Yet, at the same time with more frequent high intensity weather events, soils are mostly saturated which means that water retention capacity will be lower (e.g. Simmons et al., 2008; Wong and Tim, 2013). This signifies that during low to medium rainfall events, higher water retention can be expected (in fact, as indicated by Trinh and Chui (2013) in Lim and Lu (2016), evapotranspiration (ET) can play an important role in rainfall retention in Singapore), however, during frequent high intensity events, retention performance may be expected to be lower. This highlights the importance of high flow bypass and the need to provide for some sort of storage as previously discussed in Chapter 4, Section 4.3.2.

The design of stormwater systems in Bogor will, generally, depend on the local climatic conditions (including rainfall and evapotranspiration rate) as well as runoff quality. These parameters need to be quantified before proceeding with the design of the system. It is expected that stormwater systems in Bogor will need to be larger to ensure that 80% of the runoff is treated.

As for the greywater system, system sizing will depend on the greywater quantity and quality, which will dictate the hydraulic and pollutant loading of the system.

As highlighted in Figure 6- 1, physical clogging due to litter build-up can be detrimental to the lifespan of the system, but these can be mitigated with the set-up of structural systems (for solid removal) and employment of non-structural tools such as education and solid waste management campaigns as discussed in Chapter 4.

Precipitation and evapotranspiration play a decisive role in GI performance (in particular, constructed wetlands) under tropical conditions (Katsenovich et al., 2009). Evapotranspiration significantly reduces the outflow rate, impacting water balance and producing higher hydraulic retention times (HRTs). The process of evapotranspiration also concentrates conservative, non-degradable contaminants such as dissolved solids and nutrients, thereby increasing their concentration in the effluent (particularly for phosphorus). Conversely, during the wet season high rainfall dilutes pollutant concentrations but also reduces the HRT. Hence, it is critical to assess system performance using a mass balance approach (Katsenovich et al., 2009).

During the dry season, water deficit may lead to significant increases in conductivity values and mineralisation (Katsenovich et al., 2009); some form of irrigation of the treatment systems is recommended during the dry season.

For surface flow and open water systems, mosquito breeding can be particularly problematic. Some techniques to prevent mosquito breeding include:

- Consider application of low organic loading to avoid anaerobic conditions in the water column (Kivaisi et al., 2001);
- Manage weed and sediment build up;
- Water level fluctuations can interrupt mosquito life cycle;
- Providing access for mosquito predators such as fish and predatory insects to all parts of the water body;
- Ensure high flow bypass and overflow channels are free draining;
- Promote continuous water movement;
- Limit the detention time of water within the system, for e.g. systems are usually designed to limit the retention time to around 72 hours to ensure to prevent proliferation of mosquitoes (see further); in the case of biofiltration systems, systems

with minimum hydraulic conductivities could help ensure maximum detention periods are not exceeded;
- Avoid using plant species that can capture pools of water in their leaves or flowers (Katsenovich et al., 2009).

Systems should be sized appropriately to achieve best practice treatment targets. GI systems currently implemented in tropical countries are typically being designed in the same manner as in temperate climates. In particular, when designing systems in Bogor, the above considerations (Figure 6- 1) should be addressed during the planning and design phases (**Error! Reference source not found.**).

6.3 Technical design of GI systems

The technical design of GI systems for application in Bogor will need to take into account the local climate conditions (as outlined in Section 6.2) as well as a range of design variables as outlined in this section.

6.3.1 Biofiltration/bioretention systems/tree pits

One of the advantages of bioretention systems is their flexible design. Biofiltration systems can take several forms (Table 6- 2). Through proper selection of system configuration and thus incorporation into the existing landform, bioretention can play a significant role in enhancing the surrounding landscape aesthetically.

Table 6- 2 Different configurations of bioretention systems

Configuration	Application
Bioretention basins/rain garden	End-of-pipe system – often located adjacent to parkland or natural areas
Bioretention swales	(treats and conveys stormwater) Located within road reserves, parklands and drainage easements with small catchments < 2 ha
Biopods	At-source treatment system Used in streetscape, also have applications in commercial, industrial and multi-unit developments
Bioretention street trees (tree pits)	At-source treatment system Small systems, typically only a few m^2 Can be planted with trees, shrubs, grasses and sedges to suit landscape Trees can intercept additional rainfall in their canopy, direct rainfall to tree pits via stemflow, and percolate stormwater runoff through soil layers and root pores. Trees, additionally, provide canopy shading and increase urban cooling effects.

In Australia, stormwater bioretention systems are typically designed to capture 90% of total runoff while in Singapore, they are designed to treat a 1-in-3 month average return period. All overflows discharged into drains are then sized with a 10 year return period (Lim and Lu, 2016).

Figure 6- 2 provides an overview of the key biofilter design variables. Each variable has an important function, contributing to effective performance of the treatment system.

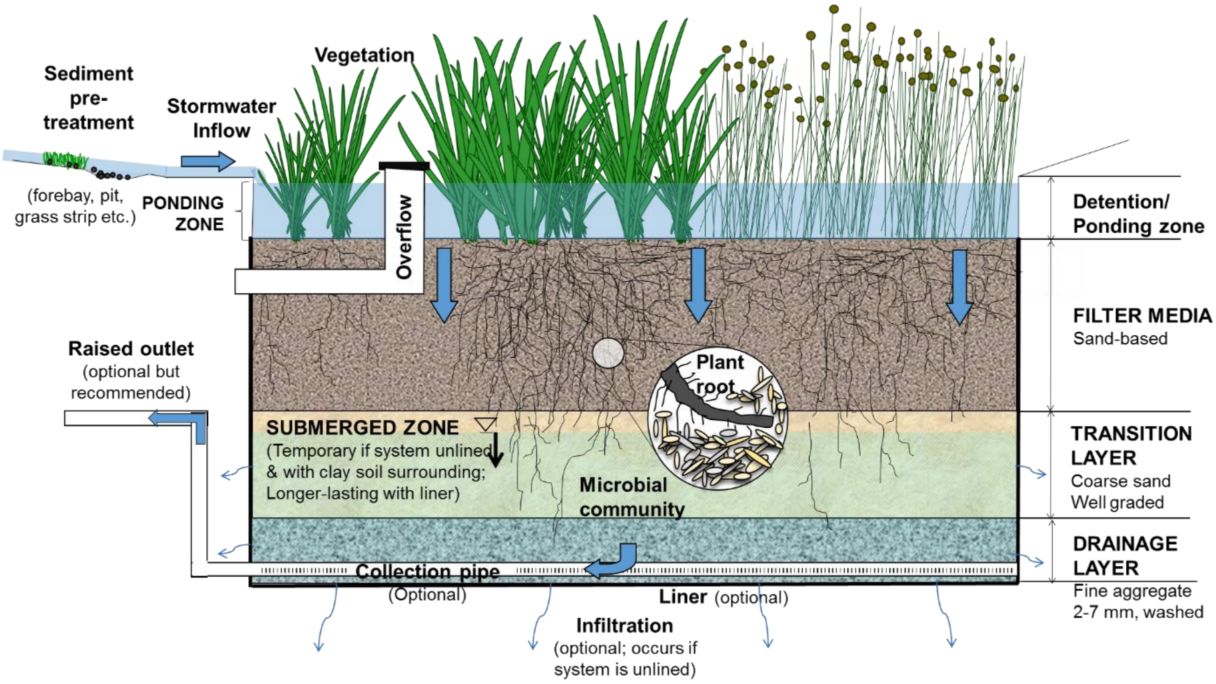


Figure 6- 2 Schematic of a typical stormwater biofilter cross-sectional profile. Source: Adoption Guidelines for Stormwater Biofiltration Systems (Payne et al., 2015)

Conceptual design

System sizing is a key parameter if the biofilter is being designed to manage stormwater flows. Research in Singapore demonstrates that a tropical basin can perform acceptably when adequately sized. System design (including sizing) will depend on (1) rainfall depth and patterns and (2) runoff quality.

Biofilters in Bogor would typically be sized larger than in temperate climates to accommodate the higher runoff volumes. Wang et al., (2017) recommend that water quality volume (WQV) or water quality depth (WQD) (that is the amount of runoff that needs to be retained to achieve desired pollutant removal rates) be used for sizing basins in the tropics rather than annual recurrence interval (ARI). According to Wang et al., (2017), ARI is not fully definitive because ARI fails to distinguish events (for instance, a 3-month ARI event in Singapore can be both intense and short or mild and long) with vastly different runoff amounts. Moreover, the authors are of the opinion that a small increase in ARI can result in more significant increase in rainfall intensity in the tropics as compared to temperate regions. Based on a study in Singapore, the authors recommend a WQD range of 10-30 mm (Wang et al., 2017).

Other sources of information that provide sizing guidance for tropical regions include the *Water Sensitive Urban Design Planning Guide* (McAuley, 2009) from Darwin, Australia and the *Active, Beautiful, Clean Waters Design Guidelines* from Singapore (PUB, 2018a). Both of these guidelines include design curves for preliminary system sizing . Sizing using these curves depends upon treatment objectives and system design (including surface area relative to area of impervious catchment, media hydraulic conductivity and ponding depth).

Two design flows are also required when sizing systems in Singapore; i.) minor storm (5 year ARI), which must be conveyed by the system without any increase in flooding, and ii.) major flood (100 year ARI), to check if flow velocities are likely to cause scour. Importantly, the inlet and overflow should be designed to avoid blockage, which could otherwise exacerbate flooding (PUB, 2014). The presence of an adequate bypass will help prevent flooding during intense rain events.

The fact that bioretention systems would need to be larger in size has several implications which must be taken into account during the design and planning stage. For instance, in locations where there is a lack of space, it can be recommended to implement smaller systems designed to treat smaller catchment areas, which can be used either in combination with other measures or with multiple bioretention systems in parallel.

Maintaining an adequate infiltration capacity is very important to prevent excessive bypass during large rainfall events (which can be very frequent during wet periods). Designing a GI system for adequate infiltration requires consideration of:

- the filter media specification,
- pre-treatment to reduce clogging with fine sediments,
- healthy vegetation cover, and
- adequate and regular maintenance of the system.

Correct specification of filter media is also important to prevent pollutant leaching into the effluent (Lim and Lu, 2016). It is also critical to maintain sufficient moisture to sustain a healthy plant community, and use of a raised outlet creating a submerged zone facilitates this. Healthy plants benefit pollutant removal.

Note: To make optimum use of these systems, biofilters could also be used to treat greywater if adequately sized to handle rainfall levels during rainy seasons. If the system is too small, this would lead to greywater overflows reaching rivers and situs untreated. See the boxes detailing greywater biofiltration systems further below.

For further technical design guidance, a range of reference materials and guidelines exist, including:

> The CRC Biofiltration Adoption Guidelines that provide detailed guidance on the design of the biofilter system (Payne et al., 2015). The *Active, Beautiful, Clean Waters Design Guidelines* and associated documents for plant selection and maintenance in tropical climates. This includes *Sustainable urban stormwater management in the tropics: An evaluation of Singapore's ABC Waters Program* by Lim and Lu, 2016 (Loh, 2012, 2013; PUB, 2014, 2018a).

- *Water Sensitive Urban Design for the Coastal Dry Tropics (Townsville): Technical Design Guidelines* and associated documents for design objectives and fact sheets (AECOM, 2011; Creek to Coral, 2011a, b)
- Darwin *Water Sensitive Urban Design Practice Guide* (McAuley, 2008)

It is strongly encouraged that these guidelines and other relevant documents be consulted for the technical design of these systems in Bogor or Indonesia with the considerations in mind presented in this section.

Case study: Soak Away Raingardens in Singapore – simple design for a passively watered garden

Garden beds are often incorporated into streetscape design, but simple designs that allow passive watering of garden beds with stormwater runoff from roads or pavements can achieve a reduction in stormwater runoff while also providing natural irrigation for the plants.

In Singapore 'Soak Away' Raingardens have been developed as a simple design that is easy to construct aand does not require connection to the drainage network. This is ideal for locations such as schools or private gardens that may lack suitable nearby drains and where the surrounding soil is permeable enough to allow some infiltration. It is effectively an unlined biofiltration systems without an underdrain, and appears as an attractive garden bed in a depression. More information can be found in the *Active Beautiful Waters Design Guide* (PUB, 2018a).

Design curves for sizing these systems have been developed by Mylevaganam et al. (2015). These allow managers to investigate how sizing impacts upon the volume of stormwater treated (versus the volume of untreated overflow), with variation in a number of design parameters. For example, for a Soak Away raingarden that is designed with a surface area that is 7% of its catchment area, using filter media with a saturated hydraulic conductivity of 100 mm/hr, that is designed with a depth to groundwater of 0.5 m, and for surrounding soil with a hydraulic conductivity of 50 mm/hr, the system is expected to overflow 33% of the time. If the raingarden were sized to 12% of its catchment (with all other parameters remaining the same), it would overflow only 0.5% of the time.


Examples of designs that allow water to runoff paved surfaces into sunken gardens passively; a simple raingarden design; at Monash University, Australia

Greywater biofiltration system

A greywater biofilter will be designed similarly in configuration to the stormwater biofilter except that the detention zone will be shallowerwith greywater designed to enter the system via a sub-surface inflow pipe. This pipe is installed in a manner so as to distribute flow across the surface of the system. Greywater biofilters are thus not designed for surface ponding.

Similar principles for filter media specification apply to the greywater system. Sizing of the greywater system will depend on greywater production within the building and its quality. For e.g., a loading rate of 55 mm/day was found to be satisfactory for nutrient, suspended solids and organic removal for greywater biofilters in Melbourne, Australia to meet unrestricted irrigation end-use (pathogens removal need to be low as well) (Fowdar et al., 2017). More local testing will help evaluate a satisfactory pollutant removal rate.

Greywater Biofiltration demonstration systems in Bogor

Demonstration biofiltration systems have been constructed at both Pulo Geulis and Griya Katulampa (Professor Hadi, UI) (photos below). The systems demonstrate the technology to the community and are also testing their design and performance. These are relatively small-scale systems in plastic containers treating greywater from neighbouring residences. Various types of media are being tested including white sand, palm fibre and dried karungori (a grass-type plant), underlain by gravel. Water quality testing of the influent and effluent is underway (with results awaited), tested before and after planting. In Pulo Geulis there have been some problems with rats eating the plants.

There is potential for a wide range of future applications, such as a new highway to be constructed in Bogor which comprises a median strip of 5-10 m width. Road runoff could be treated in biofiltration systems, but sizing is challenging given the high volume and intensity of rainfall (April FGD 2018). There is also potential for stormwater harvesting systems using biofiltration and tanks, but again sizing requirements remain unknown. There are also local landscaping contractors emerging with capability to construct functional landscapes such as bioretention. However, monitoring of system design, construction and performance is required.

Demonstration biofiltration system treating greywater in Griya Katulampa

6.3.2 Living walls

The functioning of living walls is similar to bioretention systems. Their advantage lies in the fact that they can be used to achieve comparable treatment objectives in relatively dense areas where space is a premium. Living walls can be used for both stormwater management and greywater treatment. Design components will be similar to the biofiltration system except for the presence of an external support structure and different types of plant species (living walls employ a range of climbing plants and lower storey ornamental in addition to native species) (Figure 6- 3). Design will also need to satisfy the guidelines regarding the structural and bio-physical considerations for general living wall design (Department of Environment and Primary Industries, 2014 – *Growing Green Guide*).

Figure 6- 3 Living wall at Monash University, Clayton

Additional References

- Department Of Environment And Primary Industries, S. O. V. 2014. *Growing Green Guide: A guide to green roofs, walls and facades in Melbourne and Victoria, Australia*. In: ENVIRONMENT, D. O. (ed.). Victoria, Australia.
- The FLL Guideline: "*Guidelines for the Planning, Construction and Maintenance of Green Roofing – Green Roofing Guideline*", Forschungsgesellschaft Landschaftsentwicklung Landschauftsbau, or, in English, the Landscape Development and Landscaping Research Society.

6.3.3 Green roofs

Green roofs are attractive features for use in regions with limited development space. They can be landscaped to function as recreational areas for people to sit and relax (for e.g. during lunchtime) or can be used for food production (for e.g. by planting species for agricultural or horticultural purposes).

The deployment of green roofs in Bogor has the potential to delay peak runoff (for small or medium rainfall events); hence green roofs can play a role in flood control, the extent of which is yet to be quantified through research studies. To achieve overall flood management targets of the catchment, it is recommended to couple this intervention with other flow retention devices.

In addition to its water-related benefits, green roofs may increase the lifespan of traditional roofs by a factor of two as they provide a buffer from harmful UV rays and thermal effects. For instance, in Germany, there are reports of living roofs being in place for 50+ years without the need for replacement (Lewis et al., 2015).

There are different types of green roofs, each with different purpose, design and maintenance requirements as well as hydrological performance (Table 6- 3). The two main types of green roofs are: (1) extensive green roofs, that is, roofs with <150 mm of substrate depth and (2) intensive green roofs, roofs with >150 mm of substrate depth. Semi-intensive roofs (of approximately 150 mm depth) are also used as a mid-point between the two major types of green roofs. Table 6- 3 compares the two types of green roofs in terms of their different characteristics and design attributes.

Table 6- 3 Distinctive features of extensive and intensive green roofs

Characteristic	Extensive roof	Intensive roof
Purpose	Functional; stormwater management, thermal insulation, fire proofing	Functional and aesthetic; increased living space
Structural requirements	Typically within standard roof weight-bearing parameters; additional 70 to 170 kg per m^2	Planning required in design phase or structural improvements necessary; additional 290 to 970 kg per m^2
Substrate type	Lightweight; high porosity; low organic matter	Lightweight to heavy; high porosity; low organic matter
Average substrate depth	2 to 20 cm	20 cm or more
Plant communities	Low-growing communities of plants and mosses*	No restrictions other than those imposed by substrate depth, climate, building height and exposure and irrigation facilities
Irrigation	Require little irrigation depending on the climate, higher volume of water required for irrigation compared to plants at ground level	Require irrigation
Maintenance	Little maintenance required; some weeding or mowing as necessary, drainage system inspection	Same maintenance requirements as similar garden at ground level
Accessibility	Generally functional rather than accessible; will need basic accessibility for maintenance	Typically accessible; bylaw considerations

Adapted from Oberndorfer et al., 2007, Interview of Pak Adriyadi and Pak Misrah, Manager and Engineer of Neo green savanna Hotel
*See Chapter 7 for a selection of plants suitable for green roofs

Which type of green roof to use?

Extensive green roofs seem to be generally more popular across the World (Europe and North America) because of their low cost and low maintenance requirements and less stringent building weight restrictions. In Singapore, however, intensive green roofs are more common. Stormwater management benefit (i.e. runoff volume and peak flow) tends to decrease with increasing rainfall magnitude, and is greater for intensive green roofs compared with extensive green roofs.

In Bogor, the choice between extensive and intensive roofs will depend on the specific application and will be site-specific. If the main objective for implementation is stormwater management, then extensive roofs may lose their ability to retain rainfall during intense rain events. Intensive green roofs are more useful in optimising water retention (that is, stormwater management function) because of higher retention due to higher water holding capacity of the deeper substrate. In this respect, intensive roofs may be preferred. However, to reduce costs, semi-intensive roofs may be the best option. It is important to note that choice of green roof will influence growth, drought stress and drought tolerance of green roof species. Selection of green roof species will thus differ between extensive, semi-intensive and intensive green roof systems.

The main design elements of green roofs are shown in Figure 6- 4 and described in Table 6-4. The substrate, water retention structure, green roof plants and roof slope are some of the key design elements to be considered when using these systems for stormwater management. Some key recommendations based on studies conducted in warm, tropical climatic conditions are discussed below.

One of the key factors guiding performance is correct specification of the growing media and adequate use of fertilisers. Excessive fertiliser use will contribute to increased nutrient levels in the effluent. Frequent watering during the initial establishment period is critical to ensure plant survival.

Green roof plants employed in these systems will be different from those specified in temperate climates. Green roof plants specified in temperate systems are typically characterised by high water use efficiency, ability to withstand cold winters and warm summers on a shallow-well drained medium (Simmons, 2015). Conditions are different in Bogor such as occurrence of flash flooding, prolonged drought, high day and night-time air and soil temperatures and limited available water supply (see below for recommendations of locally suitable plant species).

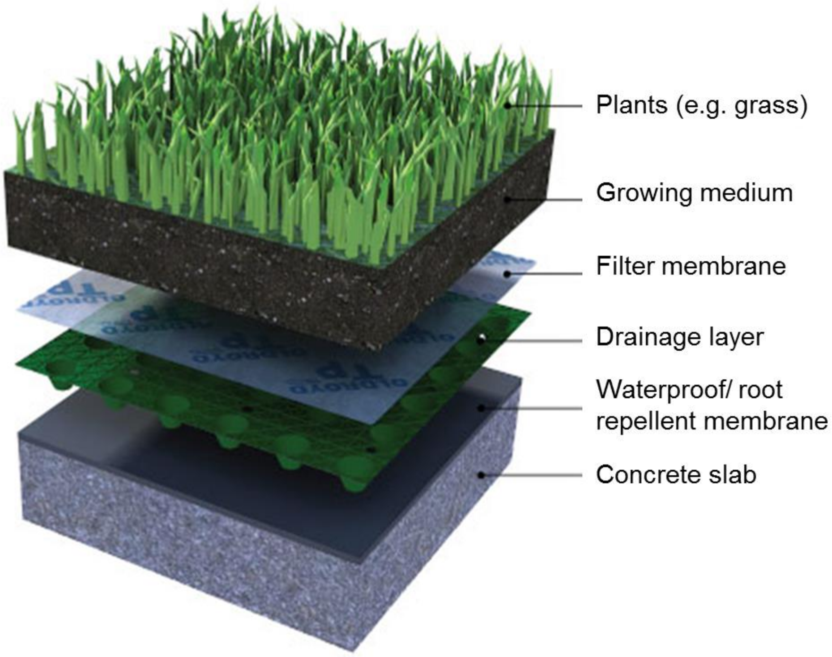


Figure 6- 4 Cross-sectional profile of a typical green roof system. Source: Image adapted from safegaurdeurope.com

Table 6- 4 Key design elements of green roofs and their characteristics

Key green roof element	**Properties**	**Examples/Recommendations**
Growing medium or substrate *Substrate depth, number and type of layers used and physical properties are important design variables.*	- Desirable media traits: **moderate drainage, high retention, low thermal conductivity** (Simmons, 2015) - Green roofs should have adequate permeability- select substrates with moderate to high water holding capacity - Substrate depths of 7 to 15 cm can support more diverse mixtures of grasses, geophytes, alpines, and drought tolerant herbaceous perennials, but are also more hospitable for undesirable weeds (Oberndorfer et al., 2007) - Low organic content of substrate to avoid nutrient and organic leaching into effluent	- Use local materials - Perlite as media was found to have good water retention capacity (desired) (Simmons et al., 2008) - Recommended to add lightweight, porous organic and inorganic material to media (50% by volume) to improve volumetric water content and reduce thermal conductivity (Simmons, 2015). Some good examples of substrate with positive water retention include hydrophilic gels, perlite and vermiculite; they hold water, air and have high CAC for plant nutrient supply (Simmons, 2015) - Presence of rockwool beneficial if the rainfall events are preceded by a prolonged dry period (Wong and Jim 2014).
Water retention structure *Some sort of water retention structure will increase the water retention capacity of*	- Good water retention capacity	- Increase the drainage or water retention layers - Use a hydroponic foam in place of a standard retention layer – this will provide for the retention of stormwater while still

the system which is highly desired under high rainfall conditions		simultaneously allow accessibility to available water by roots (Simmons, 2015).
Green roof plants *Species characteristics affecting rainfall retention include: (1) Height and spread of vegetation; (2) Type and diversity of species.* *Plant selection will also differ across green roof types.*	- Ability to withstand high leaf and root temperatures, prolonged drought and occasional prolonged media saturation - Ability to switch between low transpiration in dry periods and high transpiration in rain events, i.e. facultative CAM or equally broad soil water niche plants such as some prairie grasses and forbs would be ideal (Simmons, 2015) - Species that can tolerate local high intensity rainfall - Species that can tolerate drought, yet endure occasional saturation - Ability to survive in low nutrient conditions and extreme temperature (Vijayaraghavan et al., 2012)	- Use locally adapted plant species - Use a mix of growth forms to optimise performance across all climate conditions throughout the year - Select plants that do not reproduce by seed, hence it cannot spread to unintended areas through wind and birds (Wong and Jim 2014).
Green roof slope	- Low slope will facilitate water retention	- Slopes of < 30^{O} recommended

Green roofs should mainly be used for their hydrological function as discussed in Chapter 3. During the initial months of establishment, runoff quality may be poorer (due to leaching of nutrients from the fertilised substrate in addition to the fact that plants are not mature enough) but will improve over time. If and how much fertilisation is required is a key design issue in regards to pollutant leaching from green roofs. To buffer against any increase in the levels of nitrogen and phosphorus flowing from the roof, one possible strategy is to re-use the water (irrigation represents one potential application). Other strategies include reducing fertilisation and selecting plants that optimise the uptake of nutrients and contaminants (from the substrate).

