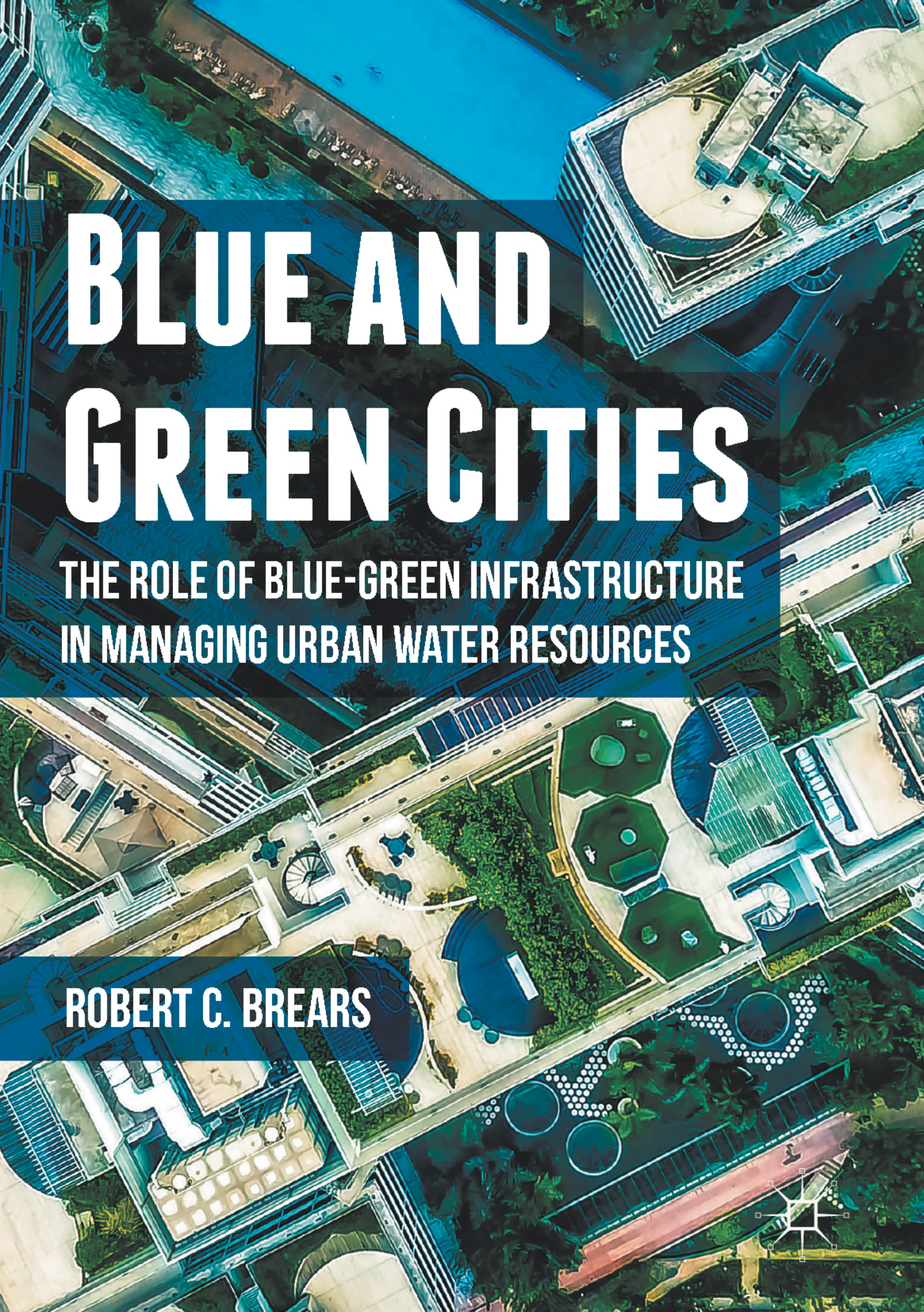
Blue and Green Cities

The Role of Blue-Green Infrastructure in Managing Urban Water Resources

Robert C. Brears



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Contents

List of Figures

List of Tables

List of Acronyms

ABC Waters	Active, Beautiful, Clean Waters
BCA	Building and Construction Authority
BGI	Blue-Green Infrastructure
CAP	Climate Adaptation Plan
CCRA	Climate Change Risk Assessment
CMP	Cloudburst Management Plan
COP	Code of Practice
CPI	City Parks Initiative
CRIAC	Clean Rivers Impervious Area Charge
CSIA	Combined Sewer Impervious Area
CSOs	Combined Sewer Overflows
DC Water	District of Columbia Water and Sewer Authority
DCP	Department of City Planning
DEC	Department of Environmental Conservation
DEP	Department of Environmental Protection
DOB	Department of Buildings
DOEE	Department of Energy and Environment
DOT	Department of Transportation
DPR	Department of Parks and Recreation
EAD	Expected Annual Damage
EDC	Economic Development Corporation
EPA	Environmental Protection Agency
ERU	Equivalent Residential Unit
GARP	Greened Acre Retrofit Program
GIS	Geographic Information Systems
GRTA	Green Roof Tax Abatement

GSDM	Green Streets Design Manual
GSI	Green Stormwater Infrastructure
HDB	Housing Development Board
IES	Institution of Engineers, Singapore
LEED	Leadership in Energy and Environmental Design
LTA	Land Transport Authority
LTCPs	Long Term Control Plans
MoU	Memorandum of Understanding
MS4	Municipal Separate Stormwater Sewer System
MTA	Metropolitan Transportation Authority
MWRD	Metropolitan Water Reclamation District of Greater Chicago
NParks	National Parks Board
NPDES	National Pollutant Discharge Elimination System
NUS	National University of Singapore
NYCHA	NYC Housing Authority
OGI	Office of Green Infrastructure
PEG	Prefabricated Extensive Greening
PPR	Philadelphia Parks and Recreation
PUB	Public Utilities Board
PWD	Philadelphia Water Department
RFI	Request for Information
RISA	Rain InfraStructure Adaptation
ROW	Rights of Way
SBI	Sites of Biological Importance
SCBA	Societal Cost Benefit Analysis
SDOT	Seattle Department of Transportation
SIA	Singapore Institute of Architects
SILA	Singapore Institute of Landscape Architects
SMIP	Stormwater Management Incentives Program
SPARC	Seattle Parks and Recreation
SPDs	Stormwater Planning Districts
SPU	Seattle Public Utilities
SRC	Stormwater Retention Credit
SWB	Sewerage and Water Board of New Orleans
TARP	Tunnel and Reservoir Plan
TPL	Trust for Public Land
UHI	Urban Heat Island
URA	Urban Risk Assessment
VA	Vulnerability Assessment
WEF	Water Environment Federation
WHG	Workforce Housing Group

WSUD	Water Sensitive Urban Design
WTD	Wastewater Treatment Division
WWTPs	Wastewater Treatment Plants

Imperial to Metric Conversion Table

For use with chapters 5, 6 and 9: conversions are rounded up to two decimal places

1 gallon = 4.55 litres
1 mile = 1.61 kilometres
1 acre = 0.40 hectare
1 foot = 0.30 metre
1 square foot = 0.09 square metre
1 cubic foot = 0.03 cubic metre
1 pound = 0.45 kilogram

INTRODUCTION

Cities are home to half the world's population and serve as global economic hubs, generating almost 80 percent of the world's GDP. With cities facing extreme weather events and rapid urban growth leading to the overuse of natural resources and creating environmental degradation, urban centres around the world need to become more resilient to climate change and reduce their ecological footprints.

Green Cities are concerned with how to design the whole city in a more sustainable, efficient, adaptive and resilient way. Green Cities recognise connections between different sectors and support development strategies that fulfil multiple functions and create multiple benefits for society and urban ecosystems. In the context of urban water resource management, a Blue-Green City calls for the holistic planning and management of water, wastewater and stormwater across the whole city to ensure that populations are resilient to climate change and extreme weather events while ensuring the health of aquatic ecosystems.

Traditionally, urban water managers have relied on grey infrastructural solutions, including dams and levees, to mitigate risks – with numerous environmental and economic consequences. For instance, traditional stormwater drainage systems, designed to prevent localised flooding, have created downstream flooding risks as well as stormwater overflows into waterways. At the same time, traditional systems have impacted the local hydrological cycle with less groundwater recharge and lower baseflows of waterways, impacting availability of water for humans and nature. In addition, traditional systems are inadequate to deal with climate change-related extreme weather events, with systems unable to cope with sudden large volumes of precipitation. Traditional systems also impact water quality, with runoff washing pollutants into nearby waterways. Furthermore, runoff causes turbidity as well as thermal pollution which can impact drinking water quality. In addition to climate change impacting water quality and quantity, urbanisation is resulting in environmental degradation. Finally, cities are facing regulatory challenges in simultaneously managing floods while also restoring the health of waterways.

In a Blue-Green City, Blue-Green Infrastructure (BGI) involves the use of natural or man-made systems to enhance ecosystem services in the management of water resources and increase resilience to climate risks. BGI solutions can also be used to support the goals of multiple policy areas. For example, green spaces and restored lakes and wetlands can reduce flooding risks to neighbourhoods while simultaneously supporting urban agricultural production and wildlife, in addition to providing recreational and tourism benefits. In Blue-Green Cities, urban water managers also use a variety of innovative fiscal and non-fiscal tools to encourage the implementation of BGI on public and private property to sustainably manage water resources and increase resilience to climate risks.

Nonetheless, our understanding of the role urban water managers have in implementing BGI to mitigate climate risks while reducing environmental degradation lags significantly behind engineering knowledge on water resource management. As such, little has been written on the actual implementation of policy innovations at the urban level that promote the application of BGI projects that not only reduce climate risk but also restore ecosystems and the numerous services they provide. In addition, because the application of BGI requires holistic planning, little has been written on how innovative policies have been developed to ensure BGI water projects fulfil multiple functions and policy goals and create multiple benefits for society and urban ecosystems.

This book provides new research on urban policy innovations that promote the application of BGI in managing water resources sustainably. In particular, the book contains case studies that illustrate how cities, of differing climates, lifestyles and income levels, have implemented policy innovations that promote the application of BGI in managing water, wastewater and stormwater sustainably to enhance resilience to climate change and reduce environmental degradation. The six case studies review leading cities that have implemented a variety of fiscal and non-fiscal policy tools to encourage the implementation of BGI on both public and private property to reduce stormwater runoff volumes, enhance the health of waterways, enhance resilience to climate change and meet regulatory requirements. Data for each case study have been collected from interviews conducted with, and primary materials provided by each city's respective department or utility in charge of implementing BGI. The six cities are Copenhagen, New York City, Philadelphia, Rotterdam, Singapore and Washington D.C., each of which are considered leaders in terms of their approach to sustainability, environmental and water resource management according to various sustainability indexes. The latter include Arcadis' Sustainability Index, which ranks cities on three pillars of sustainability: people, planet and profit, as well as the Siemens Green City Index, a research project conducted by the Economist Intelligence Unit and sponsored by Siemens. Copenhagen has been selected because it is a pioneer in showing that adaptation, in addition to managing excess stormwater, also provides significant social, environmental and economic benefits to the city. Meanwhile New York City is leading the way in combining BGI with traditional grey infrastructure to reduce combined sewer overflows. Philadelphia is implementing BGI to meet regulatory requirements and while doing so is ensuring that it creates a legacy for future generations to enjoy. Rotterdam is implementing a variety of BGI measures to help it become climateproof. Singapore, facing space constraints in developing grey infrastructure, is integrating green and blue spaces while mitigating the impacts of climate change. Finally, Washington is implementing BGI to improve the health of the city's waterways while reducing stormwater volumes that are predicted to increase with climate change. The book also contains a series of mini case studies of various cities around the world in the planning or implementation stage of initiating BGI to meet various challenges to their traditional grey infrastructure.

The book will introduce readers to the adaptive management framework that guides cities in their implementation of BGI in order to increase resilience to climate change and reduce environmental degradation. In the context of climate change, adaptive management is a process where decision-makers take action in the face of uncertainty. It is through this process of quantifying and acknowledging uncertainty that a society can decide how best to manage climate risk. Adaptive management also seeks to improve scientific knowledge and develop management practices that consider a range of future possibilities and even take advantage of unanticipated climatic events. In the context of natural resource management, adaptive management is the process of hypothesising how ecosystems work and modifying management decisions to achieve environmental objectives through improved understanding. Adaptive management can be used to restore or enhance ecosystems damaged by the impacts of urbanisation as the framework recognises that resource systems are only partially understood and that there is value in tracking responses of natural resources to management decisions. In Blue-Green Cities, adaptive management relies on monitoring, investigating and researching to build knowledge on waterways and understand the outcomes of management decisions on the environment and the effects of climate change.

In the operationalisation of BGI, the adaptive management decision-making framework involves the planning, designing, implementing and monitoring of BGI to achieve the multiple benefits it provides. Blue-Green Cities use a variety of fiscal tools to encourage the implementation of BGI practices on both public and private property, including new and existing developments. Fiscal tools are easy to implement and provide decision-makers with the flexibility and creativity to meet specific priorities as well as provide the opportunity to pilot new incentives before citywide application. Meanwhile, non-fiscal tools encourage the implementation of BGI on both public and private property and allow policy-makers to test and refine BGI programmes that could one day become mandatory requirements.

The book's chapter synopsis is as follows:

Chapter 1 provides an introduction to traditional grey infrastructure stormwater systems; this is followed by a review of the impacts of traditional grey infrastructure on water quantity and water quality before discussing the challenges posed by climate change, rapid urbanisation and meeting regulatory requirements. The chapter then introduces readers to BGI and its multiple benefits before finally discussing the barriers to its implementation.

Chapter 2 discusses two types of BGI: natural and man-made water features, both of which provide numerous multifunctional benefits in addition to managing water quantity and quality.

Chapter 3 defines urban resilience and reviews the measures that can be taken to increase it. It then introduces the concept of adaptive management and how BGI can be operationalised using an adaptive management framework. Finally, the chapter discusses how cities can use a variety of fiscal and non-fiscal tools to encourage the development of BGI.

Chapters 4–9 comprise case studies on the implementation of BGI, as part of the process of becoming a Blue-Green City, in the following cities: Copenhagen (Chapter 4), New York City (Chapter 5), Philadelphia (Chapter 6), Rotterdam (Chapter 7), Singapore (Chapter 8) and Washington (Chapter 9).

Chapter 10 includes a series of mini case studies of other cities in the implementation stage of initiating BGI to become Blue-Green Cities.

Chapter 11 includes a summary of best practices from the selected case studies for other cities planning to implement BGI in an attempt to become Blue-Green Cities.

CHAPTER 1

From Traditional Grey Infrastructure to Blue-Green Infrastructure

1.1 Introduction

Traditionally, stormwater systems, comprising stormwater drainpipes, curb inlets, manholes, minor channels, roadside ditches and culverts, are designed to remove stormwater from sites as quickly as possible to a main river channel or nearest large body of water to reduce on-site flooding.[1,2]

Many cities have implemented drainage systems as part of a larger sewer system that in addition to managing stormwater also regulates domestic and industrial wastewater. There are two types of sewer systems:

- *Combined:* Wastewater and stormwater are collected in one pipe network. Mixed water is then transported to a wastewater treatment plant for cleaning before being discharged into a river or large body of water.
- *Separate:* Wastewater and stormwater are collected in two separate networks. The wastewater is transported to a wastewater treatment plant, while the stormwater is conducted to the receiving waterway if it does not contain pollutants or needs to be treated separately before being discharged.[3]

While traditional grey infrastructure systems have, over many decades, proved to be effective in collecting stormwater runoff and draining it from the city, reliance on them has led to numerous unintended negative consequences relating to water quantity and water quality.

R.C. Brears, *Blue and Green Cities*,
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They include increased peak flows and total discharges from storm events; enhanced delivery of nutrients and toxins degrading aquatic habitats in urban waterways; and combined sewer overflows (CSOs) during wet conditions, exposing urban populations to health risks from waterborne pathogens and toxins.[4,5,6]

1.2 Impacts of Traditional Grey Infrastructure on Water Quantity

There are numerous impacts traditional grey infrastructure has on water quantity, including changes in hydrological cycles, increased peak flows and downstream flooding risks, changes in groundwater and surface water levels as well as inadequate dimensioning, resulting in increased climate change-related flood risks.

1.2.1 Changes in the Local Hydrological Cycle

In natural settings, only a limited amount of surface area is covered by impervious surfaces, resulting in most rainwater replenishing groundwater resources, filling rivers and lakes and being taken up by plants and trees. This process is assisted by infiltration, rainfall interception, evapotranspiration and soil retention. In cities, sealed surfaces including buildings, squares, streets and sidewalks act as a barrier to water, and instead of infiltrating through the soil, rainwater flows on the surface.[7]

1.2.2 Increased Peak Flows

Urban expansion, particularly in flood-prone areas, alters the natural path of waterways by increasing impermeable surfaces that reduce rainwater infiltration, thus increasing overland flows that typically exceed the capacity of drainage systems (Table 1.1).

1.2.3 Downstream Flooding Risks

Traditionally, urban drainage systems are designed to prevent local flooding by conveying stormwater away from vulnerable sites, the aim being to drain stormwater as fast as possible out of the city. However, if urban

Table 1.1 Change in watershed characteristics after urbanisation

Ground cover	*Evapotranspiration (%)*	*Runoff (%)*	*Shallow infiltration (%)*	*Deep infiltration (%)*
Natural ground cover	40	10	25	25
10–20% Impervious surface	38	20	21	21
35–59% Impervious surface	35	30	20	15
75–100% Impervious surface	30	55	10	5

Jha, A. K., Miner, T. W. & Stanton-Geddes, Z. 2013. *Building Urban Resilience: Principles, Tools, and Practice*, World Bank Publications. http://documents.worldbank.org/curated/en/320741468036883799/Building-urban-resilience-principles-tools-and-practice

districts upstream drain stormwater too quickly it may cause urban flooding downstream.[8] In addition, downstream flood risks may be amplified due to ageing systems that cause sewers to overflow, block natural flow paths and increase runoff.[9] This issue is exacerbated with many cities facing financial challenges of developing new infrastructure while also operating, maintaining, rehabilitating and ensuring environmental compliance of the current ageing infrastructure.[10]

1.2.4 Changes in Groundwater and Surface Water Levels

Stormwater systems can impact negatively on the local climate as infiltration and evaporation are reduced, resulting in cities' climates becoming warmer and drier compared to the surrounding areas. The result of warmer, drier climates is lower groundwater recharge rates, which can reduce the availability of drinking water in cities. In addition, lower groundwater levels can potentially lead to lower stream base flows, decreasing habitats and cover available for instream inhabitants, therefore increasing competition and vulnerability to predators. With reduced flow, there is also the likelihood of increased water temperatures and lower dissolved oxygen levels, both of which will cause additional stress to instream inhabitants.[11,12]

1.2.5 Increased Climate Change-Related Flooding Events

In many urban settings stormwater drains are typically designed for a one in 30-year flood occurrence. However, this dimensioning is likely to be inadequate when confronted with extreme weather events caused by climate change.[13] Heavy downpours have increased in frequency and magnitude in the past 50 years and are expected to become more frequent and intense as global temperatures continue to rise, leading to unmanageable stormwater runoff. In the United States the average 100-year floodplain is projected to increase by 45 percent by the year 2100.[14] Adapting to these changes will lead to higher running costs and investments, which will place capital budgetary pressures on municipalities in the near future.[15]

1.3 Impacts of Traditional Grey Infrastructure on Water Quality

There are numerous impacts traditional grey infrastructure has on water quality, including pollutants being easily flushed into waterways, urban runoff lowering visual quality and increased thermal pollution.

1.3.1 Pollutants Entering Waterways

When it rains, runoff from roads and highways frequently washes pollutants into nearby waterways including rivers, streams and lakes. Common pollutants include dirt, oil, grease, toxic chemicals, heavy metals, road salts, nitrogen and phosphorus, pathogens and rubbish. For example, brake pad wear-related deposits include copper and zinc; wintertime salting and sanding can deposit sodium chloride and calcium chloride onto roads, while fertiliser application on median strips is a source of nitrogen and phosphorus. In addition, roads degrade, generating pollutants as the pavement degrades. There are numerous effects of pollutants from road runoff that are harmful to both humans and ecosystems. These are summarised in Table 1.2.

1.3.2 Poor Visual Quality

Urban runoff often creates poor visual water quality too, with outbreaks of blue-green algae, piles of foam, significant fish kill, cloudy and highly coloured water and oil slicks – all examples of visual problems. In addition, floating inorganic debris and litter, for example, oil drums, car tyres, bottles

Table 1.2 Effects of pollutants from road runoff

Pollutant type	*Effect*
Suspended solids	Small solid particles that remain in suspension in stormwater causing issues including increased turbidity, decreased light penetration and toxicity to aquatic organisms
Pathogens	Viruses and bacteria cause public health impacts when they are discharged into waterways used for drinking water supplies or recreational purposes
Nitrogen and phosphorus	Excess nitrogen and phosphorus can stimulate excess algal growth As algae die and decompose, dissolved oxygen concentrations in the water decrease to low levels, a process called eutrophication
Heavy metals	Heavy metals are toxic to aquatic life and can contaminate drinking water supplies

17. NRDC. 2011a. After the Storm: How Green Infrastructure Can Effectively Manage Stormwater Runoff From Roads and Highways. Available: https://www.nrdc.org/resources/after-storm-how-green-Infrastructure-can-effectively-manage-stormwater-runoff-roads-and

and aluminium cans, raise community concerns. Organic debris including leaves, timber, paper, cardboard and food will in the short term cause visual pollution; however, when this material decays it releases nutrients that can form rich organic sediment which in turn can cause algal blooms.[16]

1.3.3 Thermal Pollution

Urban stormwater runoff is a significant contributor of thermal pollution to small waterways, which are highly sensitive to changes in temperature. Increased temperatures can damage cold water fish species by interfering with spawning and migration patterns. Meanwhile, warmer temperatures can lead to harmful algal blooms that produce dangerous toxins; these can sicken or kill people, create dead zones in water, raise treatment costs for drinking water and harm industries that rely on clean water.[17,18,19]

1.4 The Challenge of Climate Change to Traditional Grey Infrastructure

Traditional grey infrastructure used to manage stormwater will be challenged by extreme weather caused by climate change. During wet weather events, heavier storms will mean increased amounts of water and wastewater in combined sewer systems for short periods of time. As such, current designs, based on critical ‘design storms’ defined through analysis of historical precipitation data, need to be modified. Meanwhile, during extended periods of dry weather soils dry up and shrink, resulting in the cracking of water mains and sewers, making them vulnerable to infiltration and exfiltration of water and wastewater. A combination of high temperatures, increased pollutant concentrations, longer retention times and sedimentation of solids may lead to corrosion of sewers, shorter asset lifetimes, more drinking water pollution and higher maintenance costs.[20]

In addition to extreme periods of wet and dry weather resulting from climate change, cities and their infrastructure are exposed to numerous other

Table 1.3 Climate change risks to cities

Climate change impact	*Description*
Higher temperatures	Higher ambient temperatures, which reduce snow and ice volumes and increase evaporation rates from lakes, reservoirs and aquifers, will decrease natural storage of water and increase water demand
Droughts	Shifts in the timing of river flows and more frequent or intense drought will reduce the availability of water, increasing the need for artificial water storage
Flooding	Heavy downpours have increased in frequency and intensity over the past 50 years and are expected to become more frequent and intense as global temperatures continue to rise. As such, flood risks to cities are likely to increase. For example, in the United States the average 100-year floodplain is projected to increase by 45 percent by 2100, while annual damages from flooding are predicted to increase by $750 million
Contaminated water	Drier conditions will increase pollutant concentrations. This is a concern for populations that rely on groundwater sources that may already be of low quality
Increased runoff	Increased stormwater runoff will increase loads of pathogens, nutrients and suspended sediment
Urban heat island effect	Climate change will lead to more frequent, severe and longer heat waves during summer months
Coastal damage and erosion	As global temperatures continue to increase sea levels will be likely to continue to rise, storm surges will likely be amplified and heavy storm events will occur with greater frequency and intensity, damaging infrastructure

U.S. EPA. 2016a. Green Infrastructure for Climate Resiliency. Available: https://www.epa.gov/green-Infrastructure/green-Infrastructure-climate-resiliency.

Jimenez Cisneros, B. E., Oki, T., Arnell, N. W., Benito, G., Cogley, J. G., Doll, P., Jiang, T. & Mwakalila, S. S. 2014. Freshwater Resources. Working Group II to the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC). Available: https://www.ipcc.ch/pdf/assessment-report/ar5/wg2/WGIIAR5-Chap3_FINAL.pdf.
Astaraie-Imani, M., Kapelan, Z., Fu, G. & Butler, D. 2012. Assessing the Combined Effects of Urbanisation and Climate Change on the River Water Quality in an Integrated Urban Wastewater System in the UK. *Journal of Environmental Management,* 112, 1–9.

climatic risks, which are summarised in Table 1.3. Overall, traditional grey infrastructure is neither sustainable nor adaptable to changing climates.[21]

1.5 Rapid Urbanisation Increasing Environmental Degradation

The world's population is likely to grow by 30 percent between 2000 and 2025, and as much as 50 percent between 2000 and 2050. In 2011, it reached 7 billion and is projected to reach 9 billion by 2050, with population growth occurring disproportionately in low- to middle-income countries and in urban centres.[22] Rapid and unplanned urban growth has in many countries led to urban sprawl, water pollution and environmental degradation.[23,24,25]

In 2014, 54 percent of the world's population resided in urban areas. This figure is projected to increase to 66 percent by 2050. All regions around the world are expected to urbanise further, with Africa and Asia urbanising faster than all other regions, from 40 and 48 percent to 56 and 64 percent in 2050, respectively. The urban population of the world has grown rapidly, from 746 million in 1950 to 3.9 billion in 2014. By 2050 it is projected to reach 6.3 billion, with almost 90 percent of that increase occurring in urban areas of Africa and Asia.[26] Meanwhile high-income countries have been highly urbanised for several decades, while upper-middle-income countries have experienced the fastest pace of urbanisation since 1950. In 1950, 57 percent of the population in high-income countries lived in urban areas. Their level of urbanisation is expected to rise from 80 percent today to 86 percent in 2050, while in 1950 only 20 percent of the population in upper-middle-income countries lived in urban areas. This has risen to 63 percent today and is projected to rise to 79 percent in 2050.[27] Meanwhile population growth is predicted for all sizes of cities.

1.5.1 Mega-Cities

In 1990 there were 10 cities with population of 10 million or more. At that time, these mega-cities were home to 153 million people, representing less than 7 percent of the global urban population. Today, the number of mega-cities has nearly tripled to 28, with a total population of 453 million, accounting for 12 percent of the world's population. By 2030, the world is projected to have 41 mega-cities.[28]

1.5.2 Large Cities

Cities with populations of 5–10 million inhabitants account for a small, but growing, proportion of the global urban population. In 2014, just over 300 million people lived in 43 of these 'large' cities: 8 percent of the world's urban population. By 2030 more than 400 million people will be living in large cities, representing nearly 9 percent of the global urban population.[29]

1.5.3 Small- and Medium-Sized Cities

The global population living in medium-sized cities (1–5 million inhabitants) will nearly double between 2014 and 2030, from 827 million to 1.1 billion. Meanwhile, the number of people living in cities with 500,000–1 million inhabitants is expected to grow at a similar pace, increasing from 363 million in 2014 to 509 million in 2030.[30]

1.6 Regulatory Response to Managing Stormwater

In many countries changing social values and environmental legislation are challenging cities to manage floods while also restoring urban waterway ecosystems and their environmental and cultural values. For example, in the United States the Endangered Species Act requires those in charge of flood management to consider the needs of endangered aquatic species.[31] Meanwhile, Federal Clean Water Act requirements, including the National Pollutant Discharge Elimination System (NPDES), require the development and implementation of a municipal separate stormwater sewer system (MS4) programme to address post-construction runoff from newly developed and redeveloped areas to be implemented at the local level. In response, many cities are incorporating Blue-Green Infrastructure (BGI) into local stormwater codes as part of NPDES requirements.[32]

1.7 Blue-Green Infrastructure

Green infrastructure is a strategically planned network of natural and semi-natural areas, incorporating green spaces, or blue if aquatic ecosystems are concerned, and other physical features.[33] In the context of water, BGI is a strategically planned network of high-quality natural and semi-natural areas with other environmental features, which is designed and managed to deliver a wide range of ecosystem services and protect biodiversity.[34] As such, its purpose is to utilise natural processes to improve water quality and manage water quantity by restoring the hydrologic function of the urban landscape.