In summary, recommendations for application of green roofs for stormwater management in Bogor are as follows:

- Water managers need to be aware that green roofs would work best in terms of their hydrological performance for small to medium events (noting that water retention would not be that effective during high intensity events);
- Explore any opportunities to supplement the system with greywater during dry season (there are instances where green roofs have been irrigated with greywater, e.g. Chowdhury and Abaya, 2018).
- Consider use of semi-intensive roofs;
- Combine with other measures (infiltration based techniques) for high rainfall events (to address flood control);
- Plant species: use local species, species used will be different from those used in temperate climates because of higher temperature and rainfall intensity (no drought-stress etc);

- Substrates: use local material; careful specification to avoid leaching of various metal ions and anions into green roof runoff; controlled use of fertilisers to avoid leaching of high levels of nutrients.

Green roofs in Taiwan

Many green roofs have been constructed in Taiwan as a result of initiatives to move towards a low-carbon society and more sustainable cities (Chen, 2013). The main motivations behind green roofs establishment were their building energy saving benefits and to beautify the city. However, their implementation is also being encouraged because of their ability to retain water. Taiwan has an annual average rainfall of 2500 mm, most of which falls during the rainy season. With incentive from the Government, standardised regulations following the *German FLL guidelines* have been implemented. Chen (2013) provides a review of the performance of green roofs in Taiwan.

More design information/specifications on green roof substrates and plant species can be found in the following documents:

- Fassman-Beck, E A and Simcock, R (2013). Living roof review and design recommendations for stormwater management. Prepared by Auckland UniServices for Auckland Council. Auckland Council technical report TR2013/045;
- The FLL Guideline: "*Guidelines for the Planning, Construction and Maintenance of Green Roofing – Green Roofing Guideline*", Forschungsgesellschaft Landschaftsentwicklung Landschauftsbau, or, in English, the Landscape Development and Landscaping Research Society.

Please note that substrates used in the above guidelines may not be directly applicable to use in Indonesia; bearing in mind the points made in this section, the guidelines can be used for guidance as a starting point.

Green roofs in Bogor

The turf roof at the Hotel Neo Green Savana provides an example of a large green roof in Sentul City. The system does not collect and reuse runoff, but is expected to reduce the volume of rainfall runoff and provide a cooling benefit to the underlying hotel rooms. A large-scale green roof is also planned for the Aeon Mall (currently under construction). At a smaller, informal scale, many people, particularly in Jakarta, have potted plants on their roof forming a roof garden. However, similarly to green walls, green roofs require adequate structural support from the building and significant construction and maintenance costs. Hence these GI systems are most appropriate for public or corporate buildings.





Green roof system covering the Hotel Neo Savana in Sentul City. Image at top right shows an access panel opened to illustrate the depth of substrate and layers beneath; concrete, waterproofing, geomesh, geopolimer, soil and grass. Solar panels are also located on the roof (shown in centre bottom image) Source: Images provided by Raul Marino

6.3.4 Green walls

Green walls are also known as bio-walls or vertical gardens. They provide an attractive design feature to a building; they essentially enable plants to grow in locations that would not normally support vegetation. “Green walls are designed with pre-vegetated panels, vertical modules, or planted blankets that are fixed vertically to the surface, allowing plant growth without relying on rooting space at ground level” (Medl et al., 2017).

Green walls differ from living walls in that plantings are made over the entire vertical structure, as opposed to planting at the base of the structure to enable vertical and horizontal growth. In a green wall, plants, growing medium, irrigation and drainage are incorporated into the system. In contrast to living walls, green walls allow a rapid coverage of large surfaces and a more uniform growth along the vertical surface (Manso et al., 2015).

Some of the key benefits of green walls include improving the energy efficiency of the building through direct shading of the wall. It is useful to note here that green walls have higher cooling and thermal effect compared to living walls. Economic benefits include increase in property value, building envelope longevity and energy demand reduction for air conditioning which are potential cost savings for the society (Medl et al., 2017).

Characteristics of a well-designed green wall system include:

- Provision of a suitable growing environment for the plant species,
- It has a long lifespan, requires minimal component replacement and has achievable demands for maintenance (DEPI, 2014 - *Growing Green Guide*).

A wide range of plants is used on green walls, usually herbaceous species, though some small shrubs can also be suitable (DEPI, 2014 - *Growing Green Guide*).

Note: ***Green walls have a particular potential for urban agriculture, hence integration of vegetables and aromatic herbs in green wall systems should be considered.***

Table 6- 5 provides an overview of the key green wall design elements and their corresponding functions.

Table 6- 5 Functions of key green wall design elements

Design element	**Function**
Supporting structure	Frame to hold the system and a support for plants
Growing media	Lightweight considering that each element will be supported and adapted to selected plant species and environmental conditions; Media should have a good water retention capacity.
Vegetation	Selection depends on climatic conditions, the building characteristics and the surrounding conditions; Allows the integration of shrubs, grasses and several perennial; Other factors to consider include plant development, colour, blooming, foliage; Plant should be adapted to local conditions of exposure (e.g. sun, semi-shade or shade) and weather conditions (e.g. wind, rainfall, heat); Consider integration of vegetables and aromatic herbs.
Drainage	Drainage occurs along a permeable membrane. An e.g. of drainage layer is geotextile which also helps to prevent roots proliferation; A filter material can be applied at the bottom (e.g. inoculated sand) for purification of the water. A granular inert filler (e.g. expanded clay, expanded slate, gravel) can also be used to promote drainage and development of roots; A material which promotes aeration and removal of excess moisture in the substrate can also help with pollutant removal (e.g. establishment of aerobic process for biodegradation processes) (Prodanovic et al., 2017).
Irrigation	Irrigation needs depend on type of system, plants used and climatic conditions (sun, shade, wind exposure, rainfall), building orientation, height – will influence the amount of roof runoff and greywater directed to the system; Proper irrigation critical for plant health.

Source: Manso et al., 2015

Types of green walls

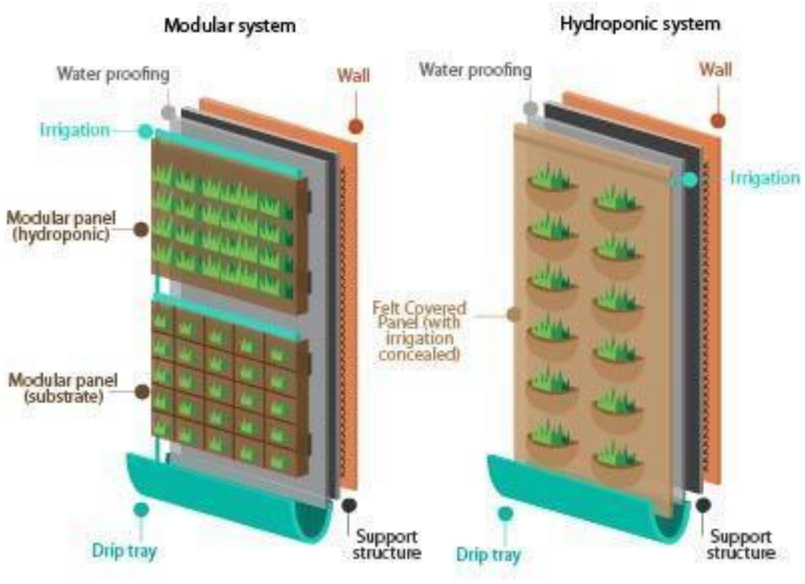


Figure 6- 5 Common types of green wall systems. Image source: DEPI, 2014 - Growing Green Guide

Figure 6- 6 Example of hydroponic system (left) and substrate-based system (right) at Monash University, Australia

The two main types of green walls are hydroponic and soil-cell systems. A definition of both systems is given by Riley, 2017 as follows: "***Hydroponic systems*** often use a dense mat or felt-like material as a growing medium for plants. The growing medium is doubled and continuously wetted with nutrient-enriched water. Plant roots grow on and in-between the two layers of felted substrate" (Figure 6- 6 – left). This substrate can act as a water retention sponge.

"***Soil-cell systems*** or ***substrate-based systems*** grow plants in soil that is compartmentalized into individual cells, which are grouped together in panels that attach to a frame (however, there are some hydroponic systems which use a modular, cell-based typology, typically replacing soil with an inorganic material such as rock wool - modular panel with substrate in Figure 6- 5; Figure 6- 6 - right). Essentially a collection of "potted" plants, the individual soil-cells are subject to the same challenges that face most potted plants: soil compaction, climatic stress, and soil nutrient replenishment" (Riley, 2017).

In the hydroponic system, there is no structural decay of the growing medium, no salt build up from fertilisers and nutrients are supplied in a precise and controlled manner which are plus points for this type of green wall system. Over time, plant roots grow and spread through the entire system to create a very robust network (DEPI, 2014 – *Growing Green Guide*).

Given the above, these types of green walls can be used to delay storm runoff – but care should be taken as the more the materials retain water, the heavier the system becomes, something to consider during the structural design stage.

If there is a need to capture excess irrigation water from the growing medium, drip trays can be used (Figure 6- 5). Their size should be sufficient to hold an entire irrigation cycle's water volume (DEPI, 2014 – *Growing Green Guide*). The run-off from the green wall can also be used to irrigate vegetation which then prelude the need for drip trays (DEPI, 2014 – *Growing Green Guide*).

There are various resources which provide information on the technical design of green wall systems. Some examples include:

- Department Of Environment And Primary Industries, S. O. V. 2014. *Growing Green Guide: A guide to green roofs, walls and facades in Melbourne and Victoria, Australia*. In: ENVIRONMENT, D. O. (ed.). Victoria, Australia
- Fassman-Beck, E A and Simcock, R (2013). *Living roof review and design recommendations for stormwater management*. Prepared by Auckland UniServices for Auckland Council. Auckland Council technical report TR2013/045

What is the prospect of using greywater for green wall irrigation and subsequent water treatment?

All green walls require irrigation, often inclusive of fertiliser. Greywater already has some levels of nutrients – which can be used – greywater as a sustainable source can be directed into the green wall system – more from a sustainability perspective. Table 6- 6 provides further recommendations for key green wall parameters when designing for *water treatment*.

Table 6- 6 Key attributes of green walls when used for water treatment

Key design parameters	Comments	Examples
Type of green wall	- Substrate-based (potted design) recommended (Prodanovic, 2018). In the event of plant death or system clogging, pots can be more easily replaced and help with system treatment performance. - Pot design is also less prone to media clogging. - Available media volume in each pot should be approximately 3-9 L (Prodanovic, 2018).	
Growing media	- Light-weight media - Media should not leach nutrients - Selection criteria: select media that can slow down flow, moderate infiltration capacity (to increase water residence time) and which favour a greater biofilm development (e.g. small particles occupying a higher surface area) (Masi et al., 2016) - Prodanovic et al. (2017) recommends a combination of slow and fast media. The authors are of the view that media selection would involve a trade-off between the volume of water that can be treated through the system daily and the desired effluent quality; for instance, a slower media would be able to produce a higher effluent quality while a faster media would be able to treat a greater volume of water for a given green wall size. - Perlite offer better aeration of the mix, which is important for avoiding the development of toxins and plant diseases in vegetated systems. - Optimal mix would also minimise the size of the system (hence costs) while at the same time maximising pollutant removal efficiency.	Light expanded clay aggregates (diameter of 4-10 mm) with sand and coconut fibres mixed in a proportion of 50-50% (Masi et al., 2016) A combination of coco coir and perlite (Prodanovic et al., 2017)
Plant species	- Similar in traits and characteristics to those specified for application in green roofs – that is, species with shallow root systems and drought-tolerant	See chapter 7 – plant selection
Irrigation	- Greywater from the adjacent building - Roof runoff directed to green walls	
Pre-treatment	Recommended to avoid premature clogging	Settling tanks
Post-treatment disinfection	Required to comply with more personal re-use applications	

Studies reporting on the use of green walls for water treatment are quite limited at this point and an area of on-going research. Similarities can be drawn between green walls and green roofs. Both employ light weight media and similar vegetation. Based on the latter, learnings from green roofs can be applied here until more research become available in this area.

Green walls in Bogor

There are a number of green walls throughout Bogor, including the large green wall at the Aston Hotel in Sentul City covering car parking buildings and a smaller and relatively new green wall at another nearby hotel covering a pump shed. These green walls primarily cover structures to improve the visual,aesthetic appeal rather than to serve a water management function. The Astor Hotel system appears to be doing relatively well, but the plants are struggling more on the side that receives the most sun. These GI systems are currently watered using the fresh water supply, but there is opportunity to modify the design to irrigate plants using roof runoff or greywater.

Similarly to green roofs, green walls appear most appropriate for hotels, shopping centres, private business or government buildings, due to their costs, structural and maintenance requirements.

Green wall at the Aston Hotel, Sentul City, and green wall covering a pump station at a new Sentul City Hotel

6.3.5 Swales/buffer strips

Vegetated swales can replace pipes to filter runoff and, more importantly, provide a pre-treatment stage for other downstream measures (e.g. bio-retention systems). Their linear nature allows the filtering of sheet flows down channel side slopes and then conveyance and further treatment of contaminants along the base of the swale (Figure 6- 7). The slowing of stormwater flows in vegetated swales increases the time of concentration for stormwater in the catchment and reduces peak flow. It also provides opportunities for infiltration to groundwater. Table 6- 7 presents the design characteristics of vegetated swale systems.

A nice description of the integration of swales into existing landscape is provided in Lewis et al., 2015 as follows: “Swales can be integrated into existing landscape elements through alignment with natural flow paths and integration with planting schemes or natural plant communities. In flat areas, swales may be very wide to form subtle undulating flow paths. The linear nature of swales make them suitable for defining boundaries, separating pedestrians from traffic, forming a boundary to mitigate unwanted views, or forming intentional axes or dominant lines within a landscape. Swales also play an important role in softening the expanse of impervious infrastructure such as within car parks or road medians.”

Buffer strips are areas of vegetation through which runoff passes while travelling to a discharge point. They reduce sediment loads by passing a shallow depth of flow through vegetation and rely upon well distributed sheet flow. The reader is referred to *Australian Runoff Quality: A Guide to Water Sensitive Urban Design* (Wong and Engineers Australia, 2006) for additional discussion on buffer strip design and for worked examples.

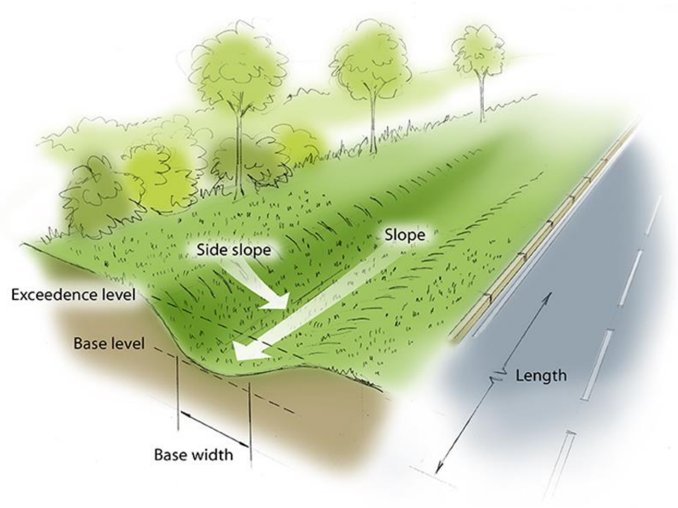


Figure 6- 7 Schematic of a vegetated swale system along a road strip; Image: Innovyze

Table 6- 7 Key design characteristics of vegetated swale systems

Design parameter	Comments
Vegetation	Dense vegetation and low velocities ensure reasonable treatment effectiveness in swales. Swales are dynamic environments experiencing both rapid inundation and drought. However, they may represent and include relatively diverse plant communities, similar to those associated with intermittent streams and floodplains. Even swales with low vegetation height (such as mown grass) can achieve significant sediment deposition rates provided flows are well distributed across the full width of the swale and the longitudinal slope is kept low enough (typically <4% grade) to maintain slower flow conditions (Brisbane City Council and the Moreton Bay Waterways and Catchments Partnership, 2006).

	Variety of plant types can be planted including turf, sedges, tufted grasses, groundcovers, shrubs, street trees. Vegetation is required to cover the whole width of swale and should be capable of withstanding design flows and be of sufficient density to prevent preferred flow paths and scour of deposited sediments. Vegetation height: 0.05 – 0.5 m
Slope	Longitudinal slope of between 1 – 4% is recommended to prevent waterlogging and stagnant ponding. For slopes >4%, measures to help distribute flows evenly across the swales as well as to reduce velocities and potential for scour required (see Brisbane City Council and the Moreton Bay Waterways and Catchments Partnership, 2006)
Hydraulics	For water quality improvement, swales need only focus on ensuring frequent storm flows are conveyed within the swale profile In Australia, for flow conveyance, design flows are taken as follows: Minor flood flow (2-10 year ARI) to allow minor floods to be safely conveyed Major flood flow (50-100 year ARI) to check flow velocities, velocity depth criteria. This is likely to be different in Bogor.

Design references:

- Brisbane City Council and the Moreton Bay Waterways and Catchments Partnership, 2006, *Water Sensitive Urban Design: Technical Design Guidelines for South East Queensland*
- Allison, R. et al., 2005. *WSUD engineering procedures: stormwater*, Collingwood, Victoria, Australia: CSIRO: Melbourne Water.

Application of vegetated swales systems in Bogor

Very heavy rainfall may saturate the soil and compromise performance which is why designers should target for small catchments (i.e., the contributing catchment should be small). Less intense but frequent rainfall can lead to constant presence of water in the swales which may cause discomfort and be dangerous from a sanitary standpoint which is why swale slope becomes an important design parameter. It is recommended to incorporate a bottom gravel storage layer to retain flow (with subsequent slow release to receiving waterways) which may further assist in flood mitigation.

Roadside vegetated open drains (V drains) in Bogor (potential swales)

Much of Bogor's drainage system comprises open concrete channels, adapted to a drainage purpose from their original use as irrigation channels (photos below). As a result, the stormwater runoff and greywater discharges carried by the channels is readily accessible and visible to the surface in many places. This facilitates the retrofit of any water sensitive technologies, such as vegetated swales. However, given the drainage issues already faced by the city it is imperative any retrofitting of technologies does not impact upon stormwater conveyance. Maintaining capacity of the drainage infrastructure is vital. In the dense urban environment this, along with the expense, would likely prohibit any technology retrofit. (March FGD 2018).

Open drains throughout Bogor. Source: Image at far right by Raul Marino

However, there is greater potential for retrofitting of water sensitive and green infrastructure into larger open, grassed drains, such as those that line the main Siliwangi Street in Sentul City. The existing drains in the almost 7km long green corridor are known as V-drains, and while they are vegetated, they are not designed to promote infiltration or retentive purposes, only to convey stormwater rapidly downstream to the nearby river. Where a road or roundabout transects the roadside, the drain incorporates underground flow in concrete culverts and pipes.

Open vegetated drain alongside Siliwangi Street, Sentul City

Research work is currently underway (Professor Hadi, UI) to consider how these V-drains can be converted into a water sensitive and functional system. While the instability of Sentul City's soils is a major consideration, as is the slope of Siliwangi Street (steep in parts, flat in others), there is potential to construct swales, small retentive ponds or biofiltration systems. Significant benefits could occur if the drains were adapted to provide greater flow attenuation, volume reduction and lower pollutant loads. Swale designs could incorporate high plant cover and underlying layers of porous material with a liner to prevent infiltration into the unstable soil.

6.3.6 Sedimentation basins

Sediment basins include all forms of stormwater detention systems that function primarily through sedimentation to promote settling of sediments through processes of temporary detention and reduction of flow velocities (see Figure Figure 6- 8). They play a role in both flow and water quality control. System sizing should take into consideration the ability of the system to cope with peak volumes and target the required particle size (see further). A common application includes pre-treatment to a wetland or bio-retention system in developments known to generate a high level of sediments.

The required size of a sedimentation basin is calculated to match the settling velocity of a target sediment size (typically 125 microns) with a design flow (typically 1 year ARI) (Allison et al., 2005). Under-sizing may lead to limited effectiveness in removing particles as well as increased maintenance while oversizing may lead to increased risk of much finer sediment accumulating and potentially having higher contaminant concentrations that could require specialist handling for maintenance (Allison et al., 2005).

Design parameters include

- Target sediment size
- Design discharge
- Basin area and shape
- Sediment storage volume
- Outlet structures
- Vegetation specification (at the littoral zones)

The influence of a permanent pool reduces flow velocities in the basin and thus increases detention times (hence removal efficiency). A starting point for basin can be 2 m depth for the permanent pool.

The ease of access for clean-outs is an important aspect to consider during the design of these systems for necessary periodic maintenance (see Section 6.4).

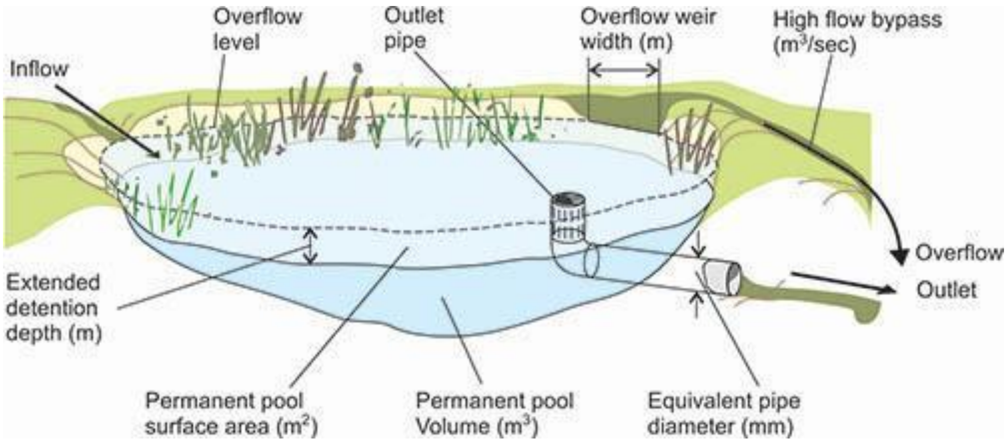


Figure 6- 8 Sedimentation pond design elements. Image source: waternsw.com.au

References

- Allison, R. et al., 2005. Chapter 4, *WSUD engineering procedures: stormwater*, Collingwood, Victoria, Australia: CSIRO: Melbourne Water
- Water by Design, 2017, Draft Wetland Technical Design Guidelines (Version 1). Healthy Land and Water Ltd, Brisbane – page 44
- The *Active, Beautiful, Clean Waters Design Guidelines* and associated documents for plant selection and maintenance. This includes *Sustainable urban stormwater management in the tropics: An evaluation of Singapore's ABC Waters Program* by Lim and Lu, 2016 – page 40

6.3.7 Constructed treatment wetlands

Constructed wetlands are promising water treatment systems because they can be employed to treat a range of water types, from different sources of wastewater to stormwater and even polluted groundwater. The design of wastewater and stormwater wetlands essentially differ from each other with each design discussed in this section. There exist different types of wetlands (Table 6- 8 and Figure Figure 6- 9).

Table 6- 8 Types of wastewater constructed wetlands

Constructed wetland (CW) type	Description
Surface flow (SF) wetland	Water level is above the ground surface. Emergent vegetation is planted – water flow is primarily above ground.
Subsurface flow (SSF) wetland	Water level is below ground; water flow is through a sand or gravel bed.
Free water surface (FWS)	A typical FWS CW with emergent macrophytes is a shallow sealed basin or sequence of basins, containing 20–30 cm of rooting soil, with a water depth of 20–40 cm. As plants promote a wide range of treatment processes, dense emergent vegetation covers a significant fraction of the surface, usually

	more than 50% (Vymazal, 2011) and for the most effective performance plant cover should exceed 80% of the wetland area (Melbourne Water, 2014). Zones of open water should be limited.
Floating wetlands	Floating wetlands consist of a buoyant mat, an organic growing media and plants. The roots of the plants are suspended in the water below the floating mat. Water is then treated via biofilms that form on the plant roots and via direct uptake from the plants. Advantages include easy retrofit into ponds or lakes and a flexible design. Minimum of 50% of open water zone is recommended to allow for diffusion of oxygen (Water by Design, 2017).

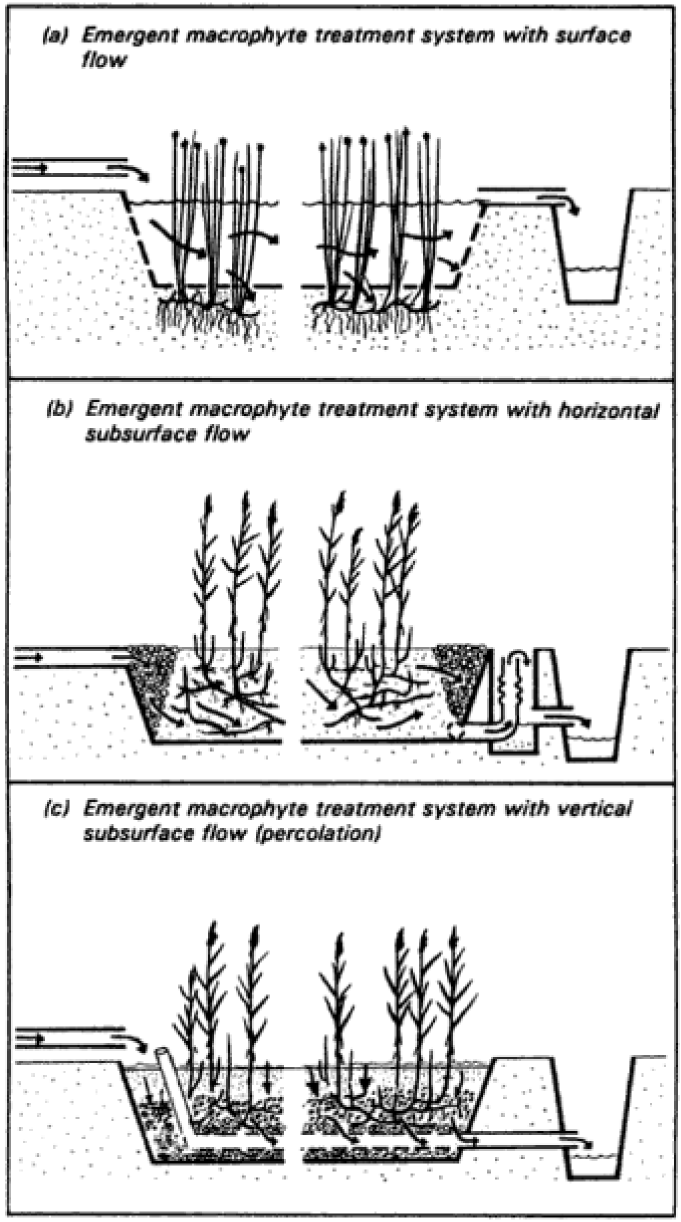


Figure 6- 9 Types of constructed wetlands. Source: Moshiri, G.A., 1993. Constructed wetlands for water quality improvement, Boca Raton: Lewis Publishers

Figure 6- 10 A surface flow wetland in Indonesia; Image: Dr. Cynthia Henny and research team, LIPI Limnology

Figure 6- 11 Examples of floating wetlands; Images: Dr. Cynthia Henny and research team, LIPI Limnology

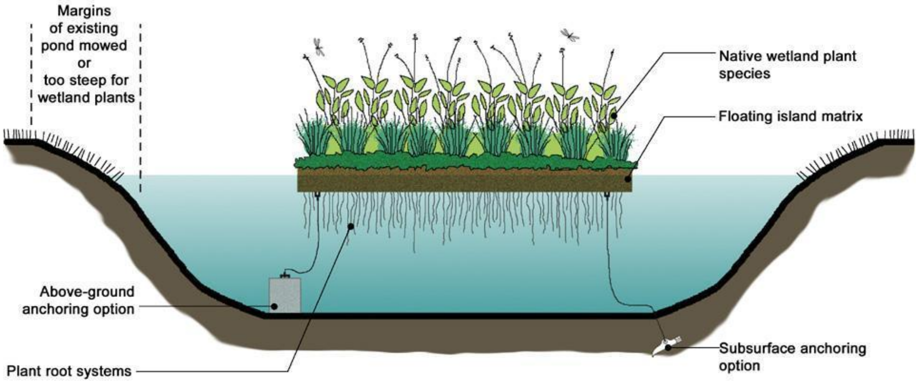


Figure 6- 12 Cross-sectional profile of a floating wetland in a lake; Image: Ozarks Living

Wastewater treatment wetlands

Constructed treatment wetlands are suitable for wastewater treatment and especially so for post-treatment, because the wetland vegetation and organisms is able to adapt to the wastewater inflow and utilize the various organic and inorganic pollutants during their metabolic and other life processes (Brix, 1997). The main components of wastewater wetlands contributing to treatment performance are the substrate and the vegetation (Table 6- 9).

Table 6- 9 Role and examples of wetland substrate and vegetation for water treatment

Component	Function	Example
Substrate	- Support living organisms in wetlands - Permeability affects movement of water through wetland - Provide storage for many contaminants	Soil Gravel Rock Organic materials, e.g. compost Granite-type gravel ranging in size from 9-37 mm with a porosity of 45% (Mburu et al., 2013)
Vegetation	- Pollutant uptake directly and indirectly through influences to the microbial community - Reduce flow velocity, hence provides conductive conditions for sedimentations and reduce system erosion - Stabilise the soil surface - Improve soil hydraulic conductivity through creation of macropores through root action into the soil - Roots release exudates that act to provide food aiding in pollutant processing - Roots releases oxygen into the rhizosphere which influence biogeochemical processes in the soil.	See chapter 7 – plant selection for recommendations regarding suitable plant species Note that the use of water hyacinth in floating wetlands is not particularly recommended because the plant is exotic and has invaded many water bodies (Kivaisi, 2001)

Constructed treatment wetlands in Bogor

The use of constructed treatment wetlands is the focus of significant local research at universities and research institutions such as LIPI. These systems have demonstrated effective performance treating various wastewaters and utilising various combinations and types of treatment wetlands (free surface flow combined with sub-surface flow) (Dr Cynthia Henny, LIPI, Green Technologies FGD, November 2017). Systems have been constructed to treat palm oil effluent, chrome plating waste and tannery waste from industry, catfish effluent from aquaculture, grey water and lake (situ) water treatment. Constructed treatment wetlands can be used to intercept and treat runoff or effluent before it enters lakes or streams. It remains uncertain if any systems have been tested locally for the treatment stormwater runoff alone, or blackwater.

There is a focus on the use of an ecosystem-based approach by replicating natural ecosystem functions for the management of lake water quality. Systems can incorporate catfish and tilapia (cichlid) fish which consume and produce waste, and consume nutrients and carbon. Overall results of wetland performance are promising for water treatment for organics, nutrients, metals and odours. For example, constructed treatment wetlands have demonstrated effective performance for the treatment of palm oil effluent with pH improved from 5 to 7.8; DO increased from 0.5 to ~5-6; COD >95% total removal efficiency, TN >90%, TP >85% and TSS >90% (Dr Cynthia Henny, LIPI, Green Technologies FGD, November 2017).

An example of wetland substrate may include sand (0.05 m), compost (0.05 m), sand (0.5 m) and gravel (0.2 m), or the gravel and sand layers may be mixed. Treatment of various wastewater streams may be enhanced by the addition of limestone or iron within the media.

Work has also been done testing the use of floating treatment wetlands for the restoration of ecological function in small to medium-sized situs, reservoirs or along the edges of canals or stream channels (Dr Cynthia Henny, LIPI, Green Technologies FGD, November 2017). This includes the treatment of eutrophic lake waters with toxic cyanobacterial blooms (blue-green algae); a common problem in situs, and also further understanding the mechanisms of algal blooms. Floating treatment wetland systems use rooted emergent plants, but instead of being rooted in the substrate, they are rooted into a floating mat on the surface of the water. They are passive, low maintenance and are constructed using low cost recycled materials and simple design. The systems provide water treatment, erosion control and aquatic microhabitat for fish and multiple other aquatic organisms (Dr Cynthia Henny, LIPI, Green Technologies FGD, November 2017 2017 and Interview). Research has investigated the optimal growing media, which is important for function and system lifespan; commercial coconut fibre is typically used but decomposes over time, leading researchers to seek other plant-based fibres such as palm fibre with slower rates of decomposition. Plant selection is also important for treatment performance and various species have been tested for their performance. Other design challenges include combating the growth of mould or fungi (Dr Cynthia Henny, LIPI, Green Technologies FGD, November 2017 and Interview).

Maintenance requirements for constructed treatment wetlands tend to be minimal (every 5 months for floating systems). While these systems are relatively low-cost to build and operate, further research is needed to address mechanisms for scaling up wetland interventions and also for mitigating clogging of the wetlands with litter (Dr Cynthia Henny, LIPI, Green Technologies FGD, November 2017 and Interview).

Constructed treatment wetlands and a floating treatment wetland system on a situ in Bogor. Images: Dr Cynthia Henny, LIPI

Wetlands constructed in tropical climates are typically designed as per guidelines established in temperate climates (e.g. Kadlec and Knight 1996 method). However, more recently design guidelines have been developed for tropical climates (AECOM, 2011; Department of Irrigation and Drainage, 2012; McAuley, 2008; PUB, 2018a, b). It is also recommended to follow the considerations outlined in Figure 6- 1. Several studies have investigated the performance of constructed wetlands in tropical regions and based their design considerations on the total area necessary to remove BOD_5, TSS, phosphorus, nitrogen, organic nutrients and pathogens (e.g. Katsenovich et al., 2009; Mburu et al., 2013). Mosquito control must be integrated in the design as well as the operation of a wetland, such as designing to promote mosquito predators in all wetland zones across the range of operating water levels (McAuley, 2008).

Given that constructed wetlands performance is in large part dependent on the type of vegetation, tropical (local) plant species suitable for constructed wetland development should be tested for use. Response of the plants to high nutrient levels and suitability to wastewater types need to be investigated (Kivaisi, 2001). See also Chapter 7 – plant selection guide for an account of research pertaining to local plant species that have been tested so far. In the tropics where growth rates (higher productivity) are high, the frequency and hence the cost of harvesting has to be considered (Kivaisi, 2001).

It is important that appropriate design models to predict wetland hydraulics be applied (Kivaisi, 2001). Bad odours are a possible problem associated with the use of constructed wetlands for wastewater treatment. Depending on the quality of the influent wastewater and dissolved oxygen, odor levels vary. Nuisance odours can be reduced by maintaining low BOD levels. Odour reduction strategies must be carefully considered especially for constructed wetlands located on non-remote public land or near residential areas (Kivaisi, 2001). High loading of pollutants including heavy metals, pesticides and other toxic substances can result in other environmental problems as well.

Stormwater wetlands

Constructed wetlands can be useful for the management of stormwater in terms of flow attenuation and quality in the tropics (Tanaka et al., 2011).

The design of stormwater wetlands slightly differs from that of wastewater wetlands. The shape of stormwater wetlands is extremely important to ensure minimisation of short-cuts in the system. Stormwater wetlands generally consist of an inlet zone (sedimentation basin or forebay), a planted zone, and a high flow bypass channel (Figure 6- 13). The planted (or macrophyte) zone generally caters for the water quality volume and the detention of post-development peak flows.

Stormwater wetlands operate as follows: water levels rise during rainfall events and outlets are configured to slowly release flows typically over 2-3 days back to the normal water level.

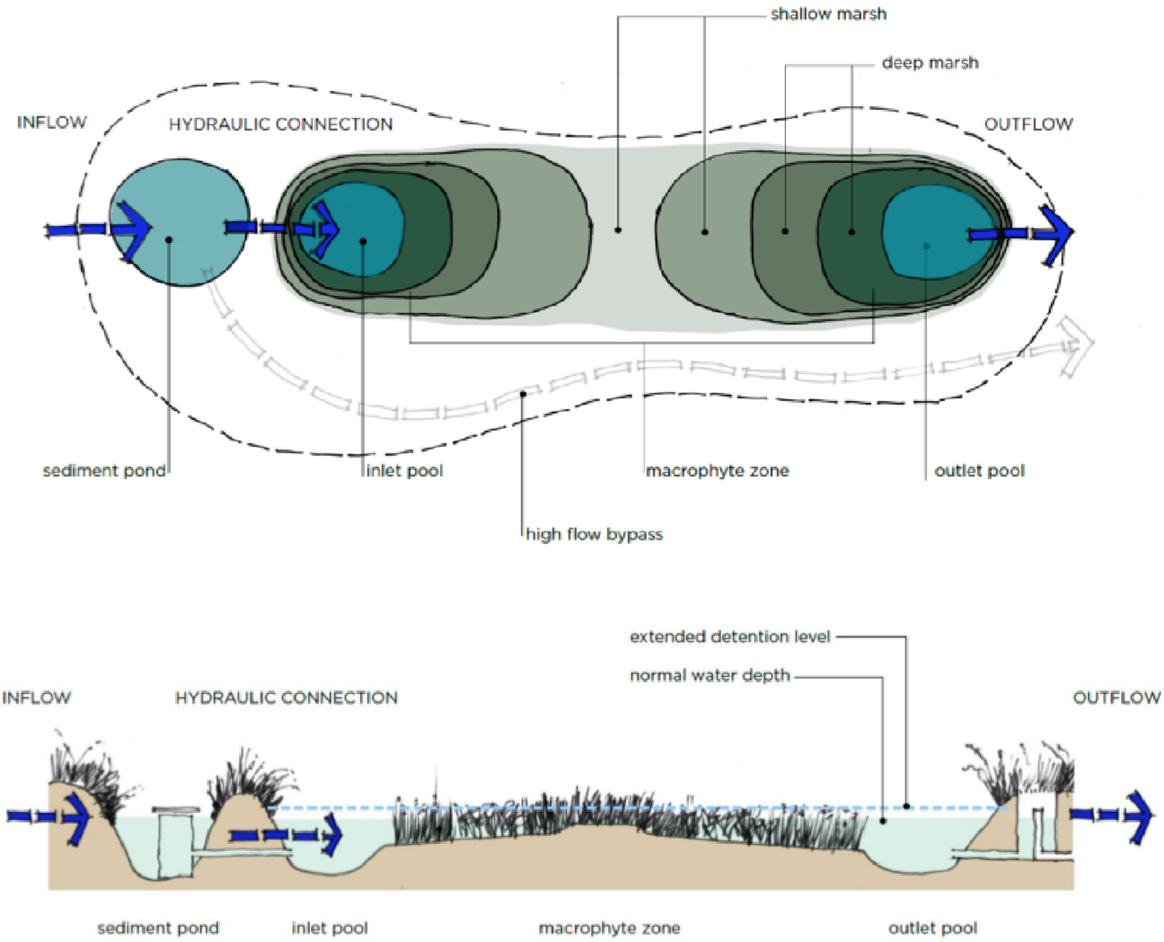


Figure 6- 13 Schematic of a stormwater constructed wetland. Source: Water by Design (2017)

Some of the key characteristics of constructed stormwater treatment wetlands to take into consideration during design are given below in Table 6- 10.

Table 6- 10 Key design factors for constructed stormwater treatment wetlands

Water residence time	Residence time of ≥ 48 hours for 90% of the time is required for pollutant removal – this can be less in tropical climates where biodegradation and biological processes are expected to be more rapid. This notional detention time also provides the hydrologic conditions that are suitable for water plant survival.
Water levels	Inundation frequency and high rainfall depths analyses can help determine the potential impacts of elevated water levels on plant health. Effective water depth must not exceed ½ of the average plant height for more than 20% of the time.
Vegetation	Plant attributes: - Adaptations to grow in water - Ability to tolerate periods of inundation - Presence of rhizomatous root systems – facilitates spreading rather than clumped forms - Most plants are perennial rather than annual - Simple vertical leaves which provide a high surface area for biofilm growth and interaction with the water column - Suitable for local landscape and ecology - Locally available

Design parameters include:

- Inlet design
- Layers, depths and levels (use of clay liners is pertinent near regions with shallow groundwater tables)
- Outlet design
- System sizing
- Vegetation

There are a number of resources that provide design information. One example is 'Water by Design (2017). Draft Wetland Technical Design Guidelines (Version 1). Healthy Land and Water Ltd, Brisbane'. While most of the design guidelines available so far are based on learnings from temperate climates, they can be used as a starting point for design of stormwater wetlands in Indonesia. Further knowledge from operating and monitoring these implemented systems will improve local design in the future.

6.3.8 Ponds

The use of ponds for flood control can be particularly beneficial for Bogor residents. They can be integrated as a storage facility for emergency water supply or for irrigation as well as for fish farming, which can then help stimulate the local economy.

From runoff management perspective, there are two types of ponds:

- **Retention pond:** is an artificial lake with vegetation around the perimeter and includes a permanent pool of water in its design. There are some design similarities between retention ponds and wetlands.
- **Detention pond:** sometimes called a "dry pond", temporarily stores water after a storm but eventually empties out at a controlled rate to a downstream water body. It is also commonly referred to as a retarding basin.

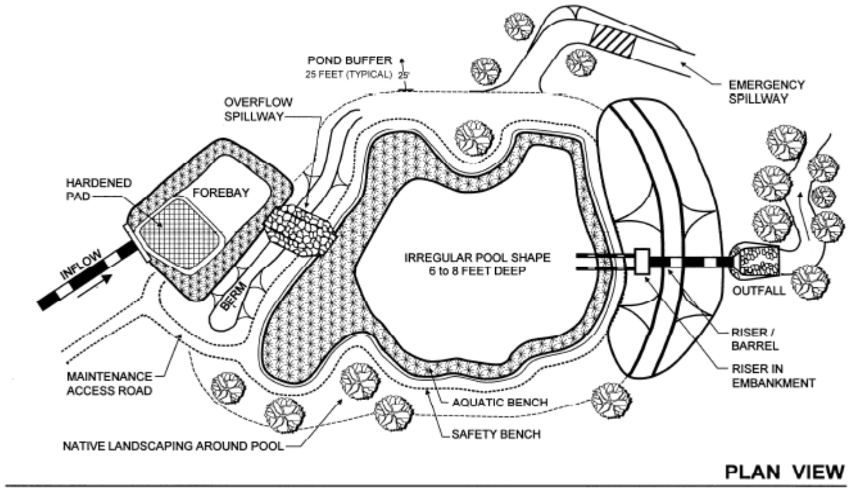
Retention ponds vs detention ponds

- Detention ponds may cost less to implement than a wet retention pond because the size is generally smaller.
- Detention ponds: best used in areas where there is 10 or more acres of land
- Detention ponds: can detract from property value while retention ponds may add value
- Retention pond is used for both stormwater quantity and quality control whereas detention pond does not provide water quality improvements. Water quality improvement occurs through settling, and moderate to high rates of pollutant removal are achieved if the permanent water volume in the reservoir is between approximately 30 and 60 mm of runoff per hectare of stormwater flows of impervious surfaces (generally, as has been found in temperate climates).

Detention ponds are not normally recommended as they need more maintenance (e.g. to get rid of standing water in areas where positive drainage is impeded to prevent mosquito problems) and have a lower water quality performance than wet ponds. In terms of preference when ponds are the selected options, constructed wetlands are a first choice, followed by wet ponds, and finally dry (detention) ponds (ARC, 2003).

Ponds are usually used as a tertiary treatment measure in the stormwater treatment train and can also serve as a storage measure. When used for flow attenuation and flood control, some pre-treatment is recommended. Large nutrient inputs into ponds may result in nuisance green algal blooms. Some steps to be taken in the design and planning of ponds (and other open waterbodies) to minimise algal growth are:

- Pre-treatment to prevent large nutrient 'spikes' entering the system
- Use of submerged macrophytes (the system then becomes a floating wetland or surface wetland)
- Facilitate mixing – orient lake to the dominant winds; provision of edge treatment to minimise wave damage.



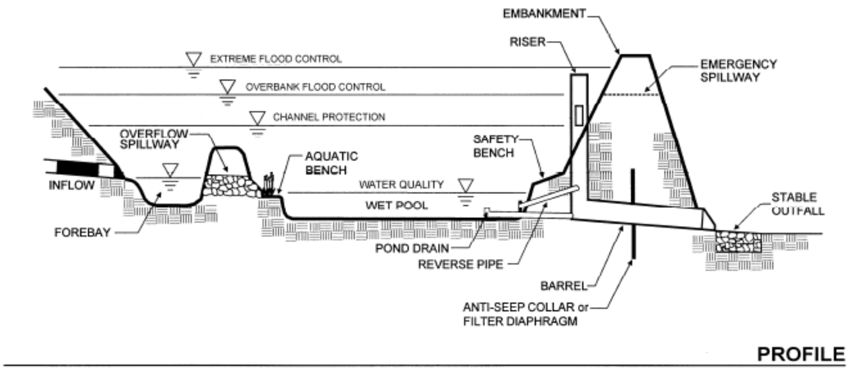


Figure 6- 14 Schematic of a retention pond for stormwater management; Source: Stormwater wet pond and wetland management guidebook, EPA 2009

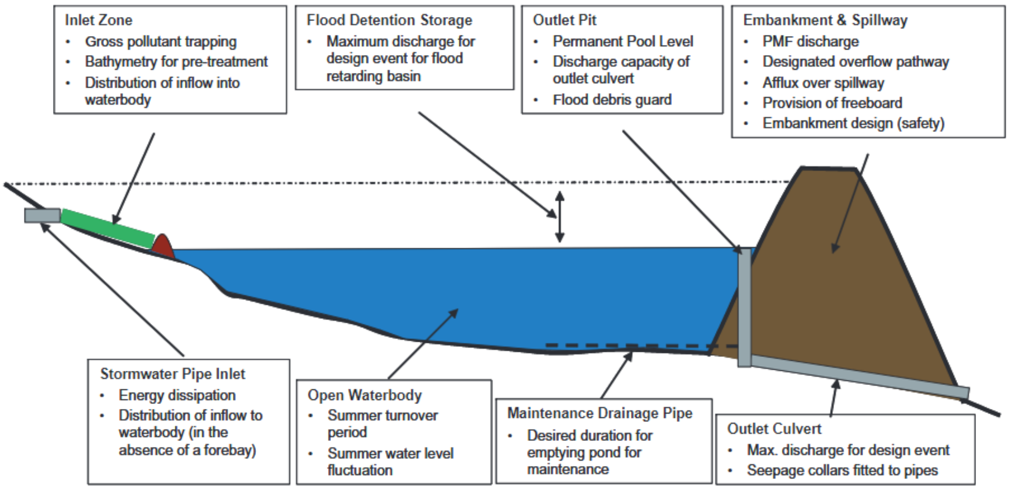


Figure 6- 15 Pond design elements and considerations; Source: WSUD Engineering Procedures, 2005

Figure 6- 16 Lake in Sentul City. Photo: Raul Marino

Pond sizes are determined to remove 75% of the incoming sediment load on a long-term basis in Auckland in line with the local water quality treatment objective of 75% TSS removal (ARC, 2003). In temperate climate, reservoir volumes are sized as the equivalent of surface runoff volume generated in a catchment as a result of a 24-hour duration storm with a return period of one to two years. The runoff coefficient is generally taken as 0.50 or 0.60. In the tropics, the highest storm intensities may force engineers to reduce the design return period in order to have an economically feasible structure).

The key design elements are as follows:

- Pond depth, for removal of pollutants and volume of fish. The depth of water in ponds is typically greater than 1.5 m and there is usually a small range of water level fluctuation although newer systems may have riser style outlets allowing for extended detention and longer temporary storage of inflows (Allison et al., 2005 – *WSUD Engineering Procedures*);
- Edge vegetation; a variety of grasses, shrubs and wetland plants is planted around the basin edge to provide bank stability, aesthetics and water quality improvement. These plants should be able to withstand dry or wet conditions;
- Residence time, generally between 2-4 weeks (Parkinson et al., 2010). If the pond receives insufficient water inflows to circulate and/or displace the water stored in the lake, water quality problems can arise. That is why circulation of flow is very important. Details regarding calculations of average residence times can be found in Allison et al., 2005. The retention time is important to promote pollutant removal through sedimentation and the opportunity for biological uptake mechanisms to reduce nutrient concentrations. However, as mentioned above, a higher retention time without adequate flow circulation can lead to other water quality problems.
- Use of pre-treatment to reduce sediment and litter
- Impervious liner (required for certain groundwater conditions)
- Maintenance access

Retention basins, ponds and lakes (situs) in Bogor

Bogor includes hundreds of natural situs but also many constructed water bodies including small ornamental ponds, retention ponds and artificial lakes. In terms of systems constructed specifically for flood mitigation or storage, retention ponds are particularly common and regulations require either a retention pond or absorption well within the community. These are commonly constructed at the scale of RT RW zones and residential level. Retention ponds not only provides flow attenuation to mitigate flooding, but the storage becomes a resource for water supply in the dry season. In this way basins, ponds or lakes can form important components of rainwater harvesting schemes.

It is critical to ensure proper construction of these systems to protect against the risk of dam failure and flash flooding. In some places shallow soils can restrict the use of retention ponds.

Examples include the small artificial lake known as 'Denan Trite' in Sentul City. This provides a water source in an emergency and has been used to supply water to Sentul City during dry season water shortages and when the water supply is of poor quality. A small Water Treatment Plant is located adjacent to the lake to treat the water before use. The lake provides some flood mitigation, but the extent of its storage capacity in wet weather is unknown. Outflows are discharged via a pipe to the river across the other side of Siliwangi Street. Sentul City are considering constructing more artificial lakes to provide water supply. However, the lake was primarily constructed for aesthetic purposes and currently provides recreational benefits to the residents with a walking track and gardens surrounding the lake, and construction of a floating restaurant underway.