1.7.1 Implementing BGI Through Spatial Planning

The most effective way of implementing BGI is through spatial planning. This enables interactions between different land uses to be investigated over a large geographical area. Strategic-level spatial planning will locate the best places for habitat enhancement projects to help reconnect healthy ecosystems, improve landscape permeability or improve connectivity between protected areas, guide infrastructure developments away from sensitive natural areas to more robust areas that might additionally contribute to restoring or recreating green infrastructure features as part of the development proposal, and identify multifunctional zones where compatible land uses that support healthy ecosystems are favoured over single-focus developments.[35]

1.7.2 Spatial Planning of BGI in Stormwater Management

Regarding stormwater management, BGI enables the cost-effective management of excess stormwater during heavy, short-duration wet weather events by increasing storage capacity on public and private properties to retain stormwater runoff until it can be processed by the stormwater infrastructure or by facilitating water loss by evapotranspiration to the atmosphere or infiltration to the groundwater system, eliminating the need to process the stormwater runoff through wastewater treatment plants or discharge it into surface waters.[36]

When BGI measures are implemented as part of a large-scale stormwater management system, they boost its ability to prevent the exceedance of the drainage system, thus mitigating the generation of flooding hazards downstream as well as lowering the volume of stormwater requiring treatment. This reduces the need for additional grey infrastructure. Nonetheless, BGI can be complementary to grey infrastructure.[37,38,39]

1.7.3 Multifunctionality

A key aspect of BGI is its multifunctionality, specifically, its ability to perform several functions and provide several benefits within the same spatial area by harnessing the interrelationships between vegetation and the water cycle to improve living conditions in the city, thus enhancing both sustainable development and water- and greenery-related ecosystem services.[40,41] For example, a green roof can reduce stormwater runoff and the pollution load of the water, while also decreasing the urban heat island effect, improving the insulation of the building and providing a habitat for species.[42,43] However, it is important to note that not all green spaces or environmental features qualify as being BGI. In addition to being high quality they must also form an integral part of an interconnected BGI network and deliver multiple benefits. For instance, an urban park might be considered an integral part of BGI if, in addition to absorbing excess water runoff, it offers recreational opportunities and enhances wildlife.[44]

1.7.4 Water Sensitive Urban Design

Water Sensitive Urban Design (WSUD) is an approach to water management in urban centres that addresses both quantity and quality issues through natural systems that are integrated with the built environment, including buildings, infrastructure and landscapes. It provides an alternative to the traditional management of stormwater by minimising the volume of runoff from impervious surfaces and mitigating changes in the natural hydrological cycle through on-site reuse of the water as well as through temporary storage. WSUD supports stormwater systems by allowing the passage of runoff to avoid flooding and consequential damage to public and private properties while also treating stormwater. Its main objectives are: (1) protect or enhance the environmental, social and economic values of downstream environments; (2) reduce the frequency, duration and volume of stormwater runoff to mitigate the risks of flooding and moderate post-development flows into waterways; (3) reduce demand on potable water supply; and (4) improve amenity in the urban environment.[45]

1.8 Multiple Benefits of BGI

In addition to the primary objective of managing stormwater onsite, BGI provides numerous secondary environmental, economic and social benefits to urban communities due to its multifunctionality.[46,47,48] BGI aims to enhance nature's ability to deliver multiple ecosystem services. This in turn fosters a better quality of life for the human population and helps enhance biodiversity, while providing a measure of protection against the impact of climate change. In addition, BGI encourages a smarter and more integrated approach to development which ensures limited space is utilised in the most efficient and coherent way.[49]

1.8.1 Economic Benefits of BGI

Listed here are several of the many potential economic benefits of BGI.

1.8.1.1 Deferring or Replacing of Costly Grey Infrastructure

BGI can defer or even replace costly grey infrastructure projects.[50] These large installations, for example major sewage expansions and deep tunnels, are costly to construct and take years to complete, making them vulnerable to rising costs of materials, labour and financing. By comparison, the costs involved in implementing BGI are easier to predict in terms of cash flow requirements, allowing for more flexible financing.[51]

1.8.1.2 BGI Is Less Capital Intensive

Overall, BGI can be less capital-intensive than grey infrastructure, with lower costs associated with equipment and installation, land acquisition, repair and maintenance and infrastructure replacement.[52]As grey infrastructure systems require increased investments in operations and maintenance over time as equipment and materials wear down, BGI in contrast is designed to increase in resilience and function as vegetation matures and adapts to local resource cycles.[53]

1.8.1.3 Reduced Water Treatment Costs

BGI can reduce the costs of water treatment, as rainfall is filtered and treated naturally.[54] BGI can also reduce the need for water purification if the runoff is stored and used for irrigation. This decreases the costs of energy and chemicals for pumping and treating water.[55,56,57,58]

1.8.1.4 Lower Landscape Maintenance Costs

BGI including rainwater harvesting systems and drought-resistant plants can reduce the costs of irrigation and maintenance of public and private spaces.[59]

1.8.1.5 Increased Groundwater Resources

BGI practices that increase groundwater recharge levels can provide significant cost savings by avoiding increased pumping costs associated with declining groundwater levels.[60,61,62]

1.8.1.6 Reduced Water Imports

Cities often rely on costly imports of water from great distances to meet demand. BGI practices that reduce landscape irrigation can reduce water demand and water imports.[63]

1.8.1.7 Reduced Energy Costs

BGI can reduce energy demand for local residents. For example, green roofs provide insulation and shade cover, reducing energy demand for heating and cooling; rain gardens can reduce the amount of energy required for pumping by raising groundwater levels, and rainwater harvesting systems can reduce energy used in treating potable water.[64,65,66,67]

1.8.1.8 Enhanced Ecosystem Service Values

BGI provides many ecosystem services necessary for economic and social well-being, including water filtration and storage, air filtration, carbon storage, nutrient cycling, soil formation, recreation and food production.[68,69] Many of these services have not been monetised and therefore the economic benefits of healthy intact ecosystems are usually undervalued. Ecosystems provided by healthy waterways are often very expensive to engineer, and they may only provide a fraction of the services supplied by a healthy functioning natural system.[70]

1.8.1.9 Increased Employment

BGI can create jobs both directly, through construction, maintenance or management of various BGI initiatives, and indirectly through increased tourism related to events – from small community-based events to those of national importance – taking place in environments with BGI.[71,72,73,74,75]

1.8.1.10 Increased Investment

Investments in BGI improve a region's image, helping to attract and retain high-value industries, new business start-ups, entrepreneurs and workers. Jobs can also be directly linked to or depend on a city's BGI.[76,77,78]

1.8.1.11 Increased Land and Property Values

Developing and improving BGI space in key locations within urban areas can increase nearby property and land values.[79,80] Greener areas also have a better image and attract more visitors, bringing increased retail and leisure spending. Specifically, BGI can improve the aesthetic quality of an area, which can result in increased inward investment, attracting businesses and customers and encouraging people to spend more time and money. This increased economic growth can lead to higher levels of employment and tourism, as well as lower levels of crime.[81,82,83,84]

1.8.2 Environmental Benefits of BGI

Listed below are a few of the extensive environmental benefits provided by BGI.

1.8.2.1 Reduced Flood Risk

Urban development typically retains little or none of the original vegetation and landscape, with impervious surfaces, including buildings, roads, gardens and parks, impacting the natural hydrology of an area as well as freshwater habitats for species. BGI provides an ability to restore natural environmental features to urban environments, thus helping to alleviate floods.[85] BGI can contribute to flood alleviation by delaying the downstream passage of water flows, reducing the volume of runoff through interception and promoting rainfall infiltration into soils.[86,87,88]

1.8.2.2 Reduced and Delayed Stormwater Runoff Volumes

BGI reduces stormwater runoff volumes and also reduces peak flows by utilising the natural retention and absorption capabilities of vegetation and soils.[89,90] By increasing pervious cover BGI can increase stormwater infiltration rates, reducing the volume of stormwater entering combined or separate sewer systems and then into waterways.

1.8.2.3 Stormwater Pollutant Reductions

BGI infiltrates runoff close to its source, helping prevent pollutants from being transported to nearby surface waters.[91] Once runoff is infiltrated into soils, vegetation and microbes can naturally filter and break down most pollutants found in stormwater.

1.8.2.4 Reduced Sewer Overflow Events

Using the natural retention and infiltration capabilities of soils and vegetation, BGI limits the frequency of sewer overflow events by reducing runoff volumes and delaying stormwater discharge.[92]

1.8.2.5 Improved Waterway Quality

BGI can remove pollutants directly from stormwater. Using natural processes, BGI can filter pollutants and degrade them biologically or chemically, both of which are particularly beneficial for separate stormwater sewer systems that do not provide additional treatment before discharging stormwater.[93] BGI can also improve the health of waterways by reducing erosion and sedimentation and reducing the pollutant concentrations in rivers, lakes and streams. This in turn leads to overall riparian health and aesthetics.[94,95,96,97,98]

1.8.2.6 Enhanced Water Conservation

The introduction of rainwater harvesting systems and drought-tolerant landscaping as part of BGI can help reduce the need for irrigation, reducing the demand for potable and recycled water.[99,100,101] This enables populations to mitigate water scarcity risks resulting from projected population increases and climate change by maximising their existing water supply sources, preventing the need for costly expansions of treatment, storage and transmission facilities.[102] BGI practices can also be designed to provide emergency drinking sources in case of natural disasters.

1.8.2.7 Increased Groundwater Recharge

BGI practices including swales and rain gardens reduce impervious surface areas, helping replenish groundwater supplies by allowing rainwater to infiltrate through the soil. This can improve the rate at which groundwater aquifers are recharged. In addition, groundwater provides around 40 percent of the water needed to maintain normal base flow rates in rivers and streams and so enhanced groundwater recharge can increase water volumes for habitats as well as human uses.[103,104,105]

1.8.2.8 Improved Air Quality and Lower Greenhouse Gas Emissions

BGI facilitates the incorporation of trees and vegetation in urban landscapes, contributing towards improved air quality.[106,107] Not only do trees and vegetation produce oxygen during photosynthesis, they can absorb pollutants from the air by absorbing gaseous pollutants and intercepting particles onto leaf surfaces.[108] In Portland, Oregon, BGI projects have the potential to reduce harmful particulate levels by more than 17 tonnes per year.[109] If trees and plants are widely planted in a neighbourhood they can also lower air temperatures through transpiration, which slows the temperature-dependent reaction that forms ground-level ozone pollution (smog).[110] Meanwhile, BGI can reduce greenhouse gas emissions by reducing the volume of wastewater requiring treatment in wastewater treatment plants.[111]

1.8.2.9 Reduced Urban Heat Island Effects

Urban heat islands form when cities replace natural land cover with dense concentrations of pavements, buildings and other surfaces that absorb and retain heat. In addition, tall buildings and narrow streets trap and concentrate waste heat from vehicles, factories and air conditioners. By providing increased amounts of urban green space and vegetation BGI can help mitigate the effects of urban heat islands.[112] In addition, trees, green roofs and other green infrastructure can lower demand for air conditioning, decreasing emissions from power plants.[113,114,115]

1.8.2.10 Improved Habitats

BGI practices including the provision of parks, urban forests, wetlands and vegetated swales provide increased habitats for wildlife, particularly birds and insects. These areas can also be linked together to create green corridors, helping to conserve and promote biodiversity.[116,117,118,119]

1.8.2.11 Carbon Sequestration

Soils and vegetation introduced as part of BGI can act as sources of carbon sequestration, whereby carbon dioxide is captured and removed from the atmosphere via photosynthesis.[120,121,122] Portland, Oregon estimates that its BGI will sequester around 8,800 metric tonnes of carbon dioxide annually.[123]

1.8.3 Social Benefits of BGI

Listed below are some of the numerous social benefits provided by BGI.

1.8.3.1 Increased Life Expectancy and Reduced Health Inequality

It is common for green spaces to be unequally distributed across socio-economic groups, with poorer social groups typically having lower access. BGI in all neighbourhoods provides opportunities for people to exercise and relax, all of which increases physical health by, for example, reducing obesity, circulatory disease, chronic stress and asthma, particularly in underprivileged neighbourhoods.[124,125]

1.8.3.2 Improved Levels of Physical Activity and Health

There is a correlation between access to BGI spaces and higher levels of physical activity; for instance, living closer to parks or recreation/leisure facilities is generally associated with increased physical activity, while communities with more parks show significantly higher levels of walking and cycling for transportation.[126,127,128,129]

1.8.3.3 Improved Psychological Health and Mental Well-Being

BGI spaces provide a restorative environment that helps alleviate stress and mental fatigue.[130] In particular, they have a beneficial impact on mental well-being and physical activity through increased physical access, usage and access to views.[131,132,133,134,135,136]

1.8.3.4 Social Interaction, Inclusion and Cohesion

By beautifying neighbourhoods and creating unique spaces, BGI practices can increase neighbourhood interactions, with neighbours working together to integrate and maintain BGI in their neighbourhoods. This increased social activity leads to improved community cohesion, development of local attachment and lower crime levels.[137,138,139,140]

1.8.3.5 Increased Quality of Neighbourhoods

Implementing BGI can increase the quality of neighbourhoods and add community amenities. Installing grey infrastructure usually means digging up streets or tunnelling deep beneath them. These projects provide incremental and essentially superficial benefits to the functionality of the street. In contrast, BGI can provide additional benefits by planting trees that offer shade, installing green roofs that provide communal open space or enhancing parks for community and social spaces.[141,142]

1.8.3.6 Increased Public Safety

BGI can be used to reduce street widths and introduce features such as curves which slow down traffic, thus enhancing pedestrian safety.[143,144]

1.8.3.7 Healthier Air

BGI can purify the air, improving health particularly for children and the elderly.[145,146]

1.8.3.8 Food Production

BGI spaces that incorporate food production provide low-income residents with access to affordable and healthy food as inner city stores often have fewer nutritional options and charge higher prices. Food production associated with BGI also provides educational and business opportunities as well as reconnecting communities with their local environments.[147,148,149]

1.8.3.9 Recreation and Leisure

BGI spaces can provide resources for recreation, sports and leisure that in turn increase health and well-being.[150,151,152]

1.8.3.10 Quality of Space

BGI can improve the quality of space to motivate people to enjoy nature and exercise.[153,154]

1.8.3.11 Safer Water Quality

BGI can reduce polluted runoff and contaminants entering local waterways, minimising illness from recreational contact or contaminated drinking water. The resulting improvement can result in lower health care costs for communities and minimise closure of beaches for shellfish collecting.[155,156]

1.8.3.12 Reduced Crime Levels

BGI can reduce crime levels by increasing actual and implied surveillance, making these areas less attractive for criminal activity: crime is less likely to occur when there are more people around or where there is a perception that people may be around.[157,158]

1.8.3.13 Educational Opportunities

The visible nature of BGI offers enhanced public education opportunities to teach the community about mitigating the adverse environmental impacts of our built environment.[159]

1.8.3.14 Beautifying Neighbourhoods

Private gardens that incorporate BGI features and public right-of-way BGI can beautify streets and neighbourhoods.[160]

1.8.3.15 Building Resiliency to Climate Change

BGI can be implemented to build community resiliency to both localised flooding and droughts resulting from climate change.[161] With localised flooding, BGI can reduce stormwater runoff, while in times of drought, BGI can be used to replenish local groundwater supplies. On individual properties, rainwater harvesting techniques, including rain barrels and cisterns, can reduce demand for potable water.[162]

1.9 Barriers to BGI

While, as enumerated above, there are significant environmental, economic and social benefits associated with BGI, implementation in urban centres continues to encounter many obstacles. These include economic, financial, institutional, regulatory and infrastructural barriers, as well as a lack of awareness and knowledge; examples are included in Table 1.4.

Table 1.4 Barriers to the implementation of Blue-Green Infrastructure

Barrier	*Type*	*Description*
Economic	High transaction costs	BGI approaches require coordination of multiple stakeholders, often across regulatory jurisdictions; collaborating with dispersed landowners can be time-consuming and costly
	High land values	BGI solutions often require more land than traditional grey infrastructure and as land can be expensive it makes BGI solutions more expensive in the short term
	Difficulty in quantifying	The difficulty in quantifying the numerous benefits BGI brings, including improving water quality and supporting aquatic ecosystems, means cost-benefit analyses often favour traditional grey infrastructure over BGI approaches, despite the former's numerous negative impacts
	Long-time horizons	BGI may require a longer period to get established than business-as-usual grey solutions. In addition, it may take several years before it can deliver a full range of benefits
	Initial high costs	Initial investments in BGI can be expensive despite relatively low maintenance costs.
Financial	Perceived higher risk	The economic analysis of BGI is relatively new, with a lack of historical cost-benefit data available compared to the wealth of data available for grey infrastructure. This increases the perceived risk associated with BGI projects
	Undefined financial responsibilities	Exactly who should pay for BGI as well as how to fund the monitoring or maintenance costs can create challenges for scaling up. First, those who benefit from existing BGI often receive these benefits for free and therefore may not be inclined to pay for the maintenance of the system; second, BGI projects often

(*continued*)

Table 1.4 (continued)

Barrier	*Type*	*Description*
		require long-term monitoring and maintenance costs that beneficiaries may not have the ability to finance themselves
	Lack of financial resources	Municipalities have limited financial resources to allocate to the many competing demands under local control. However, inadequate investment in the long-term management of BGI assets means the benefits are less likely to be realised and/or deteriorate over time. This in turn leads to a lack of appreciation of the potential multiple benefits BGI offers with a consequent lack of investment in the future
Institutional	Lock-in of traditional practices	Grey infrastructure solutions have dominated water management systems and engineering curriculum for decades, leading to informal biases and even scepticism of BGI approaches
	Lack of long-term planning	The effectiveness of decentralised BGI depends on the aggregate, cumulative effects of many small-scale measures; however, this can fail due to lack of coordinated planning involving public agencies, community groups and private landowners
	Insufficient policy coherence	The competitiveness of BGI solutions compared to grey solutions can suffer due to lack of policy coherence regarding different aspects of the water cycle that often crosses administrative boundaries and jurisdictions
	Lack of resources	Planning systems can lack sufficient resources to turn BGI strategies into completed projects
Regulatory	Regulatory standards	Standards-based approaches to open spaces have in the past emphasised quantity over quality and on single use land allocations rather than rich, multifunctional green space
	Lack of clarity of how BGI complies with regulations	Uncertainty and lack of clarity surrounding how BGI strategies align

Table 1.4 (continued)

Barrier	*Type*	*Description*
		with environmental regulations is a common deterrent to implementation. Regulators may not approve these projects due to the uncertainty of time between implementation and emergence of results and temporal variability in performance
	Regulations crossing multiple jurisdictions	Regulations across different agencies, jurisdictions or levels of government may also hinder the development of BGI solutions
Infrastructural	Lack of physical space	Implementation of BGI can be limited by lack of physical space in urban areas; for example, detention ponds are suitable for suburban areas, but are often too large to make them feasible for city centres. In addition, retrofitting is difficult, particularly in high-density areas
	Poor maintenance	Lack of proper maintenance can lead to BGI being ineffective over time and even fail. Implementing large-scale BGI programmes may be constrained by insufficient resources and people trained in installing and maintaining BGI
	Inadequate sizing	BGI is often well-suited for handling small rain events, but large storms can generate volumes that can overwhelm BGI, for example rain gardens, rain barrels and swales
Awareness and knowledge	Lack of knowledge on BGI benefits	Many communities are either unaware of the benefits of BGI or believe it is more expensive or difficult to implement than traditional grey infrastructure
	Failure to provide benefits of large-scale implementation of BGI	Many cities have built pilot or demonstration BGI projects that provide cost information and short-term performance data, but these studies are not able to provide cost information on the large-scale implementation of BGI or on the benefits of installing many BGI

(*continued*)

Table 1.4 (continued)

Barrier	*Type*	*Description*
		measures near a watershed or large community area
	Lack of awareness of private sector actors	Private sector bodies are not widely convinced of the commercial benefits of becoming involved and fail to make land available for multifunctional land use, or dedicate resources to developing BGI
	Lack of understanding	Lack of understanding of BGI and the importance of multifunctional land use planning and connectivity between spaces
	Shortage of trained professionals	A shortage of professionals who have the skills needed to plan, design and manage successful BGI
	Short-term thinking	A culture of short-term thinking means that BGI, which is a long-term contributor to environmental, social and economic benefits, fails to receive sufficient support

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CHAPTER 2

Blue-Green Infrastructure in Managing Urban Water Resources

2.1 Introduction

Blue-Green Infrastructure (BGI) is a planned network of natural and semi- natural areas that utilise natural processes to improve water quality and manage water quantity by restoring the hydrological function of the urban landscape and managing stormwater. BGI can be divided into two types: (1) natural water features comprising ponds, rivers, lakes and wetlands and (2) man-made features, including green buildings, streets and places, each of which comprises a number of individual BGI components. It is the sum of this total that enables BGI to be multifunctional; specifically, its ability to perform several functions and provide several benefits in the same spatial area by harnessing the interrelationships between vegetation and the water cycle, thus improving urban living conditions in a way that enhances both sustainable development and water- and greenery-related ecosystem services.

2.2 Natural Water Features: Ponds, Rivers, Lakes and Wetlands

BGI natural water features include stormwater detention or retention systems, riparian buffers, restored waterways and constructed wetlands, each of which provide numerous multifunctional benefits in addition to managing water quantity and water quality.

R.C. Brears, *Blue and Green Cities*,
https://doi.org/10.1057/978-1-137-59258-3_2

2.2.1 Stormwater Detention and Retention Systems

Stormwater detention and retention systems, including detention or retention basins, bioretention basins or swales, capture runoff from buildings and roadways, interrupting traditional urban stormwater pathways at locations upstream from stormwater sewer inlets.[1] The benefits of bioretention systems are summarised in Table 2.1.

2.2.1.1 Stormwater Detention and Retention Basins

Detention basins are systems that temporarily store stormwater runoff during a rain event and release it later at a controlled rate to the drainage

Table 2.1 Benefits of bioretention- and infiltration-specific systems

Benefits	*Description*
Reduced stormwater runoff	Bioretention and infiltration (BI) practices store and infiltrate stormwater, mitigating flood impacts and preventing stormwater from polluting waterways
Increased water supply	BI practices can be used to increase available water supplies
Increased groundwater recharge	BI practices can increase groundwater recharge by directing rainwater into the ground instead of stormwater pipes
Improved air quality	Vegetation can remove air pollutants, while reduced stormwater entering treatment plants reduces carbon emissions
Reduced atmospheric carbon emissions	BI practices reduce carbon emissions through direct carbon sequestration
Reduced urban heat island effect	Evaporative cooling and reduction of surface albedo help reduce urban temperatures
Improved community liveability	Well-maintained BI practices improve local aesthetics, help reduce traffic noise and improve social networks in neighbourhoods
Improved habitats	BI practices provide habitats for wildlife
Enhanced public education	Rain gardens and bioswales provide educational opportunities for local residents to understand how BGI functions and its associated benefits
Green transport	Bioretention systems can be designed to calm traffic by reducing speeds along roads

CNT. 2010. The Value of Green Infrastructure: A Guide to Recognizing its Economic, Environmental and Social Benefits. Available: http://www.cnt.org/sites/default/files/publications/CNT_Value-of-Green-Infrastructure.pdf.

University of Florida. 2008. Bioswales/Vegetated Swales. Florida Field Guide to Low Impact Development. Available: http://buildgreen.ufl.edu/Fact_sheet_Bioswales_Vegetated_Swales.pdf.

system. Retention basins, which hold a permanent pool of water, can be designed for both peak runoff control and pre-treatment. Both detention and retention basins can be configured to capture overflows and inflows from internal and external conveyance systems respectively.[2]

2.2.1.2 Bioretention Basins or Rain Gardens

Rain gardens are vegetated land depressions designed to detain and treat stormwater runoff from rooftops, sidewalks and streets. Rain gardens have three components: a drainage area that collects rainwater, a distribution system that connects the drainage area to the receiving area, and a receiving area that retains and infiltrates the rainwater. Specifically, runoff is first filtered through surface vegetation and then through engineered filter media (soil layer). A perforated pipe within the latter collects and transports filtered runoff to a downstream detention system or a designated discharge point. To be effective, rain gardens should be sited to treat as much runoff from an impervious area as possible and sized to match the volume of soil storage with the extent of the drainage area. At times, excavation may be required to increase the area available for soil storage and accommodate plant roots.[3,4]

2.2.1.3 Vegetated and Bioretention Swales

Vegetated swales are open conveyance channels that convey stormwater via overland flow while providing green open space for developments. As stormwater runoff flows through a vegetated swale it slows down, enabling sediments and other pollutants to settle. Vegetated swales alone cannot treat stormwater to meet water quality standards – as they remove mainly coarse materials – but can provide pre-treatment when combined with bioretention systems. Bioretention swales provide additional stormwater quality improvements via infiltration through filter media, with cleansed runoff collected via a subsoil perforated pipe. Bioretention swales also provide temporary surface detention of runoff, helping to reduce peak flows off developments.[5,6]

2.2.2 Riparian Buffers, Restored Waterways, and Constructed Wetlands

BGI can be implemented in the form of riparian buffers and restored waterways, as well as constructed wetlands with numerous multifunctional benefits.

2.2.2.1 Riparian Buffers

Riparian buffers act as biological filters between catchments and receiving environments, intercepting a significant proportion of nutrients. Stormwater runoff is slowed and filtered, with direct uptake and transformation of contaminants by plants. Vegetation and humus layers hold significant volumes of water, promoting infiltration into the soil and releasing it over a longer time period.[7] Riparian buffers also restrict the development of land adjacent to creeks, streams and other urban waterways to reduce erosion and preserve channel form and function. When applied throughout a watershed, riparian buffers provide multiple environmental benefits including contributing to stream base flows as well as providing an interconnected network of habitats. By preserving interconnected networks of habitats, riparian buffers can increase wildlife diversity in urban areas while providing recreational opportunities, including trails.[8]

2.2.2.2 Constructed Wetlands and Waterway Restoration

Reservoirs and catchments can be restored for purposeful retention of excess stormwater from the surrounding area as well as for improving water quality. They can improve the micro-climate, enhance groundwater restoration and the aesthetics of recreational areas, and provide habitat for fauna and flora. During rain-free periods temporary retention reservoirs can be used for other purposes, for example, sports and recreation.[9]

2.2.2.3 Constructed Wetlands

In nature, wetlands slow water down, with suspended solids becoming trapped by vegetation and settling out. Other pollutants are transformed to less soluble forms and are taken up by plants or become inactive. Wetlands also provide the necessary conditions for microorganisms to live there, which transform and remove pollutants from the water. Nutrients, including nitrogen and phosphorus, are deposited in wetlands from stormwater runoff, with excess nutrients absorbed by wetland soils and taken up by plants and microorganisms.[10] Constructed wetlands are typically built on uplands and outside floodplains or in a floodway to avoid damage to infrastructure from excess stormwater. Wetlands are usually constructed by excavating, backfilling, grading, diking and installing water control structures to establish the desired hydraulic flow patterns. If the site is located on highly permeable soils and impervious compacted clay a liner is usually installed and the original soil placed over the liner. Wetland vegetation is then planted or allowed to establish naturally.[11]

CASE: Project *Flussbad* in Berlin

In Berlin, one of the largest sources of water pollution is from the mixed wastewater system in the city's inner districts. The system overflows after heavy rainfall up to 30 times a year. Each time, a large amount of unpurified wastewater enters directly into the River Spree, impacting water quality and the ecosystem of the river. Project *Flussbad* aims to permanently transform a 1.6-km stretch of the river in Berlin's historic centre that has gone unused for more than 100 years. With funding of US$4.8 million from the National Projects of Urban Development programme and the State of Berlin, the project will create a 750-m stretch of the Spree Canal along Museum Island into a publicly accessible swimming pool: for at least half a million residents of the city this will be their closest natural bathing waters. The natural swimming pool's water will be of bathing water quality, with the filtered water coming from an upper 1.6-km stretch of the Spree Canal that will be re-naturalised into a biotope landscape and reed basin to purify the river water by natural means. On the upper stretch, which is 390 m long, a 7,200 m^2 constructed wetland will purify the running water in a natural way, while the 640-m uppermost section of the river will be re-naturalised to become a wildlife habitat. The chief environmental impact of the project will be the improvement in the water quality of the whole river produced by filtering around 16 million m^3 of water per year. In the upper section, restored to nature, the project will reduce the rate of flow to about 1.5 cm/s on a surface of about 1.8 ha. This will create an ecological 'stepping-stone' midway between potential wildlife habitats both upstream and downstream, promoting the settlement and migration of riparian flora and fauna. The project will also contribute towards raising public awareness on the need to ensure water quality in the city's river. This will in turn inform and pressure decision-makers on the steps required to ensure all rivers are maintained in healthy conditions for recreational use and ecosystem health. Finally, the project will potentially enhance the city's image, based as it is on a history of disruption and contradictions. This image drives tourism and in particular ensures a constant inflow of young people, who are vital to the city's cultural and educational landscape and to many branches of the economy.[12]

2.3 Man-Made Water Features: Green Buildings, Streets and Spaces

BGI man-made water features include green buildings, streets and spaces, each of which provides numerous multifunctional benefits in addition to managing water quantity and quality.

2.3.1 Green Buildings

In and on green buildings, BGI includes green roofs, blue roofs, disconnected downspouts and rain barrels and rainwater harvesting systems.

2.3.1.1 Green Roofs

Rooftops are often flat and so are conducive for capturing and holding rainwater. Green roofs treat stormwater through retention or bioretention. They comprise a structurally sound roof, waterproofing and root barrier, a drainage layer, a permeable fabric, a growing medium and vegetation. They can reduce annual stormwater runoff by 50–60 percent on average and capture up to 85 percent of some water nutrient pollutants. Green roofs can also filter air pollutants, including the removal of carbon dioxide, and reduce the urban heat island effect by reducing surface temperatures by 30–60°C and ambient temperatures by 5°C compared to conventional roofs.[13] There are multiple benefits of using green roofs, summarised in Table 2.2.

2.3.1.2 Blue Roofs

Blue roofs, or detention systems, have a flow restriction device around the drain that holds water back until the storm event has passed. If ponded water exceeds the established threshold, water will overflow into a roof drain. Blue roofs require a flat, watertight roof with enough load-bearing capacity to support the weight of ponded water and drains to maintain desired water flow.[14,15]

2.3.1.3 Downspouts and Rain Barrels

Many houses and commercial buildings have downspouts that are connected directly to the combined sewage system. Downspout disconnection involves removing the direct sewage connection and redirecting downspout water towards permeable areas. Downspouts can

Table 2.2 Green roof-specific benefits

Benefits	*Description*
Reduced stormwater runoff	Green roofs can absorb between 50 and 80 percent of annual rainfall. During heavy rain events, green roofs delay stormwater from entering the sewer system
Reduced energy usage	Green roofs reduce the amount of solar radiation reaching the roof's surface, decreasing roof surface and internal building temperatures during warmer months, reducing the amount of energy needed for cooling purposes. In cooler months green roofs provide additional insulation, reducing the building's heating requirements
Improved air quality	Green roofs absorb air pollutants and intercept particulate matter in the air, while the cooling effect of vegetation reduces smog formation by slowing the reaction rate of nitrogen oxides and volatile organic compounds
Reduced carbon emissions	Green roof vegetation can directly sequester carbon, while reduced energy use for cooling and heating lowers carbon emissions
Reduced urban heat island effect	Green roofs provide localised cooling for neighbourhoods
Improved community liveability	Green roofs improve local aesthetics; they increase the functionality of buildings and cities by providing vegetable gardens and communal spaces
Improved habitat	Green roofs provide habitats for animals and plants. Different growth media and depth of soils can be chosen to support animals including insects and native plants
Increased public education opportunities	Green roofs enhance community awareness of BGI

Foster, J., Lowe, A. & Winkelman, S. 2011. The Value of Green Infrastructure for Urban Climate Adaptation. *Center for Clean Air Policy,* 750.
Penn State College of Agricultural Sciences. 2016. Green Roofs. Available: http://extension.psu.edu/natural-resources/water/watershed-education/stormwater/green-roofs.
Oberndorfer, E., Lundholm, J., Bass, B., Coffman, R. R., Doshi, H., Dunnett, N., Gaffin, S., Köhler, M., Liu, K. K. & Rowe, B. 2007. Green Roofs as Urban Ecosystems: Ecological Structures, Functions, and Services. *BioScience,* 57, 823–833.

also be connected to rain barrels or cisterns.[16] Rain barrels are small above-ground receptacles that usually hold 50 gallons. They are well suited to small parcels of land as the water captured can be used for irrigation. Cisterns are larger and can be above or below ground. Cistern sizes range from 300 to 1,000 gallons and are mostly used in large buildings.[17]

2.3.1.4 Rainwater Harvesting

Rainwater harvesting systems typically divert and store runoff from residential and commercial roofs. While roof runoff does contain pollutants (metals or hydrocarbons from roofing materials, nutrients from atmospheric deposition and bacteria), the latter are generally in lower concentrations and often contain far fewer toxic compounds of the kind found in runoff from impervious surfaces.[18] The installation of a rainwater harvesting system requires diverting downspouts to rain barrels, cisterns or tanks to capture and store the runoff. The storage volume is dependent on the roof area, available space and other site-specific conditions. Small rain barrels can provide modest reductions in runoff volumes and meet some irrigation demand, while larger rain cisterns or tanks capture most rooftop runoff and meet much of the irrigation demand.[19] Specific benefits of stormwater cisterns include the fact that they are easy to design, install and maintain; they can be programmed to release water gradually during the cooler part of the year and more quickly during the summer, when water is required for irrigation, thereby reducing municipal water demand.[20] Table 2.3 summarises the numerous benefits rainwater harvesting systems provide.

2.3.2 Green Streets

There are two main BGI strategies for streets, footpaths, car parks and alleyways: capturing stormwater runoff in vegetated areas or employing BGI measures to allow water to percolate into the ground. In particular, capturing of stormwater can be achieved through a variety of BGI measures including buffer vegetation and lawns, as well as stormwater planters, bump-outs and tree trenches. Meanwhile permeable pavement, depaved areas as well as gravel trenches and underground systems allow water to percolate into the ground.[21]

2.3.2.1 Buffer Vegetation and Lawns

Vegetative buffer strips (and infiltration trenches) that increase water evaporation and infiltration can be used in place of traditional solutions that divert stormwater into open trenches alongside roads, sidewalks (pavement) and squares.[22] Meanwhile, stormwater that flows directly from roads can accumulate in nearby lawns before percolating into the ground. This helps reduce flooding of streets and sidewalks and soil erosion as well as preventing detritus from entering the stormwater drainage system.[23]

Table 2.3 Rainwater harvesting-specific benefits

Benefits	*Description*
Reduced stormwater runoff	Rainwater harvesting systems capture rainfall where it lands, enabling reuse on-site
Increased available water supply	Rainwater used for irrigation purposes can significantly reduce demand for potable water
Increased groundwater recharge	Reusing rainwater for irrigation purposes helps increase groundwater recharge
Reduced energy use	Rainwater harvesting reduces the amount of energy required to pump, treat and transport potable water
Improved air quality	Rainwater harvesting systems reduce emissions from water treatment and wastewater treatment plants
Reduced atmospheric carbon emissions	Rainwater harvesting systems reduce the amount of water treatment required, which in turn reduces emissions from power plants
Enhanced public education	Rainwater harvesting systems educate local communities on BGI and sustainable water resources management

Foster, J., Lowe, A. & Winkelman, S. 2011. The Value of Green Infrastructure for Urban Climate Adaptation. *Center for Clean Air Policy,* 750.
U.S. EPA. 2008. Managing Wet Weather with Green Infrastructure: Municipal Handbook. Green Infrastructure Retrofit Policies. Available: https://wrrc.arizona.edu/sites/wrrc.arizona.edu/files/EPA_gi_munichandbook_incentives.pdf

2.3.2.2 Stormwater Planters

These are specialised planters installed in the sidewalk area to manage street and sidewalk runoff. Typically, they are rectangular, with concrete sides, lined with a permeable fabric, filled with gravel or stones and topped with soil, plants and, at times, trees. The top of the soil is lower than the sidewalk, allowing water to flow into the planter through an inlet at street level. The planters manage runoff by providing storage, infiltration and evapotranspiration. Any excess runoff is directed towards an overflow pipe connected to the existing combined sewer pipe or separated stormwater pipe.[24]

2.3.2.3 Stormwater Bump-Outs

A stormwater bump-out is a vegetated curb extension that protrudes into the street and can be situated mid-street or at an intersection, creating a new curb at some specified distance from the existing curb. It comprises a layer of stone that is topped by soil and plants. An inlet directs runoff into the bump-out system, where the stormwater can be stored, infiltrated and evapotranspirated by plants.[25] Excess runoff can leave the structure and flow into an existing stormwater drain. In addition to stormwater management, green streets that include bump-outs can slow traffic and decrease the distance that pedestrians must travel in the roadway.[26]

2.3.2.4 Stormwater Tree Trenches

A stormwater tree trench is a system of trees connected by an underground infiltration structure. It comprises a trench dug along a sidewalk lined with a permeable fabric filled with stone or gravel and topped with soil and trees. Stormwater runoff flows through a special inlet leading to the trench. The runoff is stored in the porous stone or gravel, watering the trees and slowly infiltrating through the bottom. If capacity is exceeded, stormwater runoff can bypass the system completely and flow into an existing stormwater drain.[27]

2.3.2.5 Pervious Pavement and Depaving

Pervious pavement is a specially designed pavement system that allows water to infiltrate through the pavement, preventing it from becoming runoff. The system operates as a conventional pavement but is made of a porous surface with an underground stone reservoir. The underground reservoir provides temporary storage before the water infiltrates into the soil. There are several main types of porous surface, including pervious asphalt, pervious concrete and interlocking pavers. Interlocking pavers function differently from pervious asphalt and concrete. Instead of allowing water to infiltrate through the paving, interlocking pavers are spaced apart with gravel or grass between them, allowing for infiltration. In addition to reducing runoff, pervious pavements provide many multiple benefits (summarised in Table 2.4) Meanwhile, depaving of areas frees up underutilised paved surfaces for trees and plants, allowing stormwater to infiltrate into the ground where it falls instead of carrying pollutants into waterways, as well as providing a habitat for birds, insects and other wildlife.[28]

2.3.2.6 Gravel Trenches

A gravel trench is a non-vegetated trench filled with stones to create an underground reservoir for stormwater runoff. The stormwater gradually exfiltrates through the bottom and sides of the trench into the subsoil. The trench is usually constructed as part of a conveyance network and

Table 2.4 Pervious pavement-specific benefits

Benefits	*Description*
Reduced stormwater runoff	Pervious pavement reduces stormwater runoff volumes and rates by allowing stormwater to infiltrate underlying soils
Increased groundwater recharge	By allowing rainfall to infiltrate, pervious pavements can help increase groundwater recharge
Reduced salt use	In cold climates pervious pavements delay the formation of frost layers, reducing the need for salt use. Reduced salt use decreases pollution in local waterways and groundwater sources
Reduced energy use	Pervious pavements can reduce surrounding air temperatures, which in turn lowers energy demand for cooling purposes
Improved air quality	Pervious pavements reduce the amount of stormwater requiring treatment, which in turn lowers carbon emissions in fossil-fuel treatment plants
Reduced atmospheric carbon emissions	Pervious pavements have lower lifecycle carbon emissions compared to asphalt and cement
Reduced urban heat island effect	Pervious pavements absorb less heat than conventional pavements, helping to reduce surrounding air temperatures
Improved community liveability	Pervious pavements reduce noise pollution by increasing street porosity levels
Enhanced public education	Pervious pavements educate local communities on the numerous benefits of BGI

Foster, J., Lowe, A. & Winkelman, S. 2011. The Value of Green Infrastructure for Urban Climate Adaptation. *Center for Clean Air Policy,* 750.
Driscoll, C. T., Eger, C. G., Chandler, D. G., Davidson, C. I., Roodsari, B. K., Flynn, C. D., Lambert, K. F., Bettez, N. D., Groffman, P. M. 2015. Green Infrastructure: Lessons From Science and Practice. Available: https://s3.amazonaws.com/nyclimatescience.org/gi_report_surdna_6_29_15_final.pdf.
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designed with an overflow pipe so excess stormwater can be conveyed to a drainage pipe if detention capacity is reached.[29]

2.3.2.7 Detention Tanks/Underground Systems

Detention tanks can be placed underground to capture runoff and reduce peak flows into the drainage system. The dimensioning of underground storage systems depends on availability of space. They can be constructed from pre-cast concrete structures, pre-fabricated systems from vendors or cast in-place concrete. They can also be combined with rainwater harvesting systems to provide storage for non-potable reuse.[30]

2.3.2.8 Green Parking Spaces

Parking lots constitute a significant portion of urban and suburban impervious surface area. These lots provide opportunities for BGI, including permeable pavement, bioretention techniques and trees, to be incorporated into new parking lot designs or retrofitting existing parking lots with BGI to capture runoff from parking spaces, parking lanes and buildings before it leaves the site. Green parking can be used to

- Reduce impervious areas.
- Infiltrate runoff from parking lanes and stalls.
- Improve parking lot drainage.
- Provide shade with trees.
- Improve pedestrian safety.
- Improve aesthetics; and
- Provide a habitat for wildlife.[31]

2.3.3 Green Spaces: Urban Forests and Vegetation

Urban forests and vegetation intercept and filter stormwater runoff, preventing flooding and improving water quality as well as absorbing airborne pollutants, providing windbreaks to protect buildings from wind damage, regulating heat island effects through shading and evaporation, providing wildlife habitats and ecosystem services as well as mitigating climate change effects by storing carbon dioxide. These multiple benefits are summarised in Table 2.5.

2.3.4 Parks and Open Spaces

Parklands contain significant permeable surfaces that can easily absorb rainwater. If well designed, parks can be enhanced to create hydraulic connections to larger land areas that are mainly impervious, enabling parks to filter stormwater runoff from surrounding roadways and other impervious surfaces.

Table 2.5 Benefits of planting trees

Benefits	*Description*
Reduced stormwater runoff	Trees intercept rainfall and increase infiltration while transpiration through leaves minimises soil moisture, reducing runoff
Increased groundwater recharge	Trees contribute to local aquifer recharge
Reduced energy use	Trees provide shade that cools air temperatures, reducing energy required to cool buildings. Trees reduce wind speed so in winter this can reduce energy needed for heating buildings
Improved air quality	Trees absorb pollutants and intercept particulate matter as well as reduce carbon emissions associated with heating and cooling of buildings
Reduced atmospheric carbon emissions	Trees directly sequester carbon dioxide from the air
Reduced urban heat island effect	Trees provide shade, reducing local temperatures
Improved community liveability	Trees provide shade, a sense of well-being, enhance recreational spaces, and reduce local noise levels and pollution levels
Improved habitat	Trees increase wildlife habitat particularly when species native to the region are used
Enhanced public education	Community tree planting activities create opportunities to enhance awareness on the benefits of BGI

Foster, J., Lowe, A. & Winkelman, S. 2011. The Value of Green Infrastructure for Urban Climate Adaptation. *Center for Clean Air Policy*, 750.
European Commission. 2013. Green Infrastructure (GI) – Enhancing Europe's Natural Capital. Available: http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A52013DC0249.

CASE: London's Queen Elizabeth Olympic Park

Queen Elizabeth Olympic Park, created for the London 2012 Olympic Games, was designed around six themes reflecting the resources within and adjacent to the site, including water, infrastructure and urban form, connectivity, topography, vegetation and biodiversity, and use and activity. In addition, BGI plays a crucial role in supporting the delivery of more than 75 percent of the commitments set out in the Olympic Delivery Authority's Sustainable Development Strategy, including:

- Ensuring all buildings are completely accessible by public transport, walking and cycling.
- Meeting biodiversity and ecology targets by creating a species-rich habitat of at least 45 ha.
- Constructing the parklands with recycled aggregates and certified and legally sourced timbers.
- Conforming to all recognised inclusive design standards.
- Reducing carbon emissions through onsite renewables.
- Managing flood risk.[32]

2.3.5 Multifunctional Public Facilities

Municipal buildings, libraries, public parking lots, schools, community centres and parks provide opportunities for highly visible BGI retrofits including permeable pavements, bioretention techniques, trees and rainwater harvesting. Projects can be undertaken as part of the capital improvement process, and may include building renovations, repaving, re-landscaping and infrastructure repair or replacement. BGI in public facilities offers numerous benefits including:

- Reductions in impervious areas.
- Infiltration of runoff from paved areas and rooftops.
- Public education opportunities.
- Provision of shade when trees are used.
- Improved habitat for wildlife.
- Creation of a more welcoming environment.
- Creation of park-like areas.[33]

CASE: Canary Wharf Crossrail Station

In London, the new Crossrail station at Canary Wharf includes significant BGI measures. The space above the station and ticket hall contains a publicly accessible roof-top garden. This will contain a unique planting environment while providing a range of amenity uses for community, business and recreational visitors. Educational panels will also be installed throughout the planting. Meanwhile, the underground part of the station, surrounded by the water of the West India Dock, will contain a sunken garden within a flood storage system. Water will be directed from either end of the sunken garden through a series of weirs set within terraces that are offset to encourage water circulation. Each terrace will contain three 'ponds' of varying depths of water and soil material in order to support different types of reed planting along with some open water with a pebble surface. While the reed bed and water terraces at dock level will improve water quality and provide a habitat for wildlife, the new roof- level park will create a valuable new amenity and wildlife resource as part of the city's wider network of green spaces.[34]

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CHAPTER 3

Adaptive Management and Blue-Green Infrastructure

3.1 Introduction

The concept of resilience is gaining increasing prominence within literature on cities and climate change. In particular, the terms 'climate resilience', 'climate-proofing' and the 'resilient city' in various journals, reports and briefings all emphasise the idea that cities need to be able to rebound quickly from climate change-related shocks and stresses.[1] In addition, there is also a growing set of studies on how resilience is connected to other concepts including adaptation and sustainability.

This chapter will first define the concept of urban resilience and the qualities of resilient cities before discussing the need for an iterative decision-making framework to build resilience to climate change as well as the impacts of urbanisation. It will then discuss adaptive management, which is considered to be the most appropriate decision-support framework for cities to increase resilience to climate change and reduce environmental degradation. Finally, the chapter will discuss the implementation of adaptive management in Blue-Green Infrastructure (BGI) using a range of fiscal and non-fiscal policy tools.

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3.2 Urban Resilience

Urban resilience is the capacity of cities to function so that people living and working in them survive and thrive no matter what stresses or shocks they encounter. Urban resilience embraces climate change adaptation while recognising the environmental impacts of urban centres and urbanisation. Urban resilience occurs on three levels:

- The systems of the city survive shocks and stresses.
- People and organisations are able to accommodate these stresses within their day-to-day decisions.
- The city's institutional structures continue to support the capacity of people and organisations to fulfil their aims.[2]

3.2.1 Qualities of Resilient Cities

Resilient cities demonstrate a range of observable qualities including the following:

- *Reflectiveness:* People and institutions systematically learn from experiences with an adaptive planning mindset that accepts unpredictable outcomes. They continuously modify practices based on emerging evidence rather than apply permanent solutions based on an assessment of current shocks and stresses.
- *Robustness:* The city's systems are designed and managed to withstand the impacts of extreme conditions and avoid a catastrophic collapse of the city from the failure of a single element.
- *Redundancy:* Redundancy builds in capacity to accommodate increasing demand or extreme pressures. If one component of the system fails, other substitutable components can meet essential needs.
- *Flexibility:* The city's systems have the capacity to change, evolve and adopt alternative strategies in the short or long term. This tends to favour decentralisation of conventional infrastructure by employing new technologies.
- *Resourcefulness:* People and institutions invest in capacity to anticipate future urban conditions, set priorities and mobilise and coordinate the resources (human, financial, physical).

- *Inclusiveness:* Emphasis on collective ownership and joint vision from various stakeholders in the city.
- *Integration:* City systems, decision-making and investments should be mutually supportive of a common outcome.[3,4]

3.2.2 Actions to Build Urban Resilience

Actions to build urban resilience to counter the impacts of climate change and urbanisation should be informed by an iterative, inclusive and integrated planning process that responds to three types of analysis: Urban Risk Assessment (URA) of the city's current status and future trends (population growth, economic development, environmental quality, etc.); Climate Change Risk Assessment (CCRA) of projected direct and indirect climate impacts; and Vulnerability Assessment (VA) of the urban population exposed to climate change risks.

3.2.2.1 Urban Risk Assessment

Systems thinking enables urban areas to be considered as complex 'living' systems that undergo numerous dynamic exchanges at any one time. Spatial analysis is often used to assess the direct impacts of climate change on urban population and sectors; however, conventional spatial analysis fails to take into account the reliance of communities in one location on infrastructure located elsewhere. An urban centre's resilience to climate change and its impact on the environment is influenced by its resilience to stresses and shocks in the past. The primary requirement of a URA is an assessment of its resilience to the various impacts of future trends including climate change. This involves multiple stakeholders identifying cross-sectoral impacts and interdependencies.[5]

3.2.2.2 Climate Change Risk Assessment

A CCRA begins with an assessment of likelihood of hazards due to potential changes in the climate (i.e. changes in temperature, precipitation levels and frequency of storms). In this assessment, the units of risk used depend on how the likelihood and consequences of an event are defined; for instance, probability may be defined as the chance of occurrence of one event compared with the population of all events. In the context of floods, for example, probability is referenced to a particular event (the probability of flooding, given specific rainfall).

Meanwhile, consequences can be measured in terms of impact (economic, environmental and/or social), which may be expressed quantitatively (e.g. in monetary terms) or descriptively (e.g. low, medium or high). The resulting risk can be expressed and viewed in several ways including:

- *Expected annual damage:* The consequences reflecting the average risk, that are expected to occur within a specified time frame. This figure is usually termed 'expected annual damage' (EAD) and it is used to conveniently measure the average damage in any given year.
- *Expected event damage:* Consequences that can reasonably be expected to result from a storm event during a given period, including potential loss of life and damage to property.[6]

3.2.2.3 Vulnerability Assessment

Vulnerability is the degree to which someone or something can be affected by climate change and environmental hazards. A VA identifies the current location and dynamics of potentially vulnerable urban populations as well as vulnerabilities across different urban sectors. Vulnerabilities can be categorised into three types: physical vulnerability of people and infrastructure; unfavourable organisational and economic activities; and attitudes and motivations.[7]

3.2.2.4 Physical Vulnerability of People and Infrastructure

Urban development inherently creates risks, but people in higher income groups can avoid or bear these risks while those in lower income groups cope with them to their detriment. As such there is a segregation in terms of hazard exposure and income levels in settlement locations. Therefore, those with lower incomes often purchase or rent in parts of cities that wealthier segments of society find undesirable due to these areas being more prone to floods or other hazards. The physical vulnerability of urban populations also increases with the concentration of potentially dangerous infrastructure and substances in urban areas (e.g. bridges, electric facilities, solid and liquid waste, chemicals).[8]

3.2.2.5 Unfavourable Organisational and Economic Conditions

Lack of organisational structures can lead to chaotic circumstances in times of stress, while the existence of formal or informal organisations or institutions can constitute a stabilising force. With climate change projected to increase the magnitude and frequency of flooding, these events can impact local economies, reducing earning capacities of local populations. Economic vulnerability is particularly prevalent in households which lack financial resources and either cannot afford or are reluctant to purchase flood-related insurance for their businesses and homes.[9]

3.2.2.6 Attitudes and Motivations

Reluctance to acknowledge the need to prepare for the impact of climate change and adopt the necessary mitigation measures can be a result of lacking hazard knowledge or from taking a fatalistic attitude. Vulnerability to, for example, flooding should not be seen as a given; instead, it can be reduced through different processes that make people and belongings less susceptible to the impacts of hazards. However, factors including lack of education, economic opportunities and political participation often hinder the ability of people to decrease their vulnerability to flooding.[10]

3.2.3 Resilience Planning

The process of identifying actions to build urban resilience to climate change and reduce the impacts of urbanisation is known as resilience planning. Resilience planning brings together technical, scientific and local knowledge and incorporates it into city decision-making. It builds on iterative, inclusive and integrated processes to reduce uncertainty and complexity associated with climate change and urbanisation. A key aspect of resilience planning is that it uses an adaptive cycle of action and reflection that progressively builds capacity of decision-makers, including business, community, household or government, to incorporate new information and uncertainty relating to climate change and urban growth into future plans and actions. Resilience planning involves the bringing together of multiple stakeholders to discuss scientific information, governance or technical studies from which findings can be verified from multiple perspectives and implications and responses discussed. The outcome is the development of a strategy that documents current and future vulnerability and identifies strategies and actions to build resilience over time. Cities can therefore prioritise and identify which actions should be taken promptly and those which can, over the medium to long term, potentially reduce existing deficits in resilience.[11]

3.2.4 *Adoption of an Iterative Decision-Support Framework*

To increase resilience to climate change and the impacts of urbanisation and associated environmental degradation, there needs to be an adoption of a decision-support framework (Fig. 3.1). The framework should be an iterative process that includes:

- *Identifying projected impacts and challenges* associated with climate change and other stressors, for example, land-use changes, population growth and regulatory changes.
- *Cataloguing threshold conditions* for critical assets, operational components and utility organisation systems that may fail or suffer damage when challenged by extreme weather events caused by climate change. When compared to projected climatic conditions, thresholds represent the capacity of the city to bolster its defences through the implementation of adaptation plans. These thresholds can be determined through review of event and performance history, modelling of system performance or inspection of assets.
- *Assessing potential risks* to infrastructure and operations to gain a better understanding of both the thresholds for failure and projected impacts.

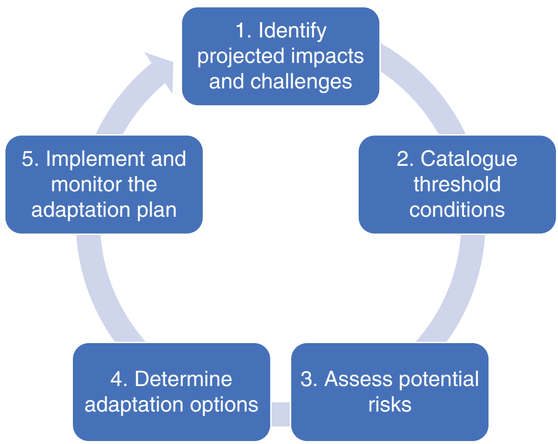

Fig. 3.1 General process for adaptation planning.

- *Determining adaptation options* that reduce system vulnerabilities. In addition to reducing risks, options should be considered with respect to current utility improvement plans and priorities and current and projected resources. These are often described as ‘no regrets’ options that provide benefits regardless of future climatic conditions.
- *Implementing and monitoring of the adaptation plan,* in which conditions are monitored, results are compared to projections and risks and adaptation options are reassessed as new information becomes available.[12]

3.3 Adaptive Management

The most appropriate decision-support framework for cities to increase resilience to climate change and reduce environmental degradation is provided by adaptive management, a systematic process for improving the effectiveness of natural resources management by learning from experience and utilising current knowledge to inform decision-making.[13,14] Adaptive management specifically is an evolving process involving learning (the accumulation of knowledge over time) and adaptation (the adjustment of management over time). The sequential cycle of learning and adaptation leads to two consequences: first, a better understanding of the resource, and second, better management based on that understanding. Feedback between learning and decision-making is a key feature of adaptive management. Therefore, learning contributes to management by helping to inform decision-making, while management contributes to learning by using interventions to investigate resources.[15] The key difference between adaptive management and trial and error is that the former involves a clear statement of objectives, the identification of alternatives, predictions of consequences, recognition of uncertainty, monitoring of resource responses and learning.[16] The core elements of adaptive management include the following:

- *Management objectives are regularly revisited and revised:* Political differences among stakeholders or competing paradigms among cooperating scientists are inherent in the process and unavoidable. Recognition and discussion of these differences should be part of adaptive management, and its learning processes. However, for adaptive management to be effective there must be some level of agreement, because if there is no agreement on goals or definitions of progress then the process is ineffective.

- *A model of the system is being managed:* An explicit baseline understanding of and assumption about the system being managed helps provide a foundation for learning. Models of the system are generated to test hypotheses with the models containing clearly defined variables that characterise the state of the system and its rates and directions of change.
- *Developing a range of management choices:* Even when an objective has been agreed on, it is common for uncertainty to exist about the ability of possible management actions to achieve the stated objective. Existing data rarely suggest an optimum management policy. For each decision the range of possible management choices is considered at the outset in light of stated objectives and the model's dynamics. This evaluation takes into account the likelihood of achieving management objectives and the extent to which each alternative will generate new information or foreclose future choices.
- *Monitoring and evaluating outcomes:* Adaptive management requires a mechanism to compare outcomes of management decisions. The gathering and evaluating of data allows for the testing of alternative hypotheses and is essential for improving knowledge of the system.
- *Building in a mechanism for incorporating learning into future decisions:* Adaptive management aims to achieve better management decisions through an active learning process. Objectives, models, consideration of alternatives and formal evaluations of outcomes all facilitate learning. As such, there needs to be a mechanism for feeding information gained back into the management process.
- *Maintaining a collaborative structure for stakeholder participation and learning:* The inclusion of parties affected by ecosystem management actions in decision-making is a widely accepted aspect of natural resources management around the world. Achieving meaningful stakeholder involvement that includes active learning and some level of agreement among participants is a challenge, but essential for adaptive management.[17]

Overall, the adaptive management framework can be summarised in terms of four main core principles:

1. Identification of competing hypotheses to explain observed patterns or processes.
2. Use of models that embed these hypotheses to predict responses to experimental management interventions.
3. Monitoring of actual resource responses.
4. Comparison of actual versus predicted responses to gain better understanding.[18]

3.3.1 Conditions for Using Adaptive Management

However, not all resource management decisions can or need be adaptive. For instance, there may be little to no chance to apply learning, or there is little uncertainty about what action to choose. As such, the decision on whether or not a problem requires adaptive management should be addressed at the outset of a project. The decision to apply adaptive management can be based on whether five conditions are met:

1. *Management is required despite uncertainty:* The problem is timely and sufficiently important to warrant management action even though its consequences cannot be predicted with certainty.
2. *Clear and measurable objectives are required to guide decision-making:* Objectives are critical for evaluating performance as well as making decisions. Without objectives and metrics it is difficult to determine which actions work best.
3. *There is an opportunity to apply learning to management:* There is a range of management alternatives from which to make a selection and a flexible management environment that allows for change in management as understanding accumulates over time.
4. *Monitoring can reduce uncertainty:* The analysis and assessment of monitoring data result in better understanding of system processes and the opportunity to improve management based on that understanding.

5. *There is a sustained commitment to stakeholders*: Stakeholders are actively involved throughout the adaptive management project from the identification of objectives to the recognition of uncertainty and collection and analysis of monitoring data.[19]

3.3.2 Adaptive Management in Climate Change Adaptation

Adaptive management is the process where decision-makers take action in the face of uncertainty. It has always been necessary and will continue to be so in future, given that society makes decisions in the absence of perfect information. Recognising uncertainty does not, however, prevent decisions from being made. Instead, it is a key requirement for appropriately designing adaptive capacity and resilience-related management choices. Only by quantifying and acknowledging uncertainty can society decide how best to manage it. As such, the goal should not be to eliminate uncertainty but to understand its importance in terms of the decision being made. If a decision remains the same despite recognised uncertainties in the evidence which the decision is based on, then no further refinement of the analysis is required.[20] There are three types of uncertainty with regard to managing climate change risks:

1. *Natural uncertainty:* Refers to randomness observed in nature. These types of uncertainties are dealt with by considering a range of different return periods, for example, storm events. This enables an extreme distribution of damages to be calculated as well as EADs, recognising that it is not possible to determine when or where the next major event may occur.
2. *Knowledge uncertainty:* Refers to our state of knowledge of a system and our ability to measure and model it and predict how it might change in the future.
3. *Decision uncertainty:* Refers to a state of doubt about what to do. Understanding how knowledge of uncertainty influences the preferred choices we make, based on our value system and the trade-offs society is prepared to make, is important as it determines the risks we find acceptable, the priority given to social equity and fairness at the

expense of ecosystems and vice versa, how much we are prepared to invest to reduce unknown future risks.

In the face of climate uncertainties, no-regret actions should be taken to maximise positive and minimise negative outcomes of climate change, where no-regret actions are activities and policies that support economic, environmental or social development goals even if climate change impacts never eventuate.[21] Specifically, these actions not only reduce vulnerability to climate change but also generate immediate benefits including improving quality of life, enhancing provision of services and contributing towards the overall resilience of a city while at the same time contributing towards reducing urban flood risks. In most cases a range of no-regret actions can ensure cities:

- Cope with current climate variability; for example, ensuring a well-maintained drainage system.
- Manage non-climate drivers of risk, for example, increasing permeability of urban areas.
- Reduce vulnerability or enhance resilience to shocks.
- Benefit from co-benefits, for example, green urban spaces.