Examples of open water features in Bogor. Left: Artificial lake in Sentul City providing emergency water supply storage, aesthetic and recreational values. Centre: Ornamental fish pond. Right: Situ in Cibinong.

References

- For design and construction advice on permanent waterbodies (retention ponds), see Allison, R. et al., 2005. *WSUD engineering procedures: stormwater*, Collingwood, Victoria, Australia: CSIRO: Melbourne Water.
- ARC, 2003, *Stormwater Management Devices: Design Guidelines Manual*, Technical publication #10, Second Ed, Auckland Regional Council
- Cunningham, A., Colibaba, A., Hellberg, B., Silyn Roberts, G.., Symcock, R., Vigar, N and Woortman, W (2017) Stormwater management devices in the Auckland region. Auckland Council guideline document, GD2017/001

6.3.9 Porous pavements

Porous asphalt or macadam pavement looks similar to conventional asphalt, except that it is permeable (Figure 6- 17). Porous pavements consist of open-graded asphalt or concrete over an aggregate base of sand or gravel medium located above well-draining soil (Figure 6- 18). The system can be overlaid by a subsurface reservoir (or retention trench) which serves to temporary store stormwater before percolation into the underlying soils or before slow discharge into the drainage system (the water could also be re-used for irrigation purposes). In this respect, porous paving systems can help in the reduction of runoff volumes and can be used to harvest and store stormwater. In terms of flood control, the main advantage that pervious pavements have over bioretention systems is their increased infiltration rate. Scholz et al. (2006) points out that "movement of water through the porous pavement installation is controlled by surface runoff, infiltration through the pavement stones, percolation through the unsaturated zone, lateral drainage at the base and deep percolation through the sub-grade." As with other infiltration systems, designing pervious pavements require consideration of the site conditions and potential contamination of the receiving groundwater environment. Systems can be designed with an impermeable membrane in sites where there is concern of groundwater pollution (e.g. low lying groundwater tables). Porous paving helps in some water quality improvements. They are most effective in removing coarse to medium sediments and attached pollutants (e.g. nutrients, free oils/grease and metals). Runoff quality is improved through several processes including filtration, degradation and biological processing.

The stormwater management function of pervious paving saves on the equivalent cost of an alternative practice and/or land area to accommodate it. In this respect, porous paving reduces the demand for stormwater infrastructure in terms of the extent of new systems required.

Figure 6- 17 An example of porous pavement at the entrance of a building at Monash University, Australia

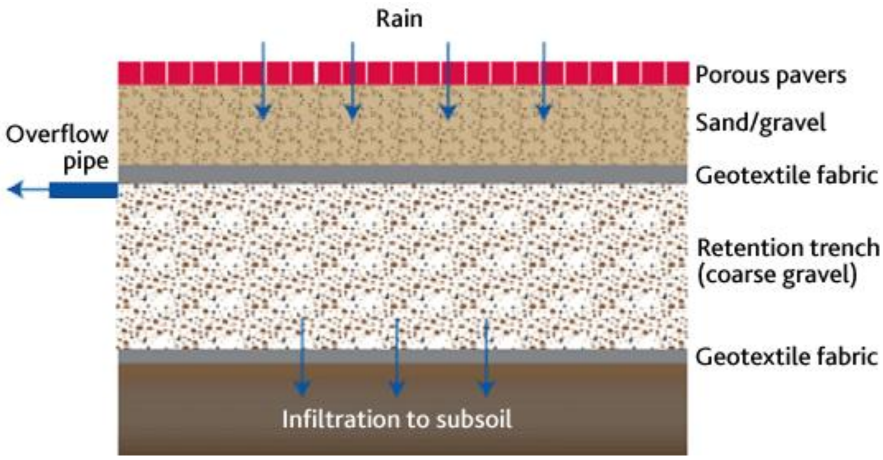


Figure 6- 18 Cross-sectional profile of a porous pavement system; Image: Melbourne Water

Pervious pavements fall into two broad categories (Government of SA, 2010 - *Water Sensitive Urban Design – Greater Adelaide Region – Technical Manual*):

- Porous pavements, which comprise a layer of highly porous material (Figure 28???); and
- Permeable pavements, which comprise a layer of paving blocks, typically impervious, specially shaped to allow the ingress of water by way of vertical 'slots' or gravel-filled 'tubes' (Figure 30??). There are generally large gaps between impervious paved areas for infiltration.

Figure 6- 19 Example of permeable pavement, comprising a layer of paving blocks (Bogor, Image: Raul Marino)

In designing a permeable pavement installation, it is fundamentally important to provide and maintain surface infiltration and storage capacity to allow an adequate volume of stormwater to be captured and treated by the facility. A restricted outlet can provide storage and achieve the required residence time for stormwater.

In Australia, pervious pavements have been found to be most practical and cost effective when serving catchment areas between 0.1 – 0.4 ha (Government of SA, 2010 - *Water Sensitive Urban Design – Greater Adelaide Region – Technical Manual*). The same guidelines recommend a contributing catchment to pervious area ratio of < 4:1. While in Bogor, this ratio will typically be smaller because of higher rainfall intensity, a ratio of 4:1 is a good starting point in modelling the ratio for this region. Where sediment and organic loads are high, the ratio should be reduced to 2:1.

Systems implemented in sites with good drainage capacity will perform better. Similar to the other water sensitive treatment systems discussed in this document, porous pavements with an underlying adequate storage layer will perform better as it is very likely that the infiltration capacity of the system will be reduced during high rainfall intensity events. In sites with soils of low infiltration capacity, under-drains may be required to drain the base course above low permeability soils. Saturation of subsoils may affect the integrity of adjacent structures – pervious pavement can be designed for the site conditions, with potential to include greater depths of drainage layers, impermeable liners and geogrids to isolate stormwater from adjacent structures.

High failure rate is attributed to poor design, clogging by fine sediment and excess traffic use (Department of Environment, WA 2004). Porous paving s prone to clogging usually within 3 years of operation (Scholz et al., 2006); this value can be lower if sediment load is high. The degree of clogging essentially depends on the type of pavement material as well as the pavement maintenance regime (Yong et al., 2011). With frequent maintenance, it is possible to extend the lifespan of these systems. The main causes of clogging are:

- Sediment being ground into the porous pavement by traffic before being washed off
- Waterborne sediments which drains onto pavements and clog pores before being washed off
- Shear stress caused by numerous breaking actions of vehicles at the same spot, resulting on collapsing pores.
- Yong et al. (2012) found that the inclusion and pore size of a geomembrane (while beneficial for pollutant removal) are factors inducing pavement clogging.

It is also important to note that while the sub-base is strong enough to ensure the pavement is trafficable, it needs to be sufficiently porous to ensure water infiltration so that the system still functions without clogging and surface ponding.

It is thus pertinent that porous pavements be cleaned regularly (Table 6- 12 – maintenance regimes) as well as be sited in suitable locations (Chapter 5, Table 5- 4).

Table 6- 11 Overview of key design features of porous pavements

Parameter	Function	Example
Permeable surface layer	Allows infiltration of runoff	Layer can be either monolithic (e.g. porous asphalt or porous

		concrete) or modular (clay or concrete blocks)
Geotextiles[#]	Prevents migration of sand into the base of the system.	Fibre area weight of 60 g/m2 usually applied (Scholz et al., 2006) Minimum perforation mesh of 0.25 mm to be used.
Storage layer (gravel trench in figure above)	Used to store water before it is infiltrated to the underlying soil or discharged towards a piped drainage system	Crushed stone or gravel
Pre-treatment	Pre-treatment of runoff recommended to minimise the potential for clogging and ensure system longevity	e.g. provision of leaf and roof litter guards along roof gutter application of buffer strips/swales small sediment forebay
Overflow pipe or pit	To direct high flows to bypass the system	
Slope	Relatively flat slope or as close to 0 gradient as possible to ensure a uniform and distributed flow coverage.	
Underdrain	Presence of underdrain connected to drainage system if underlying soils has low permeability.	

[#]Note that the incorporation of geotextiles is optional; it is possible to minimise sand migration without the use of geotextiles (Yong et al., 2012)
Ref: Government of SA, 2010 - *Water Sensitive Urban Design – Greater Adelaide Region – Technical Manual*; Scholz et al., 2007

References

Government of SA, 2010 - *Water Sensitive Urban Design – Greater Adelaide Region – Technical Manual*

Porous pavements in Bogor

The extent of existing porous pavement systems in Bogor is unknown, but this technology is being considered for use in car parking areas to allow the infiltration of stormwater runoff to mitigate flooding. This is an area of active research, particularly by Dr Dwinanti at UI and her research students, including modelling the performance of porous pavement systems.

There are examples in Bogor and Sentul City of impervious hard surfaces integrated with porous vegetated surfaces, which allows runoff infiltration and aesthetic benefits.

6.3.10 Rainwater tanks

Given the high rainfall throughout the year in Bogor, the use of rainwater tanks offers significant potential to supplement existing water supply. It is not recommended to use rainwater tanks for drinking water, but for other non-potable domestic uses such as toilet flushing. This reduces demand on other potable water sources (such as the PDAM supply and groundwater) and increases water supply security. The concept of fit-for-purpose water use is important; if the tank water is to be used for non-potable uses it does not need to be of the same quality as drinking water.

The importance of roof runoff as a potential alternative water source is also underscored by the AIC research project in Surabaya assessing the quality of potable water. This project found the quality of water in Brantas River, which is used as the source of the potable water supply, to be acutely toxic. Even after treatment, the water supply delivered to residents was in many cases chronically chemically toxic, at times more so than comparison samples from secondary treated effluent from a wastewater treatment plant in Melbourne, Australia. In comparison, commercial sources of water (such as bottled water) was safe for drinking.

The benefits of implementing rainwater tanks in Bogor include:

- Rainwater tanks can provide for an alternative source of water to supplement existing water sources, hence help promote water security;
- Rainwater tanks can be used as a flood mitigation strategy. Rainwater tanks provide temporary storage of flows that can reduce peak flow rates and retain rainfall on-site, particularly when used in residential areas;
  Rainwater tanks can be used as a storage to replenish groundwater.

The tank water source is rainwater from roofs as they tend to be the least polluted source and can have several applications with minimal additional treatment. For instance, rainwater tanks collecting rainwater from the roof can be fitted with a leaf and debris separator. Roof runoff can be directed into the tanks, located either above or below ground. Gravity fed situations or solar pumps to header tanks may be preferred in an attempt to reduce energy use. In general, roof runoff with a short travel distance to the tank tends to be of higher quality than runoff with longer travel distances (IWA, 2015).

The quality of roof runoff in Serang, Indonesia was studied by van Veen (2016). The study found that in direct rainfall concentrations of iron (Fe) and aluminium (Al) exceeded the WHO and Indonesian water quality guidelines, but lead (Pb), zinc (Zn) and microbial concentrations were below the guidelines. However, the Fe and Al concentrations decreased after roof contact to be below the guidelines. Microbial pollutants were highest in the first flush, but other pollutants did not demonstrate the same pattern. In addition, the roof runoff had a neutral pH of 7. Acidic rainfall is reported to be problematic in Bogor and a possible impediment to rainwater harvesting (March researchers workshop, 2018). Atmospheric pollutants (SO_4^{2-}, NO_3^-, H^+, NH_4^+) in Bogor and Jakarta were sampled in 1996 and found to be higher than less populated areas such as Serang (in Bogor H^+ was 24.6 µeq/L relative to 9.0 µeq/L in Serang) (Gillett et al., 2000). However, further work is required to characterise the quality of roof runoff and its suitability for various domestic uses. van Veen (2016) recommended to characterise additional pollutants that can be derived from atmospheric pollution; polycyclic aromatic hydrocarbons (PAHs), phthalate esters, pesticides and polychlorinated biphenyls, and pathogens.

Rainwater tanks can be sized using modelling to optimise the tank volume to suit the roof area, local rainfall and water demand patterns (IWA, 2015). Modelling of rainwater tank sizing, capacity to supplement household water supply and flood mitigation has been conducted for the case study sites in Bogor and reported in the AIC Urban Water Cluster Modelling report for Bogor (2018). The study assumed rainwater use for toilet flushing only. For example, in Sentul City a rainwater tank with 0.35 m^3 capacity is estimated to provide water for toilet flushing to meet demand 75% of the time (i.e. 75% reliability). van Veen (2016) noted that in Serang tank water alone was not sufficient to meet average household demand, but it provides a valuable means to reduce reliance and demand on existing water sources.

If flood mitigation is a key objective and the demand for tank water is not high enough, rain tanks can be designed to have storage capacity for re-use, and a separate detention volume with a controlled discharge rate, also known as ‘leaky’ rainwater tanks. New innovations in the area are also enabling ‘smart’ rainwater tank systems that monitor water levels in the tank and assess rainfall forecast data to automatically pre-release water ahead of large rainfall events (thus increasing storage capacity and reducing stormwater runoff volumes). A *Talking Tanks* program at South East Water in Melbourne, Australia, demonstrates these systems (2014). While the user sets the points at which the tank releases water and can actively control the system remotely, the system also ‘learns’ from its past performance and re-calibrates itself for future rainfall events.

Please note that caution should be applied when using runoff from roofs that are suspected to be contaminatedwith rat, bird, bat and cat faeces. In this case, a first flush diverter may be installed to divert the first few mms of the runoff to the conventional drainage system while the remaining water can be used for applications of less personal end-use such as irrigation. A closed tank is also important to reduce deposition of pollutants, animal access or light which can promote algae (van Veen, 2016). Regular maintenance cleaning the tank is recommended at least once a year to maintain water quality. Depending upon the use of the water, other tank design elements that can enhance water quality include (IWA, 2015):

- Inlet design for calm flows, reducing resuspension
- Use of fine wire mesh on the tank’s inlet and overflow devices to reduce mosquito access (van Veen, 2016)

- A barrier and drainpipe at the inlet to capture sludge and allow its drainage
- A floating suction device that draws water from below the water surface to avoid any surface scums, and siphonic discharge to remove surface scum

In Serang, cloth is used to filter out particulate organic matter prior to the tank, fine wire mesh reduces mosquito access, in some cases small fish live in tanks to consume mosquito larvae and the water is boiled as a precaution if the water is used for potable purposes (although not recommended) (van Veen, 2016).

Water storage can be incorporated into architecture to integrate with or enhance the building design and structure. Water tanks can also be placed behind buildings or under decks with the use of a pump system. Construction should also consider stress loading of a full tank and the necessity for maintenance access.

In Bogor, communal systems for multiple units may provide for economies of scale where rainwater tank deployment is concerned.

The use of rainwater tanks need to consider several issues:

- Supply and demand
- Water quality
- Cost
- Available space (use of underground tanks)
- Competing uses for stormwater runoff
- Maintenance
- Local availability of materials and skills; these were utilised for the construction of rainwater harvesting systems in Serang, Indonesia (van Veen, 2016)

Rainwater tanks and harvesting in Bogor

Rainwater tanks are implemented in some areas of Bogor including private residences, new developments and some government buildings. Local companies are involved in the supply of rainwater tanks. Large-scale examples include an underground tank, buried beneath the carpark, collecting roof runoff from Bappeda Kota Bogor offices in central Bogor, which provides storage and the reuse of rainwater. Buried tanks also allow multiple uses of space in dense urban environments, and can be buried beneath areas of Public Open Space, but this does add significantly to the cost of installation. In addition, traditional architecture can promote the capture of roof runoff in ponds (photos below) and many new housing estates are collecting and harvesting rainwater in tanks for watering purposes.

However, a community preference for use of groundwater is reported, given its availability and the common use of wells in most households. Across the Jawa Barat Province, rainwater collection only provides 0.1% of drinking water supplied within households; the majority is supplied by piped water (from PDAM), groundwater wells or springs, or bottled water (Statistical Yearbook of Indonesia, 2017). The quality of roof runoff is also unknown, and issues with acidification of rain (such as ~pH 5) after one to two week dry periods are reported to make the water unsuitable for drinking purposes (April FGD 2018). Further research assessing roof runoff quality and its variability within Bogor and Indonesia, the suitability of roof runoff for a range of household uses, and tank designs that can be used to better manage rainwater quality is required. In addition, in some neighbourhoods, such as Pulo Geulis, space availability is extremely limited, requiring careful consideration and possibly narrow or communal tank designs.

Given the cost involved in purchasing rainwater tanks, it is vital to clearly establish a use for the water to create incentive to invest in the system. The collection of water at the household scale or local neighbourhood scale is important for future water supply resilience, given a changing climate and increasing water demand from population growth. Rainwater can also be useful for watering of parks, gardens or urban agricultural systems or greenery. Hence, rainwater harvesting can form part of a number of green infrastructure solutions. It is important to note that water storage does not have to be provided by tanks, but may also be provided by detention ponds, lakes or wetlands. Rainwater harvesting can also be used in conjunction with biofiltration to first treat the water.

Systems will also require ongoing maintenance, and this is particularly important for the quality of water from the tank. Individual householders or the community will need to be actively involved in regular maintenance. Operational issues for existing rainwater harvesting systems include the theft of pump parts, so where possible, passive systems are recommended.

It also should be noted that the local community may think of roof tanks for another purpose; small tanks are common for the balancing of pressure within the PDAM supply system (filling overnight when demand is low and pressure is higher). Hence, clear terminology must be used.

Traditional architecture in Sentul City that promotes the capture of roof runoff and storage in ornamental ponds or a drainage network

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6.3.11 Riparian vegetation design

Riparian zones are strips of land that run adjacent to streams and rivers along their length, providing the interface between the terrestrial and aquatic environment.

It should be noted that while upgrading the riparian area is one strategy to prevent erosion and siltation issues in situs, it is imperative that management efforts be directed at fixing the water issues in the catchment first. Doing so will help fix the cause of the problem first (i.e. the high flows and water quality issues); the latter should be prioritised.

A healthy and functioning riparian zone has multiple ecological functions, namely:

- Riparian floodplain land can absorb high river flows and prevent flooding;
- The filtration of catchment-sourced nutrients by floodplain vegetation, soils and microbes enables riparian zones to protect or buffer streams from nutrient inputs, helping to prevent eutrophic conditions and the associated algal blooms, fish kills and nuisance insect plagues;
- The riparian zone can provide a place for recreation, relaxation and connection with nature.

Processes that support the instream aquatic environment include (Beesley et al., 2017):

1. Light and temperature regulation (vegetation absorbs incoming light, preventing it from reaching the stream)
2. Nutrient processing and sediment trapping (slowing of runoff and flood flows so that suspended sediments from the catchment or stream bed can deposit and nutrients can be processed)
3. Bank stabilisation – vegetation stabilises by protecting stream and river banks from various forms of erosion. Groundcover on the bank (e.g. grass, herbs, sedges) also protects soil from erosion during high flows. Deep-rooted vegetation such as trees reduce the probability of bank collapse by anchoring the riverbank, while roots and rhizomes of perennial understorey vegetation increases the tensile strength of the soil.
4. Flood attenuation – vegetation absorbs runoff from the catchment, reducing flows into the stream; store and infiltrate overbank flood waters; vegetation on the floodplain and

in the channel increases flow resistance, slowing flood flows and reducing the magnitude of flood pulses downstream.

5. Aquatic habitat: riparian land enhances the diversity of instream aquatic and floodplain habitats for a variety of biota.
6. Shade from riparian vegetation regulates water temperatures and improves dissolved oxygen levels in streams, allowing more sensitive species to thrive. Shade also reduces light levels to prevent nuisance growth of algae.
7. Tree roots provide bank stabilisation benefits, as well as opportunities for overhanging banks and fish refuge and thus can be important for fish populations. Trees and shrubs provide inputs of leaves, wood, and insects as sources of food for fish and aquatic invertebrates.

Riparian vegetation in Bogor can be food crops such as Cassava.

Left: Situ in Cibinong. Right: Artificial lake constructed in Sentul City, Image: Raul Marino.

Riparian vegetation restoration

Local research institutions such as LIPI have studied vegetation structure in the riparian and shoreline zones, development activities within the catchment and the impact of this on water quality. Lakes (situ) face threats from their complete loss due to development, riparian vegetation destruction, siltation, eutrophication and pollution from stormwater runoff, sewage inflows and solid waste (Henny and Meutia, 2014). In Jakarta, land use change and other drivers have reduced the area of lakes within catchments classified as urban village, rural village, rural-urban village, urban village-industrial and agricultural areas, while those in planned residential, high-rise residential and industrial areas tended to be managed for recreational purposes were less likely to be reduced in area (Henny and Meutia, 2014). Invasive plants, often growing in monocultures, displace diverse native plant communities and degrade water quality, reduce diversity, endanger native species, shift plant-animal interactions, promote detritus accumulation and change sediment chemistry (Dr Cynthia Henny, LIPI, Green Technologies FGD, November 2017 2017).

Using an ecosystem-based approach, revegetation work has been undertaken to restore the natural lake ecosystem and its biogeochemical and ecological functions. This includes different types of vegetation in various zones including submerged, floating, floating leafed, floating mat, emergent vegetation in the littoral zone; bushes and trees in the riparian zone and bank; and forest canopy trees in the buffer zone and beyond (Dr Cynthia Henny, LIPI, Green Technologies FGD, November 2017 2017). Methods to revegetate the lakeshore have been tested including using tyres to create a terrace with reduced erosion and sedimentation, and to facilitate plant establishment (Dr Cynthia Henny, LIPI, Green Technologies FGD, November 2017).



Riparian vegetation Left: situ in Cibinong, Centre: Ciliwung River at Pulo Geulis, Right: situ in Cibinong.

Resource:

Riparian design guidelines to inform the ecological repair of urban waterways, CRCWSC, October 2017

Beesley LS, Middleton J, Gwinn DC, Pettit N, Quinton B and Davies PM. (2017). Riparian Design Guidelines to Inform the Ecological Repair of Urban Waterways, Melbourne, Australia: Cooperative Research Centre for Water Sensitive Cities.

Henny CH, Meutia, A. (2014). Urban Lakes in Megacity Jakarta: Risk and Management Plan for Future Sustainability. The 4th International Conference on Sustainable Future for Human Security, SustaiN 2013. *Procedia Environmental Sciences* 20 (2014) 737-746.

6.4Maintenance of Green Infrastructure Systems

It is important to maintain GI systems: (1) To ensure success of the systems during their design life-span; (2) To extend the design life of the systems and; (3) to reduce more costly restorative maintenance - an increased rate of preventative maintenance will decrease the occurrence of more costly restorative maintenance (Lewis et al., 2015).

The pollutant removal, channel protection, and flood control capabilities of ponds and wetlands will decrease if:

- Sediment accumulates reducing the storage volume,
- Debris blocks the outlet structure,
- Pipes or the riser are damaged,

- Invasive plants take over and out-compete the planted vegetation,
- Slope stabilizing vegetation is lost, or
- The structural integrity of the embankment, weir, or riser is compromised.

Table 6- 12 outlines the maintenance considerations for the different GI systems. Readers are referred to appropriate resources as required.

Table 6- 12 Maintenance considerations for different green infrastructure systems

Technology	Maintenance considerations
Biofiltration systems	Refer to the *CRC Stormwater Biofiltration Adoption Guidelines*, Chapter 4; Payne et al., 2015
Living walls	Refer to *CRC Adoption Guidelines for Green Treatment Technologies*, Chapter 5; Fowdar et al., 2018 *CRC Stormwater Biofiltration Adoption Guidelines*, Chapter 4; Payne et al., 2015
Green roofs	Extensive green roofs: - Weeding, pruning and fertilising 3 times a year; - Around 10% of new plants need to be replaced annually (Mithraratne, 2013) Intensive green roofs: - Regular maintenance (daily to fortnightly); - Plant replacement at about 20% per annum (Mithraratne, 2013) Utilise safety barriers for access. Set in place irrigation systems and slow release fertilisers for plants to establish coverage quickly and to minimise ongoing maintenance requirements. Inspect the living roof to ensure it is still in place and that plants are healthy (Lewis et al., 2015). Please note that without maintenance, green roofs can become a source of pollution (Chen, 2013).
Green walls	One year after installation is most critical time for green walls, especially the first few months. Refer to DEPI, 2014 – *Growing Green Guide*, Section 3
Constructed wetlands	Wetlands are relatively self-maintaining once established, with only periodic checks required for inlet and outlet structures. Maintenance tasks involve weeding and cleaning the inlet of large floating solids. Non routine works involve detecting leaks in the system (e.g. cross-connections due to piercing of clay liners). Correctly maintained wetlands have a design life exceeding 100 years. If maintenance is not carried out, sedimentation and scour can significantly reduce lifespan (Lewis et al., 2015). An example is Troups Creek wetland in Melbourne, Australia. Poorly designed outlet structure meant vegetation scour and sediment scour. An illegal connection also pierced the clay liner and distributed clay throughout the system each time the connection flowed. These reduced the lifespan of the wetland.
Swales	Inspection should be carried out every two years. Any issues identified during inspection should be rectified.