Adaptive management seeks to improve scientific knowledge and develop management practices that consider a range of possible future outcomes and even take advantage of unanticipated events. In the context of climate change, documentation and monitoring of each step and all outcomes advances the scientific understanding of climate change and informs adjustments in policy or operations as part of an iterative learning process. As such, adaptive management is a long-term, structured, iterative process for decision-making aimed at:

- Reducing uncertainty through monitoring and modelling and taking no-regret actions to minimise risk by assessing key vulnerabilities to extreme water levels.
- Addressing climate change uncertainty and extremes.
- Ensuring new regulations have the intended results and can be adjusted if needed; and ensuring decisions being made are based on the best available information.[22]

3.4 Adaptive Management and Natural Resource Management

In the context of natural resource management, adaptive management is the process of hypothesising how ecosystems work, monitoring results, comparing them with expectations and modifying management decisions to achieve conservation objectives. An adaptive management approach deals with uncertainty present in managing ecosystems by treating policies or practices as experiments.

Adaptive management is a tool that enables natural resource managers to evaluate how they are meeting their short-term and long-term natural resource goals. Three main groups benefit from adaptive management in natural resource management. First, natural resource agencies and organisations will be able to provide better information and use resources more efficiently. Improved information will help organisations in their outreach efforts with the community and elected officials; second, the public benefits from an improved natural resource base, and third, natural resources will benefit as better data enables better decisions to be made as corrections or adjustments in project and programme design and implementation can be made early.[23]

Adaptive management can be used to restore or enhance ecosystems damaged by the impacts of urbanisation as the framework is based on the recognition that resource systems are only partially understood and there is value in tracking resource conditions and using what is learned as the resources are being managed. Adaptive management is useful in cases where natural resources are responsive to management, but uncertainty exists about the impacts of management interventions. The application of adaptive management in natural resource management usually includes the following features:

- The natural resource system being managed is dynamic with changes over time that occur in response to environmental conditions and management actions, which themselves vary over time.
- Environmental variation is only partially predictable and is sometimes unrecognised. Variation in environmental conditions includes randomness in ecological processes that in turn leads to unpredictability in system behaviours.

- The resource system is subjected to periodic management interventions that vary over time. Management actions influence resource systems either directly or indirectly.
- Effective management is limited by uncertainty about the nature of resource processes and the influence of management on them. Reducing this uncertainty can lead to improved management.[24]

3.4.1 *The Role of Time in Adaptive Management*

The role of time in adaptive management is important as management, environmental variation, resource status and uncertainty are all expressed over time, which enables management improvements by learning over the course of the management time frame.[25]

3.4.2 *Uncertainty in Natural Resource Management*

Uncertainty is always present in natural resource management and it nearly always limits management effectiveness. There are four types of uncertainty that can influence the management of natural resources:

1. *Environmental variation:* This is the dominant source of uncertainty and it is largely uncontrollable. It often has a dominating effect on natural resource systems through factors including climate variability.
2. *Partial observability:* This is uncertainty about the actual status of a resource.
3. *Partial controllability:* This refers to the difference between outcomes intended by decision-makers and the outcomes that actually occur. This type of uncertainty can arise when indirect means are used to achieve intended outcomes.
4. *Structural or process uncertainty:* This refers to a lack of understanding about the structure of the biophysical processes that control resource dynamics and the influence of management on them.[26]

3.5 Adaptive Management and BGI

In the context of BGI, adaptive management relies on monitoring, investigation and research to build knowledge on waterways and understanding changing environmental conditions, outcomes of management approaches and the effect of climate change.[27] Only relatively recently has adaptive management become a major tool in water resources management. This is due to the increasing rate of complexity in issues and stresses related to water resources management including climate change, increasing populations and urbanisation.[28] Overall, adaptive management strategies should aim to:

- Ensure short-term decisions contribute to long-term objectives.
- Search for pathways with successive decision points in time rather than envisage a final situation at a point in time.
- Seek and value flexibility in individual measures and comprehensive strategies that facilitate either speeding up or slowing down and to prevent either underperformance or overinvestment.
- Aim for synergies with goals and development initiatives by both public and private participants.[29]

3.5.1 Operationalising BGI Using the Adaptive Management Decision-making Framework

Developing BGI in order to increase resilience to climate change and reduce environmental degradation involves implementing an adaptive management decision-making framework that includes planning, designing, implementing and monitoring the design and implementation of BGI to achieve many social, environmental and economic objectives.[30] The components of the framework are summarised in Fig. 3.2.

1. *Developing a plan for implementing BGI*

    - Define a vision that is relevant to the area and commands wide support.
    - Identify the geospatial extent of the project, unconstrained by political or administrative boundaries.

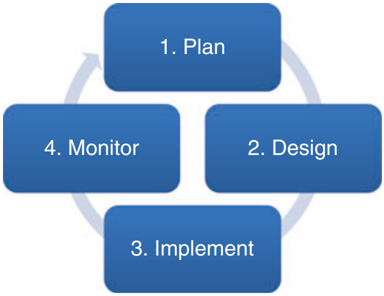

Fig. 3.2 Components of the adaptive management decision-making framework

- Establish cross-cutting steering groups with authoritative leadership and with key stakeholder and community representation.
- Promote collaborative working across political and organisational boundaries, multiple landowners, disciplines and scales.
- Identify multifunctional benefits from existing and potential BGI.
- Identify local issues, challenges, risks and community needs.
- Establish resources required for successful, sustainable implementation and long-term management.

2. *Designing BGI*

- Prepare and communicate a draft strategy, plan or design incorporating the vision and objectives.
- Use responses to refine and improve the plan, strategy or design and its delivery.
- Ensure the plan, strategy or design meets requirements for functionality, durability and beauty.

3. *Implementing BGI*

- Set design and management standards by establishing locally relevant criteria.
- Ensure the provision of adequate funding mechanisms for ongoing management and maintenance costs.
- Build the project in line with the agreed strategy.
- Set milestones, targets and programme.

4. *Managing/maintaining BGI*

 - Regularly compare delivery of the programme against its objectives, using key performance indicators and stakeholder consultation.
 - Deliver aftercare management and supervise maintenance projects.[31]

3.6 Implementing BGI: Fiscal Tools

Cities can use fiscal tools to encourage the implementation of BGI practices on both public and private properties as well as new developments and existing developments (retrofits).[32] Fiscal tools are easy to implement and provide decision-makers with the flexibility and creativity to tailor programmes to specific priorities or to geographic areas in a community. This enables a city to focus its resources and programme efforts on a more manageable scale and can provide the opportunity to pilot new incentives to determine the potential for city-wide application.[33]

3.6.1 Stormwater Fees/Rates

To generate funds to manage stormwater and its impacts some cities have created stormwater fees or rates for residential, industrial and commercial water customers. This mechanism is used to fund the cost of services directly related to the implementation of stormwater programmes. By creating stormwater fees/rates it ensures there is an equitable and transparent relationship between the volume of stormwater generated by a property, the benefit received by the paying customer and the corresponding fee required. The rate structure should reflect property characteristics, for example, property area and relative impervious cover that are directly related to runoff generation. Fees can be added to property tax bills or water bills or take the form of a stand-alone stormwater bill. There are three common stormwater fee or rate structures for customers: (1) a flat fee, (2) a fee based on the size of a property or (3) a tiered rate. Establishing a stormwater fee/rate is considered a viable option for financing BGI as it:

- Is more equitable, linking fee levels to the service benefits payers receive.
- Provides incentives for payers to reduce their fees by installing BGI solutions on their properties.

- Can be dedicated to stormwater services only, removing the need for BGI to compete for funding with other programmes and obligations.
- Can be designed to include tax-exempt properties, for example, schools, hospitals, public properties.[34]

CASE: City of Victoria's New Stormwater Utility Fee
In 2016, the City of Victoria, in Canada, moved from a system whereby stormwater fees were incorporated in property taxes to separate billing. The new stormwater utility fee is a user-pay system that connects the impact a property has on the stormwater system directly to the bill. The computation for each property is based on the following factors:

- *Hard or impervious surfaces:* The roof area has the largest impact on what a customer pays. Building plans, aerial photography and Geographic Information Systems (GIS) technology help determine this area, which also includes driveways and other hard surfaces.
- *Street cleaning:* Keeping the streets clean enhances the city's ability to keep stormwater clean. The length of street frontage on each property has been calculated.
- *Property type:* Properties have been identified as low density (1–4 units), multi-family residential (5 or more units), commercial or civic/institutional.
- *Code of practice programme:* If a property has 10 or more parking spaces, then it will be charged a fee for a programme that works to keep pollutants out of the city's stormwater system.[35]

3.6.2 Stormwater Fee Discounts and Credits

Stormwater utility fee structures often include incentives to encourage BGI retrofits of existing properties and the implementation of BGI in new developments. Fee discounts and credits provide an opportunity for property owners to reduce the amount of stormwater fees they pay by reducing impervious surfaces or by using BGI that reduces the amount of stormwater runoff.

Table 3.1 Framework for establishing stormwater fee discounts and credits

Goal of discount	*Mechanisms for fee reduction*	*Process for implementation*
Reducing impervious surfaces	Percentage fee reduction Per-square-metre credit	Percent reduction in impervious surface Square metre of pervious surfaces
On-site management	Percent fee reduction Quantity/quality credits (performance based)	List of practices associated with credits Total area (square metre) managed
Volume reduction	Percent fee reduction Performance-based quantity reduction	Percent reduction in impervious surface Performance-based Total area (square metre) managed Practices based on pre-assigned performance values
Use of specific practice	Percent fee reduction One-time credit	List of all practices associated with credits

U.S. EPA. 2009. Managing Wet Weather with Green Infrastructure. Municipal Handbook: Incentive Mechanisms. Available: https://www.epa.gov/sites/production/files/2015-10/documents/gi_munichandbook_incentives_0.pdf.

3.6.2.1 Stormwater Fee Discounts

Stormwater fee discounts are usually based on the level of performance where the discount is primarily given for stormwater quantity reductions and at times for pollution reduction for water quality purposes. Discounts are also offered for impervious surface reductions. Table 3.1 provides an outline of common frameworks for setting goals and the process for implementing fee discounts.

3.6.2.2 Stormwater Credits

Stormwater credits are usually based on encouraging BGI practices and goals the city has for private lands, such as installing green roofs.[36]

CASE: City of Waterloo's Stormwater Credit Programme

The City of Waterloo, in Canada, has a stormwater credit programme that rewards customers who have reduced the amount of stormwater runoff from their properties. To receive credits customers must install adopt approved best management practices that include the installation of rain barrels, cisterns, permeable pavement and green roofs, on their property. After approval, the customer will receive a credit on the stormwater fee portion of the water utility invoice. Both residential and non-residential customers can receive discounts of up to 45 percent, based on the type of property and other criteria. Computations for residential properties are based on the amount of runoff captured on the property and diverted from the municipal stormwater management system, while multi-residential and non-residential properties have their stormwater credit calculated on three aspects: quantity control (flood prevention), quality control (pollution reduction) and education programmes for students, employees or the public about flood prevention and pollution reduction.[37]

3.6.3 Development Incentives

Development incentives apply to private property developers who take the initiative in implementing BGI practices. These incentives are usually provided within the framework of existing land use or development regulations and often involve the removing or decreasing of fees, requirements or steps in the permissions process.[38] These incentives can be used to improve environmental performance and support economic development, as well as encourage BGI beyond the site scale by recommending, for example, infill development, aesthetically pleasing walking trails and mixed-use community designs.[39]

CASE: Amsterdam's Subsidy for Green Roofs
Since 2010, Amsterdam has offered a subsidy programme to encourage residents to create green roofs on their properties to filter rainwater and reduce energy costs of heating and air conditioning throughout the year. Residents can apply for a subsidy of EUR 50 per square metre up to a maximum of 50 percent of the total installation costs. A maximum EUR 20,000 subsidy will be awarded for each individual project.[40]

3.6.4 Grants

Grant programmes can be set up to distribute money directly to individual, commercial and other property owners and community groups for BGI projects. Grants can be used to encourage site-specific BGI practices, as well as neighbourhood and municipal scale projects. They are designed to reward homeowners, property owners and developers who take these additional steps.[41]

CASE: Pittsburgh's Green Infrastructure Mini-Grant Programme
Pittsburgh's Water and Sewer Authority's Green Infrastructure Mini-Grant programme is providing grants of $3,000 to $10,000 to non-profit organisations, community organisations and civic groups for projects or activities that will advance the city's objective of attaining compliance with the Clean Water Act of 1972 regarding water quality. The goal of the programme is to support local, grassroots efforts that employ BGI practices to improve water quality, enhance conservation, restore habitat, stimulate economic growth and educate people about stormwater issues and associated stewardship actions. Grants awarded must comply with the following objectives:

- Implement cost-effective projects resulting in measurable water quality improvements.
- Make measurable progress in protecting or improving water resources.
- Provide community environmental education related to stormwater management, water quality or related issues.[42]

3.6.5 Rebates and Installation Financing

Municipalities offer rebates and installation financing to provide incentives for property owners to install a specific range of BGI practices on their property. These rebates and financing options are often targeted at specific areas with the greatest need for BGI, such as those which are prone to flooding. Financing can also be tailored to achieve a range of water quality goals and community-wide initiatives. In addition, financing is also an effective tool for educating the public on the benefits of BGI and how it can be applied to a variety of property types and settings.[43]

CASE: Seattle's Residential RainWise Rebate Programme
RainWise is a programme offered by Seattle Public Utilities and King County Wastewater Treatment Division that provides an incentive for residential customers to install rain gardens and/or cisterns on private properties in parts of Seattle to reduce the amount of polluted runoff entering the combined sewer system. The rebates cover 50–100 percent of the project cost depending on site conditions and customer choices. Currently the programme pays customers $3.50 per square foot of roof area where the runoff is directed into a rain garden. Customers not connected to a rain garden are rebated at a lower rate because they are not efficient. The actual rebate amount for a cistern varies depending on the size and number of cisterns installed.[44]

3.7 Implementing BGI: Non-Fiscal Tools

Cities can implement a variety of non-fiscal tools – voluntary mechanisms – to encourage the development of BGI on public and private land including new developments and retrofits. As non-fiscal tools are less intrusive than fiscal tools, they create less resistance from stakeholder groups and allow policy makers to test and refine programmes that may one day develop into mandatory requirements.[45]

3.7.1 Information and Awareness

Lack of information about site-specific costs, maintenance needs and benefits of BGI can discourage property owners from considering BGI in new developments or retrofits of existing buildings and property. Providing a free consultation can allow property owners who are interested in BGI to overcome their initial uncertainty.[46]

CASE: Sydney's Green Roofs and Walls

In 2014 the City of Sydney approved a Green Roofs and Walls Policy to increase the number of high-quality green roofs and walls in the city. Its municipal website provides an overview of the multiple benefits green roofs and walls provide, as well as links to resources, including an inspiration guide and a resource manual to help guide residents and businesses. Finally, a map is provided of all the green roof and wall projects throughout the city, that informs the public about the projects accessible to them.[47]

3.7.2 Fast Track Project Review

City agencies can implement a fast track project review process for new developments that implement BGI to reduce significant volumes of runoff entering the combined or separate sewer system. This provides project developers with time savings that can translate into financial savings.[48]

CASE: City of Chicago's Green Permits

The Chicago Department of Buildings (DOB) Green Permit Program provides developers and owners with an incentive to build BGI by streamlining the permit process timeline for projects that are designed to conserve resources. It has two elements: the Green Permit Benefit Tier Program and the Green Elements Permit Program. The former offers qualifying projects an expedited permit process and possible reduction of permit fees. The latter also offers projects with BGI, including green roofs, a priority review process. Under the Tier Program commercial projects must earn certification within the Leadership in Energy and Environmental Design (LEED) or Green Globes rating system, while residential projects must earn certification under LEED for Homes or Green Globes rating system. Under the Permit Program projects consisting solely of green roofs, rainwater harvesting systems and other green installations can receive their permits in less than 30 working days.[49]

3.7.3 Pilot and Demonstration Projects

Pilot and demonstration projects can initiate change by showcasing new solutions that can be implemented on a broader scale.[50] BGI projects located in areas of high visibility not only exhibit a local commitment to BGI but also allow residents to experience the benefits of these practices first hand. In addition, these BGI projects provide an opportunity to educate the community about that particular BGI practice while gathering support for future projects.[51]

CASE: Kansas City's Middle Blue River Basin Green Solutions Pilot Project
This is Kansas City's first BGI project to be completed as part of its 25-year combined sewer overflow (CSO) control programme. The Pilot Project allowed the city to examine the effectiveness of BGI solutions in addressing CSOs. It tested a wide range of infrastructure solutions and streetscape improvements throughout the 100-acre area of the Middle Blue River Basin located in the city. Kansas City residents collaborated with design and construction professionals as well as city representatives and local utility companies to maximise the benefits of the project. The project included the installation of permeable pavers, porous sidewalks, rain gardens, vegetated curb extensions and bioretention systems. It has led to improved water quality, reduced peak stormwater volume and flow at the Pilot Area Outlet, increased community green space, traffic calming through curb extensions, and enhanced neighbourhood beautification. The positive results will now be used to effectively install additional BGI solutions throughout Kansas City.[52]

CASE: Sewerage and Water Board of New Orleans' Demonstration Projects
The Sewerage and Water Board of New Orleans (SWB) issued in 2014 and 2015 requests for proposals from qualified environmental professionals to implement a variety of BGI projects that include the installation of demonstration projects as well as education and out-reach. SWB will spend $2.5 million averaged over a 5-year period on these projects, with successful proposers working closely with SWB

representatives throughout the entire process of the project. Proposals to date that have been funded include a green roof project in downtown New Orleans that will perform an analysis of the green roofing system's performance, conduct maintenance of the installation as well as provide a supplemental education curriculum for students and guided tours for community organisations and the public.[53]

3.7.4 Learning Alliances

Learning alliances comprising a variety of stakeholders promote innovation and transfer of knowledge. Meetings with decision-makers can often lead to better coordination of current actions and wider support for new actions. Local media can also contribute by shaping public opinion and knowledge on the role of BGI in cities.[54]

CASE: Seattle Public Utilities Partnering with Communities
Beginning in 2018, Seattle Public Utilities (SPU) will partner with local residents and community organisations to identify areas to build BGI rain gardens along residential streets. SPU's natural drainage system map shows which blocks may be eligible for rain gardens between the sidewalk and the street based on an initial assessment in these areas. A follow-up assessment will be conducted to determine actual feasibility. If a street does not have a sidewalk, one will be constructed as part of the project. To nominate streets for a natural drainage system, community organisations can check the map to make sure it is highlighted as eligible and then email that location to the programme's designated email address.

The programme has made progress. In 2015, blocks were identified and assessed by local residents and community organisations in terms of their potential for natural drainage. The following year SPU staff began to collaborate with residents on specific locations.[55]

3.7.5 Technology Standards

City agencies can directly mandate in the building code that all buildings of a certain type must install BGI (e.g. green roofing) on all or part of their roof. Public and large commercial buildings with flat roofs are usually identified as candidates for this type of regulation. Design specifications may also include, for example, water retention capacity.[56]

CASE: Toronto's Green Roof Bylaw
In 2009, Toronto City Council adopted a Green Roof Bylaw that requires and governs construction of green roofs on new commercial, institutional and many residential developments with a minimum gross floor area of 2,000 m^2, with compliance required for new industrial developments starting in 2012. The green roof coverage requirement is graduated, depending on the size of the building. Table 3.2 shows the requirement ranges as a percent of available roof space, which is defined as the total roof area minus areas designated for renewable energy, private terraces and residential outdoor amenity space (to a maximum of 2 m^2/unit). A tower roof on a building with a floor plate less than 750 m^2 is also excluded from available roof space. In addition, residential buildings less than six storeys or 20 m in height are exempt from being required to have a green roof.[57]

Table 3.2 Size of green roof required under Toronto's Green Roof Bylaw

Gross floor area (size of building) (square metres)	*Coverage of available roof space (size of green roof) (percentage)*
2,000–4,999	20
5,000–9,999	30
10,000–14,999	40
15,000–19,999	50
20,000 or greater	60

City of Toronto. 2016a. Green Roofs. Available: http://www1.toronto.ca/wps/portal/contentonly?vgnextoid=3a7a036318061410VgnVCM10000071d60f89RCRD.

3.7.6 Performance Standards

Cities often identify sections of their city or areas of new development that are to be bound by tighter environmental controls. For example, they may mandate that new developments implement strict stormwater management controls or develop urban greening spaces.[58]

CASE: Toronto's Mandatory Downspout Disconnection Bylaw
Toronto City Council has passed a bylaw that makes it mandatory for all property owners (residential, industrial, institutional and commercial) to disconnect their downspouts. It is to be implemented over three phases based on location in the city, with property owners able to check when they are required to disconnect by consulting a map on Toronto Water's website by entering their address.[59]

3.7.7 Awards and Recognition Programmes

Awards and recognition programmes highlight successful examples of BGI in the community. Award winners can include individuals, schools or community organisations, including non-profits as well as property owners and businesses. Awards are provided to recognise innovative BGI practices that could include plans or projects that focus on water conservation and reuse, stormwater mitigation and management, flood protection or waterway restorations. Overall, awards raise public awareness on local BGI projects and encourage others to follow suit.[60]

CASE: Kansas City's KC Green Neighborhood Recognition Program
In April 2016 Kansas City announced a call for nominations for its KC Green Neighborhood Recognition Program as part of an initiative that aims to incorporate green programs into a broader triple bottom line approach that simultaneously promotes social equity, economic vitality and environmental quality. This programme recognises registered neighbourhoods that have broadly implemented sustainable practices including managing stormwater runoff. Neighbourhoods selected for recognition receive neighbourhood signage, acknowledgement of their efforts in city publications and

on the city's cable channel, access to various sustainability workshops and an eco- gift to help them continue their neighbourhood's progress towards sustainability.[61,62]

3.7.8 *Leading by Example*

Municipalities can lead by example in showcasing the range of BGI innovations that justify incentives and mandates. These investments can familiarise planning, zoning and public works staff as well as the private sector with the installation, maintenance and best practice techniques of BGI.[63]

CASE: Milwaukee's BaseTern Stormwater Catchment Pilot Programme
The BaseTern programme is an innovative and cost-effective approach to managing stormwater runoff that also helps neighbourhoods become more resilient to extreme stormwater events. BaseTerns are underground stormwater management or rainwater harvesting structures that have been created from basements of former houses that have been slated for demolition. Vacant, city-owned foreclosures located in neighbourhoods with high prevalence of localised flooding are evaluated for the programme. Razed houses located in these areas will have their basement utilised as a cistern. Porous fill material, including coarse gravel and stormwater harvesting cells, is inserted into the basement void space along with the installation of a permeable layer of soil to cover up the system and provide public safety. Depending on the size of the foundation structure and porosity of any infill used, these basements can hold up to 30,000 gallons of water.[64]

3.7.9 *Education*

Direct education of the community on stormwater risks and BGI solutions is critical, as many property owners will become stewards of the BGI system.[65]

CASE: City of Lancaster's Schoolyard Habitat Program

The Lancaster County Conservancy and City of Lancaster in Pennsylvania are partnering with Hand Middle School to assist in developing BGI that will capture stormwater while educating youth in the school and throughout the community on environmental issues. The Schoolyard Habitat Program aims to create a natural space for human and non-human life to enjoy. The space will provide students with an opportunity to experience nature observation and cross-curricular learning. The overall aims of the Schoolyard Habitat Program are to:

- Increase ecological literacy amongst urban youth.
- Increase the diversity of habitat space in an urban environment while mitigating stormwater runoff.
- Supply a nutritional source of food for the youth and their families.[66]

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CHAPTER 4

Copenhagen Becoming a Blue-Green City

4.1 Introduction

In Copenhagen, wastewater from households and businesses is managed in closed pipes underground. The majority of the city has a combined sewer system where stormwater from roads and household wastewater is discharged for treatment in the city's central treatment plants. A separate sewer system only exists in part of the city close to the port. Wastewater is treated at the Lynetten and Damhusåen treatment plants through mechanical, biological and chemical processes before being discharged to Øresund through 1.5- and 1.2-km- long outfall sewers with diffusers that ensure the treated wastewater is well mixed with sea water.[1]

The sewers are designed so that, statistically, overflows only occur once every 10 years in the combined system, while the separate system is designed to overflow once every five years.[2] To reduce combined sewer overflows (CSOs) Copenhagen has been building reservoirs, which has resulted in the number of CSOs declining from 20–70 overflows per year to 2–6 per year. This has seen the discharge volume to the port being reduced from 1.6 million m^3 per year to less than 300,000 m^3 per year.

R.C. Brears, *Blue and Green Cities*,
https://doi.org/10.1057/978-1-137-59258-3_4

4.2 Challenges to Traditional Stormwater Infrastructure

Copenhagen faces multiple challenges to its traditional stormwater infrastructure from climate change and rapid urbanisation and population growth.

4.2.1 *Climate Change: More and Heavier Rainfall*

Meteorologists predict that precipitation in Copenhagen will increase by 25–55 percent during the winter and decrease by up to 40 percent in the summer. The heavy downpours that typically occur in late summer, often accompanied by thunder, will become 30 to 40 percent heavier while at the same time there will be longer periods of drought between them. Heavy summer rain will create more extensive floods resulting in flooded cellars and streets. Even though the sewer system is large, its capacity is limited, resulting in the potential for flooding in the future. The City Council has decreed that water must only flood in this way once every 10 years on average. At present, the sewers meet this requirement, but they will not be able to meet a future increase of the order of 30–40 percent.

4.2.2 *Rapid Urbanisation and Population Growth*

Copenhagen's population is expected to increase over the coming decades, from 583,000 in 2015 to 715,000 in 2030 and 755,000 in 2040. As a result, the city will increase its urban area by an additional 5,000 ha over the next 30 years.[3]

4.3 Strategic Vision: Copenhagen's Climate Adaptation plan

Copenhagen's Climate Adaptation Plan (CAP) assesses which climate change challenges are greatest and where the city can derive the greatest benefits by taking action now and in the coming years. Copenhagen's strategy is to choose initiatives that prevent damage, including expanding the sewers' capacity to reduce the risks from flooding. However, if these strategies are too expensive or technically challenging, initiatives that minimise the extent of the damage will be prioritised, for example, adapting areas where rainwater can be stored.[4]

4.3.1 Securing Copenhagen from Heavy Rainfall in the Future

With Copenhagen facing more frequent and serious floods in the future, the CAP calls for three methods that must be used to adapt to heavier rainfall. It may be necessary in some parts of the city to implement a combination of the methods depending on local conditions:

1. *Increasing the capacity of sewers, underground basins and pumping stations:* Copenhagen's current system is reaching capacity in dealing with heavy rainfall and so new drains need to be laid to provide extra capacity. However, it will cost DKK 10–15 billion if they are laid out across the city, in addition to a DKK 3–5 billion outlay to separate rain from wastewater in individual dwellings. As such, the city will focus on method 2 in all places where it is possible.
2. *Managing rainfall locally instead of guiding it to sewers:* Traditionally, rainwater is considered by society as something to be got rid of. However, water is a resource and can be used to make the city a better place to live in. This can be achieved by managing rainwater locally through low-tech Blue-Green Infrastructure (BGI) solutions that can absorb rainwater and purify it. By managing rainwater where it falls, the city can minimise the amount of rainwater entering the sewer system, reducing the need for excavating and laying down larger capacity sewer pipes. This method can be achieved by investing DKK 5 billion and therefore is less expensive than method 1. It will be adopted throughout the whole city, not only where rainwater leads to obvious problems.
3. *Ensuring flooding takes place only where it does least damage:* In the future, water in the streets and squares will become more common with heavier rainfall. Currently, heavy rainfall halts traffic and floods cellars. However, rainwater can be guided to places where it does no damage, such as playing fields and parks, though this method is only relevant in areas where the floods start.

Overall, rainwater will be managed locally throughout the city to reduce pressure on the sewer system. During heavy rain events water will be channelled to areas where it causes no damage.

4.3.2 *Multiple Benefits of the Climate Adaptation Plan*

The CAP aims to show that adaptation is not a negative measure to manage excess stormwater from cloudburst events, but instead one that provides significant benefits. These include increased recreational areas and quality of life for Copenhagen residents; increased synergies with current green infrastructure – including private gardens, backyards, allotments, public parks, areas of nature, green sports fields, lakes, rivers and streams – found in the city (Table 4.1), and increased biodiversity and economic benefits (Table 4.2). The specific benefits of implementing BGI to adapt to climate change include:

- *Reduction of atmospheric pollution:* Shrubs and trees help remove pollutants from the air.
- *Added real estate value:* Urban green areas have a beneficial impact on housing prices (around 1 percent per hectare of urban green space).
- *Increased yield from real estate taxes:* Higher property prices and land values increase the real estate tax collected by the city.

Table 4.1 BGI creating synergies with existing green infrastructure

Focus	*Description*
Preserve and care for existing green areas	BGI will contribute to climate adaptation of the city as well as highlight the identity of individual sites and offer interesting and valuable experiences and activities to citizens
Supplement the city with more green and blue spaces	Trees, green roofs, water gardens, underground basins, etc., can contribute to the climate adaptation while revitalising schools, institutions, backyards, public spaces, streets and neighbourhoods at the same time
Create coherent green networks	A coherent green network can consist of trees, green roofs and façades, and gardens. Meanwhile, a city-wide coherent green network connects green spaces and blue areas creating attractive links between citizens and the environment while contributing to the local dissipation of rainwater and improving the urban climate

City of Copenhagen. 2011. Copenhagen Climate Adaptation Plan. Available: http://en.klimatilpasning.dk/media/568851/copenhagen_adaption_plan.pdf.

Table 4.2 Economic benefits of climate adaptation measures

Socio-economic benefit	*Year benefit (EUR millions)*	*Total benefit (net present value) (EUR millions)*
Reduction of atmospheric pollution	0.8	21
Added real estate value	–	149
Increased yield from real estate taxes	5.1	110
Real estate taxes adding socio-economic benefits	1.9	42
Saved damages	16	338
Total	23.8	660

City of Copenhagen. 2013. The Copenhagen Case. Available: http://www.deltacities.com/documents/presentations/07CopenhagenCloudburstJune2013.pdf.

- *Real estate taxes adding socio-economic benefits:* Increased real estate taxes due to greener urban spaces increase socio-economic benefits through a multiplier effect.
- *Financial savings consequent on reduced flood damage:* Reducing and preventing stormwater flooding by absorbing and holding rainwater.

Additional benefits include:

- *Reduced urban heat island effects:* Moderating and balancing temperature by providing shade and improved air circulation, which reduces the city's future energy demand for cooling buildings.
- *Healthier lifestyles:* Preventing stress by encouraging a healthier lifestyle through improved recreational opportunities.
- *Improved habitats:* Providing a habitat for animals and plants.

4.3.3 The Cloudburst Management Plan

The Cloudburst Management Plan (CMP) is an offshoot of the CAP. The CMP outlines the methods, priorities and measures recommended to adapt to climate change, including extreme rainfall. The plan will constitute the basis for the implementation of mitigation efforts in

Copenhagen and form part of the general City Administration planning. It is estimated that the CMP will take around 20 years to implement, as initiatives need to be launched in the City Administration area as well as several neighbouring local authorities. In addition, a partnership approach, including the City Administration, utility companies and the people of Copenhagen, is required to 'action' the plan.

4.3.3.1 Becoming Resilient to Extreme Rainfall

The CMP recommends that Copenhagen achieve a level of resilience that limits potentially damaging floods from extreme rainfall – defined as water levels reaching 10 cm – to once every 100 years. Currently, the city's sewer system is only required to handle 10-year rainfall events and so no system is in place to handle extensive flooding from an extreme rainfall event. As such, the plan recommends that Copenhagen reduce sewer discharge reaching ground level to once every 10 years and average water levels exceeding ground level by 10 cm once every 100 years, except for areas designated for flood control storage.[5] To do so requires the city to:

- *Plan and invest in adaptive action* that simultaneously protects the city from pluvial flooding and relieves the pressure on surface drains on all other days with precipitation.
- *Combine solutions that make the city more green and blue* by draining off rainwater at ground level with tunnels used in parts of the city where no opportunities exist for drainage solely at ground level.
- *Prioritise the implementation of adaptive measures* by considering the risk of flooding and scope for synergies with other infrastructure projects, for example, road renovation and urban development.

4.3.3.2 Adapting to Extreme Rainfall: Draining Excessive Stormwater Out to Sea

Originally the CAP recommended that rainwater from extreme rainfall events be managed locally or directed to places where the flooding would cause minimum disruption, for example, parks, sports grounds and open spaces. However, recent extreme events have shown these methods to be inadequate in preventing surface flooding in large parts of the city and so four extra-large cloudburst pipes will be constructed to ensure any excess water is conveyed to the harbour. As such, the CMP will combine measures that make the city more green and blue by draining stormwater at ground level with tunnels in areas where ground-level drainage is not possible.

4.3.3.3 Prioritising Cloudburst Management Measures

Because Copenhagen lacks both the capacity and financial resources to implement BGI measures across the city over the short term, the CMP will be implemented over a minimum period of 20 years. To prioritise which solutions and measures will be implemented over this period, Copenhagen has been divided into seven catchment areas (further subdivided into over 50 cloudburst branches or 'sub-catchments'), with each catchment area having a detailed plan on how to manage cloudbursts. A catchment area is an area where all precipitation will flow along the same route during extreme rainfall events, with ground level variation determining which way it will flow. However, in a city, built-up areas redirect flows, and these routes taken by the water are known as flow routes.

To prioritise which BGI initiatives go ahead, each water catchment and sub- catchment area is assessed per the four elements of risk, implementation, coherence and synergy. Specifically, adaptation initiatives in catchment areas are ranked in order of priority, based on a series of elements including:

- *High-risk areas:* A risk analysis is prepared with a risk map pinpointing the city areas with the highest risk of flooding (expressed in DKK) and consequently where adaptation measures will have the greatest effect.
- *Areas where measures are easy to implement:* Areas where, by applying simple measures, surface water can be drained to localities where it will not have any impact. These areas are close to the harbour where pluvial flood projects were carried out in 2012, in which openings in the quay were made allowing rainwater to drain out into the harbour.
- *Areas with ongoing urban development projects:* The costs of reducing surface flooding can be reduced significantly if projects are implemented in conjunction with other urban development projects, for example, road renovations.
- *Areas where synergies can be achieved:* Synergies can be gained by combining flood risk initiatives with those of other urban schemes such as local water quality directives.

Table 4.3 Economic consequences of floods

Scenario	*Costs (DKK million)*	*Remarks*
2010 20-year rain event	2,039	
2010 100-year rain event	4,548	
2011 20-year rain event	4,548	Without climate adaptation
2011 100-year rain event	5,625	Without climate adaptation

City of Copenhagen. 2011. Copenhagen Climate Adaptation Plan. Available: http://en.klimatilpasning.dk/media/568851/copenhagen_adaption_plan.pdf.

The result is that action will be given highest priority in areas with a high flood risk where measures are easy to implement and will achieve synergy with other urban development projects or planning.

4.3.3.4 Costs of Implementing BGI in Copenhagen

The estimated construction costs of BGI up to 2033 amount to a total of DKK 3.8 billion. However, this amount pales in comparison to the economic consequences of various flooding events where costs include loss of earnings, delays and expenditures on renovation of basements/ground floors, replacement of furniture, etc. (Table 4.3).

4.3.3.5 Breakdown of Cloudburst Management Plan Costs

The estimated costs of implementing the CMP over the 20-year period have been broken down into three intervals: 2013–2016, 2016–2025 and 2026–2033. Measures that are easy to implement and those able to drain

Table 4.4 Breakdown of investment costs

Type	*2013–2016*	*2016–2025*	*2026–2033*	*Total investments (DKK million)*
Private measures against surface flooding	0.2	1.0	1.2	2.4
Revenues from charges for adaptive measures	0.5	1.8	2.2	4.5
Municipal share	0.1	0.4	0.4	0.9

City of Copenhagen. 2012. Cloudburst Management Plan. Available: http://www.deltacities.com/documents/WEB_UK_2013_skybrudsplan.pdf.

Table 4.5 Method of financing the Cloudburst Management Plan

Method of financing	*Description*	*Capital costs*
Private financing	Homeowners paying for flood protection measures; for example, installation of anti-flood backflow valves that block the drain if flood water is pressured back through the service pipe	Approximately DKK 1.2 billion
Financing by charge revenues	The majority of adaptive measures will be financed by the revenues collected from the utility company	If the city is protected against a 100-year event including the implementation of combined measures, it will cost approximately DKK 2.2 billion
Financing by taxes	Adaptive measures carried out at ground level, and combined with green and recreational solutions, must be financed by municipal tax revenues if they exceed the limit imposed by financing via revenues from charges	Measures will amount to DKK 400 million

City of Copenhagen. 2012. Cloudburst Management Plan. Available: http://www.deltacities.com/documents/WEB_UK_2013_skybrudsplan.pdf.

the largest volumes of water and therefore limit most incidences of surface flooding are expected to be implemented during the first two investment periods (Table 4.4).

4.3.3.6 Financing of the Cloudburst Management Plan

The CMP will be financed by a combination of private and public investments. In particular, public investments will come from city taxes and revenue from HOFOR's drainage charges, while private investments will come from homeowners and businesses (Table 4.5).

4.3.3.7 Allocating Responsibility for Implementing the Cloudburst Management Plan

To make the city more resilient to extreme rainfall events and surface flooding, the CMP requires actions by three players: property owners, the utility company and the City Administration. Property owners are responsible for flood-proofing their properties on privately-owned land.

This may involve, for example, protecting basements from flooding by using anti-flood backflow valves or raising the height of basement entrances. The utility company is responsible for ensuring drainage systems meet adequate service levels; that is, an average occurrence of one sewer discharge to ground level is permitted per 10 years. The plan will also allocate responsibility to the utility company for implementing adaptive measures. Meanwhile, the City Administration, as the urban planning authority and owner of the utility company, is responsible for ensuring that adaptive measures are incorporated into municipal master plans and implemented. The City Administration is also responsible for climate adaptation/redirection of waterways.[6]

4.4 Implementing BGI: From the Cloudburst Management Plan to 300 Projects

Three hundred specific BGI projects have been selected for implementation across the city's seven catchments and 50 sub-catchment areas to relieve the pressure on the sewer network and protect the cultural heritage and homes of the people of Copenhagen and commercial properties against floodwater, as well as reduce other climate change-related challenges (e.g. the urban heat island effect). In addition, the projects will contribute towards preserving the city's existing green areas, increasing the number of green and blue surfaces, and creating a coherent green network in the city.[7]

However, not all 300 projects can be started at once due to mainly financial constraints. The City Administration will make an annual selection of the projects that are to be started in the seven water catchment areas. When a project is selected it will be developed in cooperation with the citizens and a budget memorandum will be prepared if the project includes urban space improvements. The selection of projects will be made on the basis of an annual climate change adaptation statement and proposals for project packages for individual water catchment areas. In deciding between the 300 projects, the city has established the following priorities:

- Design the large pipes so that they are fit for purpose from day one.
- Pick 'low-hanging fruit' and search for simple solutions.
- Establish retention spaces and retention roads that will be effective immediately.

- Find urban space improvements and present proposals for these.
- Systematically classify and apply the same design solution and method to all the projects.[8]

4.4.1 *The 300 Cloudburst Projects*

The hydraulic function is the decisive factor in determining the location for each of the cloudburst projects. Once the catchment areas were defined and plans made for each, the whole plan was reviewed. One of the main outcomes of the review was the realisation that at times excess stormwater can be channelled from one catchment to another efficiently. As such, Copenhagen will simultaneously implement the cloudburst projects both upstream, to store and delay excess water, and downstream, to discharge excess stormwater into the harbour or streams. Finally, it will implement cloudburst projects that connect the upstream and downstream projects, for example, cloudburst boulevards (BGI green streets that have not been included as part of the 300 projects). This will ensure the city does not simply move a problem from one area to another. Once all the cloudburst projects have been implemented, Copenhagen should have a city-wide connected system that can handle a 100-year storm at any given time.

4.4.2 *Interlinking BGI Projects with Urban Development*

When the prioritised project is selected it will also ensure cloudburst management is interlinked with urban development in Copenhagen. This interlinking ensures that all the projects give the city a boost and that they become cheaper as cloudburst management is applied in places where construction projects have already begun. Moving forwards, this will mean cloudburst management will partly take place in conjunction with stream conversion and road restoration in Copenhagen. Finally, urban renewal projects will include cloudburst management in their planning.[9]

4.4.3 *Cloudburst Project Types*

Overall, the cloudburst projects can be aggregated into four types of climate adaptation solutions:

- *Cloudburst roads:* These roads are designed to direct rain towards lakes or the harbour. They are established by, for example, re-profiling the road, making changes to terrain or raising the curb. Generally, no green elements are incorporated into a cloudburst road.
- *Retention roads:* These roads are designed to store and delay the water from cloudburst events. This is achieved by integrating various retention elements into the road, including roadside and rain beds. In addition, the roads can incorporate urban space improvements through the use of green and blue elements.
- *Retention spaces:* These are open spaces intended to store large volumes of water. They can be designed as multifunctional urban spaces including parking spaces, squares and sports fields.
- *Green roads:* These roads retain and store water locally. This solution is mainly used on smaller roads, for example, private shared roads.

The solutions have different hydraulic characteristics but all can be designed to conform with local needs and make improvements to urban spaces; therefore, the solutions can be combined in specific projects.[10]

4.4.4 Cooperation Between Stakeholders

The process of cooperation between the City Administration departments on BGI and between the city and HOFOR is an ongoing process. HOFOR's work is increasingly becoming visible across the city. Previously, it was hidden away from public view as it involved digging beneath the streets to replace pipes. Now, HOFOR is visible in the streets implementing BGI as well as having to follow regulations that differ from those it is usually obliged to adhere to. In addition, the utility is now dealing with a variety of issues that were formerly outside its remit, such as ensuring adequate car parking spaces when constructing BGI.

4.4.5 Changing Organisational Culture

Implementing BGI has been a challenge for the city's water quality regulators too, as they need to balance protecting the citizens against flooding and protecting the environmental qualities in the city. As such, the process of implementing BGI is an ongoing learning process as it involves people from different departments and agencies having to work together to arrive at the correct, or best possible, solution to a problem. Hitherto, the department responsible for maintaining water quality has considered applications for work that will disturb the environment based on the usual criteria; however, with BGI, some of the applications require innovative thinking, with staff now having to say ‘Okay, this is not a good idea but if we do it like this it may work.’ This change in mindset has been a challenge in the work culture and mentality for many people in the city: as such it’s an ongoing learning process. The key to ensuring this process works out in the long run is that the staff in these departments have a strong backup from both the politicians and management to implement challenging BGI solutions, with the management in particular essentially saying ‘Okay, it is extremely important that we work with these cloudburst measures and it’s the backbone of the physical development in the city.’

4.4.6 Training Staff in the Implementation of BGI

Currently, Copenhagen has very limited references on how best to maintain BGI across the city. To increase knowledge, the city, in addition to running its own training courses for employees, learns from other cities that have implemented and maintained BGI for a longer period of time. For instance Copenhagen has studied similar-sized cities in the United States, including Portland and Seattle, evaluating how successfully their BGI measures have managed excess stormwater and how often the infrastructure requires maintenance to remain hydraulically effective. In addition, the city conducts research with local universities on various aspects of BGI. Overall, the learning process on how to effectively implement and maintain BGI across Copenhagen will be ongoing over the next 20 years. Through a process of experimentation the city will, over time, test which solutions are best when it comes to implementing and maintaining BGI, with the goal of becoming as efficient as possible.

4.4.7 Maintenance-Related Learning

HOFOR is responsible for financing the maintenance of BGI, including cleaning up after cloudburst events, for instance, restoring a park after it has retained water during a storm. The city needs to ensure BGI is maintained at sufficient standards as it has a clear hydraulic function. The first concern is the choice of plants and the general maintenance of parks that incorporate BGI, as flooding takes a significant toll on them over time. Second, there is the issue of running costs: will BGI be more expensive for the city to maintain than traditional infrastructure? Rather than BGI being a 'nice-to-have' component of managing excess stormwater, it is an essential component of the CMP; there are, therefore, constant discussions on balancing the costs and benefits of ensuring they function well. In addition, there is a cultural learning process for the city's maintenance people regarding maintaining BGI, as it is different from maintaining traditional grey infrastructure. It will take time for them to fully understand BGI and for it to become part of the utility's working culture.

4.5 Implementing BGI: Fiscal Tools

Copenhagen does not provide rebates or grants for the installing of BGI on private property as this comes under the jurisdiction of the national government. However, the city is in dialogue with the government on the city's BGI experiences to date, with the aim of influencing changes in legislation to facilitate an increased uptake of BGI. In addition, because implementing BGI is new for cities and municipalities in Denmark, Copenhagen believes that over time it will lead to changes in the national legislation on how local governments can incentivise the uptake of BGI as currently there are very limited possibilities for them to do so. This is why, as already mentioned, Copenhagen is looking at other cities implementing BGI, in order to provide the national government with information about best practices that will help it work out the best means of mainstreaming BGI.

4.6 Implementing BGI: Non-fiscal Tools

Copenhagen uses a variety of non-fiscal tools, including mandating green roofs and exploring the possibilities of mandating the disconnection of downspouts; it is also looking into developing partnerships with various stakeholders and engaging with the community on BGI.

4.6.1 Mandating Green Roofs

Since 2010, Copenhagen has mandated green roofs in new local plans to adapt to climate change, enhance biodiversity and create a greener city.

They can absorb between 50 and 80 percent of annual rainfall, delay water entering the sewer system, reduce the urban heat island effect in built-up areas and provide habitats for animals and plants. The city will not rely on green roofs alone when it comes to cloudburst events. The reasoning is that when green roofs are saturated they can only manage a small amount of additional water.

4.6.2 Mandating the Disconnection of Downspouts

Copenhagen will, in due course, mandate the disconnection of downspouts to reduce the volume of stormwater entering the city's sewer system. Its analysis has shown that it is both economically and technologically efficient to disconnect much of the stormwater that falls on private property from the main system. However, before any type of regulation can be enacted, the citizens will need to be given a long period of notice, as requested by politicians; districts will be given at least 5 years' advance notice of disconnection. This should provide residents with enough lead-time to figure out what they will do and how they will actually finance the disconnection because they will bear the expense themselves. Copenhagen has seen from examples across Denmark that there is a lot of resistance from citizens required to meet the cost of expensive measures with only six months' warning. In addition, the city will aim to work with the local communities on increasing their understanding of how disconnections can also improve the quality of their streets by making them greener and more attractive.

4.6.3 Public–Private Partnership

The city hires consultants – architects and engineers – to implement the BGI projects; however, they frequently attempt to revise the catchment plans instead of devising how a BGI square or street can handle X volume of water at a given time. In particular, the consultants often start analysing the catchment area as a whole and suggest smarter ways of implementing BGI. However, because the whole catchment plan is interconnected it would require recalculations of each individual catchment area every time a project was modified. This would be extremely time-consuming and expensive.

4.6.4 Public Agency–Utility Cooperation

There is a department that oversees the permissions process with regard to roads and infrastructure construction. This office has to agree with HOFOR that the BGI measures that need implementing will, for instance, not be too disruptive to traffic: to limit disruptions the city ensures that as part of the maintenance process BGI will be installed to increase efficiency and reduce the impact on local residents. In addition, the City Administration also has an office working on water quality regulations, ensuring that BGI does not lower the quality of the city's waterways and harbour.

4.6.5 Lobbying Central Government/Financing BGI

Copenhagen has hitherto been successful in modifying the national legislation so that it can finance the implementation of surface BGI measures using the water fee that citizens are paying to the utilities for water services (because that was not possible under previous legislation). Nonetheless, the city recognises that the argument for modifying legislation has to be convincing in that the city is not simply trying to transfer municipal responsibilities to the utilities but also shift the financial burden to them. In fact, in Denmark there are very strict controls enforced by the Danish Competition and Consumer Authority, ensuring that utilities are not using their water fees to perform tasks outside of their jurisdiction. However, there is a city–utility jurisdiction divide that can hamper the implementation of BGI; for instance, cloudburst boulevards are 99 percent of the time normal streets used by cars, cyclists and pedestrians. However, for a limited period of time during a cloudburst they will actually become part of the water infrastructure in the city. Therefore, a number of questions remain to be addressed, including how the city actually regulates the construction costs, how much of these costs can be added to the utility's customer bills, and how much the city will, at the end of the day, have to pay.

4.6.6 Community Engagement to Maximise Social Benefits

Despite the social benefits of BGI being recognised as very important, the issue is that the city selects its BGI projects based on their hydraulic potential in managing cloudbursts. Nonetheless, the city does recognise that when it implements a BGI project, for example, storing or transporting water across a square, there are many social issues that need to be accounted for. These include: (1) whether the project is located in a neighbourhood in need of regeneration; (2) whether the city can work with the neighbourhood in developing the project; (3) whether particular social or cultural aspects need to be incorporated in the project; and (4) whether any natural qualities could be added to the project to enhance the liveability of the area to the benefit of the residents. As such, the city invites residents of neighbourhoods to suggest how the cloudburst management projects located in their neighbourhood might look and what additional activities can be included in the project.

4.7 Implementing BGI: Examples

Copenhagen has initiated and facilitated the implementation of a variety of BGI projects on both public and privately owned land, including green roofs, large-scale rainwater harvesting systems, green roads, green public spaces, a green shopping district, a climate-resilient neighbourhood and a blue harbour.

4.7.1 Green Roofs

The new National Archives building, constructed in 2009, incorporates a green roof garden that directs all the precipitation water through the growth media and reservoir plates before the excess water reaches the drainage system. Up to 70 percent of precipitation is held back per annum. The roof thereby provides a landscape and publicly accessible garden in an area of Copenhagen (Kalvebrod Brygge, in the district of Vesterbro) that is characterised by large buildings with an industrial focus. The roof garden will in the future be part of an elevated pedestrian passage accessible to the public that will connect two areas in the centre of the city in addition to offering a quiet place to relax in.[11]

A pilot project that is part of Copenhagen's Building Renewal programme has installed a green roof on Norrebrogade 184 to increase biodiversity locally, reduce water runoff and create an aesthetically pleasing view for residents in neighbouring buildings. The project provides a platform for further research on how to incorporate a biodiverse green roof on existing roofs and how to incorporate it into a historic heritage building.[12]

4.7.2 Large-Scale Rainwater Harvesting

The construction of a 115,000 m^2 commercial space in Kalvebod Brygge will incorporate, beneath the landscape, car parks, services and rainwater reservoirs. The space will include an urban park and landscape that varies in urbanity and intensity of vegetation. Kalvebod Park will create a green oasis for employees and for the inhabitants of Vesterbro to use in their spare time. It will also create a green corridor connecting two separate areas of the city that is accessible to the public, enabling them to walk and cycle along it. Local rainwater from the buildings and park will be absorbed or collected and reused. The inclusion of holding tanks will enable the site to store and delay excess water from both the surrounding areas and the development, minimising the overloading of the sewerage system during heavy rain events.[13]

4.7.3 Green Roads

Copenhagen is testing the use of curb extensions next to roads to manage large volumes of water during heavy rainfall events and reduce the amount of heavy metals that end up in the city's waterways. The city, in partnership with the utility company, universities and private companies, has begun testing four curb extensions that employ a soil filter and soakaways underneath the curb extensions (or road beds). The curb extensions, 8 m in length, consist of a special soil filter that absorbs heavy metals and organic materials. As it exits the soil filter, the water seeps into an underground soakaway where it will then gradually leach down into groundwater. The system has a regulator in which water from mild rain events is directed into the sewer while during heavy downpours water is stored by the curb extension. However, installation of the extension requires digging large holes in densely inhabited urban areas and the design has to ensure that residents and traffic can access the road unhindered by the extension.[14]

4.7.4 Green Public Spaces

Copenhagen has developed a variety of green public spaces that have incorporated BGI, including St. Anne Square, several park renewal schemes and the development of a multifunctional skatepark.

4.7.4.1 St. Ann Square

The four-year renovation of St. Ann Square, in the historic part of Copenhagen, was completed in 2016. It was designed to create a green area with the capacity to hold 21 million litres of water. Together with new underground 'rainpipes' the square can now cope with 2,100 l of rain a second. The challenge of renovating the historic square was to combine the aesthetics of the historical location with a new recreational area and climate adaptation measures for heavy rainfall events. Not only does the square have to function as a water channel but also be a high-quality urban space. As such, the renovation had to incorporate the demands of the citizens, respect for the historic area and the requirements of a functional drainage solution during heavy rain events.[15]

4.7.4.2 The Renewal of Enghave Park

The renewal of Enghave Park aims to combine Vesterbro's modern outdoor life and the park's existing structure with the need to reinforce Vesterbro's resilience to extreme weather events. Rainwater will be managed on paved surfaces and in a closed underground reservoir or by (in the case of extreme rain) establishing dykes in the park's three lowest sides. The park's proposed rainwater solutions will be able to handle 24,000 m^3 of water. It will also be a place of food cultivation with the establishment of allotments.[16]

4.7.4.3 The Renewal of Fredens Park

Fredens Park's urban nature has been restored to create a single unregulated wetland with surrounding meadows. Rainwater management takes place by both detaining and directing rainwater through a series of hollows. When percolation is not possible the water is collected in the last hollow towards the lakes, from which the water is cleaned and discharged into Sortedams Sø.[17]

4.7.4.4 The Musicon Skatepark

A large skatepark – Musicon – has been built which during cloudbursts serves as a reservoir for rainwater directed from the surrounding area.[18]

4.7.5 Green Shopping District

In 2012, it was decided that Amagerbrogade, the main street in the Amager Shopping Centre, Copenhagen, needed renovation. The objective was to provide better conditions for pedestrians, cyclists and buses, as well as for businesses and residents. Although greener streets were high on many people's priorities, it was not part of the plan as the street was too busy and congested. This was until the CMP required the securing of the whole district against future cloudbursts. As a result, the renovation project was combined with the CMP. One of the ideas involves lowering part of the road so it can collect rainwater and lead it into a green area, 'Stadsgraven', nearby. This also enables a design where drains underneath the surface can be integrated to channel water to the roots of the trees during normal rainfall. The street will also be designed to handle a 100-year rain event.[19]

4.7.6 Climate-Resilient Neighbourhood

In 2012, St. Kjeld became Copenhagen's first climate-resilient neighbourhood ('Klimakvater' in Danish), having previously been selected as a showcase for climate adaptation in the city. One of the main reasons for selection is that the area has wide streets and large asphalt-covered surfaces. The plan is for 20 percent of the covered surface area to be converted into into a green area and that 30 percent of the daily rainfall should be managed locally rather than ending up in the sewer system.

4.7.6.1 St. Kjeld's Square: Green Heart of the Neighbourhood

Currently, St. Kjeld's Square is a large roundabout that is 13 m wide: three times as wide as traffic actually requires. The plan is for the square to become the 'green heart' of the neighbourhood. At 8,000 m^2 the square has the potential to be a leading example of urban climate adaptation for Copenhagen and other cities around the world.

4.7.6.2 The Tåsinge Plads Central Square

One of the main features of the neighbourhood is Tåsinge Plads, a central square that has been sloped so that the lower part collects rainwater which then seeps into the ground. At a cost of DKK 16 million, Tåsinge Plads has been transformed from 2,000 m^2 of concrete into a 'green oasis', with rainwater becoming a resource for lush flora. The roads and pavements of the neighbourhood have been remodelled with water collection systems above and below ground, while green roofs and green gardens delay and reuse the rainwater in the neighbourhood before leading it towards the harbour in the event of extreme rainfall.[20]

4.7.6.3 Bryggervangen: The Green Stream

The heavily asphalted intersection where Bryggervangen meets Landskronagade is typical of the neighbourhood. The plan is to create a 'green stream' that runs through the neighbourhood, making the street lush and engineered to channel rainwater to the harbour during a cloudburst. On selected corners the stream will branch out, contributing to new green spaces for residents.

4.7.6.4 Green Enclosed Courtyards

The enclosed courtyards of St. Kjeld are typical of Copenhagen in being both spacious and intimate at the same time. Most blocks have large green enclosed courtyards where many social activities take place. Copenhagen Communal Courtyards will remodel several of these courtyards over the coming years to enable them to manage daily rainfall locally. Roof water will be collected in rain gardens, water towers or detention ponds and used locally for irrigation or recreation. At the same time the courtyards will channel rainwater from cloudbursts to the streets so it does not flood basements. It is hoped that the remodelled courtyards will inspire other districts in Copenhagen to remodel their own.

4.7.6.5 Public Involvement in Managing the Water

One of the key reasons for the project's success is the involvement of the public since its earliest stages, with the City Administration hosting a meeting in Tåsinge Plads for residents to attend and voice their concerns, thoughts and ideas. Through this dialogue over 170 citizen-led projects have emerged in the neighbourhood, with public finances supporting local solutions to absorb, recycle and lead away rainwater. Today, St. Kjeld manages around 6,400 m^2 of surface water without it being flushed directly into the sewer system. Instead, the water is reused or allowed to leach into the groundwater or evaporate.[21]

4.7.7 Blue Harbour

Copenhagen's harbour up to the end of the 1990s was severely polluted from the discharge of wastewater from sewers and industrial companies impacting its water quality. Stormwater runoff entered the sewer system carrying contaminants and 93 overflow channels fed wastewater into the harbour. After an overhaul of the system the city was able to open its first public bathing area in the harbour in 2002, providing Copenhageners with a unique recreational area. To ensure the harbour remains clean the city has constructed 12 underground halls that hold excess wastewater during cloudburst events to prevent contamination of the harbour from sewage overflows.[22]

4.8 Monitoring of BGI Implementation

The main aspect of monitoring the results of BGI projects across Copenhagen involves assessing whether the projects are successful or not on two levels. First, do the various BGI projects work in cloudburst situations, that is, do they prevent flooding in neighbourhoods? Second, do these projects increase the quality of life in these neighbourhoods? In particular, do the residents express their satisfaction in using green spaces more often?

The city has an 'urban life account' that measures how many people are accessing different parts of the city and expressing their satisfaction with what the City Administration is doing. The Administration hopes people will respond to the BGI projects by saying 'This is a great place that we now have here' and the life account can measure, for example, a 50 percent increase in the people who are spending time in a specific location.

4.9 Case Study Summary

Copenhagen aims to show that adaptation goes beyond being a measure to manage excess stormwater from cloudburst events, and is, rather, one that provides significant benefits, including increased recreational areas and quality of life for residents and increased synergies with current green infrastructure.

To prioritise which BGI solutions and measures will be implemented, Copenhagen has been divided into seven catchment areas, further sub-divided into over 50 cloudburst branches or 'sub-catchments', with each catchment area having a detailed plan on how to manage cloudbursts, from which 300 specific BGI projects have been selected for implementation. Given the financial constraints under which the city is operating, not all the projects can be started at once and an annual selection is made.

When prioritised BGI projects are selected they are interlinked with other urban development projects in Copenhagen. This is cost-effective as cloudburst management projects are implemented in places where construction projects have already begun. Moving forwards, BGI projects will be implemented in conjunction with stream conversions and road restorations, while urban renewal projects will include cloudburst management in planning.

The process of implementing BGI is an ongoing learning process as it involves cooperation between the city and the utility company (HOFOR) and between different city departments and agencies working together to achieve the best possible BGI solutions. To enhance the capacity of its staff to cope with implementation measures, the City Administration conducts research with local universities and studies the experiences of other cities.