	Correctly maintained filtering and conveyance practices that utilise an underdrain have a design life of 50 years. If no underdrain is used, design life can exceed 100 years. Lack of maintenance can cause blockage and scour, which may require the replacement of the asset to restore function (Lewis et al., 2015). Examples of maintenance tasks include: - Maintaining healthy vegetation growth – weeding, pruning, mowing and pest control - Checking swale for erosion or gully formation - Clearing swale of any litter or debris - Removing deposited sediments - Clearing of blockage from inlet and outlet pipes - Irrigation may be needed during the dry season
Porous pavements	Porous pavement should be inspected every two years if other areas drain to the surface and every five years if the installation is standalone. Porous pavements are subject to clogging if not maintained properly. In order to mitigate this, regular cleaning of the ground should be conducted using high-pressure flushing equipment, particularly if sediment from an erosion event or spill has clogged the pervious pavers. Regular (approximately every 3 months) vacuum sweeping and/or high pressure hosing required to free pores in top layer from clogging (Department of Planning and Local Government, 2010). Beware of oils and spills as they can be difficult to clean and may require replacement of the surface. If maintenance is performed correctly and the right pavement is chosen for the site, pavement life should be similar to non-pervious surfaces. Surface designs adjust construction materials to ensure pavement servicability is equivalent to their non-pervious alternatives. For example, pervious concrete mixes can contain up to 30% more cement than traditional concrete to provide extra strength to offset the effect of removing fines from the mix (Lewis et al., 2015). Brattebo et al. (2003) report no significant wear in comparison to the asphalt paving after 6 years of operation under their operational conditions. Hu et al. (2018) found that permeable interlocking concrete paving (PICP) is less prone to clogging compared to permeable asphalts and permeable concretes. Also, refer to *Water Sensitive Urban Design Technical Manual for the Greater Adelaide Region*; Department of Planning and Local Government, 2010
Ponds	Proliferation of mosquitoes is usually an early indication that there is a maintenance problem. Special stormwater and mosquito abatement scheme can be set up, possibly with scheduled emptying during critical periods of mosquito development (Parkinson et al., 2010). Key maintenance tasks include: - Routine maintenance such as mowing and removing debris in and around ponds – needed multiple times a year and can be performed by citizen volunteers

	- Removing sediment off inlet and outlet pipes as well as around and in the ponds – needed less frequently and may require more skilled labor and special equipment - Checking the pond for erosion, gully formation and other disturbances on the bank – a few times a year and after major storms - Maintaining healthy vegetation growth around the pond Orifices are important for maintaining permanent pool of water. Clogging of low flow orifices and weirs is a common maintenance item. Reasons are: debris (dead plants, twigs, branches and leaves)/sediment accumulation, vandalism and nuisance problems such as beavers. For additional maintenance advice, refer to: - Stormwater wet pond and wetland management guidebook, EPA 2009 - https://www3.epa.gov/npdes/pubs/pondmgmtguide.pdf - ARC (Auckland Regional Council) , 2003, Stormwater Management Devices: Design Guidelines Manual, Technical publication #10, Second Ed, Auckland Regional Council, Chapter 5, page 5-20
Rainwater tanks	Rainwater tanks should be checked every two years. Inspections should include: - checking that pumps are still operational; - checking if drainage connections to the tank are still functioning; and - checking that connections to internal plumbing are operational, including backflow prevention valves. Any issues identified during the inspection should be the responsibility of the owner to fix. Correctly maintained rainwater tank systems have a design life of approximately 20 years. If maintenance is not performed, lifespan will reduce depending on whether pumps are used in the design and the potential for clogging of the tank inlets and outlets (Lewis et al., 2015).
Sedimentation basins	Importantly, maintenance access to sediment removal areas should be provided. Typical maintenance of sedimentation basins will involve: ● Routine inspection of the sedimentation basin to identify depth of sediment accumulation, damage to vegetation, scouring, or litter and debris build up (after the first three significant storm events and then at least every three months); ● Routine inspection of inlet and outlet points to identify any areas of scour, litter build up and blockages; ● Removal of litter and debris; ● Removal and management of invasive weeds (both terrestrial and aquatic); ● Periodic (usually every five years) draining and desilting, which will require excavation and dewatering of removed sediment (and disposal to an approved location); ● Regular watering of littoral vegetation during plant establishment; ● Replacement of plants that have died (from any cause) with plants of equivalent size and species as detailed in the planting schedule; and ● Inspections are also recommended following large storm events to check for scour and damage.

	Department of Planning and Local Government, 2010, *Water Sensitive Urban Design Technical Manual for the Greater Adelaide Region*, Government of South Australia, Adelaide, Chapter 12

Useful References

Brisbane City Council and the Moreton Bay Waterways and Catchments Partnership, 2006, Water Sensitive Urban Design: Technical Design Guidelines for South East Queensland

Department of Planning and Local Government, 2010, *Water Sensitive Urban Design Technical Manual for the Greater Adelaide Region*, Government of South Australia, Adelaide

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Chapter 7

Plant Selection Guide

7.1 Selection principles

An abundance of healthy plants are the key to effective functioning of green infrastructure. Plants provide multiple functions that drive many of the benefits delivered by green infrastructure; water quality treatment, flow attenuation, greenery, amenity, biodiversity, urban cooling and human health and well-being benefits.

Plant species will vary in their capacity to survive, grow and provide the functions of different green infrastructure systems. Conditions will also vary between the different technologies, such as the high heat exposure and typically shallow substrate of green rooves, the intermittent inflow and drying period in biofiltration systems, and the wetter conditions of constructed wetlands. For example, studies have shown that plant species with extensive root systems and relatively high biomass are most effective for nitrogen removal in stormwater biofiltration systems (Payne, 2017; Read et al., 2010). In the context of green rooves, plant species need to effectively regulate their water use (to use water and reduce runoff when it is available but survive the intervening dry periods), a characteristic linked to high root mass (Farrell et al., 2013). In constructed treatment wetlands plant species with high productivity, biomass and extensive root systems have also been shown to be most effective for nutrient uptake (Heers, 2006; Shutes, 2001).

Ideally, the choice of plants to use in these systems will not only consider their local availability, adaptability and pollutant removal capabilities but also their potential to contribute to the character and amenity of the surrounding landscape. For instance, the stormwater biofiltration guidelines in Australia recommend that 50% of plants be selected according to their nutrient removal performance while the remaining 50% can be selected based on their other amenity functions (Ellerton et al., 2012; Payne et al., 2015).

In addition, in the Indonesian context higher economic benefits may be associated with plants grown in green water treatment systems, relative to more developed countries. The scope for plant harvesting for consumption (if vegetables or fruit), fibre, biogas, paper manufacture or animal fodder may contribute to significant economic benefits (Katsenovich et al., 2009; Upadhyay et al., 2007).

Some general principles to help guide plant selection in various green infrastructure are illustrated in Figure 7- 1. More specific recommendations for the use or avoidance of various plant species in different green infrastructure are provided in Appendix A. A sub-set of plants recommended for use are listed in tables in the following section, but for a full list please refer to Appendix A.

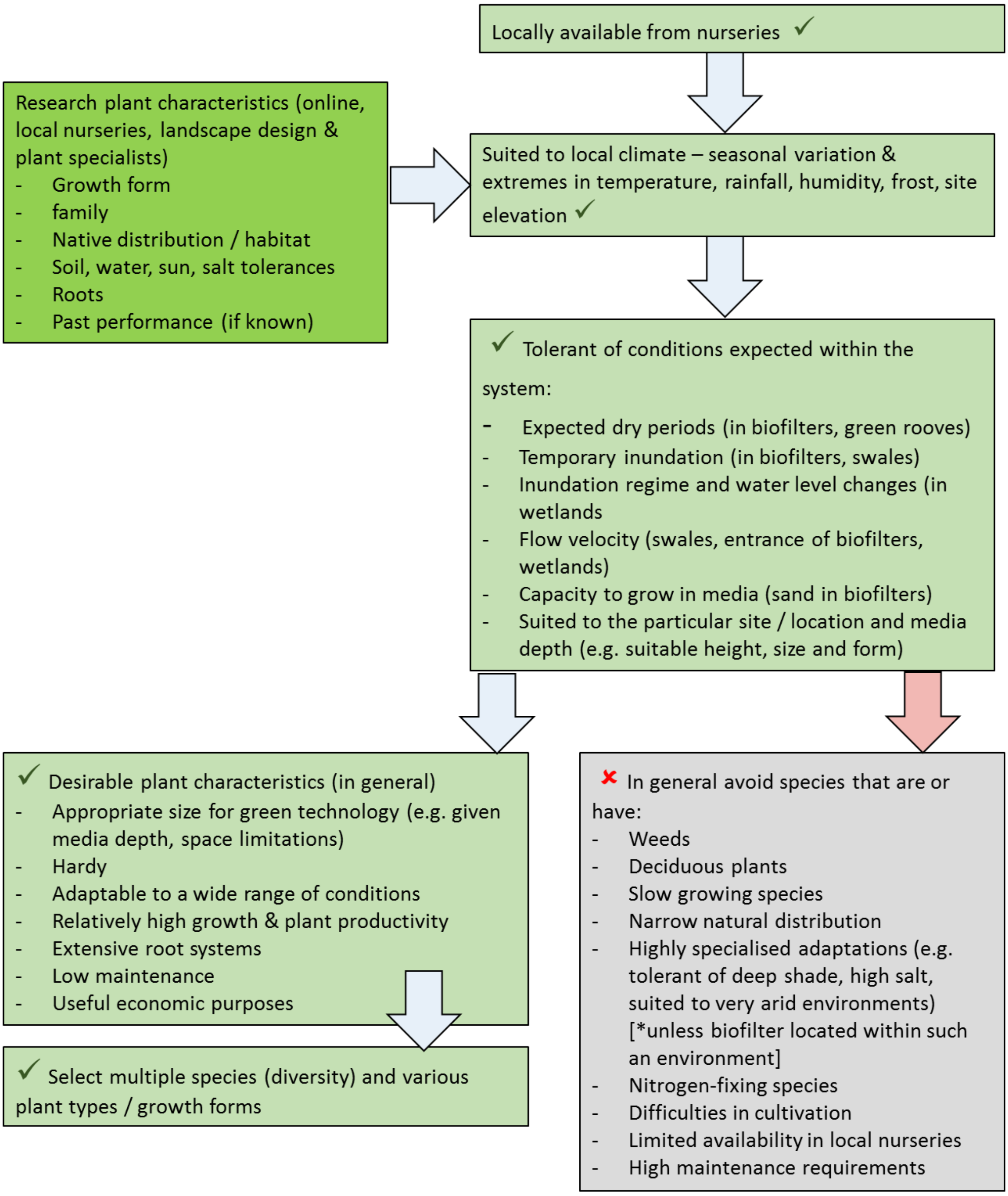


Figure 7- 1 General principles for the selection of plants for green infrastructure systems

7.2 Plant recommendations for green infrastructure

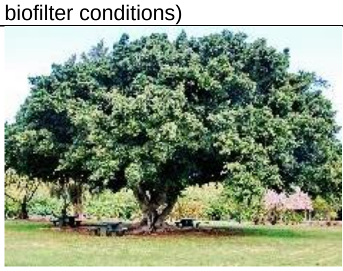
Detailed plant selection tables for green infrastructure have been provided in Appendix A. For each species the tables include a photo and information on plant common names, size, characteristics, habitat, native origin, growth rate, soil, sun and water preference, root characteristics and potential economic uses for the plant. In the final column species are either recommended or not recommended, but with brief justification given and often caution regarding further local information that needs to be confirmed (such as local weed status, availability or growth in the local climate).

Due to space limitations, the details are provided in the Appendix and instead tables have been compiled below to summarise some of the recommended species for local trialling in green infrastructure systems. It is important to note that these species have been recommended based upon a desktop review only, and in some cases, limited information. Their suitability needs to be confirmed by local plant experts and by testing their survival and performance in green infrastructure locally.

7.2.1 Biofiltration systems

 *Bambusa vulgaris* **Bambu Kuning**, Golden Bamboo Bamboo Poaceae ✓ (widely cultivated, adaptable, economic uses for biomass)	 *Dimocarpus longan* (**Kelengkeng**, Dragon's Eye) Tree Sapindaceae ✓ (if tolerates Bogor's climate and moisture availability in biofilters)	 *Dracaena sanderiana*, also known as *Dracaena braunii* (**Drasaena**, Lucky Bamboo) Shrub Asparagaceae ✓ (but note not native to Indonesia)	 *Ficus benjamina* (**Beringin**, Weeping fig, benjamin fig, Ficus tree) Tree Moraceae ✓ (but not alongside structures which roots may damage)
 *Muntingia calabura* *(***Kersen**, Panama Berry, Strawberry Tree, Jamaica Cherry) Tree Mutingiaceae ✓ (Rapid growth, adaptable, tolerant of many soils, including contamination, economic uses)	 *Schefflera actinophylla* (**Wali Songo**, Umbrella tree) Tree Araliaceae ✓ (Adaptable, widely cultivated. Note – sensitive to waterlogging; need to test if tolerates biofilter conditions)	 *Swietenia mahogoni* (**Mahoni**, Boynton Beach, American Mahogany) Tree Meliaceae ✓	 *Syzygium polyanthum* (**Salam**, Indonesian bay leaf) Tree Myrtaceae ✓

		(Valuable wood, widely cultivated, grows in roadsides. Grows in well-drained sandy soils, but preference reported for rich, deep soil – test if suited to biofilter conditions)	(Easy to grow, adaptable, grows on roadsides, economic uses, particularly for cooking)
 *Catharanthus roseus* (former name *Vinca rosea*) (**Tapak Dara**, Madagascar/ Rose/ Rosy/ Cape periwinkle) Herbaceous, flowering plant Apocynaceae ✓ (Hardy, commonly cultivated. Note – prefers well-drained; need to test in biofilter conditions. *Note- poisonous if consumed by humans)	 *Equisetum hyernale* (**Paku eko kuda**, Rough horsetail, scouring rush) Herbaceous Equisetaceae ✓ (Riparian and wetland zone plant, ornamental. Note – may not tolerate dry conditions of biofilters – need to test, may need to be placed near inlets (wettest points))	* No images available on google *Fimbristylis globulosa* (**Mendong**, Globe fimbry, Mendong Grass) Sedge, perennial Cyperaceae ✓ (Limited information available on species. Suited to moist conditions. Recommend testing in biofilter conditions)	 *Osmoxylon lineare* (**Aralia,** Miagos Bush, Green Aralia) Shrub, herbaceous Araliaceae ✓ (Tolerant of a wide range of conditions, including wet and dry, ornamental and reported use in raingarden, including relative effective performance for nitrate in Singapore)
 *Vetiveria zizanioides* (**Akar wangi**, Ushira, Khus, Khus Khus grass, Vetiver / grass) Grass Poaceae ✓ (Hardy, tolerates wide range of climatic conditions and soil types, dense growth, many economic uses)	 *Acalypha wilkesiana* cultivar (Copper plant, Copperleaf Joseph's Coat) Shrub Euphorbiaceae ✓ (high performer for nitrate removal in Singapore testing, popular and ornamental. Note – drought sensitivity so may need to be used in conjunction with a submerged zone in biofilters)	 *Arundo donax var versicolor* (Carrizo, Arundo, Varigated Giant Reed, Spanish Reed, Wild Cane) Shrub, Grass Poaceae ✓* (very high performer for nitrate removal in Singapore testing, rapid growth, used in phytoremediation studies, but *Note potential for invasiveness – check weed risk in Indonesia)	 *Canna* spp. Flowering plant Cannaceae ✓ (Popular, species with tested high performance in treatment wetlands in Indonesia. *Note – do not consume if used in biofilters receiving stormwater or greywater runoff (only roof runoff)

 *Cordyline fruticosa* (**Hanjuang**, Cabbage palm, good luck plant, palm lily) Shrub, woody Asparagaceae ✓ (Popular ornamental plant, identified but not tested for use in Singapore's biofilters. *Note – do not consume if used in biofilters receiving stormwater or greywater runoff (only roof runoff)	 *Cymbopogon citratus* (**Tanglad, Serai**, **Sereh**, Lemon Grass, West Indian Lemon Grass, Oil Grass, Fever Grass, Serai Makan, Sereh Makan) Grass Poaceae ✓ (Performed with high efficiency for nitrate removal in Singapore testing, abundant in Indonesia. *Note – do not consume if used in biofilters receiving stormwater or greywater runoff (only roof runoff)	 *Pennisetum alopecuroides* (Chinese Fountain Grass, Swamp Foxtail Grass, Swamp Foxtail, Chinese Pennisetum) Grass Poaceae ✓ (Hardy, ornamental grass, performed with high efficiency for nitrate removal in Singapore testing)	 *Pennisetum x advena* 'Rubrum' (Purple Fountain Grass, Red Fountain Grass, Rose Fountain Grass) Herbaceous shrub, creeper Poaceae ✓ (Popular, ornamental grass. Medium performance when tested for nitrate removal in Singapore)
 *Sanchezia oblonga* (Zebra plant, Yellow Sanchezia) Shrub Acanthaceae ✓ (High nitrate removal performance in Singapore testing, ornamental. *Note not native to Indonesia)	 *Serissa japonica* (Japanese Serissa, Snowrose, Tree of a Thousand Stars, Japanese Boxthorn) Shrub Rubiaceae ✓ (High nitrate removal performance in Singapore testing, ornamental, but *Note – plant is not adaptable to variation in conditions – may be difficult to grow, test under local biofilter conditions)	 *Scaevola toccada* (Ambung-ambung, Merambung, Palampung, Sea Lettuce) Goodeniaceae Tree, shrub ✓ (High nitrate removal performance in Singapore testing, ornamental)	 *Dianella ensifolia* (Umbrella Dracaena, Common Dianella, Siak-siak, Flax Lily) Sedge Phormiaceae ? (Relatively poor nitrate removal in Singapore testing, also noted to be toxic if ingested. However, native to Indonesia and ornamental; could be used alongside more effective plant species, or in shaded situations)
 *Dracaena reflexa* (Song of India, Song of India, Pride of India, Song of Jamaica) Shrub Dracaenaceae ✓ (Adaptable, popular, ornamental and medium performance for nitrate removal in Singapore testing)	 *Ficus microcarpa* 'Golden' (Indian Laurel Fig, Chinese banyan, Malayan banyan) Tree Moraceae ✓	 *Galphimia glauca* (Shower of Gold, Rain of Gold)	 *Ipomoea pes-caprae* (Beach Morning Glory) Ground cover Concolvulaceae ✓✓

	(Adaptable, popular, ornamental, native to Indonesia, and medium performance for nitrate removal in Singapore testing)	Shrub Malgiphiaceae ✓ (Easy to grow, drought tolerant, ornamental, useful barrier plant for edges, medium performance for nitrate removal in Singapore, but *Note – not native to Indonesia. *Note – do not consume if used in biofilters receiving stormwater or greywater runoff (only roof runoff))	(High nitrate removal performance in Singapore testing, hardy, widely distributed, ornamental, well suited to sand and provides stabilisation)
 *Leucophyllum frutesce* (Barometer Bush, Ash Plant, Cenizo, Texas Ranger, Texas Silver Leaf, Purple Sage) Shrub Scrophulariaceae ✓ (High performance for nitrate removal in Singapore testing, ornamental, hardy, drought tolerant. *Note – prefers well-drained conditions)	 *Loropetalum chinense* (Chinese Loropetalum, Chinese fringe flower) Shrub Hamamelidaceae ✓ (Medium performance for nitrate removal in Singapore testing, popular and widely grown ornamental)	 *Melastoma malabathricum* (Common Sendudok, Singapore / Indian Rhododentrum, Sessenduk, Malabar Gooseverry, Straights Thododentron, Sendukok, Senduduk) Shrub Melastomataceae ✓ (Medium performance for nitrate removal in Singapore testing, ornamental plant, but Note - *beware capacity to dominate & invade crops, pastures, plantations and native grasslands. *Note – do not consume if used in biofilters receiving stormwater or greywater runoff (only roof runoff))	 *Marraya paniculata* (Mock Lime, Kemuning, Mock orange, Burmese Boxwood, Chinese Box, Orange Jasmine, Kuming Ladia, Orange Jasmine / Jessamine, Kemuning Lada, Kemuning, China Box) Shrub Rutaceae ✓ (Popular, ornamental plant with its orange blossom fragrant flowers, wide distribution and fast growth)
 *Ophiopogon jaburan* (Lilyturf, Mono-grass, Giant Lilyturf, Snake Beard) Groundcover Convallariaceae ✓ (Popular, ornamental plant, useful groundcover including below trees, high nitrate removal in Singapore biofilter testing, grows easily in a wide range of soils)	 *Hibiscus* spp. (Rose mallow) Flowering herbaceous plants, woody shrubs, small trees. Malvaceae ✓ (Popular, adaptable species with tested high performance in treatment wetlands in Indonesia. Use a terrestrial-based species in biofilters *Note - choose species carefully to suit biofilter conditions)	 *Imperata cylindrica* (**Alang-alang**, Cogon Grass) Grass Poaceae ✗ (weed potential)	 *Albizia chinensis* (**Sengon,** Chinese albizia, silk tree) Tree Fabaceae ✗ (N-fixing – not ideal for nitrogen removal) but extensive roots

 *Cerbera manghas* (**Bintaro**, Starfruit, Sea mango, Native frangipani, Beach Milkwood Tree Apocynaceae ✗ (grown ornamentally, but poisonous; not safe near children)	 *Averrhoa carambola* (**Belimbing**, Carambola, Starfruit) Tree Oxalidaceae ✗ (does not tolerate waterlogging, relatively slow growth, shade tolerant)	 *Lansium domesticum* (**Duku, Langsat, Kokosan**) Tree Meliaceae ✗ (soil preference appears too narrow for biofilter conditions)	 *Dialium indum* (**Asam Kranji**, Tamarind-plum, Keranji) Tree Leguminosae ✗ (N-fixing not ideal for N removal)
 *Leucaena leucocephala* (**Lamtoro**, White leadtree, Jumbay, River tamarind) Tree Fabaceae ✗ (N-fixing not ideal for N removal; soil & water requirements not suited to biofilters, weed in urban areas)	 *Pterocarpus indicus* (**Angsana**, Amboyna wood, Malay paduak, Papua New Guinea / Burmese rosewood) Tree Fabaceae ✗ (Despite popular uses and wide tolerance, N-fixing not ideal for N removal)	 *Lantana camara* (**Tembelekan**, big-sage, wild-sage) Small perennial shrub, flowering plant Verbenaceae ✗ (Despite ornamental use, this plant is a highly invasive weed in tropical areas, threatening biodiversityand agricultural productivity. Also toxic to livestock.)	 *Axonopus compressus* (also known as *Milium compressum* or *Paspalum compressum*) (Broadleaf Carpet Grass, Blankey Grass, Tropical Carpet Grass, Wide-Leaved Carpet Grass, Cow Grass, Rumput Parit) Groundcover, turf grass Poaceae ✗ (Not particularly effective when tested in Singapore for nitrate uptake, also has slow growth, limited root system. *However, could be useful in situations where turf grass is desirable and/or in shady areas.)
 *Complaya trilobata* (also known as *Sphagneticola trilobata* and *Wedelia trilobata*) (Yellow Creeping Daisy, Singapore Daisy) Herbaceous perennial plant Asteraceae ✗ (Many favourable traits for use in bioretention – very tolerant of wet and dry, hardy to range of conditions, also tested as highly effective in Singapore. However,	 *Pisonia grandis* (Lettuce Tree, Kemudu, Mengkudu, Moonlight Tree) Tree Nyctaginaceae ✗ (Poor performance for nitrate removal in Singapore testing, high water demand. *However, may be used alongside other more effective	 *Rhodomyrtus tomentosa* (Kemunting, Rose Myrtle) Shrub Myrtaceae ✗ (Poor performance for nitrate removal in Singapore testing)	

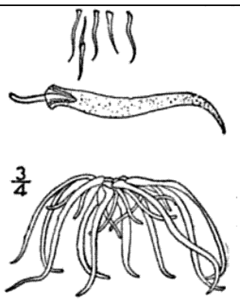
highly invasive, including in Indonesia)	species, in situations when nutrient removal is not a key objective, or coastal/salty locations. *Note – do not consume if used in biofilters receiving stormwater or greywater runoff (only roof runoff))		

7.2.2 Living walls (biofiltration system at the base, using climbing plants)

 *Bignonia capreolata* (Crossvine) Vine Bignoniaceae ? (Fast growth, attractive flowers *Note not native to Indonesia Recommend checking if invasive in Indonesia – avoid if so)	 *Bougainvillea* 'Sakura Variegata' (Bougainvillea) Climber, shrub Nyctaginaceae ✓ (Popular, commonly grown and hardy species, high ornamental value, performed very effectively for nitrate removal in Singapore testing. *Note – potential to damage buildings with thorns if not cut back or maintained)	 *Jasmimum sambac* (**Melati,** White Jasmine, Arabian jasmine, Sambac jasmine) Vine or small shrub Oleaceae ✓ (Popular, occurs widely in Indonesia and highly valued as a National Flower, ornamental with fragrant flowers. *Note – need to test growth and performance in biofilter conditions)	 *Monstera deliciosa* (**Duan Jendela Besar**, Swiss Cheese plant/ vine, Split-leaf philodendron, Fruit salad plant/tree) Climber, epiphyte Araceae ✓ (Popular, ornamental, *Note – not native to Indonesia, an epiphyte, also shady, moist and humid conditions. Test growth in biofilter conditions)
 *Monsoa alliaceae* (also known as *Pseudocalymma alliaceum*) (Garlic vine) Climber, vine Bignoniaceae ? (Popular, ornamental, *Note – not native to Indonesia, need to test growth in sand-based biofilter media, given preference for humus-rich soil)	 *Thunbergia grandiflora* (**Bunga Madia,** Trumpet Vine, Sky Vine/ Flower, Bengal Trumpet) Climber, vine Acanthaceae ✓* (Ornamental, fast growth, but *Note – highly invasive; beware weed potential and check local weed status in Indonesia before use, also not native to Indonesia)	 *Epipremnum pinnatum* 'Aureum' (**Sirih Gading**, Pothos, Variegated Philodendron) Climber, can be epiphytic Araceae ✓* (Ornamental ntal, fast growth, found in Indonesia, but *Note – invasive nature – check local weed status before use)	 *Bauhinia kockiana* (Kock's Bauhinia) Woody climber Fabaceae ✗ (Attractive plant, suited to tropical conditions, but as a member of the Fabaceae family, fixes nitrogen, so not suited to biofiltration systems intended to remove nitrogen)

7.2.3 Constructed treatment wetlands

 *Cyperus papyrus* (**Papirus**, Papyrus, Papyrus sedge/plant, Paper reed) Sedge, flowering plant Cyperaceae ✓ (Fast growing, reported water quality & flow reduction performance, economic uses)	 *Nymphaea lotus* (**Teratai**, White Egyptian lotus) Water lily, flowering plant Nymphaeaceae ✓ (Ornamental value high)	 *Equisetum hyernale* (**Paku eko kuda**, Rough horsetail) Herbaceous Equisetaceae ✓ (Ornamental, common, adaptable and tolerates wide range of conditions)	 *Echinodorus palaefolius* (**Melati Air**, Mexican Sword Plant) Herbaceous, flowering plant, emergent aquatic plant Alismataceae ✓ (Ornamental, appears suited to conditions. Note, not native to Indonesia and limited information available on this species)
 *Ipomoea aquatica* (also known as *I. repens, I. reptans, Convolvulus repens*) (**Kangkung**, Water/ river spinach, water morning glory) Semi-aquatic herbaceous vine Convolvulaceae ?* (Popular crop in Indonesia, fast growth, but note – not native to Indonesia; take care to contain within system and avoid dominance beyond design intent)	 *Salvinia molesta* (**Kiambang**, Giant salvinia, Kariba weed) Aquatic fern, free-floating Salviniaceae ?* (Fast-growing, useful mulch once harvested, but high capacity for dominance & invasion which can be detrimental to waterways)	*No image available on google *Paspalum paniculatum* (Russell River Grass) Grass Poaceae ?* (Fast-growing, suited to marshy areas noted for use in constructed wetlands, but limited information available and noted as an invasive species. *Note – need to confirm weed potential in Indonesia before use)	 *Thalia geniculata* (Alligator flag, bent alligator-flag, arrowroot) Herbaceous perennial plant, often growing as an emergent aquatic plant Marantaceae ✓ (Suited to wet conditions, ornamental benefits)
	 *Iris* spp. (Flags)	 *Arundo donax var versicolor* (Carrizo, Arundo, Varigated Giant Reed, Spanish Reed, Wild Cane)	 *Wolffia* spp. (Minute Duckweed, Watermeal) Small free-floating aquatic plants Araceae

Canna spp. Flowering plant Cannaceae ✓ (Popular, species with tested high performance in treatment wetlands in Indonesia)	Iris, flowering plants Iridaceae ✓ (Tested in constructed treatment wetlands locally in Indonesia, also widely cultivated, adaptable)	Shrub, Grass Poaceae ✓* (used in phytoremediation studies, common, rapid growth, fibrous roots. Also effective performance for nitrate uptake in biofiltration study but *Note potential for invasiveness – check weed risk in Indonesia)	✓ (Tested in phytoremediation and aquaculture systems in Indonesia, high protein content. *Note small size – suited to small systems or in conjunction with rooted macrophytes)
 *Spirodella* (Water Lettuce) Small free-floating aquatic plants Araceae ✓ (Tested in phytoremediation and aquaculture systems in Indonesia. *Note small size – suited to small systems or in conjunction with rooted macrophytes)	 *Wolfiella* (Bogmat, Mud-midget) Aquatic plants Araceae ✓ (Tested in phytoremediation and aquaculture systems in Indonesia. *Note small size – suited to small systems or in conjunction with rooted macrophytes)	 *Lemna* (Duckweed) Small free-floating aquatic plants Araceae ✓ (Tested in phytoremediation and aquaculture systems in Indonesia, high protein content. *Note small size – suited to small systems or in conjunction with rooted macrophytes)	 *Phragmites australis* (Common Reed) Reed Poaceae ✗ (Commonly used in constructed wetlands, but invasive weed, can form monocultures)

7.2.4 Green roofs and green walls

The list of plant species for green roofs and green walls have been combined due to overlap in potentially suitable species in tropical climates. However, there are still distinct differences between the growing conditions of green roof and living walls and their plant selection can be quite different. For example, green roofs are likely subject to be subject to more sun exposure and drying – hence, drought tolerance is a key characteristic. The depth of substrate on the green roof is also critical for plant selection but varies between designs. Plants suited to dry, rocky and shallow soil environments will be most suitable if shallow media is used. For green walls, shade tolerance may be an important factor depending upon positioning of the wall. Plant selection should consider sun exposure, container/substrate volume and the watering system specific to each green wall.

 *Ophiopogon japonicus* (**Rumput kucai mini**, Dwarf lilyturf, mondograss) Evergreen, clumping perennial plant. Asparagaceae **√ Green roof or green wall** (Useful groundcover, particularly useful in shady conditions. *Note - need to test survival in green roof conditions)	 *Arachis pintoi* (**Kacang-kacangan**, Perennial Peanut, Pinto peanut) Perennial legume, creeping form. Fabaceae **√* Green roof or green wall** (Useful groundcover, adaptable and shade tolerate. If harvested provides useful animal fodder. *Note – as a N-fixing plant may contribute nitrogen to effluent from green roof – NOT suited if nutrient removal is a key objective for the roof).	 *Sansevieria* (Snake plant, Mother-in-law's tongue) Flowering plant Asparagaceae **√ Green roof** (Highly tolerant. Used in Taiwan for green roofs. Wide variation across genus to dry or wetter conditions; tropical species likely most suitable for Indonesia)	 *Alternanthera* spp. (Joyweeds, Joseph's coat) Flowering plants. Amaranthaceae **√ Green roof or green wall** (Used in Taiwan for green roofs, but *Note potential invasive weed species in genus and avoid)
 *Zephyranthes rosea* (Cuban zephyrlily, rosy rain lily) Lily Amaryllidaceae **√ Green roof or green wall** (Used in Taiwan for green roofs, suited to warm climates, ornamental, widespread, low maintenance, but * Note the toxic bulbs – do not use in urban agriculture systems or if risk of consumption by children)	 *Cryptanthus bivittatus* (Earth Star, Starfish plant, Red Star Bromeliad) Groundcover Bromeliaceae **√ Green roof or green wall** (Used in Taiwan for green roofs, tropical plant. Grow in numbers. *Note – not native to Indonesia)	 *Callisia repens* (Creeping inch plant, jellybean plant, little jewel, tiny buttons) Groundcover Commelinaceae **√ Green roof or green wall** (Used in Taiwan for green roofs, forms groundcover. *Beware potential to be a weed and check if locally available or a weed in Indonesia, not native)	 *Zebrina purpusii* (Wandering traveller) Groundcover Commelinaceae **√ Green roof or green wall** (Used in Taiwan for green roofs, ornamental, grows in pots. *Note – not native to Indonesia)
 *Rhoeo spathaceo* cv. Compacta, also known as *Tradescantia spathacea* (Moses in the Cradle, Spiderwort) Groundcover	 *Dichondra micrantha* (Kidney weed, Asian ponysfoot)	 *Sedum pallidum* (Pale Stonecrop, Turkish Sedum) Groundcover, succulent.	 *Sedum sarmentosum* (Stringy Stonecrop, Gold moss stonecrop, Yellow moss) Groundcover, succulent.

Commelinaceae √ **Green roof or high sun green walls** (Used in Taiwan for green roofs, ornamental foliage, groundcover)	Groundcover Convolvulaceae √ **Green roofs or green walls** (Used in Taiwan for green roofs, succulent groundcover, ornamental, hardy)	Crassulaceae √ **Green roofs or high sun green walls** (Used in Taiwan for green roofs, succulent groundcover, ornamental, hardy*Note – not native to Indonesia)	Crassulaceae √ **Green roofs or high sun green walls** (Used in Taiwan for green roofs, succulent groundcover, ornamental, hardy)
 *Sedum mexicanum* (Mexican stonecrop) Groundcover, succulent. Crassulaceae √ **Green roofs or high sun green walls** (Used in Taiwan for green roofs, succulent groundcover, hardy, ornamental*Note – not native to Indonesia)	 *Sedum lineare* var. variegatum (Cream/ Green Carpet sedum) Groundcover, succulent Crassulaceae √ **Green roofs or high sun green walls** (Used in Taiwan and China for green roofs, well suited to green roof conditions, tolerant & hardy, requires minimal soil depth)	 *Euphorbia milii* (Crown of thorns, Christ plant) Succulent, climbing shrub Euphorbiaceae √ **Green roofs or high sun green walls** (Used in Taiwan for green roofs, hardy, drought tolerant, but * Note poisonous sap. *Note – not native to Indonesia)	 *Belamcanda chinensis* (Blackberry Lily, Leopard Flower) Herbaceous, Iris. Iridaceae √ **Green roofs** (Used in Taiwan for green roofs, ornamental, flowers and seed pods have use in arrangements, * but note preference for deep soil – use only in deeper green roofs)
 *Ophiopogon japonicas* (**Rumput kucai mini**, Dwarf lilyturf, mondograss) Evergreen, clumping perennial plant. Asparagaceae √ **Green walls and green roofs** (Widely cultivated, suited to shady conditions, but note slow growth – unlikely to provide superior nutrient uptake; used in green walls and roofs. *Note – not native to Indonesia)	 *Asparagus densiflorus* (Asparagus fern, plume asparagus, foxtail fern) Fern, groundcover Asparagaceae √ **Green walls and green roofs** (Used in Taiwan for green roofs, widely cultivated, but *Note potential to invade native forest – check weed status locally in Indonesia, not native)	 *Chlorophytum comosum* cv. Picturatum (Spider plant) Groundcover Liliaceae √ **Green walls and green roofs** (Used in Taiwan for green roofs, widely cultivated, ornamental, drought tolerant)	 *Schizocentron elegans* or *Heterocentron elegans* (Spanish shawl) Groundcover Melastomataceae √ **Green walls and green roofs** (Used in Taiwan for green roofs, widely cultivated, ornamental, fast growth. *Note – not native to Indonesia)

 *Nephrolepis auriculata* also known as *Nephrolepis cordifolia* (Tuberous sword fern, Fishbone fern) Fern Nephrolepidaceae √ **Green walls and green roofs** (Used in Taiwan for green roofs, naturally grows in rocky areas, note preference for shade)	 *Portulaca gilliesii* Succulent, groundcover Portulacaceae √ **Green roofs and green walls in sun** (Used in Taiwan for green roofs, tolerant of dry conditions. *Note – not native to Indonesia)	 *Portulaca oleracea* (Common purslane, verdolaga, red root, pursley) Succulent, groundcover Portulacaceae √ **Green roofs and green walls in sun** (Used in Taiwan for green roofs, tolerant of dry conditions, economic uses)	 *Portulaca grandiflora* (Rose moss, ten o'clock, Mexican rose) Succulent, groundcover Portulacaceae √ **Green roofs and green walls in sun** (Used in Taiwan for green roofs, suited to growing between stones, drought tolerant, ornamental)
 *Eremochloa ophiuroides* (Centipedegrass) Grass Poaceae √ **Green roofs** (Used in Taiwan for green roofs, suited to poor and sandy soils, but *Note low drought tolerance – need to test if suited to green roof conditions in Indonesia. *Note – not native to Indonesia)	 *Pilea nummulariifolia* (Creeping Charlie) Groundcover Urticaceae √ **Green walls** (Used in Taiwan for green roofs, grows in rocky conditions, but * Note preference for moist, partly shaded conditions. *Note – not native to Indonesia)	 *Zoysia japonica* (Japan Grass, Korean lawngrass) Grass Poaceae √ **Green roof** (Used in Malaysian green roof experiment, native to Indonesia)	 *Bouteloua curtipendula* (Sideoats grama/grass) Perennial grass. Poaceae √ * **Green roofs** (Hardy and drought tolerant good traits for surviving dry roof environment. *Not native to Indonesia, but widespread.)

 *Pennisetum x advena* 'Rubrum' (Purple Fountain Grass, Red Fountain Grass, Rose Fountain Grass) Herbaceous shrub, creeper Poaceae ✓ **Green roofs** (Popular, ornamental grass. Medium performance when tested for nitrate removal in bioretention systems in Singapore)	*No image available *Bouteloua rigidiseta* (Texas grama) Small bunchgrass Poaceae ✓* **Green roofs** (Drought tolerant. *Note not native to Indonesia and limited information available on this species; commercial availability may be limited)	 *Carex texensis* (Texas Sedge) Sedge Cyperaceae ? * **Green roofs** (Tolerates dry conditions in shade, so survival uncertain. *Note not native to Indonesia)	 *Hilaria belangerii* (Curly mesquite) Grass Poaceae ✓ * **Green roofs** (Drought tolerant. *Note not native to Indonesia and limited information available on this species; commercial availability may be limited)

7.2.5 *Urban agriculture systems*

It is important to note that when plants are grown for human consumption, it is not recommended to water the system with urban stormwater runoff or greywater, due to the risk of pollutant accumulation in the edible plant parts and in the soil over time. However, if the system is only receiving rainfall runoff directly from a roof, this is suitable for the watering of plants for consumption.

 *Capsicum annuum* (**Cabai rawit**, Capsicum, Peppers) Perennial herb, shrub, vegetable Solanaceae ✓ (Common & popular)	 *Amomum cardamomum* (also known as *Elettaria cardamomum)* (**Kapol**, Green/ True cardamom) Herbaceous evergreen perennial Zingiberaceae ✓ (popular spice, but note right conditions must be provided – requires filtered light, humus-rich soil and water availability – not a hardy species)	 *Amaranthus spp.* (**Bayam**, amaranth, pigweed) Annual or short-lived perennial herbaceous flowering plants Amaranthaceae ✓ (fast growth, nutritious seeds and leaves, cultivated in Indonesia and other tropical countries. However, note weed potential and select appropriate species carefully)	 *Brassica rapa* (**Sawi**, turnip rape, field/ wild mustard) Herbaceous annual or biennial plant Brassicaceae ✓ (hardy, fast growth, widely cultivated and used for crops)

 *Solanum lycopersium* (**Tomat**, tomato) Herbaceous plant (vine). Solanaceae ✓ (Widely cultivated, popular food)	 *Cucumis sativus* (**Timun**, cucumber) Creeping vine, herbaceous annual Cucurbitaceae ✓ (Popular vegetable and widely cultivated, but note low nutritional value and need for rich soil and constant water; need to test if suited to biofilter conditions)	*No image available on google. *Solanum melongena* (**Terong**, eggplant) Perennial herbaceous vine, grown as an annual Solanaceae ✓ (Popular vegetable, widely cultivated, fast growth. Prefers rich soil and regular water; need to test performance in sandy biofilter media)	*No image available on google. *Ociumum citridorum* (**Kemangi**, Lemon / lime basil, Thai lemon basil) Perennial herb, grown as an annual herbaceous plant Lamiaceae ✓ (Popular in Indonesian cooking, hardy and easy to grow. Note warning about essential oil not being suited to pregnant women or small children).
 *Solanum tuberosum* Potato (**Kentang**, Spud) Herbaceous perennial Solanaceae ✓ (Popular vegetable in Indonesia and globally)	 *Brassica oleracea* var. capitata Cabbage (**Kubis**) Biennial plant Brassicaceae ✓ (Popular vegetable in Indonesia, suited to various soils)	 *Mangifera indica* (**Mangga**, Mango) Tree Anacardiaceae ✓ (widely cultivated, suited to variable conditions, valuable fruit. Note size may restrict use in certain biofilter situations)	*No image available on google. *Artocarpus heterophyllus* (**Nangka**, Jackfruit, Jack tree, fenne, jakfruit, jack or jak) Tree Moraceae ✓ (if tolerates Bogor's dry season)

 *Dimocarpus longan* (**Kelengkeng**, Longan, Mata Kuching, Lungen, Dragon's Eye) Tree Sapindaceae ✓ (if tolerates Bogor's climate and moisture availability in biofilters)	 *Garcinia mangostana* (**Manggis**, Purple Mangosteen, Mangosteen) Tree Clusiaceae **?*** (*Note - if used as part of biofiltration system receiving roof runoff, this species is not be suited to sandy biofilter media, but could form part of other urban agriculture systems if appropriate water and soil conditions are provided)	 *Mimusops elengi* (**Tanjung**, Bulletwood tree, Spanish cherry, medlar) Tree Sapotaceae ✓ (Adaptable and edible raw fruit, along with other economic uses)	 *Muntingia calabura* (**Kersen**, Panama Berry, Strawberry Tree, Jamaica Cherry) Tree Mutingiaceae ✓ (Rapid growth, adaptable, edible berries and other economic uses)
 *Moringa oleifera* (**Kelor**, Moringa, Drumstick tree, Horseradish tree) Tree Moringaceae ✓ (Valuable and nutritious food source, adaptable, suited to dry periods, useful water purification properties)	*No image available on google. *Planchonia valida* (**Putat**, **Telisai**) Tree Lecythidaceae ✓ (Economic uses including food source. Note – limited information on this species & characteristics; need to test if suited to biofilter conditions)	 *Pandanus amaryllifolius* (**Pandan wangi,** Pandan leaf) Tree Pandanaceae ✓ (commonly cultivated, many economic uses. Note – limited information on growth conditions – need to test if suited to biofilter conditions)	*No image available on google. *Gigantochloa vertilcillata* (**Bambu**, Giant bamboo) Evergreen, perennial bamboo Poaceae ✓ (fast growth, multiple economic uses, but large size – ensure suitable for system)
 *Cymbopogon citratus* (**Tanglad, Serai**, **Sereh**, Lemon Grass, West Indian Lemon Grass, Oil Grass, Fever Grass, Serai Makan, Sereh Makan) Grass Poaceae ✓ (Performed with high efficiency for nitrate removal in Singapore testing, abundant in Indonesia. *Note – do not consume if used in biofilters receiving stormwater runoff)			

Sources of images: Pixabay, Wikimedia Commons, Flikr, Wikipedia

Chapter 8

Case Studies

This chapter presents a discussion on green infrastructure adoption in four case study sites in Bogor: Pulo Geulis, Cibinong, Sentul City and Griya Katulampa. The context and key water management issues and constraints in each of the four sites are summarised. Existing infrastructure present and key lessons are reviewed (for Sentul City and Griya Katulampa)**.** Potential green infrastructure solutions are provided. Please note that these are examples of conceptual solutions for green infrastructure implementation at each site.

8.1Pulo Geulis

Located on a raised island in the Ciliwung River, Pulo Geulis is an informal yet historic settlement, reportedly dating back over 300 hundred years. In an area of just over 3.58 ha there are approximately 2,500 inhabitants in under 400 dwellings, yielding a population density of 700 people per hectare (Design brief). The island includes an 18th century temple named Mahabrahma. The community is multicultural yet live harmoniously, sharing use of the temple for meetings of multiple religious groups (site visit). RT RW's play a key role in community organisation and governance of the island.

There is no large vehicle access to the island, with only pedestrian bridges crossing the Ciliwung River to connect Pulo Geulis to surrounding areas. People are attracted to live and stay on Pulo Geulis due to its history and location close to the Botanic Gardens. The community is poor with generally low education levels, but have a strong desire for capacity building, education and economic opportunities (Prof Hadi's research).

As a result of the dense environment there is virtually no public open space, aside from narrow walkways. A relatively large vacant block currently provides a meeting space, but this is privately owned and does not include amenities. Childrens playgrounds are non-existant. Many buildings protrude beyond the island perimeter wall, but the community would ideally like accessibility around the island perimeter.

In terms of water management, sanitation on the island is poor with houses on the perimeter discharging untreated blackwater and other domestic wastewater directly to the river via small pipes, despite this practice being restricted by law. This is the result of dense and small houses, often lacking space for an individual septic tank. The rest of the island is serviced by septic tanks but proper maintenance is hindered by the lack of vehicular access, forcing long suction hoses to be set up to cross the river or a cart that can fit in the narrow alleyways. These challenges lead to reduced emptying of septic tanks. A communal septic tank system was planned to service 100 households, but could not be implemented due to a lack of available land (April FGD 2018).

The polluted Citarum river is used by the community for bathing, washing, even tooth brushing, and as a public gathering place for socialising. This connection with the river is important to the people and there is a long history of people using the river. To the community the water looks clean and appears to be simply a natural source of water. These activities cannot be restricted by regulations, as people's basic needs are not being met by the government. In addition to the health risk from polluted water, flash floods occur regularly meaning that activities at the water's edge are very dangerous. However, people do not tend to fish in the river around Pulo Geulis, as there are stones in the river diverting water towards canals that flow to ponds in the Botanic Gardens. People divert water from the canals for fishing ponds.

The island is approximately 10 m above the water level of the river. Fluvial flooding is reportedly not problematic as river water levels do not come within more than 1.5 m below the island's elevation. However, internal flooding does cause issues when heavy rainfall is trapped within the impervious and dense urban environment (April FGD 2018). Small drainage systems, in the forms of small trenches in front of houses, aims to minimise the impacts.

There is no groundwater access within Pulo Geulis and the majority of households use PDAM water that is pumped to the island. There are no rainwater harvesting systems, all rain water discharges directly to the river. Householders do not drink from the tap directly, but generally boil water before ingestion. Despite this, the community suffers from water-borne diseases such as diahorrea. Solid waste management is also a significant problem with garbage discarded directly into the river by approximately 60% of the population (Prof Hadi's research), unless it is instead taken off the island to the local government garbage collection area.

The community also desire Pulo Geulis to become a tourist destination. In the evenings people from the surrounding areas come to Bogor to visit small traditional food stalls (Co-design workshop March 2018). The community wish to build upon this and become a culinary destination (Prof Hadi's survey). This provides a good foundation for the further development of urban agricultural systems.

Key issues

- ➢ **Lack of space** – this dominates the consideration and placement of technological solutions. In addition, there is a great community need and desire for public open space (Prof Hadi's work). There are currently no playgrounds, meeting spaces or green open spaces. Below the alleys and around the perimeter offer possible solutions to overcome the lack of public open space for communal essential infrastructure. There are limited open spaces but these are privately owned. Consideration of the potential to purchase property should be included.
- ➢ **Health impacts from lack of clean water access** – the community still use the polluted river for clothes washing, washing and personal hygiene, at the same time as it is receiving discharges of black water, as well as heavy levels of pollution from upstream. The community suffer from poor water security and clean water access.
- ➢ **Surrounding communities** - solutions should also consider application to the houses on the other side of the river (Co-design workshop, March 2018). As there are many other inhabited islands in the Ciliwung River, demonstration of effective GI solutions will promote adoption elsewhere.
- ➢ **Capacity building** – This is most important. The communities desire for greater skills and economic possibilities is high (Prof Hadi's survey, FGDs, interviews). It is also important to engage the young generation to promote change.