Regarding non-fiscal tools to encourage the implementation of BGI, Copenhagen mandates the development of green roofs in new local plans to adapt to climate change, enhance biodiversity and create a greener city. In the near future, it will mandate the disconnection of downspouts to reduce the volume of stormwater entering the city's sewer system. To encourage public participation in the development of BGI, Copenhagen invites residents of neighbourhoods to suggest how the cloudburst management projects located in their neighbourhood look and what additional activities can be included in the project.

Regarding the monitoring of BGI projects across Copenhagen, success is defined as whether they are effective in cloudburst situations and whether they increase the quality of life in the various neighbourhoods; an 'urban life account' has been set up to monitor this.

4.10 Adaptive Management Decision-making Framework

To increase resilience to climate change, reduce environmental degradation and become a Blue-Green City, Copenhagen has implemented an adaptive management decision-making framework that involves planning, designing, implementing and monitoring the design and implementation of BGI to achieve multiple social, environmental and economic objectives (summarised in Table 4.6).

Table 4.6 Copenhagen's adaptive management decision-making framework

Developing a plan for implementing BGI	
Define a vision	Copenhagen's Climate Adaptation Plan (CAP) aims to maximise the benefits of adapting to climate change. The Cloudburst Management Plan (CMP) is an offshoot of the CAP and outlines the methods, priorities and measures recommended to adapt to climate change, including extreme rainfall
Identify the geospatial extent of the project	The CMP will be implemented across the city's seven catchment areas
Establish cross-cutting steering groups	The City Administration, as the urban planning authority and owner of the utility company(HOFOR), is responsible for ensuring that adaptive measures are incorporated into municipal master plans and implemented. This requires cross-departmental cooperation as well as cooperation between the city and HOFOR
Promote collaborative working across different stakeholders	The City of Copenhagen works with HOFOR, engineers, architects as well as local residents in implementing cloudburst management projects
Identify multifunctional benefits of BGI	The CAP aims to show that adaptation is not simply a negative measure to manage excess stormwater from cloudburst events, but instead one that provides multiple environmental, economic and social benefits
Identify local issues, challenges, risks and community needs	Highest priority given to areas with high flood risk and where adaptation measures are easy to implement and will achieve synergy with other urban development projects or planning.
Establish resources for successful implementation	The CMP will be financed by a combination of public and private investments

Table 4.6 (continued)

Designing BGI	
Prepare and communicate a draft strategy/ plan/design incorporating the vision and objectives	300 cloudburst management projects have been selected for implementation. They form a coherent plan to manage cloudbursts at various scales across the city
Use responses to refine and improve the plan, strategy or design and its delivery	The city invites residents to suggest what the 300 cloudburst management projects could look like in their neighbourhoods. The city will then try to incorporate additional social or cultural aspects into the cloudburst management projects
Ensure the plan/strategy/design meets requirements for function, durability and beauty	Irrespective of multifunctional benefits the city will primarily select its BGI projects based on their hydraulic potential in managing cloudbursts
Implementing BGI	
Set design and management standards by establishing locally relevant criteria	The city hires architects and engineers to implement individual BGI projects that cumulatively provide catchment-wide management of excess stormwater
Ensure the provision of adequate funding mechanisms for ongoing management and maintenance costs	The implementation of BGI will be funded by a combination of financing from private sources, charges, and taxation, with HOFOR providing maintenance
Build the project, launch the strategy and adopt the policies	The city's 300 cloudburst management projects include green spaces and a climate-resilient neighbourhood among others. Copenhagen also mandates the installation of green roofs and will explore mandating the disconnection of downspouts. Residents in areas with cloudburst management projects can suggest what they will look like and what additional activities can be included in the project
Set milestones, targets and programmes	Copenhagen will ensure sewer discharges reaching ground level occur only once every 10 years and average water levels exceed ground level by 10 cm only once every 100 years

(*continued*)

Table 4.6 (continued)

Managing/maintaining BGI	
Monitor the strategy's delivery against its objectives regularly, using key performance indicators and stakeholder consultation	The 'urban life account' measures how many people are accessing different parts of the city and how many are expressing their satisfaction with what the City Administration is doing

Notes

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CHAPTER 5

New York City Becoming a Blue-Green City

5.1 Introduction

The remit of New York City's Department of Environmental Protection (DEP) is to protect public heath and the environment. It monitors air quality and seeks to reduce pollution created by noise and hazardous materials; it is also responsible for supplying clean drinking water and for collecting and treating wastewater. DEP treats on average 1.3 billion gallons of wastewater per day, inclusive of all dry and wet weather flows. This flow is conveyed through 7,400 miles of sewers, 149 miles of interceptor sewers and 113 pump stations to 14 wastewater treatment plants (WWTPs). The WWTPs have the capacity to handle the city's wastewater in dry weather and during most storms: 13 are designed with a capacity of double dry weather flows. Treated wastewater is then discharged into the city's harbour.

Almost two-thirds of New York City's sewer system is a combined sewer that collects wastewater and stormwater runoff from properties and streets. During heavy stormwater events excess flows through WWTPs can wash out the micro-organisms of the biological treatment units that break down and treat waste. To protect WWTPs and prevent upstream flooding during heavy rainfall, the interceptor sewers are designed with 'regulators' that have overflow weirs to divert combined wastewater and stormwater into the city's waterways when storms exceed

R.C. Brears, *Blue and Green Cities*,
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the capacity of the system. These are termed combined sewer overflows (CSOs). The city's system has 422 regulators that can discharge CSOs, with CSO outfalls classified by tiers depending on the volume of annual discharge:

- Tier 1 outfalls discharge over 500 million gallons per year (mgy).
- Tier 2 outfalls discharge between 250 and 500 mgy.
- Tier 3 outfalls discharge between 50.7 and 250 mgy.

Over time, DEP upgrades to WWTPs and sewers and construction of storage tanks have allowed the capture of a greater amount of CSO volume from around 30 percent annually in the 1980s to over 72 percent today. In the past CSOs were approximately 30 percent sanitary waste; today this has decreased to 12 percent. In some parts of New York City's tributaries, water quality standards would not be achieved even if CSOs were eliminated, as water quality is impacted by other sources of pollution, strength of tidal flow and historic dredging, filling and other alterations to the waterbed that affect flows and mixing of surface and deep water. To further reduce CSOs, the city has invested over $1.5 billion on sewage, regulator and pumping station improvements as well as upgrades to CSO storage tanks.

5.2 Challenges to Traditional Stormwater Infrastructure

New York City faces multiple challenges to its traditional stormwater infrastructure from climate change and meeting regulatory requirements of the Clean Water Act.

5.2.1 Climate Change

New York City is likely to experience increases in average temperatures (of the order of 2.3– 3.2°C) by the 2050s, with the number of days per year above 32°C expected to double. The city is likely to face increased average precipitation of between 4 and 11 percent.[1] This change in precipitation patterns will increase the frequency and magnitude of flooding as well as droughts. Heavier precipitation events and more frequent storms will wash additional nutrients and particles off impervious surfaces, impacting the quality of surface water. Furthermore, more frequent and intense rainfalls could cause more flooding of streets and basements and overwhelm the capacity of the sewer system as well as treatment facilities.[2]

5.2.2 *Regulatory: Clean Water Act 1972*

The Clean Water Act directs municipalities to meet water quality standards where attainable and not to reduce discharges for the sake of reduction. DEP has examined areas of the harbour where water quality standards have not been met yet and analysed the source of contamination. One of the largest challenges for New York City is limiting CSOs to levels that do not affect water quality.

In 2012, DEP signed the CSO Order on Consent (the Order) with the New York State Department of Environmental Conservation (DEC) to reduce CSOs using grey and green infrastructure. The Order requires specific green infrastructure application rates – manage one inch of runoff from 10 percent of impervious surfaces in combined sewer areas citywide by 2030 – but allows the city to develop waterbody-specific application rates for its 10 waterbodies as part of the Long Term Control Plans (LTCPs) for New York City, with the final citywide LTCP due at the end of 2017. In these plans DEP must identify appropriate CSO controls, which can include a mix of green and/or grey cost-effective stormwater management infrastructure projects, to achieve waterbody-specific water quality standards. Waterbody-specific application rates include varied percentages or targets for managing impervious areas in different combined sewer tributary areas. DEP will adjust these rates based on lessons learned during implementation, monitoring of data from projects and the development of green infrastructure performance metrics.

5.3 Strategic Vision: Green Infrastructure Plan

In 2010, DEP launched the Green Infrastructure Plan to manage stormwater runoff that would otherwise discharge into the combined sewer system and contribute to CSOs. Over the next 20 years the city aims to achieve better water quality and sustainability benefits than an all-grey strategy by:

- Reducing CSO volume by an additional 3.8 billion gallons per year (bgy), or approximately 2 bgy more than an all-grey strategy.

- Managing one inch of rainfall on 10 percent of impervious surfaces in CSO areas through green infrastructure and other source controls.
- Providing substantial, quantifiable sustainability benefits that the current all-grey strategy does not provide.

The Green Infrastructure Plan has five components:

1. *Build cost-effective grey infrastructure:* DEP has already built, or is planning to build, over $2.9 billion in targeted grey infrastructure to reduce CSO volumes. These projects were set out in Waterbody Watershed Facility Plans (facility plans) submitted to DEC. These cost-effective projects will reduce CSOs by around 8.3 bgy.
2. *Optimise the existing wastewater system:* DEP will optimise the existing wastewater system through targeted and system-wide enhancements to ensure it can store as much combined flow as possible. DEP will also encourage water conservation efforts to reduce sanitary waste from household and other uses to maximise plant capacity during wet weather. Prudent water usage will also reduce wear on infrastructure, chemical and energy costs for pumping and treating flow and greenhouse gas emissions.
3. *Control runoff from 10 percent of impervious surfaces through green infrastructure:* Green infrastructure is at the core of the plan, with the city aiming to capture the first inch of rainwater on 10 percent of the impervious areas in its combined sewage watersheds through detention and infiltration techniques over the next 20 years. This will reduce CSOs by approximately 1.5 bgy. DEP proposes to meet this goal by achieving 1.5 percent impervious area capture by 2015, an additional 2.5 percent by 2020, a further 3 percent by 2025 and the remaining 3 percent by 2030.
4. *Institutionalise adaptive management, model impacts, measure CSOs and monitor water quality:* The Green Infrastructure Plan is an adaptive management strategy where incremental measures are continuously evaluated and rejected or improved. This ensures better decisions about investments and overall resource allocation to achieve water quality objectives.
5. *Engage and enlist stakeholders:* Partnerships with community and civic groups and other stakeholders will be necessary to build and maintain green infrastructure. As part of the plan, DEP provides

resources, technical support and education so communities can propose, build and maintain green infrastructure.

5.3.1 Prioritising Green Infrastructure

As mentioned in section 5.2.2, the Order allows for the development of waterbody-specific green infrastructure application rates. These were developed based on a review of current and expected water quality conditions and an overall prioritisation of waterbodies (Table 5.1 provides a summary of the 2030 green infrastructure implementation targets for each waterbody). DEP then uses this approach to identify specific waterbodies for public and private green infrastructure investment. A criterion was

Table 5.1 2030 green infrastructure implementation targets

Waterbody	*Combined sewer impervious area (CSIA) acreage*	*Application rate targets*	
		Managed acres	*Percent of CSIA*
	Initial phases		
Alley Creek	1,490	45	3
Bronx River*	2,331	322	14
Coney Island Creek	694	7	1
Flushing Bay*	4,049	522	13
Flushing Creek*	5,923	479	8
Gowanus Canal*	1,387	162	12
Hutchinson River*	1,128	158	14
Jamaica Bay and CSO tributaries*	7,891	675	9
Newtown Creek*	4,524	593	13
Westchester Creek	3,480	487	14
Total waterbodies	**32,897**	**3,450**	**10**
	Future phases		
Citywide	**78,749**	**7,875**	**10**

*Priority Area

NYC DEP. 2012. Green Infrastructure Annual Report. Available: http://www.nyc.gov/html/dep/pdf/green_infrastructure/gi_annual_report_2013.pdf.

applied to compare and prioritise waterbodies in order to determine waterbody-specific green infrastructure application rates:

- Water quality standards (faecal coliform, total coliform, dissolved oxygen).
- Baseline cost-effective grey infrastructure (planned/constructed grey investments, projected CSO volume reductions, remaining CSO volumes, total capital costs).
- Ratio of separate stormwater discharges to CSO discharges.
- Additional planned CSO controls not captured in watershed/waterbody facility plans or Order.
- Preliminary waterbody sensitivity to green infrastructure in terms of cost per gallon of CSO reduced and additional considerations (background water quality conditions, public concerns and demand for higher uses, eliminated or deferred CSO storage facilities).

5.3.1.1 Priority Areas

To meet the 1.5 percent, 4 percent, 7 percent and 10 percent citywide combined sewer tributary areas managed by green infrastructure application rates by 2015, 2020, 2025 and 2030 respectively, Priority Areas were identified based on discharges in receiving waterbodies from specific CSO outfalls. DEP analysed annual CSO volume and frequency of CSO events at each outfall to target large volume and high frequency outfalls.[3]

In addition, DEP considered outfalls that may be affected by DEP's facility plans, other planned system improvements and outfalls in close proximity to existing and planned public access locations, with DEP continuously reviewing and expanding Priority Areas to ensure sufficient green infrastructure implementation to meet the 2030 goal.

In 2014, DEP added over 29,000 gross acres to the Priority Areas, which now total more than 68,000 gross acres, representing 70 percent of the city's combined sewage areas. By identifying Priority Areas DEP can focus resources on specific CSO tributary areas, analyse all opportunities, saturate these areas with as much Blue-Green Infrastructure (BGI) as possible and achieve efficiencies in design and construction. To date, DEP has focused on area-wide right-of-way bioswales and stormwater green streets.

5.3.1.2 Selecting Green Infrastructure Projects in Priority Areas

Once Priority Areas are identified, steps are taken to select potential, preliminary and final sites for right-of-way bioswales and stormwater green streets to further the design. The steps include a hydraulic analysis followed by a block-by-block site visit ('walk-through') by multiple city agencies including Department of Transportation (DOT), Department of Parks and Recreation (DPR) and DEP to determine the specific location. Siting criteria also include evaluation of traffic and pedestrian safety, mature street trees, bus stops, etc. These existing conditions can eliminate hundreds of potential green infrastructure locations in the right of way of a Priority Area with each neighbourhood varying in terms of available space for right-of-way bioswales and green streets. At the end of the walk-through all acceptable sites are considered preliminary and will move to a geotechnical investigation. The geotechnical investigation and survey steps have also been standardised to ensure each site does not conflict with utilities and allows water to infiltrate as designed. After a geotechnical investigation sites are either eliminated or move towards being final.[4]

5.3.1.3 Mass Bids to Capture Economies of Scale

To capture efficiencies in construction and minimise construction impacts on neighbourhoods, DEP and other partner agencies will bid out construction of approximately 200–300 right-of-way bioswales and 10 green streets at a time, with typical construction time for each batch being 10 months. Over the next 15 years DEP will widen its focus to include right-of-way installations as well as public and private property retrofits.[5]

5.3.1.4 Standardised Designs to Enhance Efficiency

The area-wide strategy is made possible by DEP's standardised designs and procedures that enable systematic implementation of green infrastructure. Developed by the Office of Green Infrastructure (OGI), the design standards are used by engineers, architects, landscape architects and other city agencies to prepare contracts. The standards facilitate the design of green infrastructure practices in rights of way, streamline the development of contract plans and drawings and reduce the timelines and costs associated with design and approval processes. Standardised designs also provide DEP with the ability to measure and evaluate CSO benefits of area-wide green infrastructure at the outfall level.

5.3.1.5 Cooperation Between Partner Agencies

DEP works directly with partner agencies on retrofit projects at public schools, public housing, parkland and other city-owned property within the Priority Areas. DEP also coordinates with partner agencies to review designs for new projects and identify opportunities to integrate green infrastructure into planned public projects.

5.3.2 BGI Benefits

The overall cost of the Green Infrastructure Plan is approximately $5.3 billion, $1.5 billion less than the $6.8 billion required for an all-grey strategy. As part of the plan, green infrastructure will be spread throughout the city and provide many additional sustainability benefits. After a 20-year period, DEP estimates green infrastructure will provide between $139 million and $418 million in additional benefits, including reduced urban heat island effects, energy conservation, lower carbon emissions, improved air quality, higher property values, restored ecosystems and operational benefits of reduced flow in the city's water supply and wastewater treatment system. None of which would accrue through an all-grey strategy that involves large investments with long lead times for design and construction and is subject to risks from changes in climate, labour and economic conditions, in addition to significant amounts of energy and carbon associated with their construction.[6]

5.4 Implementing BGI in Public and Private Spaces

New York City uses a variety of BGI measures to manage urban stormwater runoff, with water either passing through engineered systems for infiltration or detained to a slower rate before it enters the combined sewer system. BGI is implemented in rights of way, green streets, parking lots, public spaces as well as encouraged in private spaces including on or around buildings (Table 5.2).[7]

5.5 Implementing BGI: Fiscal Tools

To encourage the implementation of BGI, DEP uses a variety of fiscal tools including grants, tax abatements and a pilot stormwater fee.

Table 5.2 BGI implementation

BGI measure	*BGI tool*	*Description*
Green rights of way and spaces	Right-of-way bioswales	DEP right-of-way bioswales are planted areas in the sidewalk that are designed to collect and manage stormwater runoff. Rainwater flows down the street gutter along the curb through an inlet into the right-of-way bioswale. The collected stormwater infiltrates engineered soil layered over stones while any remaining surface water is absorbed by vegetation. If right-of-way bioswales reach capacity during heavy rain events stormwater will overflow into a catch basin
	Stormwater green streets	Vegetated areas designed to collect and manage stormwater runoff from streets and sidewalks. Stormwater green streets are usually constructed in the roadway, are typically larger than bioswales and vary in length, width and soil depth depending on the characteristics of the existing roadway. Green street BGI measures include bioswales, tree pits and gravel layers to store stormwater
	Parking lots	Parking lots make up 6 percent of New York City's impervious area. Design alternatives to reduce stormwater runoff include porous asphalt, catch basins, bioinfiltration swales and subsurface detention systems. DEP is partnering with DOT and Department of City Planning (DCP) and Metropolitan Transportation Authority (MTA) to encourage BGI measures in parking lots
BGI buildings	Green roofs	Green roofs in New York City can be intensive, with thick soils that support a variety of plants or extensive, covered only in a light layer of soil with minimal vegetation. Blue roofs are designed without vegetation for the primary purpose of detaining stormwater. Weirs in the roof drain inlets create temporary ponding, gradually releasing stormwater over time
	Rain gardens	Rain gardens are vegetated or landscaped depressions designed with an engineered soil layer that promotes infiltration of stormwater runoff. In addition to managing direct rainfall, stormwater runoff from surrounding impervious surfaces including sidewalks and rooftops can be directed to rain gardens

(*continued*)

Table 5.2 (continued)

BGI measure	*BGI tool*	*Description*
	Permeable paving	Permeable pavers or porous concrete allow water to seep in between the paving materials and be absorbed into the ground. Permeable paving can be used instead of traditional impermeable concrete or asphalt
	Subsurface detention systems	These systems, with infiltration capability, provide temporary storage of stormwater runoff underground. The systems have an open bottom and can incorporate perforated pipe and stormwater chambers for increased detention volume. The systems are designed mainly with a gravel bed that stores water until it can infiltrate into the ground
	Cisterns and rain barrels	Cisterns can be located underground, at ground level or on an elevated stand to catch and store stormwater off impervious surfaces, for example, roofs. Rain barrels are connected to the existing downspout of a roof and reuse stormwater for watering plants and other landscaping uses
Public spaces	Constructed wetlands	Stormwater controls in parks include constructed or restored wetlands, bioswales and rain gardens

5.5.1 Green Infrastructure Grant Program

In 2011, DEP established a Green Infrastructure Grant Program to strengthen public–private partnerships and public engagement in the design, construction and maintenance of green infrastructure on private property. To date the programme has committed over $13 million to 33 private property owners to build green infrastructure projects, including green roofs, rooftop farms and rain gardens, in combined sewer areas. DEP evaluates grant applicants after each yearly grant cycle to improve the application and submission process. Survey results indicated that two submission deadlines and pre-meetings with DEP on possible projects before application development were ideal. In response, DEP in 2014 offered two grant application deadlines, with one in the spring and one in the fall. Also, in advance of the application deadlines, DEP offered workshops to grant applicants and allowed them to meet with DEP engineers before applications were due. This allowed applicants to receive substantial feedback and submit stronger proposals.[8]

5.5.2 Green Roof Tax Abatement

Green roofs provide numerous benefits to the city but are expensive for property owners to install. To offset some of these costs the city provides a Green Roof Tax Abatement (GRTA) from city property taxes of $5.23 per square foot of green roof, up to $200,000. Property owners qualify for the GRTA if they install a green roof on at least 50 percent of a roof and have a maintenance plan to ensure the viability of the vegetation and expected stormwater benefits.[9] In 2014 there were five green roof permits filed with the New York City Department of Buildings (DOB) that indicated the intention to apply for the GRTA. DEP also works with DOB and environmental advocates to advise interested property owners, developers and designers on the application process. Due to the programme's success to date, it has been extended to 2018. As part of this extension the definition of a green roof now includes native and/or agricultural plant species in response to growing public enthusiasm for local food production as well as the option for typical green roofs, without agricultural plant species, to use controlled flow roof drains as a mechanism to provide temporary ponding on a rooftop surface and slowly release the ponded water.[10]

5.5.3 Parking Lot Stormwater Charge Pilot Program

Launched in 2011, the Parking Lot Stormwater Charge Pilot Program generates revenue for the operation and maintenance of the city's wastewater system. It charges a fee to privately owned standalone lots that contribute stormwater runoff to the city's wastewater system but do not receive city water services. The DEP fee is, at the time of writing, $0.063 per square foot, with 557 accounts for a total of $501,882. Property owners who implement BGI measures are exempt from the fee.

5.6 Implementing BGI: Non-Fiscal Tools

To encourage the implementation of BGI, DEP also uses a variety of non-fiscal tools, described below in sections 5.6.1–5.6.16.

5.6.1 Stormwater Performance Standard

DEP uses a stormwater performance standard to enable the city to manage stormwater runoff more effectively, and reduce the rate of runoff into the city's combined sewer system, from new developments or major site expansions. Implemented in 2012, the standard requires new houses or site connections to the city's combined sewer system to comply with stricter stormwater release rates, effectively requiring greater on-site detention.

- *New developments:* For new developments, the stormwater release rate is required to be 0.25 cubic feet per second (cfs) or 10 percent of the drainage plan allowable flow, whichever is greater, where allowable flow is the stormwater flow from a development that can be released into existing storm or combined sewer based on drainage plan and built sewers. If the allowable flow is less than 0.25 cfs, then the stormwater release rate is equal to the allowable flow.
- *Altered developments:* For altered sites the stormwater release rate is directly proportional to the ratio of the altered area to the total site area and no new points of discharge will be permitted.

In 2012, DEP developed the *Guidelines for the Design and Construction of Stormwater Management Systems* to assist developers and licensed professionals in the selecting, planning, designing and constructing of on-site stormwater management practices. Since the rule went into effect, 140 sites have required measures to be implemented with sites using a variety of BGI measures (Table 5.3).

5.6.2 Public Property Retrofit Projects

Another tool in meeting the 10 percent goal of the Order will be green infrastructure retrofits on public property. DEP is working with partner agencies to identify the best opportunities to retrofit parks, playgrounds, schoolyards, NYC Housing Authority (NYCHA) properties, public parking lots, libraries, etc., with green infrastructure. The goal of public property retrofits is to manage the first inch of rainfall over a site's impervious surfaces, for example, driveways, pathways, paved sitting

Table 5.3 BGI measures used by sites and houses affected by the stormwater performance standard

*Stormwater management type**	*Planned*	*Constructed*
Blue roof	43	6
Blue roof/tank combination	0	0
Drywell	6	0
Perforated pipe	1	1
Tank	85	14
Total	135	21

*Sites may contain more than one stormwater management type
New York City DEP. 2014. Green Infrastructure Annual Report

areas or recreation surfaces. Green infrastructure retrofits are selected based on a site's particular characteristics, the needs of the owner agency and the surrounding community. To sort through hundreds of potential public properties, DEP screens sites with partner agencies to identify opportunities and challenges early in the process. DEP's site screening starts with Geographic Information Systems (GIS) mapping, interagency and capital planning coordination and research into existing agency records and site drawings. Sites selected will then be assessed for feasibility involving environmental assessments and geotechnical investigations. Sites deemed feasible then proceed to the design phase.[11]

5.6.3 *Public Property Retrofit Project: Community Parks Initiative*

In 2014, DEP committed $36 million towards green infrastructure construction as part of DPR's new $130 million City Parks Initiative (CPI) that targets park improvements in underserved neighbourhoods. As part of CPI, DPR aims to maximise management of stormwater runoff from impervious surfaces both on CPI sites and from adjacent rights of way. In phase one, DPR will reconstruct 34 parks in their target areas, 29 of which are within combined sewer areas. Types of BGI measure built on parkland will vary depending on the needs of each community but will in general include bioretention practices including rain gardens, permeable paving and subsurface detention systems or synthetic turf fields with infiltration capacity.[12]

5.6.4 Public Agency Cooperation: High-Density Residential Complex Retrofit

Multi-family residential complexes make up around 4 percent of all combined sewer watershed areas. In partnership with NYCHA, DEP will construct multiple BGI elements in a high-density residential housing complex. On the roof of a community building DEP will test a modular tray system for detaining stormwater. Around the complex, two parking lots will be constructed with different source control technologies: a perforated pipe system that stores up to 600 cubic feet of stormwater and a subsurface storage chamber that stores up to 780 cubic feet of stormwater. A system of bioswales and bioretention areas will manage stormwater runoff from the sidewalk area. In addition, a 150-foot by 8-foot section of sidewalk will be replaced with porous concrete drained by a stoned reservoir that delays discharge of stormwater.[13]

5.6.5 Public Agency Cooperation: Permeable Pavement Pilot Programme

In 2013, New York City Council passed a local law requiring DEP and DOT to embark on a study of three permeable pavement installations in the city's streets and sidewalks. In 2014, the agencies worked together to identify pilot locations in the Hutchinson River and Flushing Bay Priority Areas and developed a monitoring protocol. In 2015, DEP established rain gauges and pipe-flow monitors to collect rainfall information and combined sewer flow data to establish the pre-conditions in the two pilot areas. Near the end of 2015, DEP and DOT finalised the design for the porous concrete panels that will be installed in the street parking lanes throughout these locations.[14]

5.6.6 Public–Private Partnership: Green Infrastructure Schoolyards

Since 2011, DEP has partnered with the not-for-profit Trust for Public Land (TPL), DPR, New York City School Construction Authority (SCA) and the New York City Department of Education to renovate neighbourhood school playgrounds with DEP committing $20 million over 4 years to implement BGI measures. In 2014, the partnership increased efforts to screen and identify project sites, expanding into all combined sewer areas citywide. To date the partnership has built six schoolyards and design is complete at two additional sites. In total the six sites manage 3 acres of impervious area and more than 2.1 million gallons of stormwater per annum. Moving forwards, the partnership has added seven new schoolyards to the schedule, three of which are in the design stage.[15]

5.6.7 *Expanding Public–Private Partnerships to Large Private Property Owners*

DEP is expanding its outreach efforts to private property owners, with the agency collaborating with the Mayor's Office of Sustainability and New York City Economic Development Corporation (EDC) to target owners of properties with large impervious surfaces including industrial lots, hospitals and universities. DEP has also held meetings with real estate managers and Business Improvement Districts. The overall aim is to educate private property owners on the importance of sustainable stormwater management and encourage owners to apply for grant programme funding.[16]

5.6.8 *Enhancing BGI Capacity and Interagency Cooperation*

DEP's OGI expanded in 2014 with six new engineering project managers, bringing total staff to 21 including engineers, planners, project managers and administrative support staff. DEP also funds three positions at DPR and one at DOT to enable these agencies to support the BGI programme.

5.6.9 *Neighbourhood Demonstrations*

The Order required DEP to implement three Demonstration Areas, monitor the projects and report on the results. In particular, the Neighbourhood Demonstration Areas provided the city with data on actual combined sewer flow measurements before and after the BGI was installed and other associated benefits on a multi-block scale. This information was then used to develop BGI performance metrics that related the benefits of CSO reduction to the amount of BGI installed. The data were extrapolated for calculating and modelling BGI water quality and cost-benefit analyses on a water-body and citywide basis. From the results the city submitted in 2014 a Post-Construction Monitoring Report which demonstrated the performance of BGI. The report found a 20–23 percent decrease in stormwater runoff entering the combined sewers in all three areas after construction of green infrastructure measures.[17]

5.6.10 BGI Research and Development Programme

In 2015, DEP established a $10 million, 5-year comprehensive research and development programme to collect performance and cost-benefit analyses of BGI through long-term monitoring. The programme will review performance over time, ensuring performance-based maintenance and operations as well as the conducting of cost-benefit analyses of various BGI designs.[18]

5.6.11 Green Infrastructure Co-benefits Calculator

In 2014, DEP completed a project to identify, characterise and quantify co-benefits of green infrastructure practices constructed through the city's green infrastructure programme and pilot projects. The study quantified the co-benefits of six different types of green infrastructure used in New York City (right-of-way bioswales, larger bioretention areas, porous pavement, constructed wetlands, blue roofs and green roofs) and then conducted monitoring of vegetation coverage and measuring of temperature and soil health. A lifecycle analysis was then conducted to calculate greenhouse gas emissions and long-term construction and maintenance costs for each green infrastructure practice. All the findings were incorporated into an online co-benefits calculator that allows users to input green infrastructure parameters (size of area, number of trees, vegetation coverage) and calculate the costs and non-stormwater benefits for each different green infrastructure practice.

5.6.12 NYCityMap

The NYCityMap enables the public to search for BGI projects by address or by type. The map also allows the public to add a BGI project, for example, a green roof or rain garden to the map so users can see the true scale of BGI implementation across the city. DEP also encourages individual property owners to add their projects into the map. DEP will also start populating the map with the newly completed BGI projects on a regular basis.