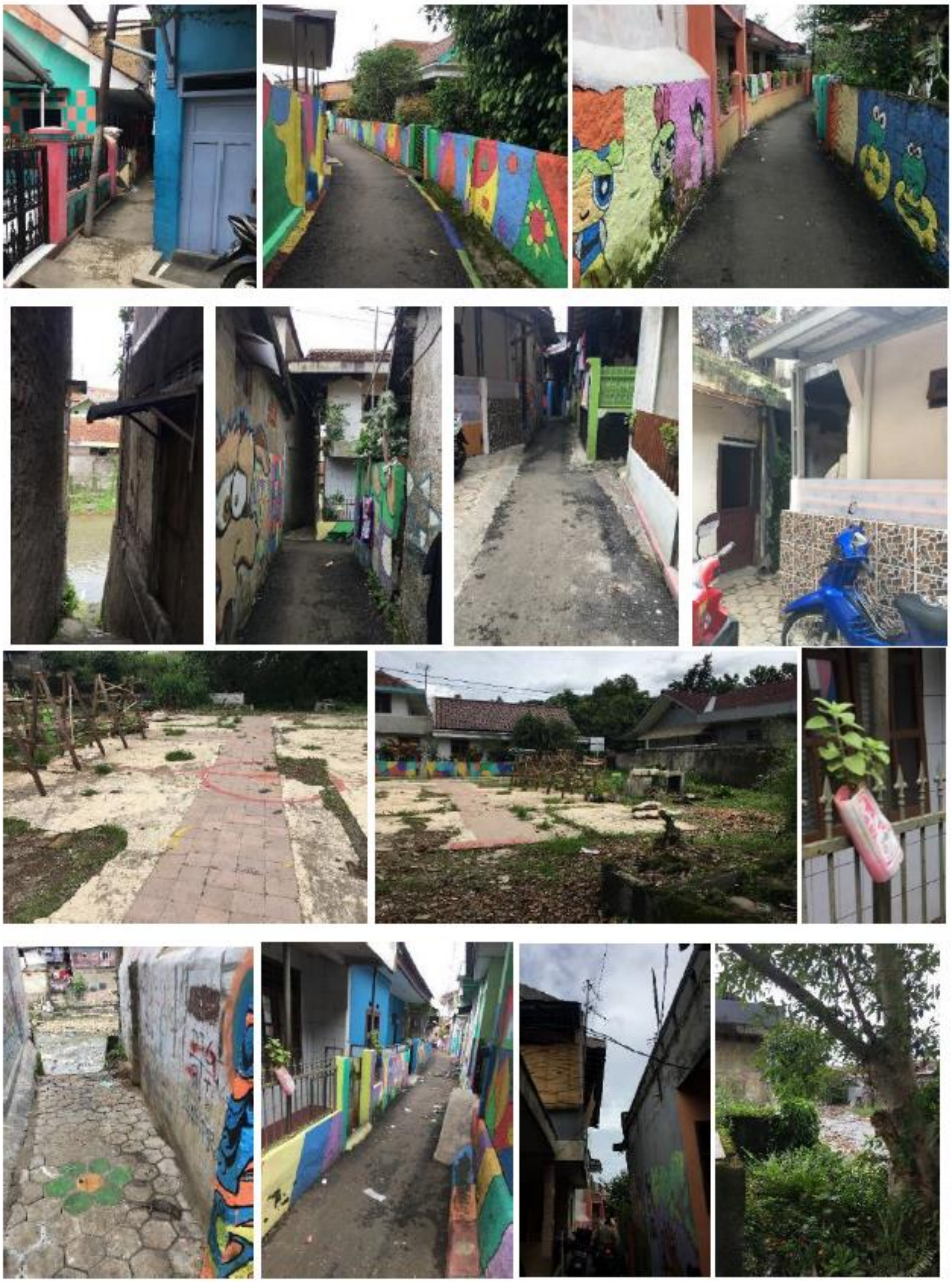


Figure 8- 1 Sites within Pulo Geulis that hold potential for GI application

Potential solutions

Based upon this literature review and workshops, a number of potential green infrastructure options have been identified for possible implementation within Pulo Geulis (Table 8- 1). The suitability and selection of each technology will depend on a more detailed understanding of the specific objectives to be achieved and any constraints or opportunities at a given location (please refer to Chapters 4 and 5 for guidance).

Table 8- 1 Potential green infrastructure solutions for implementation in Pulo Geulis

Potential solution	**Recommendation**	
Green rooves	✗	Relatively high cost and require structural support; many structures not likely to be sufficiently strong to support green rooves. Not the most effective solution to remedy the immediate issues in PG.
Green walls treating greywater	✗	Relatively high cost and require structural support, not suited to the informal settlement structures. Note that simple, low-height and standalone vertical potted systems for urban agriculture or garden are suitable in the dense Pulo Geulis environment. Rather, tall and extensive vertical systems that require support from a building are not generally recommended.
Stormwater treatment and reuse	✓	The harvesting and treatment of stormwater runoff (including roof runoff) will mitigate flooding and provide an alternative water supply for various purposes, including potential garden/vegetable garden watering if the quality is suitable.
Rainwater tanks collecting roof runoff for suitable household or outdoor uses (not for drinking or cooking uses)	✓	Rainwater tanks capturing roof runoff offer the capacity to enhance water supply security and reduce demand on other water sources. > Need to study quality of roof runoff to identify appropriate uses. Investigate acidification after dry periods, metal leaching from roofs and pathogen contamination. > Consider slimline tank design to fit into small spaces and/or communal tank systems located on public land and servicing a number of households. Recommend further work to determine the quality of roof runoff and suitable uses.
Biofiltration systems treating stormwater runoff and greywater	✓	Demonstration system already operating within Pulo Geulis using biofiltration in containers receiving domestic greywater. Potential to build upon this initial work. Technology offers water treatment, flow retention and amenity benefits.
Biofiltration systems with climbing plants and/or **constructed treatment wetlands** possibly located around island perimeter	✓	Technologies offer water treatment, flow retention and amenity benefits. Climbing plants provide vertical greenery within a dense environment. Possibility to locate around the island perimeter in places where there are relatively wide ledges.
Urban farming using roof runoff for watering	✓	Initial demonstration with passionfruit vine and butternut squash plants planted and positively received by the community. Small container gardens also present throughout Pulo Geulis. Proposal for further agricultural plantings planned, including vertical community gardens (Professor Hadi, UI). Small vertical pot systems are well suited to the dense environment and already in use. Extensive or tall vertical systems that require structural support from a building are not recommended. Systems offer multiple advantages including enhanced nutrition, economic benefits, capacity building and greenery. It is not recommended to water vegetables or other edible plants with water other than roof runoff. Other stormwater runoff carries a higher

		level of pollutants, particularly heavy metals, that can accumulate in the plant and garden soil over time. Urban farming has been attempted in the past in Pulo Geulis, but there were difficulties due to a lack of skills and maintenance (Interview with Pulo Geulis Leader, 15th April 2018). Hence, capacity building needs to be part of any program to support urban agriculture.

8.2 Cibinong

The area of Cibinong is the capital of the Bogor Regency, covering an area of 209 ha. The district incorporates a number of large lakes (situs). Within Cibinong there is a large development planned along the lake-front of the situ Cikaret and Bentenan by the Bogor Regency Planning Department. This proposed development site is the focus of this case study. The Masterplan is complete, based upon the winning design from a competition, and construction is due to commence in 2018.

As a government-led project the Cibinong lake-front development differs from the private-development of Sentul City. The project also has a lower budget than the high-end offering at Sentul City, and so tends to be more organic in nature. At this scale, Cibinong is a much larger case study site than Pulo Geulis and Griya Katulampa.

The waterfront development recognises the value of water in terms of branding and real estate, but also well-being, recreation and ecological functions. This differs from other community and developer attitudes to the situs which see them of no value and reclaim the land. The Cibinong Masterplan envisages the integration of blue and green assets, alongside cultural activities such as outdoor events, recreational facilities, outdoor dining facilities, arts and musical events (Cibinong Design Brief). This includes infrastructure such as parks, trails, gardens, playgrounds and forest where human health and well-being can be promoted with physical activities, alongside habitat for flora and fauna. The blue assets are intended to provide waterfont living, water sport opportunities and natural swimming pools to the community alongside Water Sensitive Urban Design assets such as wetlands that provide flood mitigation. Renewable energy is also part of the vision. The development will also incorporate many multistorey office buildings.

The development will require a large-scale relocation of the existing communities and the plans include connecting three lakes to form one large body of water. The area was formerly paddy-fields and waterways, illustrating the flood-prone nature of the land. Flooding and drainage are the core issues for the development, particularly flooding in the southern area. While there is a flood gate in place within the system, allowing some control, in 2017 there was a flooding problem in the irrigation channels (April FGDs). These channels have been adapted from their original purpose for irrigation to stormwater drainage. However, the channels tend to become smaller and smaller downstream, which leads to flooding issues. The flooding problem is exacerbated by new areas of housing along the river. Hence, land use change is having a significant impact on the landscape hydrology.

Key issues

- **Flooding** due to low-lying land and inadequate drainage
- **Pollution** within the lakes and waterways
- **Increasing price of land**, which restricts the land available for technologies
- **Degradation and loss of situs**

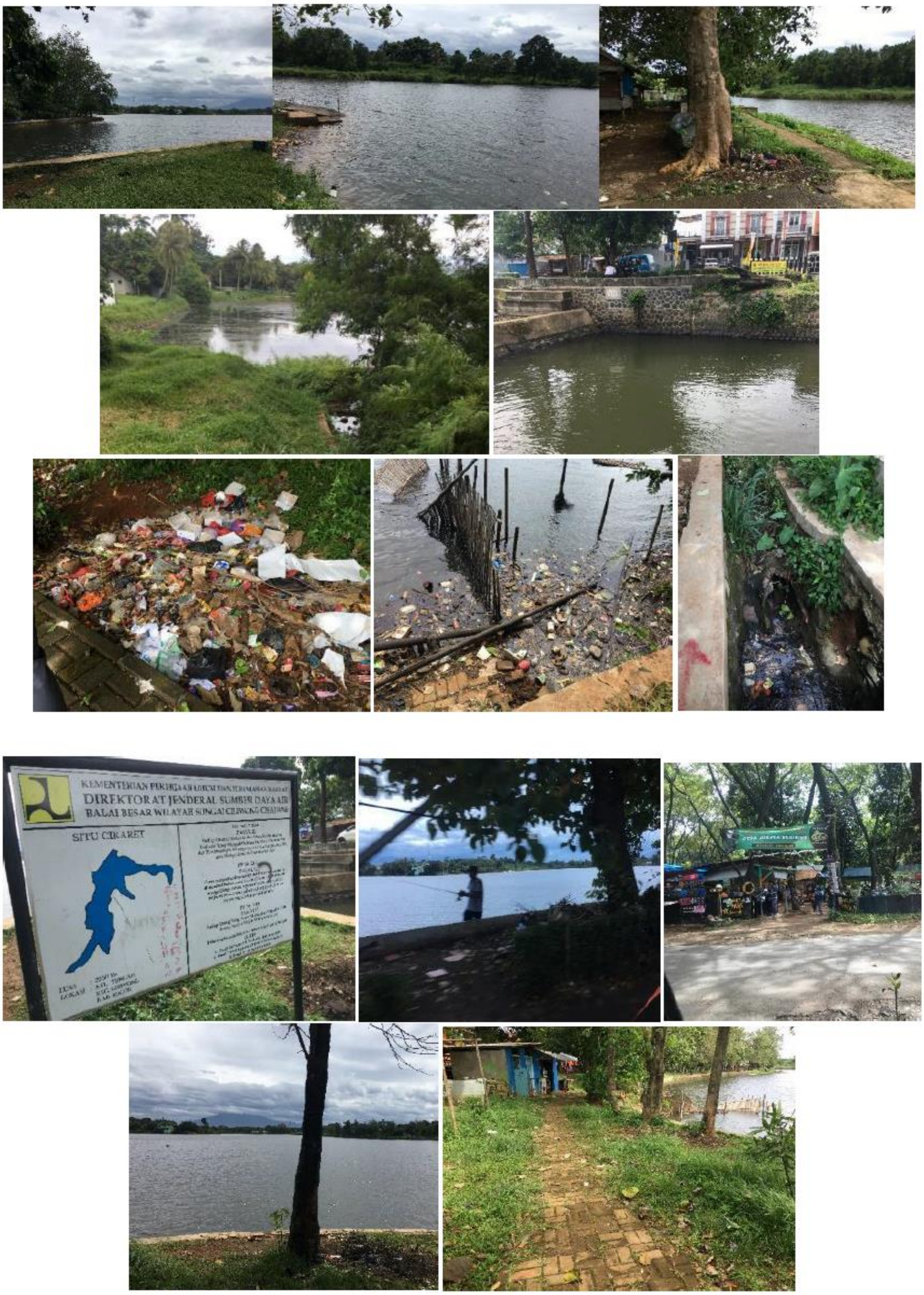


Figure 8- 2 Cibinong

Potential solutions

Based upon this literature review and workshops, a number of potential green infrastructure options have been identified for possible implementation within Cibinong (Table 8- 2). The suitability and selection of each technology will depend on a more detailed understanding of the specific objectives to be achieved and any constraints or opportunities at a given location (please refer to Chapters 4 and 5 for guidance).

Table 8- 2 Potential green infrastructure solutions for implementation in Cibinong

Potential solution	Recommendation	
Stormwater treatment and reuse	✓	The harvesting and treatment of stormwater runoff (including roof runoff) will mitigate flooding and provide an alternative water supply for various purposes, including garden/vegetable garden watering.
Promote **infiltration** of stormwater if soils are suitable. **Use lined systems** where soil has low infiltration capacity, shallow groundwater or alongside sensitive structures.	✓	Using **infiltration trenches** (roadsides, backyards)**, swales** (roadsides)**, biofiltration systems** (street trees, roadsides, backyard raingardens, larger systems in parks & reserves)**, porous pavements** (pedestrian walkways, carparks) and **passively watered garden beds.** This reduces the pollutant load received downstream and reduces the volume of runoff and peak flood flow. Biofiltration, swales and passively watered garden beds provide amenity & greenery. Promote infiltration into surrounding soils **only if** the soil infiltration capacity is appropriate, the groundwater is not shallow and there is sufficient distance from sensitive structures such as roads or buildings. However, noting that large parts of Cibinong are reportedly not suited to infiltration (which led to the construction of drainage and situs in the Dutch colonial era), **systems should be lined in these areas**. > Where appropriate; check if soil is suitable, groundwater table is not too shallow, and not immediately alongside sensitive structures such as roads or buildings
Protect situs using constructed treatment wetlands treating lake inflows, **floating treatment wetlands** in channels & lakes, **riparian vegetation restoration**	✓	To protect situ water quality, ecosystem, amenity and enhance water supply potential. Constructed wetlands also provide flood mitigation. Building upon the established research and demonstration projects of LIPI, UI, IPB and other research organisations.
Promote water storage & flow attenuation	✓	Using **retention ponds, retarding basins, biofiltration & passively watered garden beds, rainwater tanks** To provide flood mitigation, reduced pollutant transport. Blue and green systems (biofiltration, garden beds, ponds, vegetated retarding basins) will also provide amenity and urban cooling.
Greywater treatment and recycling	✓	Using **biofiltration systems** or **green walls** For large commercial and government buildings to reduce the demand for potable water. This will reduce the demand and costs for potable water, particularly important during the dry season if water shortages occur.
Biofiltration systems treating stormwater and greywater (**raingardens, tree pits, biofilters**)	✓	Providing water treatment, flood mitigation and amenity, greenery, biodiversity, human health and cooling benefits. Systems can form part of stormwater harvesting systems, also providing water supply for suitable reuse purposes. Applications can vary in scale, complexity and site, from roadsides (including tree pits), parks and reserves to private land (including

		backyard raingardens). Street trees in particular provide greenery in dense CBD areas where space is limited.
Rainwater tanks	✓	Capture, store and reuse rainfall for suitable purposes such as garden irrigation, urban agriculture or toilet flushing. This enhances water supply security and provides flood mitigation. > Research required to characterise the quality of roof runoff, suitable uses and tank designs for optimal water management
Green rooves	✓	To provide treatment and a reduction in roof runoff, cooling for the building, greenery and amenity. Suitable for large commercial or government buildings with suitable structural support and funding. Such features can provide a branding opportunity for a company or government department to distinguish their building.
Retention ponds and retarding basins	✓	To help store (either longer-term or temporarily) peak storm flows, reducing the flood volume and peak. Where stored, there is an opportunity for reuse of the water for a suitable purpose (and if required following some water treatment processes).
Promote runoff flow onto pervious surfaces (such as garden beds, grassed areas)	✓	To reduce slow and reduce stormwater runoff, thereby reducing the flood peak and volume downstream. Achieved via urban design. However, it is important not to exacerbate flooding; large flows must be able to continue downstream once the pervious area is overwhelmed. Similar concept to Singapore's soak away gardens which offer low-cost and simple solutions diverting stormwater runoff onto garden beds
Urban farming using roof runoff as a water source	✓	Provide nutrition, community capacity building, economic benefits and amenity. As a district Cibinong already has some environmental programs, including the green village program (Kabupaten Bogor Green) which incorporates urban farming opportunities. This can be implemented at the scale of private backyards or larger community gardens in areas of Public Open Space. It is not recommended to water vegetables or other edible plants with water other than roof runoff. Other stormwater runoff carries a higher level of pollutants, particularly heavy metals, that can accumulate in the plant and garden soil over time.

8.3 Sentul City

Sentul City is a high-end estate under development by a private company. Located in a mountainside region, close to Mount Salak and Mount Mas, it is also conveniently close to the toll road, it is home to 8,000 permanent residents who live and work in Jakarta or Bogor. It also functions as a resort, with approximately 1,000 residents living in Jakarta during the week and using Sentul City as a weekend retreat. 9 villages are also located within the Sentul City area, and many local villagers are employed to farm the land banks. The city is projected to grow five-fold from its current area of 3,020 ha to cover an area of 15,000 ha.

Currently, one of the largest shopping malls in Indonesia covering an area of 100,000 m^2, Aeon Mall, is under construction and due to open in late 2018. The 7.2 ha precinct surrounding Aeon Mall will form the Central Business District. Sentul City also includes two golf courses, an international racing circuit, international convention centre, national drug rehabilitation centre and an eco-tour development (Design brief, 2017).

High quality, sustainable and green living is an integral part of Sentul City's development plan. The overall aspiration is to become a pioneering Global Green City embodying Water Sensitive Urban design (Design brief, 2017). Set in a hillside location, the development is surrounded by greenery from forests to agricultural land. The land banks for future development are currently farmed and house local villages. Despite the plans for high growth and expansion, Sentul City management aim to maintain green open space at 60%, including blue open space. The future vision is for the city to be green, eco-friendly and sustainable. More specifically, the sustainable city will focus upon three aspects;

1. Agricultural products – known as an ‘Agropolitan’ city, with its own produce production to supply restaurants and the community
2. Technology – known as ‘Technopolis’, the objective is to incorporate high technology into the functioning of Sentul City
3. Water – known as ‘Aquapolitan’, this concept aims to adopt sustainable water management principles

The management of Sentul City are also keen to attract more businesses and education providers to the area. It is currently home to one television network and two university campuses and a high school.

Due to its location, in parts Sentul City includes steep slopes (8-15%) and flooding is not a problem in the area. Rainfall is generally higher than other parts of Bogor due to its mountainous location. The soils underneath Sentul City are karst/shale soils with high clay content and present a significant challenge as they are unstable, very difficult to excavate, not suited to infiltration and prone to erosion and landslides. As a result, the management plan for Sentul City does not allow excavation. The soils also severely restrict the capacity to infiltrate or store water in the ground. Previously the land of Sentul City, although agricultural, was not particularly productive, growing rubber trees.

Water supply is a critical issue for Sentul City, for both the current and future population. Currently, Sentul City is supplied with water from PDAM, but supply is not sufficient to meet demand in the dry season. However, development of a diversity of water supply options is urgently required as dry season water shortages occur. In addition, Sentul City households are charged a higher price for the water than other households in Bogor. This variation in price is causing discontent amongst the community. The management of Sentul City are currently considering a number of alternative options to supplement supply and plan for future growth, including supply to Aeon Mall. Possibilities include sourcing water from upstream and constructing a distribution network, including via a joint venture investment for the pipeline. However, this involves high cost and jurisdictional issues with BPAM and regulatory restraints which prevent Sentul City from charging for the water supplied. This prevents any proposals from being economically viable.

There are no significant surface water resources, such as major lakes or rivers, and the construction of ponds or lakes is difficult due to the unstable soil. Residents are not permitted to dig wells as, even if groundwater can be found, the potential for extraction is very low (Interview with Sentul City Management, 20th April 2018). This is in stark contrast to many other parts of Bogor Regency where groundwater forms a significant source of household water, alongside PDAM water if it is available.

In terms of wastewater management, a wastewater treatment plant was constructed by Sentul City’s private management to service the community. However, the relatively small facility is currently not functioning; it is utilised for emergencies only; and only capable of treating a small proportion of wastewater (in the order of 10%). Instead, new houses have individual septic tanks and commercial buildings are required to construct their own wastewater treatment plant. For solid waste roughly 7 tonnes per day are currently generated. While there is some management and reuse, community education and awareness regarding waste management issues is limited.

The management of stormwater runoff is challenging given that the use of recharge wells is problematic in the unstable shale soil, which has low infiltration capacity (April FGD 2018).

Management of Sentul City wish to incorporate green infrastructure into the future development of Sentul City.

Key issues

- **Unstable clay soils and landslides** - This makes construction of water bodies challenging and promoting the infiltration of water needs to be avoided.
- **High stormwater runoff –** as a result of the high rainfall, ongoing urban development and limited soil infiltration, runoff generation is high
- **Limited water supply –** While this is a high rainfall area, it lacks groundwater or large surface water bodies. Hence, water sources are limited and in the dry season water shortages occur. This is a significant issue for the community and Sentul City management. In addition, the large-scale future expansion planned for the population and area of Sentul City must also be catered for.
- **Management of future growth –** the forecast growth requires careful planning for water supply security, protection of existing greenery and environmental resources, and mitigation of future pollution and flooding impacts.

Current initiatives

Sentul City already incorporates a number of green or environmentally-sustainable systems. Some systems have been implemented for reasons such as aesthetics, but have the potential to be adapted to also provide water treatment and retention purposes. The initiatives in Sentul City include:

- **Green roof at the Neo Green Savana Hotel** – this system is comprised of five different layers; a geocell and soil base approximately 30 cm deep, covered by a turf grass. This provides greenery and amenity benefits, treatment and retention of rainfall, and cooling for the hotel rooms below, but the effluent is not collected for reuse. The system is functioning well, but for some leakage into the rooms below (Interview with manager, April 2018).



Photo credit: Green roof (Raul Marino)

- **Green wall at the Aston Hotel** - this system was constructed approximately 2 years ago and covers a large car parking structure, and the car park of an adjoining property, and so primarily serves an aesthetic purpose. The green wall was designed by the Indoneta Company. It is watered hydroponically using the PDAM water supply from three tanks on the roof and liquid fertiliser, but there is future potential to use rainwater. It contains approximately 20 different plant species. The hotel owner decided to construct the green wall to reduce UV radiation to the building and provide the amenity value of greenery to the hotel (Interview with hotel manager, May 2nd 2018). It is working well.

- **Green wall at new hotel** – this system primarily serves an aesthetic purpose, covering the façade of a small pumping station building, located opposite to the hotel's main entry. It is based upon a pocket design. This systems is fairly newly installed, more recent than the Aston Hotel green wall. The hotel entry also incorporates a 'dry garden' in pots alongside the road.



- **Green infrastructure at Aeon Mall and the CBD** – while under construction, the plans for Aeon Mall include a large-scale green roof and other green infrastructure. With rapid expansion and the construction of Aeon Mall underway, there are many new projects on the way.


- **Solar heating of hot water at the Neo Green Savana Hotel** – six solar panels provide provide hot water for all 70 hotel rooms and other hotel requirements, eliminating gas or electricity use. The system is reportedly working well (Interview with manager, April 2018). However, in general the government is not promoting the use of solar energy and this conflicts with the agenda of the energy companies (April FGD 2018).

Photo credit: Green roof (Raul Marino)

- **The development is highly landscaped around water and green features** - … for example, some of the traffic island landscaping was designed by a private landscaping firm (April FGD 2018)

Photo credit: View from Aston Hotel roof at left (Raul Marino)

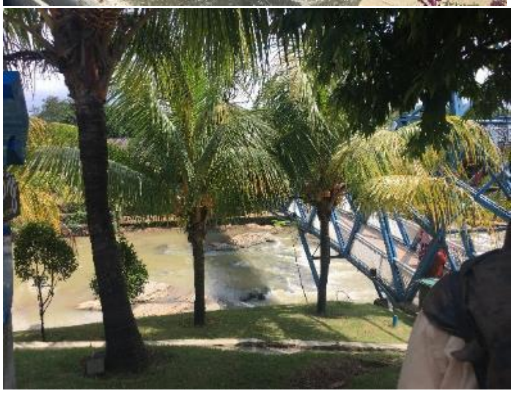
- **Gardens, vegetated drains and artificial creeks lining the 6.2 km main road (Ciliwung road)** – The gardens along the main road cover an area of 27 ha and deliberately incorporate a high plant biodiversity as part of the eco-city strategy. They include more than 6,000 trees and 49 species, alongside additional small trees, shrubs and bushes (Design brief, 2017). A natural vegetated drain is located in the road median. However, it primarily serves a conveyance purpose with little retentive capacity and carries heavy rainfall straight into the river, as frequently as twice a day in the wet season. In places where it transects intersections and roundabouts, the drainage line includes underground culverts, pits and pipes. An artificial creek has been constructed on one side of the road, but also has reportedly little retentive capacity (April site visits, 2018). In places a river runs alongside the other side of the road.

- **Urban farming –** the origins of Sentul City are rooted in agriculture, as a past land use and the current use of the land banks set aside for future expansion. In these areas local villages are provided with employment in cassava plantations. There is potential to integrate water reuse strategies that benefit agricultural production and reduce flooding and pollution of downstream environments. Sentul City aims to become more sustainable using local produce in the restaurants. Management also has a memorandum of understanding with Japan and Singapore to collaborate for urban farming systems. IPB is currently researching the potential for various agricultural commodities for export, such as vegetable and fruit supply to Singapore.
- **Retention ponds/lakes –** there are two retention ponds in the city (March FGD 2018). While primarily providing aesthetic and recreational purposes, one lake stores rainwater for an emergency water supply in the dry season when PDAM water supply is not sufficient for demand. A small water treatment plant is located adjacent to the lake. Lake primarily constructed for aesthetic purposes. Sentul City keen to construct more.



- **Floating Market (Apong)** - At this section the river was naturally straight, but a meander was created when the Apong was built. Problem with erosion of the retaining wall. Floating boats used to be used here but now as a result of the erosion they had to move, also dangerous flow conditions. Outlet pipes discharging into the river visible. Likely to be releasing greywater and blackwater. Artificial small water course built recently for floating boats. Not sure about water supply or quality. Main problem here is erosion of the retaining wall. In the artificial water course an aerator is visible. Can see fish in the water but it is turbid.






Lessons learned

- **Commercial opportunities** have been achieved **through the innovative approach to water management** within Sentul City. Water serves as a key feature of the Apung Floating Market, green walls provide notable aesthetic features at the Aston Hotel and the new hotel nearby.
- The **upmarket private development** provides opportunities for **individual households to shoulder the cost of system construction and maintenance**, in return for the multiple potential amenity, water supply, treatment, greenery and cooling benefits.
- **Green water treatment technologies can be a motivation for buyers**, both private and commercial.
- Many of the **existing systems provide scope for modification to provide water treatment and retention benefits**. For example, the conversion of V-drains into swales and bioretention systems.
- **The existing open space and greenery will facilitate future technology adoption**. Unlike many parts of Bogor, land availability for systems is not a critical limitation. However, **early planning into the future development** of Sentul City is required to set aside land in optimal locations for green infrastructure.
- There is **high potential for widespread technology adoption as part of the large future growth** in Sentul City. If system design is incorporated into projects from the outset, it also greatly reduces costs relative to retrofit situations.
- **Traditional preference and reliance on certain water sources** (such as the PDAM supply, or also groundwater in other parts of Bogor) **should not provide a barrier to the adoption of alternative water supplies** (such as rainwater harvesting schemes) which will diversify supply and enhance resilience against future changes in supply. Community education, supporting research (such as demonstrating the water quality of roof runoff) and demonstration projects will help to promote the adoption of new water supply options.

Recommendations

Based upon this literature review and workshops, a number of potential green infrastructure options have been identified for possible implementation within Sentul City (Table 8- 3). The suitability and selection of each technology will depend on a more detailed understanding of the specific objectives to be achieved and any constraints or opportunities at a given location (please refer to Chapters 4 and 5 for guidance).

Table 8- 3 Potential green infrastructure solutions to build upon the existing systems within Sentul City

Potential solution	**Recommendation**	
Infiltration systems (i.e. unlined systems that promote infiltration)	✗	Soils in Sentul City are generally unsuitable for infiltration due to their instability and the potential for landslides. Instead, use impervious liners in water treatment systems to prevent infiltration. However, there may be localised areas within Sentul City that have suitable soils to promote infiltration. Individual site assessments should be conducted to determine suitability.
Backyard raingardens (household scale) treating and retaining runoff from roof and paved surfaces	✓	Providing flood mitigation, water treatment, greenery and amenity. It is expected that some residents would welcome this technology. The costs and maintenance requirements can be undertaken by households, who also reap the benefits of functional landscaping.
Rainwater collection and harvesting (household and community scale)	✓	Using **rainwater tanks, ponds and lakes** for storage. Where required for the reuse purpose, water treatment can be provided passively by **biofiltration systems or constructed wetlands** with additional water treatment (such as UV treatment) as required. This utilises the most available water resource within Sentul City; high rainfall, to enhance water supply security. This will mitigate dry season water shortages and help meet the needs of future population growth. Can be implemented at various scales from individual households, clusters of households to neighbourhoods and commercial buildings. IPB and other institutions are currently helping Sentul city to develop the technology and capacity for rainwater harvesting.
Enhance the retentive & infiltration capacity of the Siliwangi Street vegetated drain and other drainage networks	✓	By **incorporating features of swales** (with porous underlying media, lined systems due to the unstable soils, and significant vegetation). Provide flood mitigation and reduced pollutant transport. Also consider the use of **terraced biofiltration, small wetlands and ponds** with weirs where the slope is too steep for the use of swales. > However, the use of some of these technologies may first require geological assessment considering the underlying soil and nearby road. Also implement these technologies in place of other drainage networks. As Siliwangi Street is privately owned by Sentul City, there are less regulations governing any potential modifications.
Biofiltration systems & constructed wetlands along roadsides and other public open space parks	✓	Provide flood mitigation, reduce pollutant transport, enhance amenity, biodiversity, human health, urban greenery and microclimate cooling.
Restore & protect local stream networks	✓	Restore riparian vegetation, natural channel structure, pre-development flow regimes & in-stream habitat, building upon the research work of LIPI and others. Treat inflows using **biofiltration** (for irregular stormwater flows) **or constructed wetlands** (for either irregular or constant inflows). These zones provide flood mitigation, amenity, greenery and protect water quality within the catchment.
Green roofs treating stormwater and **green**	✓	Build upon the existing systems, but instead of using potable water supply for watering, use roof runoff or greywater.

walls treating stormwater or greywater **on public or commercial buildings**		These systems are often implemented for their amenity benefits alone but can also provide flood mitigation, amenity and building cooling. They can also provide a unique branding opportunity for businesses to distinguish their premises.
Urban agriculture using rainwater harvesting to water crops	✓	This is well established in Sentul City with management planning future development with the supply of local restaurants with local produce, and potential export overseas. Urban agriculture provides enhanced nutrition, community capacity building and economic benefits. It should be combined with rainwater harvesting to reduce demand on the potable water supply (already under high demand in the dry season) and mitigate the potential for water shortages to impact upon crops. The existing program should be broadened from the farming villages to the entire community to promote productive backyard or community gardens. It is not recommended to water vegetables or other edible plants with water other than roof runoff. Other stormwater runoff carries a higher level of pollutants, particularly heavy metals, that can accumulate in the plant and garden soil over time.

8.4Griya Katulampa

Griya Katulampa is an island covering an area of 19.10 ha, flanked by the Kalibaru River and settled from 1992. The Kalibaru River is an irrigation canal and its construction originates from the period of Dutch colonisation in the 1940's when the nearby Katulampa Dam was also constructed. It flows from the dam towards Muara, Jakarta (Design brief, 2017). The case study considers only a sub-area within Griya Katulampa which incorporates a spring-fed water collection and distribution system constructed and managed by the local community.

The sub-area is home to approximately 240 people and all houses are connected to the springwater distribution system. While originally developed by a developer, once construction finished, management reverted to the government and the RT RW system is fundamental to local governance.

In places where the ground is sloped the community captures springwater in small pipes, and channels it down to each household. The water distribution system includes two ponds; one for fish which are consumed by the local community at community celebrations, and the other pond just for washing. The source of the springwater is unknown, but may originate from the Kalibaru River.

At Griya Katulampa the banks of the Kalibaru River are relatively flat, making the river highly accessible to families at this point. In comparison, many parts of the Ciliwung River at not readily accessible.

Uniquely to other parts of Bogor, water is relatively abundant in Griya Katulampa. Most households utilise springwater for uses such as small fish ponds. The community are also serviced by PDAM's water supply network, and utilise this for other water demands.

Currently, all runoff goes directly into the river. No rainwater collection systems are in place. Most houses are one storey and have septic tanks, which are maintained by each household with help from government agencies.

Key issues

- ➢ **Risks to the future quality and quantity of spring water** – there are a number of risks that may risk the ongoing viability of the spring distribution system. These include upstream development and increasing pressure on ground and surface water resources upstream.
- ➢ **Water pollution** – with some discharge of untreated stormwater runoff and wastewater into the drains and river.
- ➢ **Flooding** - The Kalibaru River, originally constructed to convey irrigation water to agricultural land, does pose a flood risk to Griya Katulampa, which is positioned in a slope with the river on both sides (Design brief, 2017).
- ➢ **Solid waste –** the drains in the springwater distribution network are choked with rubbish.

Current initiatives

The initiatives already implemented in Griya Katulampa include:

- **Community-led springwater collection and distribution system, including fish ponds** – the community alone organised to construct a piping and drainage system and connect all houses to the distribution system. There was no government support, the initiative was entirely community-driven. The spring was already present when development of the site commenced 30 years ago. It took time to work out how to manage the water flow.

Photo credit: Raul Marino

- **The annual Festival of boats** – this is hosted within the community and celebrates water, also providing a tourism opportunity.
- **Garbage bank and composting site –**there are facilities available for solid waste management. Griya Katulampa is one location selected by the government as a garbage bank. Organic and non-organic waste are separated. While there are other communities with more advanced waste management systems, Griya Katulampa do have a system (April FGDs, 2018).
- **Community vegetable garden / urban farming** – some houses have small plots where they are cultivating produce. Again, this appears to be community-based, but there is some debate if this may have been a government-led initiative and the community got on board.

- **Demonstration biofiltration system for greywater treatment** – this is a demonstration project of Prof Hadi. The objective is to upscale the technology.
- **Communal green open space –** this area is planted with lawn grass, trees and gardens, providing valuable open green space for the community.

Photo credit: Raul Marino

- **Community recreation facility – basketball court –** the community actively requested these facilities from the government. The process took about 5 years from the initial request to construction, but the outcome is a big achievement for the community and provides much-needed recreation opportunities.
- **Waste separation** – non-organic is separated from organic waste

Lessons learned

- Demonstration of **community organisation, engagement, initiative, self-management and self-sufficiency**. This allows initiatives to move forwards without waiting for government support, or the community actively pursues government support.
- The **community gained knowledge** of water management and practical skills by developing and operating the system themselves. Observations reported by the

community on springwater quality (such as its greater clarity in the dry season) demonstrate this local knowledge.

- **Water is valued by the community**. The community can touch, use and have an interest in the water resource, this promotes ongoing maintenance of the system, and each household participates in maintenance.
- **People have invested their own time and resources** into the system construction and maintenance.
- **Demonstration of the multiple benefits** provided by passive and natural water supply and treatment systems. The system in Griya Katulampa is considered an added value to living in the area and expected to add to property values.
- The **passive gravity-fed system** avoids potentially expensive operating costs
- **Fish in the ponds help to prevent mosquito habitat** by eating the mosquito larvae.
- Further understanding of the key drivers behind the community self-motivation would be valuable to promote this in other communities. For example, the community comprises a high proportion of older adults; was the knowledge and experience of older community members a key factor in driving development of the system?

Recommendations

Based upon this literature review and workshops, a number of potential green infrastructure options have been identified for possible implementation within Griya Katulampa (Table 8- 4). The suitability and selection of each technology will depend on a more detailed understanding of the specific objectives to be achieved and any constraints or opportunities at a given location (please refer to Chapters 4 and 5 for guidance).

Table 8- 4 Potential green infrastructure solutions to build upon the existing systems within Griya Katulampa

Potential solution	Recommendation	
Green rooves and green walls	✗	Not recommended due to their relatively high cost and structural support requirements. Residential buildings within Griya Katulampa may not be structurally strong enough. However, simple, low-height and standalone vertical potted systems are suited for urban agriculture or gardens where space is limited.
Diversify water sources	✓	To make water supply more resilient to future changes in the springwater quality or quantity, such as increased upstream extraction, pollution or climate change.
Characterise the springwater - Determine the spring **catchment** and test the water **quality**	✓	Upstream pollution may be impacting upon the springwater quality. However, both the source and quality of the springwater are unknown. If established, this will determine treatment requirements and allow risks to supply to be better understood and managed.
Treatment of the springwater using **constructed wetlands** (surface flow and/or floating)	✓	Treat the springwater close to source, upstream of its use by the community. Use a constructed treatment wetland to enhance the quality. Allowing the water to pass slowly through shallow heavily vegetated zones (not only perimeter vegetation) will facilitate sedimentation and pollutant removal. Vegetating the the fish ponds and channel network and implementing a floating treatment wetland could provide low-cost initial solutions to enhance water quality. Also treat the springwater downstream of its use by the community, including the treatment of stormwater and greywater.

Community education	✓	Through education and understanding the water source and quality, enhance community capacity to maintain the spring and its future viability.
Promote **rainwater harvesting** using rainwater tanks to diversify water sources	✓	This will provide an alternative water supply to enhance community resilience against future changes in the springwater quality or quantity. It also provides flood mitigation.
Vegetate the perimeter of the existing fish pond, washing pond & channels to enhance water quality	✓	To enhance water quality and provide treatment of surface water runoff entering the pond or channel network. It will also provide a barrier to deter human or animal access to the water which may disturb sediment, trample vegetation and increase turbidity. Access for washing and other purposes could be provided at certain points to limit sediment disturbance.
Urban farming using rainwater (roof runoff) as a water source	✓	Build upon the existing urban farming activities to enhance nutrition, community capacity and provide economic benefits and amenity. The use of collected rainwater from roof runoff will reduce the water demand on the spring or piped water supply systems. Urban farming can be implemented in private backyards or a larger community scale garden. It is not recommended to water vegetables or other edible plants with water other than roof runoff. Other stormwater runoff carries a higher level of pollutants, particularly heavy metals, that can accumulate in the plant and garden soil over time.
Biofiltration (raingardens) in backyards and communal area treating stormwater & greywater	✓	Provide flood mitigation, water quality treatment, amenity, biodiversity and greenery. The technology can be scaled from small to large systems, simple to more complex designs, and is suited to various types of spaces.
Enhance efficiency of spring water collection system	✓	The current system involves many small pipes. Improvements could be made to develop a more efficient communal collection system. This could involve water treatment upstream of the offtake point (as noted above), a communal tank and distribution system piped to individual houses.

Chapter 9

Summary of Key Findings

9.1 Key findings from review and case studies

- **Green infrastructure such as bioretention systems, constructed treatment wetlands, green roofs and others have been demonstrated to perform for water quality treatment, flow attenuation and other multiple benefits in tropical climates (Chapter 3)**. Technologies have been adopted and local guidelines have been developed in Singapore, Malaysia and northern Australia. This provides a strong business case for technology adoption and preliminary design guidance until more specific, local guidelines can be developed.

- **There are solid foundations for the adoption of green infrastructure in Bogor**, with many examples to build upon and natural green and blue assets that can be adapted to provide more ecological services. There are also existing local skills and resources. Examples include:
  - Green infrastructure already in action across Bogor. For instance, there are a number of infiltration systems already present in Bogor, e.g. ecodrains, biopiori, absorption wells and groundwater recharge wells. It is recommended that infltration devices be coupled with some form of storage. In fact, on-site detention and storage and subsequent release via infiltration, evapotranspiration and various applications such as landscape irrigation may represent an effective runoff management strategy.
  - Significant existing urban greenery, rivers and situs
  - Local resources including plant nurseries, horticultural and landscaping skills
  - Research capability at institutions such as LIPI, UI, IPB and others

- The case studies highlight how **multiple issues at a site can be mitigated by green infrastructure**. The implementation of green infrastructure in Bogor can help mitigate some of the water and associated issues, including minimising the problem of erosion (through vegetation); promote groundwater recharge; reduce runoff volume (through infiltration, site-detention and storage of GI measures) hence alleviate localised flooding impacts; treat runoff and greywater and thus provide for an alternative water source for the local community; enhance water security during dry seasons and reduce the discharge of wastewater into situs and rivers through greywater treatment and re-use.

- In order to have a more sustainable and resilient water supply, **diversification of water sources offers potential**. Evidence for this is provided in one of the case studies, where one sub-sectional district in Griya Katulampa is able to ensure secure water supply throughout the year by supplementing PDAM water with spring water. In this case, a viable water source is through rainwater harvesting.

- **Given Bogor's high rainfall volume, rainwater harvesting offers significant potential** to supplement existing sources of water for appropriate uses. This provides greater water security, reduces demand on other water sources (such as the PDAM supply and groundwater) and provides flood mitigation. Chapter 4, Section 4.3.4 provides examples of rainwater harvesting technologies for implementation at the micro- and macro-scale.

- **Treated greywater through GI systems could also provide for an alternative water source** for less personal end-use applications and can also help reduce wastewater discharge into rivers and situs. See Chapter 4, Section 4.3.4.

- **Tropical climates present both advantages and challenges for the adoption of green infrastructure**. For example, higher temperatures, rainfall and humidity drive higher plant productivity and microbial functioning throughout the year, relative to tropical climates. However, the high rainfall volume and intensity requires careful sizing of stormwater treatment systems to receive the runoff.

- **Given the high rainfall volume, intensity and frequency, careful sizing of systems is critical** to ensure sufficient treatment capacity. Designing systems to protect them from high flows and high flow velocities is also important (such as incorporating routes for high flows to bypass the system).

- **Protecting systems from sediment and gross solids is vital** for long-term functioning and reduced maintenance / rectification costs. Pre-treatment structures such as gross pollutant traps, grass filter strips, sediment forebays and sediment ponds should be placed before green infrastructure that are designed to treat fine and dissolved particles (such as biofiltration systems and wetlands).

- **There are multiple local and widely cultivated plant species that offer potential for use in green infrastructure. Many plants are also associated with potential economic uses**. However, <u>it is critical to note that plants should not be consumed if they are used in systems to treat stormwater runoff, greywater or wastewater</u>. Plants for consumption should only be used in systems watered with roof runoff or other high quality water sources.

- **The most appropriate technologies differ between sites**. This is illustrated by the case studies. Technology selection requires an understanding of the key issues for the site, careful defining of objectives, and design that considers the opportunities and constraints of the site. Careful technology selection is thus imperative for optimal benefits at each location.

- **Technologies can be selected and the complexity of designs modified to suit the site and available resources for construction and maintenance**. For example, the design of bioretention systems (or raingardens) is highly adaptable and can take the form of simple, passive systems. Benefits can also be achieved by simply directing runoff into passively watered garden beds, similarly to Singapore’s Soak-away raingarden design (PUB, 2018a).

- **Community education is very important** and could play a significant role in strengthening the relationship of the local community with water but also for maintenance of selected green infrastructure.

- **Solid waste management is equally important** to ensure satisfactory performance of green infrastructure over their life span. Community education and active campaigns for litter and solid disposal were found to be important. There are already some initiatives in place (e.g. community programs and other government sponsored programs in place – e.g. for waste separation and the production of compost, fertiliser and biogas from organic waste, providing economic incentives).

- In a broader sense, **the implementation of GI can benefit Bogor in other arenas**; for instance, GI in Bogor can
    - Help reduce infrastructure costs for managing runoff in a holistic and long-term way;
    - Improve Bogor residents' physical and mental health – save on health costs, increase productivity;
    - Help boost Bogor's tourism industry by increasing the general liveability and attractiveness of the city;
    - Provide for greater community engagement and collaboration by improving public open space for family gathering and group activities and;
    - Boost local productivity through urban farming.

- **There are a number of existing guidelines for the adoption of green infrastructure in tropical climates**. These can be utilised for preliminary guidance until sufficient local testing of technologies has been undertaken to develop guidelines to suit local conditions and meet local needs. The available guidelines include:
    - The *Active, Beautiful, Clean Waters Design Guidelines* and associated documents for plant selection and maintenance. This includes *Sustainable urban stormwater management in the tropics: An evaluation of Singapore's ABC Waters Program* by Lim and Lu, 2016 (Loh, 2012, 2013; PUB, 2014, 2018a).
    - *Water Sensitive Urban Design for the Coastal Dry Tropics (Townsville): Technical Design Guidelines* and associated documents for design objectives and fact sheets (AECOM, 2011; Creek to Coral, 2011a, b)
    - Darwin's *Water Sensitive Urban Design Practice Guide* (McAuley, 2008)
    - *Urban Stormwater Management Manual for Malaysia* (Department of Irrigation and Drainage, 2012)

In addition, many comprehensive green infrastructure guidelines from other regions exist and provide detailed knowledge for design, construction and maintenance practices, including:

- *Adoption Guidelines for Stormwater Biofiltration Systems* and the *Adoption Guidelines for Stormwater Biofiltration Systems – Summary Report, CRC for Water Sensitive Cities* (Payne et al., 2015)
- *Growing Green Guide; A guide to green roofs, walls and facades in Melbourne and Victoria, Australia (Department of Environment and Primary Industries, 2014)*
- *The suite of guidelines by Water by Design, including Construction and establishment guidelines – swales, bioretention systems and wetlands (Water by Design, 2009a); Stormwater harvesting guidelines (Water by Design, 2009b); A Business Case for Best Practice Urban Stormwater Management (Water by*

Design, 2010); Bioretention Technical Design Guidelines (Water by Design, 2014). Maryland's *Bioretention Manual (The Prince George's Country Maryland, 2007)*

Chapter 10

Recommendations for Further Research

10.1 Recommendations and future work

- **Local testing of green infrastructure, under laboratory and field conditions**: this is important to enable designs to be adapted to best suit local conditions and to develop an understanding of appropriate local construction, operation and maintenance procedures and costs. This work is vital to provide a foundation for the development of local adoption guidelines for green infrastructure. Some recommendations are as follows:
    - **Testing of local plant species performance in GI systems** – desirable plant characteristics outlined in Chapter 7 and the plant list in Appendix A could be used as a starting guide for plant species testing.
    - **Development of demonstration pilot projects**. This will help to provide proof-of-concept for more widespread adoption of an effective technology, illustrate the multiple benefits of green infrastructure, as well as form lessons learnt for future technology development. For example, a biofiltration system can be located within a visible streetscape setting to treat road runoff. System monitoring will help obtain performance data - which can be used to guide design (system sizing, loading rate, optimal plant species and filter media) and form the basis of local technical guidelines for design, construction and maintenance practices.

- **Building field demonstration systems** will help to illustrate the multiple benefits of green infrastructure and collect performance data to inform design, construction and maintenance practices.

- **Develop a local database of runoff and greywater quality**: this will help identify suitable technologies to use for different sites and applications and provide important data for system modelling and design. This will ensure that systems are designed so as to meet its treatment objectives in the most cost-effective manner.
    - Given the great potential for rainwater harvesting (Section 4.3.4), it is pertinent that efforts be directed to characterise the quality of rainwater and roof runoff to establish fit-for-purpose water sources which will facilitate the adoption of rainwater harvesting.
    - Characterise the greywater quality and generation from domestic and commercial buildings. The latter is particularly important given greywater recycling can potentially have the most benefits at this scale.

- The green infrastructure mentioned in this document should be **optimised for harvesting purposes**: design modification and testing to enhance the quality of runoff and greywater for re-use applications in accordance with re-use guidelines such as for heavy metals and pathogens treatment could be beneficial.

- **Investigate the potential for using stormwater GI systems** (e.g. green roofs, green walls, and bioretention systems) **for food production** – what type of food crops can be safely grown in these systems? Quantify the extent of toxic accumulations in crops and plants (e.g. metals and pathogens). E.g. Tom et al., 2014 found that different crop types tended to accumulate different levels of metals. Studies to improve our understanding of the risks – even with greywater irrigation.

However, it is critical to note that **currently it is not recommended to irrigate food crops with stormwater runoff** (distinct from rainwater runoff from roofs alone) as pollutant accumulation within the plants does not consistently meet FAO/WHO guidelines using current design practices.

- **Development of GI systems for greywater treatment**: given the space constraints issues in certain regions in Bogor (e.g. in informal settlements), research could help develop and optimise vertical gardens for greywater treatment. These gardens could be used to grow non-food crops of ornamental value that could provide for a source of income for local residents.

- **Development of local technical guidelines**: use existing technical guidelines for tropical climates (see Chapter 6, Section 6.3 and Section 9.1 above) and build local knowledge through field demonstration systems. Results from these could contribute towards the development of local guidelines. The following are also recommended in this endeavour:

    - **Development of water quality and flow management objectives or targets** similar to those outlined in Chapter 5, Table 5- 2: this will help guide the selection and design of technologies appropriate for an application.

- **Protect and leverage off the existing foundations within Bogor for green infrastructure.** This includes protecting the existing green and blue assets, and adapting the function of existing assets to enhance their functions as green infrastructure.

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