5.6.13 Public Education: BioswaleCare

In 2013 DEP launched BioswaleCare with MillionTreesNYC to encourage local residents to become environmental stewards of green infrastructure in the rights of way. It held a workshop in 2014 in partnership with The Church of St. Luke and St. Matthew in downtown Brooklyn with DEP and DPR staff providing information on trees, plant species and bioswale function. Workshop participants also practised caring for bioswales by clearing inlets and outlets, removing weeds and using tools to maintain the grading. Participants then had the opportunity to 'adopt' or care for green infrastructure installations in their neighbourhoods.[19]

5.6.14 Green Infrastructure Education Module

DEP has developed interactive, multidisciplinary science, technology, engineering and maths (STEM) lessons and activities on green infrastructure. The module will introduce students and educators to NYC's hidden infrastructure and innovative green infrastructure techniques that help transport and manage the city's wastewater and stormwater. The module will answer questions including: Where does rainwater go? What happens to precipitation and runoff on NYC streets? How can we help understand and manage stormwater runoff?[20]

5.6.15 Public Outreach and Engagement: Website Information

In 2013, DEP launched its new website design with new content on green infrastructure. Users can access information on the city's green infrastructure programme including common types of green infrastructure practices and DEP's research and development programme. Users can also view a map of Priority Areas to learn if green infrastructure is coming to their area.[21]

5.6.16 *Public Outreach and Engagement: Green Infrastructure YouTube Video*

DEP has created an educational YouTube video on its green infrastructure programme with viewers receiving brief explanations on the environmental challenges of CSOs while featuring green infrastructure technologies including green roofs, rain gardens and permeable pavers.

5.7 Implementing BGI: Examples

DEP has initiated and facilitated the implementation of a variety of BGI projects on both public and privately owned lands including school playgrounds and community gardens.

5.7.1 *Public–Private Partnership: School Playground*

In 2014 DEP partnered with TPL and J.H.S. 162 (a secondary school in Brooklyn) to create a green infrastructure playground with a rain garden, synthetic turf and permeable pavers and trees. Together these BGI measures capture the first inch of rainfall from more than 12,000 square feet of impervious area, managing more than 400,000 gallons of stormwater annually. At the lowest point of the playground, designers, along with input from a group of sixth and seventh graders, sited a rain garden with water-tolerant plants and engineered soil to maximise storage and infiltration. A new synthetic turf and permeable pavers and trees store and infiltrate stormwater with an underlying layer of broken stone. The new asphalt is graded to direct stormwater towards BGI installations.[22] To encourage even infiltration across the site, a system of subsurface perforated pipes connects the BGI measures. TPL also introduced a classroom curriculum to educate students on the new BGI on-site. In the course of three classroom sessions students created a topographical model of an urban watershed and drainage basin and investigated the city's combined sewer system through a small-scale model. Students then added the BGI to the Climate and Urban Systems Partnership's online crowd-sourced map to see how their school's BGI related to BGI projects elsewhere in the city. With DEP funding nearly 30 percent of project costs, with the remainder from TPL and private donors, the project provides an example for the rest of the city on how this mix of funding sources represents a successful public–private partnership that meets the goals of all parties, including increased educational opportunities, upgraded facilities, water quality improvement and increased access to public space.[23]

5.7.2 *Public–Private Partnership: Community Garden*

In 2014, DEP collaborated with the Banana Kelly Community Improvement Association, the Workforce Housing Group (WHG), the New York City Department of Housing Preservation and Development and GrowNYC on the design and installation of the Kelly Street Green community garden. Kelly Street Green was in the final stages of a 16-month redevelopment of five buildings for affordable housing. Seeing potential for the unused land on-site, WHG applied for a Green Infrastructure Grant and worked with GrowNYC on the design and implementation of a garden plan. The project features a 1,400-square foot green roof along with over 2,700 square feet of gravel and permeable pavers with infiltration systems. Eight water cisterns collect roof runoff for the raised planters in the 3,675-square foot garden. The BGI measures in total manage more than 250,000 gallons of stormwater annually. Two full-time caretakers live on Kelly Street and foster residents' understanding of stormwater management maintenance, gardening and food production. In the first year, the community harvested over 450 pounds of produce. It is estimated the garden can generate up to $43,000 in sales each growing season.[24]

5.8 Monitoring of BGI Implementation

DEP has standardised the designs and procedures for the systematic implementation of BGI, providing the city with an ability to measure and evaluate CSO benefits of area-wide BGI at the outfall level. DEP has established a comprehensive research and development programme to collect performance and cost-benefit data of BGI through long-term monitoring. The programme will review performance over time, ensuring performance-based maintenance and operations as well as the conducting of cost-benefit analyses of various BGI designs.

DEP is developing NYC Greenhub, a GIS-based project tracking and asset management system that compiles, tracks, manages, maps, reports data and provides asset management for BGI assets, including right-of-way bioswales, stormwater green streets, right-of-way rain gardens and installations on public and private properties, for example, rain gardens and bioretention systems, permeable paving, subsurface systems with infiltration capability, rainwater harvesting and green and blue roofs, throughout their lifecycle. Prior to its launch in 2016 the system was tested. Now live, the system is used by DEP staff, DEP design consultants and other partnering agencies as a centralised hub for all BGI data.[25]

5.9 Case Study Summary

New York City's Green Infrastructure Plan aims to achieve better water quality and sustainability benefits than an all-grey strategy. After a 20- year period the DEP estimates green infrastructure will provide additional benefits including reduced urban heat island effects, energy conservation, lower carbon emissions, improved air quality, higher property values, restored ecosystems and operational benefits of reduced flow in the city's water supply and wastewater treatment system.

To prioritise the implementation of BGI, DEP has identified Priority Areas, enabling it to concentrate on specific CSO tributary areas, analyse all opportunities, saturate these areas with as much BGI as possible and achieve efficiencies in design and construction. To ensure that other public agencies implement effective BGI, DEP reviews their designs. In addition, it identifies opportunities to integrate green infrastructure into planned public projects. To capture efficiencies in construction and minimise construction impacts on neighbourhoods, DEP and other partner agencies bid out construction of BGI projects. DEP funds job positions inside a variety of public agencies to ensure BGI is implemented in their programmes. Furthermore, it partners with other agencies to implement BGI in housing projects, school playgrounds and streets. DEP also collaborates with the Mayor's Office of Sustainability and EDC to target owners of properties with large impervious surfaces and inform them of the importance of BGI and funding opportunities.

DEP has established a variety of fiscal tools to encourage the implementation of BGI, including a stormwater grant programme that: (1) funds the design, construction and maintenance of BGI on private property; (2) provides a GRTA for the installation and adequate maintenance of green roofs, and (3) includes a pilot parking lot stormwater fee that encourages the reduction of stormwater runoff to the city's wastewater system.

DEP has developed a stormwater performance standard for new developments or major site expansions that require greater on-site detention. To assist developers and licensed professionals meet these standards the city has developed guidelines that detail BGI best management practices. To enhance public awareness of BGI, DEP has developed a map that enables the public to search for BGI projects throughout the city. It has created a website that informs the public on the various types of BGI implemented throughout the city and whether any BGI projects will be coming to Priority Areas where they live. Finally, DEP has created an educational YouTube video that describes the environmental challenges of CSOs and BGI measures to measure stormwater runoff.

To enhance knowledge of BGI, DEP has created the BioswaleCare programme that holds educational workshops for the public on how bioswales work and how to maintain them as well as STEM education lessons for students and educators to learn about BGI and the various measures the city uses to manage stormwater runoff.

DEP has standardised designs and procedures for the systematic implementation of BGI, providing the ability to measure and evaluate CSO benefits of area-wide BGI at the outfall level. It has established a comprehensive research and development programme to collect performance and cost-benefit data of BGI through long-term monitoring. The programme will review performance over time, ensuring performance- based maintenance and operations as well as the conducting of cost- benefit analyses of various BGI designs. DEP is also developing a GIS- based project tracking and asset management system for its BGI assets.

5.10 Adaptive Management

To increase resilience to climate change, reduce environmental degradation and become a Blue-Green City, DEP has implemented an adaptive management decision-making framework that involves planning, designing, implementing and monitoring the design and implementation of BGI to achieve multiple social, environmental and economic objectives (summarised in Table 5.4).

Table 5.4 DEP's adaptive management decision-making framework

Developing a plan for implementing BGI	
Define a vision	DEP has launched its Green Infrastructure Plan to manage stormwater runoff that would otherwise have contributed to CSOs
Identify the geospatial extent of the project	DEP has identified Priority Areas to enable the city to focus resources on specific areas that will reduce CSOs significantly
Establish cross-cutting steering groups	DEP works with multiple city agencies including DOT and DPR to determine the specific locations for BGI in Priority Areas
Promote collaborative working across different stakeholders	DEP works with partner agencies on BGI retrofits on city-owned property within Priority Areas. DEP provides resources, technical support and education so communities can propose, build and maintain green infrastructure
Identify multifunctional benefits of BGI	DEP has identified the environmental, economic and social benefits of implementing BGI. DEP has earlier completed a project to identify, characterise and quantify co-benefits of green infrastructure practices constructed through the city's green infrastructure programme and pilot projects
Identify local issues, challenges, risks and community needs	To identify ideal locations for BGI, DEP enacts a process involving other agencies to label BGI sites in public spaces as potential, preliminary and final, with final sites undergoing geotechnical survey to determine suitability
Establish resources for successful implementation	DEP's OGI has increased its number of personnel to include engineers, planners, project managers and administrative support staff. DEP also funds positions at other public agencies to help them implement BGI. DEP has standardised designs and procedures that enable systematic implementation of BGI and ease of measuring impact on CSOs

Table 5.4 (continued)

Designing BGI	
Prepare and communicate a draft strategy/plan/design incorporating the vision and objectives	DEP and other partner agencies will bid out construction of approximately 200–300 right-of-way bioswales and 10 green streets at a time to reduce CSOs in Priority Areas
Use responses to refine and improve the plan, strategy or design and its delivery	to review designs for new projects and identify opportunities to integrate green infrastructure into planned public projects
Ensure the plan/strategy/design meets requirements for function, durability and beauty	DEP projects that involve partnerships (e.g. with schools) will ensure the surrounding community's needs are taken into account
Implementing BGI	
Set design and management standards by establishing locally relevant criteria	DEP coordinates with partner agencies to review designs for new projects and identify opportunities to integrate green infrastructure into planned local public projects
Ensure the provision of adequate funding mechanisms for ongoing management and maintenance costs	DEP has already built, or is planning to build, over $2.9 billion in targeted BGI to reduce CSO volumes
Build the project, launch the strategy and adopt the policies	The Green Infrastructure Plan will involve the implementation of BGI in rights of way, green streets, parking lots and public spaces through partnerships, both public and private. To further encourage BGI, DEP offers grants, a GRTA and is piloting a green car parking pilot charge. DEP has also established guidelines for on-site stormwater management and provides information on BGI and its multi-benefits for all stakeholders in NYC
Set milestones, targets and programme	NYC aims to capture the first inch of rainwater on 10 percent of the impervious areas in the city's combined sewer watersheds with BGI over the next 20 years

(*continued*)

Table 5.4 (continued)

Managing/maintaining BGI	
Monitor the strategy's delivery against its objectives regularly, using key performance indicators and stakeholder consultation	The Green Infrastructure Plan is an adaptive management strategy where incremental BGI measures are continuously evaluated and rejected or improved. This ensures better decisions about investments and overall resource allocation to achieve water quality objectives. DEP is developing NYC Greenhub, a GIS-based project tracking and asset management system that compiles, tracks, manages, maps, reports data and provides asset management for BGI assets

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CHAPTER 6

Philadelphia Becoming a Blue-Green City

6.1 Introduction

During the mid-nineteenth century, when Philadelphia's population was growing rapidly, it was common to dump industrial waste and human sewage into creeks and streams that naturally transported the waste via gravity into large water bodies: the Schuylkill and Delaware Rivers. With bacteria and pollutants impacting human health, city officials and engineers created an infrastructure network of combined sewers. Natural watersheds were utilised to facilitate drainage, with most of Philadelphia's creeks and streams becoming the framework of this infrastructure. Sewers were placed in creek beds while natural stream valleys were levelled off, allowing for the subdivision of land. This enabled the street grid system to be implemented more easily and polluted waterways no longer impacted inland development. Of the 283 linear miles of streams that once existed in Philadelphia to carry runoff into the Schuylkill and Delaware Rivers, only 118 miles remain today.[1]

Today, the Philadelphia Water Department (PWD) is responsible for maintaining the health of the city's local waterways. Stormwater runoff is the primary source of pollution in the city's river and streams. When it rains, stormwater runoff contributes to combined sewer overflows (CSOs); pollutes waterways with fertilisers, oil and sediment; destroys valuable aquatic and riparian habitats; and floods homes and

R.C. Brears, *Blue and Green Cities*,
https://doi.org/10.1057/978-1-137-59258-3_6

businesses. PWD manages stormwater by building and maintaining public stormwater infrastructure and by regulating private development in the city.

Philadelphia has one of the oldest sewer systems in the United States; there are sections dating back to the second half of the nineteenth century that remain operational today. It comprises two systems. The first, the combined system, covers 48 percent of the city and transports sewage and stormwater in one pipe to a wastewater treatment plant before releasing it into the waterways. During moderate to heavy rainfall events the system will reach capacity and overflow, discharging a mixture of sewage and stormwater into the city's streams and rivers from 164 permitted CSO outfalls within the city. The city's four watersheds receive the CSO discharges. The second, separate system, serves the remainder of the city; it collects stormwater in a storm sewer pipe and discharges it directly into a waterway, while sewage collected from domestic and non-domestic customers is collected in a sanitary sewer pipe and taken to a wastewater treatment plant before release into the waterways.[2]

Approximately one quarter of all land in Philadelphia, some 37 square miles, is devoted to transportation. It comprises street pavement (18 sq mi), sidewalks, plazas and medians (11 sq mi), airports (2.5 sq mi) and other (including marine and rail, 5.5 sq mi). PWD has analysed the impervious cover associated with various land-use categories and grouped the percentages under their green program headings (Table 6.1).

Table 6.1 Breakdown of impervious cover within combined sewer system

Green program	*Percentage of impervious cover*
Green streets	38
Green schools	2
Green public facilities	3
Green parking	5
Green open space	10
Green industry, business, commerce and institutions	16
Green alleys, driveways and walkways	6
Green homes	20

6.2 Challenges to Traditional Stormwater Infrastructure

Philadelphia faces multiple challenges to its traditional stormwater infrastructure from climate change and meeting regulatory requirements of the Clean Water Act 1972.

6.2.1 Climate Change

Climate projections indicate that Philadelphia will experience wetter and warmer conditions in all seasons over the course of this century. It is projected to experience an increased frequency of heavy and extremely heavy precipitation events, with the majority occurring during the winter months. They can be caused by a variety of weather systems, including tropical storms and hurricanes, thunderstorms and frontal activity. When these heavy events occur they typically exceed the capacity of the city's sewer system. It is likely that the city will experience 4 to 10 times as many days per year above 95°F and as many as 16 days a year above 100°F by 2100 (up from the 1950–1999 average of less than one). Many of these hot days will be successive, arriving as heatwaves that will increase the risk of residents experiencing heat-related health problems including dehydration, heat exhaustion and heat stroke.[3]

6.2.2 Regulatory Environment

Philadelphia's drive towards implementing Green Stormwater Infrastructure (GSI, the terminology used by the city and equivalent, within the context of this chapter, to Blue-Green Infrastructure (BGI)) is due to the city's partnership with the US Environmental Protection Agency and the Pennsylvania Department of Environmental Protection to meet federal water pollution standards set by the Clean Water Act by advancing GSI for urban wet weather pollution control.[4]

6.3 Strategic Vision: Philadelphia's Green City, Clean Waters

PWD has developed the Green City, Clean Waters plan to protect and enhance the region's waterways by managing stormwater runoff and reducing the reliance on additional underground infrastructure. The plan's objective is to reduce CSOs through an investment of $2.4 billion over the next 25 years to manage more than one-third of the impervious cover within the sections of the city served by the combined sewer system.

The Green City, Clean Waters vision is to 'unite the City of Philadelphia with its water environment, creating a green legacy for future generations while incorporating a balance between ecology, economics and equity'.[5] Its features include:

- Large-scale implementation of GSI to manage runoff at source on public land and reduce demands on sewer infrastructure.
- Requirements and incentives for GSI to manage runoff at source on private land and reduce demands on sewer infrastructure.
- A large-scale street tree planting programme to both improve the appearance of the city and manage stormwater at source.
- Increased access to and improved recreational opportunities within green and attractive street corridors and waterfronts.
- Preserving open space and utilising it to manage stormwater at source.
- Converting vacant and abandoned lots to open space and responsible redevelopment.
- Restoring streams with physical habitat enhancements that support healthy aquatic ecosystems.
- Implementing additional infrastructure-based controls when necessary to meet appropriate water quality standards.

6.3.1 Principles of Green City, Clean Waters

The basic principles underlying the Green City, Clean Waters approach are as follows:

- Utilising rainwater as a resource by recycling, reusing and recharging neglected groundwater aquifers.
- Maintaining and upgrading ageing water infrastructure.
- Collaborating to revitalise the city, with an emphasis on sustainability.
- Energising citizens, partnerships, public and regulatory partners to adopt and join PWD in implementing the watershed-based strategy.

6.3.2 Integrating GSI within Highly Developed Areas of Philadelphia

Integrating GSI within highly developed areas of Philadelphia requires a creative and strategic approach to design and planning. Green City, Clean Waters outlines three components of implementing GSI:

1. *Water Department-initiated GSI projects:* PWD will collaborate with partners to leverage opportunities to maximise GSI investments and identify projects through a strategic planning process. An initial set of PWD-sponsored projects will include implementing GSI on PWD-owned facilities, initiating large-scale planning and implementation of Stormwater Planning Districts (SPDs), creating green streets, coordinating and leveraging opportunities for greening schools, greening publicly owned parking facilities, and evaluating greening opportunities on vacant land.
2. *GSI coordinated with public-works projects:* Critical to realising the Green City, Clean Waters goals is to create standard practices for city agencies to follow when undertaking public work investments that involve stormwater management features. In addition, PWD is committed to incorporating GSI into the planning and design of water and sewer projects.
3. *Private investment:* With a city-wide redevelopment rate of 0.5–1 percent per annum, over the 25-year programme an estimated 3,000–6,000 green acres could be achieved by private development within the combined sewer system drainage area.[6]

6.3.3 Greened Acres

PWD's commitment to achieving the Green City, Clean Waters goals is measured in a unit called a Greened Acre, which represents one acre of impervious cover within the combined sewer system drainage area that uses GSI to manage the first inch of stormwater. One acre receives one million gallons of rainfall per year. Currently, if the land is impervious this rainfall runs off into the sewer and becomes polluted. A Greened Acre will stop 80–90 percent of this pollution from occurring.[7] Overall, the Green City, Clean Waters programme aims to create nearly 10,000 Greened Acres across the city.

6.3.4 GSI Benefits

The overall goal of the vision is to create a green identity for Philadelphia that draws in more residents, which in turn increases revenues for PWD to support more greening, which can increase property values and enhance awareness of the benefits of GSI, creating a positive feedback loop that helps the programme thrive.[8] By the end of the programme the city aims to have reduced stormwater pollution entering its waterways by 85 percent. In addition, by employing GSI, rather than traditional infrastructure, Philadelphia will meet standards set by the Clean Water Act while saving around $5.6 billion.

6.4 Implementing GSI in Public and Private Spaces

PWD will implement GSI through its various green programmes that will each utilise a unique mix of tools to filter, store and manage stormwater above- and below-ground (Tables 6.2 and 6.3) in a smart and cost-effective way. The green programmes include:

- *Green streets and sidewalks:* Streets and sidewalks are the single largest category of impervious cover in Philadelphia, accounting for around 38 percent of impervious cover within the combined sewer drainage area. A green street acts as a natural stormwater management system, capturing rain or melting snow (runoff), allowing the water to soak into soil, filtering it and at the same time reducing the amount of stormwater that would have made its way into the city's combined sewer system. Green streets will also provide additional societal benefits, including shading, cooling, traffic calming and visual enhancement.
- *Green schools:* Schools make up 2 percent of all impervious cover in the combined sewer area but are highly visible, providing opportunities to educate the local community on GSI. Stormwater tools that can be implemented include rain gardens, green roofs and rain barrels.
- *Green public facilities:* Public parcels of land comprise 3 percent of impervious cover in the combined sewer area. The value of retrofitting public facilities is that it enables the city to lead by example, establishing credibility of the programme and demonstrating the effectiveness of the measures to members of the development community. PWD is leading this initiative by greening its own facilities in

Table 6.2 Above-ground green stormwater infrastructure tools

GSI tool	*Description*
Stormwater tree trenches	A system of trees connected by an underground stone bed used for infiltration. The trees take up and transpire water from the trench and provide shade, while a perforated pipe distributes stormwater throughout the trench
Stormwater bump-outs	Landscaped extensions of the curb that protrude into the street intersections. The bump-out part has a layer of stone that is topped with soil and plants to capture stormwater runoff. In addition to managing stormwater, bump-outs reduce traffic speeds and make intersections safer for pedestrians
Stormwater planters	Manage stormwater runoff from the street and sidewalk. They are situated below the sidewalk and are filled with plants, soil and stones. Stormwater inlets collect water from the street and direct it into planters where plant roots can absorb it. The planters also have small openings to capture stormwater flowing off the sidewalk
Rain gardens	Planted shallow depressions designed to catch and filter stormwater runoff from a downspout or nearby street or sidewalk. Plants used in rain gardens are selected based on their ability to thrive in extremes of wet and dry weather. Rain gardens filter pollutants and replenish groundwater
Porous pavements	Include permeable asphalt, concrete, pavers or rubber-surfaced playgrounds, allowing water to pass through their surfaces via a stone layer to the ground below. These surfaces slow, redirect and filter water through the soil instead of allowing it to run unhampered into the sewer system
Swales	Used to channel stormwater from a street or sidewalk into a rain garden or basin
Stormwater trees	Planted in individual, deep stone pits to help manage stormwater, unlike street trees that are typically planted in trenches

Philadelphia Water Department. 2014. City of Philadelphia Green Streets Design Manual. Available: http://www.phillywatersheds.org/what_were_doing/gsdm.

addition to encouraging the installation of green streets around major public facilities.

- *Green Parking:* Parking lots comprise 5 percent of the impervious cover. Because they have significant visual impact, green parking lots can contribute towards the overall improvement in the appearance of the city's commercial and business districts. City-owned parking facilities will be targeted as a demonstration of the city's commitment to GSI.

Table 6.3 Below-ground green stormwater infrastructure tools

GSI tool	*Description*
Green inlets	Located at a corner or near the middle of a city block, they allow for stormwater to first flow into the green infrastructure. The second inlet leads to the sewer system and collects flow that the first inlet may have missed
Inlet filter bags	Protect sewer pipes by capturing rubbish, leaves and other debris; allow stormwater to flow directly into green infrastructure
Curb cuts	Allow stormwater to directly enter green infrastructure and are usually found in stormwater bump-outs, planters and stormwater trees
Trench drains	Allow water to flow directly off the street into green infrastructure. Trench drains have metal covers that protect the drain and surrounding sidewalk
Observation wells	Allow PWD to monitor the effectiveness of green infrastructure. A small pipe connects to the stone basin at the base of the infrastructure enabling engineers to measure the amount of water being managed using sensors
Clean-outs	Feature a separate pipe that connects into the pipework within the green infrastructure allowing PWD to vacuum out dirt, sediment or rubbish that has entered the system

Philadelphia Water Department. 2016l. What Does it Look Like – Green Stormwater Infrastructure. Available: http://www.phillywatersheds.org/what_were_doing/community_partnerships/programs/soak-it-adoption/green-stormwater-tools/what-does-it-look-like.

- *Green Public Open Spaces:* Public open space, including streets adjacent to parks, make up around 10 percent of the city's impervious cover. While impervious cover comprises a relatively small proportion of these spaces, PWD sees them as an opportunity to route and manage stormwater from the surrounding areas without impacting the quality of the public land itself.
- *Green Industry/Business/Commerce/Institutions:* The city's industry, business and commerce collectively account for around 16 percent of the city's impervious cover. Because they are generally controlled by private entities, PWD will undertake a supporting role in seeing GSI implemented.
- *Green Alleys/Driveways/Walkways:* Philadelphia has many alleys located behind houses and commercial buildings that are currently impervious. While they only comprise 6 percent of all impervious cover in the city, GSI provides PWD with an inexpensive opportunity to allow the infiltration or collection of roof runoff.

- *Green Homes:* Residential roofs make up 20 percent of all impervious cover in Philadelphia. To ensure success for this programme, PWD promotes small-scale stormwater management solutions that can be applied by homeowners themselves and achieve benefits at a minimal cost.

6.4.1 Triple Bottom Line Benefits of GSI

PWD has undertaken a triple bottom line analysis of the environmental, social and economic benefits of the programme (Table 6.4) in an attempt to compare the green approach with traditional infrastructure alternatives. This enables PWD to justify the programme with the rate-payers who ultimately pay for the initiative.

6.5 Implementing GSI: Fiscal Tools

Fiscal tools include stormwater billing and a variety of grants.

6.5.1 Stormwater Billing

PWD bills property owners for the cost of treating stormwater runoff in their monthly water bill. For non-residential, commercial customers the stormwater charge is based on the square footage of impervious area covering the property. Residential customers pay a standard amount based on the average surface area of impervious cover in residential properties throughout the city: the average gross area for a residential property is 2,110 square feet, approximately half of which (1050 square feet), is impervious. Based on these averages a uniform monthly stormwater charge has been defined for all residential properties, which is, at the time of writing, $14.12.[9] To encourage the uptake of GSI by the private sector, PWD offers the Stormwater Management Incentives Program (SMIP) Grant as well as the Greened Acre Retrofit Program (GARP) Grant. Both programmes are supported by a $10 million annual budget.

6.5.2 Stormwater Management Incentives Program

The SMIP was established in 2012 to provide funding for non-residential property owners to design and construct stormwater retrofit projects.

Table 6.4 Triple bottom line benefits of green stormwater infrastructure

Benefits	*Type*	*Description*
Economic	Job creation	GSI creates around 250 jobs per year. The jobs require no prior experience and are suitable for individuals who might be unemployed or living in poverty
	Property values	GSI is expected to increase property values by 2–5 percent – $390 million for properties near parks and green spaces – over the next 45 years
Social	Enhances recreation	Improved access, appearance and opportunities along waterways make them more desirable destinations for the public. Recreation will also be facilitated in newly greened neighbourhood streets and public places
	Improves community quality of life	Trees and parks can transform neighbourhoods into inviting, exciting places to live, work and play
	Reduces effects of excessive heat	Heatwaves are common during Philadelphia's summers and will become more frequent and severe with climate change. GSI, including trees and green roofs, will reduce the severity of heat by creating shade, reducing the amount of heat absorbed by pavements and rooftops and promoting the emission of cooling water vapour. This will potentially reduce, by up to 140, the number of fatalities from excessive heat over the next 45 years
Environmental	Improved air quality	GSI will improve air quality by reducing emissions of pollutants and by removing ozone and particulates from the air, resulting in 1–2 avoided premature deaths, 20 avoided asthma attacks and 250 fewer missed days of school or work per year
	Energy savings and lower carbon emissions	GSI reduces energy use, fuel use and carbon emissions in two ways: first, the effects of trees and plants shading and insulating buildings decrease energy needed for cooling and heating; second, rain is managed where it falls, reducing energy needed to store, pipe and treat it. Trees also act as carbon sinks, absorbing carbon dioxide from the air. Overall, GSI will potentially result in up to 1.5 billion

Table 6.4 (continued)

Benefits	*Type*	*Description*
		lbs of carbon emissions avoided or absorbed, equivalent to taking 3,400 cars off the road each year
	Restores ecosystems	GSI allows rain to soak into the ground and return slowly to streams, reducing erosion of stream channels from high flows, benefiting aquatic species

Philadelphia Water. 2011. Green City, Clean Waters. Available: http://www.phillywatersheds.org/what_were_doing/documents_and_data/cso_long_term_control_plan.

Projects are evaluated based on a variety of criteria including total volume of runoff managed, cost competitiveness and environmental and educational benefits. All SMIP applications must be limited to $100,000 per impervious acre managed or less and manage at least the first inch of stormwater runoff. All successful applications must also include an Economic Opportunity Plan as well as an Operations and Maintenance Agreement. The Plan is a document that provides a written commitment by the contractor to work in good faith to provide subcontracting opportunities for businesses owned by minorities, women and people with disabilities. The Agreement details how the property owner plans to maintain the infrastructure in a way that ensures it performs its designed functions. Typical maintenance tasks include removal of sediment and debris from inlets, watering of new plants and minor concrete repairs, etc.[10]

6.5.3 Greened Acre Retrofit Program

The GARP was established in 2014 to provide funding to companies or contractors planning to construct stormwater retrofit projects on private property across multiple properties in Philadelphia's combined sewer area. In particular, recipients of the grant funds must be able to implement stormwater retrofits over large areas, often over multiple properties, with the minimum project size being 10 acres. Applications cover a variety of criteria, including total land managed, cost to PWD and quality of long-term maintenance and availability of matching funds. In addition, owners of properties participating in GARP must execute an Operations and Maintenance Agreement while project aggregators must execute an Economic Opportunity Plan.

6.5.4 *Suggested Projects for Both SMIP and GARP*

A variety of green infrastructure projects are eligible for funding under both PWD stormwater incentive programmes. Examples of eligible projects include developing underground infiltration/storage basins, infiltration trenches, rain gardens, porous paving, green roofs and vegetated detention basins. Projects will be evaluated on a set of criteria summarised in Table 6.5.

6.5.5 *Rain Check*

Rain Check is a PWD programme that helps residents manage stormwater at their homes. They first attend a workshop to learn about stormwater tools available through Rain Check and determine which will be best for their home. After the workshop, PWD can help them connect with a contractor to install the tools selected. If residents are unsure of which tools are best, PWD will hire a residential stormwater expert to assess their property, determine which tools will work best and discuss with the homeowner the benefits of each. The assessment is valued at $300, but homeowners will only pay $25. Once customers have chosen the tools they wish to have installed, Rain Check will assign an approved contractor to set up the appointment for installation. Customers pay a $25 deposit and Rain Check pays the rest ($200). All participants can receive a rain barrel for free and/or select a downspout planter, rain garden or porous paving installed at a reduced price.

6.5.5.1 Price of Different Tools

The goal is to keep as much stormwater as possible out of the sewer system, so the amount PWD pays is based on the amount of water managed by the tools. In addition, each tool costs a different amount to install. Table 6.6 provides the average costs of installation by contractors with the amount PWD pays fixed with homeowners paying the balance of the costs.

6.6 Implementing GSI: Non-Fiscal Tools

Non-fiscal tools include partnerships with stakeholders, the drafting of regulations, a fast-track process, the preparation of design manuals, challenges and awards, and public outreach and education.

Table 6.5 Greened Acre Retrofit Program Grant project evaluation criteria

Criteria	*Description*
Economic advantage	Projects are evaluated based on the total dollars requested per impervious acre, managed with competitive projects limited to grant funding requests of $100,000 per impervious acre or less
Total acres managed and volume managed	Projects are evaluated based on the total number of impervious acres managed by proposed GSI, with consideration given to proposals that manage more than one inch of runoff, with the most competitive applications managing at least 1.5 inches of runoff
Management practice	PWD encourages applicants who infiltrate stormwater, as this helps reduce both pollution and volume
Public rights of way	Projects are evaluated based on their ability to manage stormwater from public rights of way
Partnership with PWD	Projects are evaluated on their ability to be integrated with other public and private projects. Applications are vetted by multiple PWD green infrastructure teams to determine potential for collaboration
Expected benefits	Projects are evaluated on the amount of expected CSO reductions
Feasibility	Projects are evaluated on their feasibility of construction and/or implementation as demonstrated by their concept design, maps and stormwater calculations
Visibility and accessibility to the public	Projects are assessed on their visibility and accessibility to the public as well as their potential educational benefits
Advances goals of the Green City, Clean Waters plan	Projects are evaluated on their ability to advance the goals of the Green City, Clean Waters plan. These include greenhouse gas reduction, habitat creation, improved possibilities for recreation and reduction of the urban heat island effect. They also include the ability to inform the adaptive management of the programme and use of GSI, including emerging technologies and designs
Application quality	Projects that are detailed and provide accurate information about project scope and concept design are rated higher than those with inadequate or less detailed information. In addition, verification of property ownership and funding must be included in the application

Philadelphia Water Department. 2016i. Stormwater Incentives Grant Manual. Available: https://www.phila.gov/water/wu/Stormwater%20Grant%20Resources/StormwaterGrantsManual.pdf.

Table 6.6 Cost of Rain Check stormwater tools

Tool	*Approximate total cost*	*PWD pays*	*Participant*
Rain barrel	$150	$150	Free
Downspout planters	$975	$875	$100
Rain gardens	$17/sq. ft.	$16/sq.ft. or $2,000 (whichever is lower)	Participant pays the remainder
Depaving	$15/sq. ft.	$8/sq.ft. or $2,000 (whichever is lower)	
Porous paving (including removal of existing surface)	$30/sq. ft.	$15/sq.ft. or $2,000 (whichever is lower)	

Philadelphia Water Department. 2016f. Pricing Information. Available: https://www.pwdraincheck.org/en/.

6.6.1 Interagency Partnerships

Philadelphia Parks and Recreation (PPR) manages over 10,000 acres of public open space, as well as hundreds of structures and buildings. As such, the partnership between PWD and PPR is critical to implementing the Green City, Clean Waters initiative, as it prioritises the use of public land in providing many social, economic and environmental benefits for the city, along with managing stormwater. To increase the availability of public land for GSI, PPR's Green Plan for 2015 called for the adding of 500 acres of new public green space to the city, enabling the integration of GSI into the parks and providing recreational areas that also manage stormwater runoff.[11,12]

6.6.2 PWD Stormwater Management Regulations

In Philadelphia, any development that involves disturbing 15,000 square feet of earth or more comes under PWD's Stormwater Management Regulations that require the property to manage the first inch of stormwater runoff. These projects must have a proposed stormwater management design approved by PWD's Stormwater Plan Review Office that: (1) manages water quality (removing pollutants from stormwater and reducing the volume of water entering sewers) and quantity (monitoring the rate of runoff from a property to prevent localised flooding) and (2) protects waterway channels (e.g. stream banks) by minimising the rate of erosion from stormwater runoff. Overall, this involves a four-step process:

1. *Design:* During the design process PWD encourages applicants to attend pre-arranged walk-ins and other meetings prior to making their application.
2. *Conceptual plan review:* PWD reviews the preliminary stormwater management approach for the site. This plan must be approved before Licenses and Inspections (L&I) will issue a zoning permit.
3. *Technical plan review:* PWD formally reviews the construction plan and engineering calculations for regulatory compliance. PWD must approve the technical plan before L&I will issue a building permit.
4. *Construction:* Prior to construction, PWD meets with the contractor, engineer and property owner. During construction, a PWD inspector will visit the site periodically with a particular focus on when the stormwater management practice is about to be installed. After construction, PWD holds a final inspection and drawings are submitted documenting the constructed conditions of the site.

6.6.3 Fast-Track Development Project Review

Projects with a target of 95 percent or more of the impervious area disconnected from the combined or separate storm sewer can qualify for a fast-track review process in which the stormwater management section of the project will be reviewed within 5 days of submission.

6.6.4 Information Tool: The Green Streets Design Manual

The Green Streets Design Manual (GSDM) provides standard design details and specifications for GSI. In particular, it provides guidance for both public and private entities, including design professionals, interested in incorporating GSI within a given right of way. It provides users with design standards, guidance on siting, information on flexibility in stormwater management practices and an implementation process to guide users through the various steps of planning, designing and constructing green streets. However, the GSDM does not mandate green street implementation, establish a method to incentivise green streets on a large scale, define responsibilities for funding, ownership and maintenance of GSI in the right of way by third parties or limit design to single ‘drop-in’ details without site-specific design work.[13]

6.6.5 *Philadelphia Green Stormwater Infrastructure Challenge*

PWD, in partnership with the City's Office of Innovation and Technology, is seeking innovative solutions to reduce the cost of the city's GSI programme, beginning with more effective assessment of subsurface geologic conditions and utility locations. The Infrastructure Challenge consists of two stages. The first stage is a Request for Information (RFI) during which the city will review information on products, technologies, services and other creative cost reduction strategies. This is designed to provide the city with industry insight, experience and understanding of the solutions available on the market. In stage two, responses to this RFI will then inform future Requests for Proposals to implement the solution. The Infrastructure Challenge is open to anyone with a solution to reduce the costs of implementing the city's GSI programme, with ideas welcomed from social entrepreneurs, engineers, architects, designers, NGOs and enthusiasts working locally or internationally.[14]

6.6.6 *GSI Excellence Awards*

In March 2016, PWD held its inaugural GSI Excellence Awards, in which nearly 200 people involved in creating and maintaining GSI in Philadelphia came out to celebrate some of the best regional projects in green stormwater management that provide triple bottom line benefits.[15] Awards were given in recognition of excellence in the following categories:

- *Public Projects:* Projects managed at least in part by a public agency and/or are on public property (local/city/state/federal).
- *Private Projects:* Projects managed by a private entity and/or are on private property.
- *Early Adopters:* Public or private projects that have been operative for 10 or more years.
- *Research in GSI:* Peer-reviewed, published, and/or presented academic, non-profit, government or private research on one or more elements of the triple bottom line performance of GSI.
- *Leadership in GSI:* An individual whose work has transformed the understanding and/or use of GSI in the Greater Philadelphia region.

The winning applications highlighted triple bottom line (environmental, social and economic) benefits of a green infrastructure approach to stormwater management, with an emphasis on recognising projects that involved collaborative efforts.

The winners in each category received

- A Certificate of Award from the GSI Partners on behalf of The Sustainable Business Network of Greater Philadelphia.
- Region-wide media attention through multiple outlets.
- Opportunities to present the project as a case study for an upcoming GSI Partners event drawing in over 60 industry professionals from Philadelphia and the surrounding counties.
- An opportunity to be included in a GSI Precedent Library that will be made available to a national audience.[16]

6.6.7 Community Input for GSI

PWD is seeking partnerships with community stakeholders across the city to develop green stormwater management projects. It is accepting community input on potential GSI projects at schools, recreation centres, parks, public spaces and parking lots. It will also review neighbourhood-wide submissions of GSI opportunities. Communities that wish to see GSI in public spaces can visit PWD's website in order to acquire information about project requirements and selection priorities, and to learn how to: (1) research the kinds of project that are eligible; (2) identify opportunities for stormwater management on a particular site; (3) identify the steps required for project submission and (4) develop a community input form if the project is selected. The website also provides instructions for neighbourhood-based organisations to submit proposals for multiple GSI sites throughout a specific neighbourhood.[17]

6.6.8 Green Schools Program

In Philadelphia, schools within the combined sewer area cover more than 1,400 acres and 67 percent of school sites are covered in impervious surfaces, including rooftops and asphalt paving. The Green Schools Program aims to build green infrastructure to manage stormwater runoff from these surfaces, to reduce the impacts of CSOs into the city's waterways. This programme also provides educational opportunities for students and enhanced recreational amenities and aesthetic improvements to schools. PWD is working with the School District of Philadelphia, private schools, charter schools and faith-based schools to implement green infrastructure projects. To be part of this programme, schools can be nominated for green infrastructure improvements on PWD's Community input for GSI website and can also apply for a SMIP Grant to help pay for GSI.

6.6.9 Public Engagement Program

The goal of public engagement is to generate public support for PWD's green and grey investments. The approach taken by PWD is to inform, involve and inspire customers, particularly residents and community groups, as the success and sustainability of these investments depend on the support of the community. The two main public engagement programmes are Soak It Up! Adoption, and the city-sponsored Fairmount Water Works Interpretive Center.

6.6.9.1 Soak It Up! Adoption

The Soak It Up! Adoption program provides grants to civic organisations to help maintain the beauty and functionality of GSI in Philadelphia's neighbourhoods. Adoptees assume responsibility for the care of one or more GSI sites. Responsibilities include weekly maintenance visits, reporting activities on site and community engagement. Currently, there are 12 active adoptees that manage 38 GSI sites and approximately 107 stormwater management practices. The adoptees range from 501(c)(3) organisations, civic organisations, community development corporations, behavioural and social science centres to tree tenders and urban farmers. Participants in the programme are encouraged to share their knowledge through public engagements, including:

- Sharing with friends and neighbours about what they do during weekly site visits.
- Writing an article in local neighbourhood papers or newsletters.
- Discussing the Adoption program at community meetings.
- Hosting a table at a block party or community event.*
- Leading a community tour of the adoption sites.*
- Hosting a community event at one of the adoption sites.*
- Leading a trip to the Fairmount Water Works.*
- Helping PWD partner with local schools to educate students on stormwater and green infrastructure.*

**PWD provides resources to help make these events successful.*

6.6.9.2 Fairmount Water Works Interpretive Center

PWD sponsors the Fairmount Water Works Interpretive Center to educate citizens on the connections between human activities and the health of the city's natural environment and waterways. Meanwhile, environmental education centres promote stewardship of the environment through learning. The aim of these centres is for participants to educate neighbours and friends about how the small actions of individuals can lead collectively to large improvements of the city's waterways.

6.7 Implementing GSI: Examples

PWD has initiated and facilitated the implementation of a variety of GSI projects on both public and privately owned lands, including green streets, multipurpose public parks and spaces, wetlands and stormwater basins.

6.7.1 Green Streets: Stormwater Tree Trench at West Mill Creek

Runoff from the street and sidewalk is diverted into a stormwater tree trench at the intersection of Ogden and Ramsey Streets through modified inlet structures. Trees have been planted in soil within a continuous stone trench that stores stormwater until it can infiltrate. Porous pavers have also been installed to replace the brick sidewalk, allowing runoff from the sidewalks to infiltrate into the trench.[18]

6.7.2 Green Streets: Stormwater Bump-Outs on Queens Lane

Philadelphia's first stormwater bump-outs on Queens Lane help reduce runoff and prevent CSOs. Runoff from the street is diverted into the landscaped curb extensions, from which it infiltrates the soil. Each bump-out is custom designed on a site-by-site basis, with each structure 8 feet deep and ranging in length from 24 feet to 80 feet. Each bump-out is planted with a mix of native grasses, perennials and trees and the entire system manages the first inch of runoff from an acre of drainage area. This means that these bump-outs manage between 800,000 and 900,000 gallons of runoff each year.[19]

6.7.3 *Multipurpose Public Park: Clark Park*

At Clark Park a subsurface infiltration bed underneath a new basketball court manages stormwater runoff from the court as well as from an adjacent street and parking lot. The system has been designed to capture the first 1.5 inches of rainfall from the contributing drainage area; however, it is anticipated that with well-drained soil the actual stormwater capture will be greater.[20]

6.7.4 *Multifunctional Public Spaces: Lea Elementary School*

Lea Elementary School was awarded a PWD SMIP Grant to capture and infiltrate stormwater, increase tree canopy and establish a strong identity for Lea through a revitalised landscape. The GSI project involves a cost-effective design to manage stormwater from both the school yard and the public right of way that in addition to managing stormwater provides opportunities for play and education. Three thousand perennials, 35 shrubs and 19 trees were planted to transform the mainly paved school yard into a dynamic landscape with four-season appeal and habitat. In addition, 5,500 sq. ft. of porous pavers were installed to further disconnect the school yard. During the design process, parents, students, school staff and neighbours were engaged through a variety of forums. The school also hosted planting days and will in the future hold maintenance events and continue to engage the neighbourhood and school community in greening efforts.[21]

6.7.5 *Multifunctional Public Spaces: Stroud Water Research Center*

The Stroud Water Research Center is a leading freshwater research institution that also provides an environmental education programme, which is housed in the Moorhead Environmental Complex, a new Leadership in Energy and Environmental Design (LEED) Platinum educational facility. The facility has rain gardens that overflow to an infiltration trench that overflows in turn to additional rain gardens; the runoff is eventually dispersed to a restored meadow and woodland. Overflow from the green roof as well as from the standard roof discharges into cisterns for reuse. Pathways made from porous pavers have also been constructed. All of these initiatives create a living classroom for the region's students and professionals as well as county and state employees.[22]

6.7.6 Stormwater Wetland at Saylor Grove

Saylor Grove is a constructed wetland located on a parcel of land in Fairmount Park, the largest municipal park in Philadelphia. It has been designed to treat a portion of the 70 million gallons of urban stormwater generated in the storm sewershed per annum before it is discharged into the Monoshone Creek, a tributary of the Wissahickon Creek, which is a source of drinking water for Philadelphia. The constructed wetland's function is to treat stormwater runoff to improve source water quality while also minimising the impacts of stormwater-related flows on the aquatic and structural integrity of the waterways' ecosystem.[23]

6.7.7 Stormwater Basin at Cliveden Park

The stormwater basin at Cliveden Park – a demonstration project – captures runoff from adjacent streets and uses the park's natural topography to detain stormwater before it flows into the combined sewer system. Small upland depressions enable water quality treatment and infiltration of stormwater, while a modified outlet structure allows water to pond in the existing wetland before it is slowly released. The basin overall will reduce stormwater volume through evapotranspiration and infiltration and will reduce the flow rate to the combined sewer system during small, frequent storms that cause the majority of CSOs.[24]

6.8 Monitoring of GSI Implementation

It is part of PWD's culture to learn from mistakes. If the agency implements a GSI design that does not work, it ensures this type of mistake will not be made again. As the Green City, Clean Waters programme is new there is a focus on learning from mistakes quickly. The agency has monthly meetings on and how the GSI projects are going. PWD assesses the maintenance of GSI and has monthly maintenance meetings. PWD also learns from inspecting private GSI installations as well as from their design submittals. The private sector learns from PWD as the agency will pass on best practices or lessons learnt on various designs that capture the volume of stormwater required by regulations.

6.9 Case Study Summary

The overall goal of Green City, Clean Waters is to create a green identity for Philadelphia that draws in more residents, which in turn increases revenues for PWD to support more greening, which can increase property values and enhance awareness of the benefits of GSI, creating a positive feedback loop that helps the programme thrive.

PWD implements GSI within the sections of the city served by the combined sewer system through its various Green Programs in streets, schools, public facilities and so forth that each utilise a unique mix of measures. PWD also cooperates with Philadelphia Parks and Recreation in the development of GSI on public green spaces, providing recreational areas that also manage stormwater runoff.

To encourage the reduction in stormwater runoff, PWD bills commercial and residential property owners for the cost of treating it in their monthly water bill. For commercial customers, the stormwater bill is based on the square footage of impervious area covering the property, while residential customers pay a standard amount based on the average surface area of impervious cover on residential properties throughout the city.

To reduce stormwater bills and improve water quality, PWD offers a Stormwater Management Incentives Program (SMIP) to design and construct retrofit projects, which provides not only environmental benefits but educational benefits too. PWD's Greened Acre Retrofit Program (GARP) provides funding to companies or contractors to construct retrofit projects on private property across multiple properties in Philadelphia's combined sewer area. For homeowners, PWD offers the Rain Check programme in which residents attend workshops on GSI tools available and determine which are best for their home. After the workshop, PWD can help residents connect with a contractor to install a variety of subsidised tools selected.

Throughout the city, any development that disturbs a significant amount of earth comes under PWD's Stormwater Management Regulations that require the property to manage the first inch of stormwater runoff using an approved design plan. Projects that disconnect 95 percent or more of the impervious area from the combined or separate storm sewer can qualify for a fast-track review process. Furthermore, to guide the implementation of GSI, PWD has developed the Green

Streets Design Manual that provides design details and specifications for both public and private entities implementing it in rights of way.

To encourage private sector innovation, PWD has launched the Green Infrastructure Challenge to find creative solutions to reduce the cost of implementation. The challenge, open to anyone nationally and internationally, will lead to Requests for Proposals. In addition, PWD has launched the GSI Excellence Awards to celebrate the best regional projects that provide triple bottom line benefits.

To encourage participation in GSI, PWD is seeking partnerships with community stakeholders across the city. PWD is also accepting community input on potential projects at schools, recreation centres, parks, public spaces and parking lots. To facilitate this process, PWD has a dedicated website where stakeholders can learn about project requirements and selection priorities, funding opportunities and the steps required for project submissions. The website also provides instructions for neighbourhood-based organisations to submit proposals for multiple projects.

PWD runs the Soak It Up! Adoption Program that provides grants to civic organisations to help maintain the beauty and functionality of BGI in Philadelphia's public spaces and neighbourhoods. Adoptees assume responsibility for the care of one or more BGI sites, including maintenance, monitoring activities on site and engaging the community on GSI.

In order to monitor and learn from the implementation of GSI, PWD has monthly meetings on the status of projects, as well monthly maintenance meetings. PWD also increases its knowledge from inspecting private installations as well as from their design submittals on best practices in GSI. The private sector in turn also learns from PWD, as the agency will pass suggestions on how GSI can be designed to capture the volume of stormwater required by regulations.

6.10 Adaptive Management

To increase resilience to climate change, reduce environmental degradation and become a Blue-Green City, PWD has implemented an adaptive management decision-making framework that involves planning, designing, implementing and monitoring the design and implementation of GSI to achieve multiple social, environmental and economic objectives (summarised in Table 6.7).

Table 6.7 PWD's adaptive management decision-making framework

Developing a plan for implementing BGI	
Define a vision	PWD has developed the Green City, Clean Waters plan to implement GSI that protects and enhances the region's waterways by managing stormwater runoff and reducing the reliance on additional underground infrastructure
Identify the geospatial extent of the project	GSI will be implemented in sections of the city served by the combined sewer system
Establish cross-cutting steering groups	PWD cooperates with Philadelphia Parks and Recreation to implement GSI on parklands. PWD also works with the School District of Philadelphia
Promote collaborative working across different stakeholders	PWD is seeking partnerships with community stakeholders across the city to develop green stormwater management projects. PWD is accepting community input on potential GSI projects at schools, recreation centres, parks, public spaces and parking lots
Identify multifunctional benefits of BGI	PWD has undertaken a triple bottom line analysis of the environmental, social and economic benefits of the programme to compare the green approach with traditional infrastructure alternatives
Identify local issues, challenges, risks and community needs	PWD enables communities, as well as individual property owners and developers, to identify the most appropriate GSI required to manage stormwater on their properties, subject to approval
Establish resources for successful implementation	The city is investing $2.4 billion over the next 25 years to manage more than one-third of the impervious cover within the sections of the city served by combined sewers
Designing GSI	
Prepare and communicate a draft strategy/plan/design incorporating the vision and objectives	PWD will implement GSI through its various green programmes that will each utilise a unique mix of tools to filter, store and manage stormwater above and below ground

Table 6.7 (continued)

Designing GSI	
Use responses to refine and improve the plan, strategy or design and its delivery	Projects receiving funding under PWD's stormwater incentive programmes are evaluated on a set of environmental, economic and social criteria. Properties that are subject to PWD's Stormwater Management Regulations must have their GSI designs approved by PWD's Stormwater Plan Review Office
Ensure the plan/strategy/design meets requirements for function, durability and beauty	The GSI must contribute to the vision of creating a green identity for Philadelphia that draws in more residents, which in turn increases revenues for PWD to support more greening, which can increase property values and further enhance awareness of the benefits of GSI
Implementing GSI	
Set design and management standards by establishing locally relevant criteria	PWD is creating standard practices for city agencies to follow when undertaking public work investments that involve GSI features. The GSDM provides standard design details and specifications for GSI, providing guidance for both public and private entities, including design professionals
Ensure the provision of adequate funding mechanisms for ongoing management and maintenance costs	PWD's Green City, Clean Waters plan is to reduce CSOs through an investment of $2.4 billion over the next 25 years
Build the project, launch the strategy and adopt the policies	PWD will implement GSI through its various green programmes including green streets, green schools, green public facilities, green businesses and green homes among others. To facilitate the private sector's uptake of GSI PWD has implemented stormwater billing, grants, mandatory GSI on large-scale developments and an annual GSI Excellence Award
Set milestones, targets and programme	The Green City, Clean Waters programme aims to create nearly 10,000 Greened Acres across the city. By the end of the programme the city aims to have reduced stormwater pollution entering its waterways by 85 percent

(*continued*)

Table 6.7 (continued)

Managing/maintaining BGI	
Monitor the strategy's delivery against its objectives regularly, using key performance indicators and stakeholder consultation	PWD has monthly meetings on GSI and how the projects are going, as well as monthly maintenance meetings. PWD learns from inspecting private GSI installations as well as from their design submittals on best practices. The private sector in turn learns from PWD as the latter will pass suggestions on how GSI can be designed to capture the volume of stormwater required by regulations

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CHAPTER 7

Rotterdam Becoming a Blue-Green City

7.1 Introduction

Rotterdam is home to 615,000 residents and is situated around 40 km inland on the New Meuse River, which is one of the channels in the North Sea delta formed by the rivers Rhine and Meuse. The city grew around a dam that was constructed in the river Rotte in the thirteenth century. After construction of the New Waterways in 1872, which created a direct connection to the North Sea, the city developed into one of the world's largest ports and the second city of the Netherlands.[1]

Throughout the nineteenth century the level of hygiene in Rotterdam was very poor due to open water being used for both extraction of drinking water and as an open sewer. In 1854, Rotterdam's city council accepted Willem Nicolaas Rose's plan for an urban water system – the Water Project – which involved the development of a system of pumping stations, locks, culverts and a 30-km-long *singel* (a green belt that included a waterway) to achieve four outcomes: flushing out water from the city; lowering the groundwater level so that the city could expand; creating an elevated pathway around the city for its inhabitants to walk on; and developing a new residential area.[2] In 1890, Rotterdam constructed an underground sewer system to improve conditions. This created a division among the systems required for

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groundwater level control, wastewater discharge and drinking water supply. During this time, many of the city's canals were filled in due to a shift from traffic and transport by water to transport by train, tram and motor vehicle.[3] Today, Rotterdam has 3,000 km of sewer system, 400 km of canals and 900 pumping stations in its overall stormwater and sewer system.

7.2 Challenges to Traditional Stormwater Infrastructure

Rotterdam faces challenges to its traditional stormwater infrastructure from climate change and extreme weather events including heavy storm events, droughts and increasing temperatures (summarised in Table 7.1).

7.2.1 Impacts of Heavy Storm Events

The current system – comprising canals, lakes, other waterways, drainage outlets and a sewer system that directs post-treatment rain and wastewater into the New Meuse – lacks the flexibility to meet the

Table 7.1 Impacts of climate change on Rotterdam

Impacts of climate change	*Examples*
Higher sea and river levels	Increased risk of outer-dike flooding More frequent closure of the storm surge barrier Increased risk of inner-dike flooding
More intensive rainfall	Water is less able to drain away Increased risk of disruption
Longer periods of drought	Lower water tables Decrease in water quality Increased likelihood of damage to built-up areas, flora and fauna Lower river levels obstructing shipping
Longer periods of hot weather (heatwaves)	Decrease in thermal comfort of city Negative effects on health and well-being Increased likelihood of damage to flora and fauna

City of Rotterdam. 2013b. Rotterdam Climate Change Adaptation Strategy. Available: http://www.rotterdamclimateinitiative.nl/documents/2015-en-ouder/Documenten/20121210_RAS_EN_lr_versie_4.pdf.

potential challenges of more intensive rainfall. Peak downpours are already resulting in disruption and damage as water floods streets and inundates cellars and sewage overflow discharges directly into the city's canals and waterways. Climate change is projected to lead to heavy downpours during summer becoming more frequent and intense: for each degree rise in temperature the intensity of rainfall will increase by 14 percent. By the middle of the present century the type of rainfall that occurs once every five years will occur once a year. Increased frequency and magnitude of rainfall will increase the pressure on the current system and therefore increase the probability of flooding, resulting in damage to infrastructure and buildings and disruption from inundation of roads and tunnels. Vulnerability to the risks of extreme rainfall varies within the city, depending on the physical characteristics of each area. Outer-dike Rotterdam is the least vulnerable area as ground levels are relatively high and future rainfall can be drained directly into the river. The post-war outskirts usually have sufficient space for extra blue and green spaces to store excessive water. The more central, urban districts constructed primarily in the nineteenth-century are more vulnerable, due to the density of buildings and high proportion of impervious surfaces, which leaves relatively little space for Blue-Green Infrastructure (BGI). It is the inner-city area, however, that is most at risk from extreme rainfall, as it is densely built up with public spaces intensively used and has little vegetation. In addition, these areas are uneven as a result of subsidence due to their having been built on peat. Because the urban areas of Rotterdam are diverse and computational models are inadequate at this stage, it is not possible to accurately predict the exact consequences of increased rainfall from climate change across the city.[4]

7.2.2 Risk of Droughts

Rotterdam is also at risk of experiencing long periods of drought, leading to groundwater deficit and lower water tables. The drying up of land will lead to further subsidence. During wet periods subsidence can lead to flooding as the ground level sinks down to the water table. In addition, droughts will impact the quality of surface water with higher concentrations of nutrients leading to algal growth, which will be further exacerbated from sewage overflows resulting from extreme rainfall events.

7.2.3 *Impacts of Urban Heat Island Effect*

Rotterdam will experience an increase in the Urban Heat Island (UHI) effect. It is projected that the difference in temperature between the city and the surrounding countryside can be as high as 8°C. The UHI effect combined with more frequent and prolonged periods of higher temperatures can lead to health problems, particularly in older people and those suffering from respiratory diseases, as well as warmer surface water enabling blue-green algae and botulism to flourish, which in turn will increase fish mortality and render the water unsafe for swimming.[5]

7.3 Strategic Vision: The Rotterdam Climate Proof Programme

In 2008, the City of Rotterdam ratified the Rotterdam Climate Proof Programme. The aim of the programme is to make Rotterdam '100 percent climate-proof' by 2025, while creating maximum economic benefits in the process. Specifically, by 2025 Rotterdam will have taken measures to ensure every region in the city is minimally disrupted by, and maximally benefits from, climate change throughout the following decades. It also takes into account long-term foreseeable climate change in all spatial development of Rotterdam while allowing for associated uncertainties. The programme consists of three core activities: (1) increasing the store of knowledge about climate change; (2) implementing appropriate adaptation measures, and (3) promoting Rotterdam's international image as an innovative delta city. Research and applied technology will be the basis for adaptations and international collaboration. Investing in a climate-proof city will therefore contribute towards the creation of a safe, healthy and attractive living environment and a strong economy for the residents and business communities. Finally, it is hoped that the programme will contribute to the development of international knowledge agreements and partnerships on climate change adaptation.

7.3.1 *Rotterdam Climate Adaptation Strategy*

The Rotterdam Climate Adaptation Strategy provides an outline of how the city plans to meet its climate-proofing targets while creating maximum economic benefits, improving the environment, enhancing natural resources and increasing the involvement of inhabitants in climate change adaptation. It has been estimated that the cost of making Rotterdam climate-proof will result in investments totalling between EUR 4 and 5 billion.[6] The overall objective is for Rotterdam to be a safe and liveable city with added value. To achieve this Rotterdam will ensure the following:

- *The city and its inhabitants are safe from flooding:* It is vital that Rotterdam and its inhabitants remain protected from flooding and that investors retain their confidence in the city and region.
- *The city and its inhabitants experience minimal disruption from too much or too little rainfall:* Rotterdam needs to be able to cope with extreme weather events, including prolonged downpours, heatwaves and periods of drought.
- *The port of Rotterdam remains safe and accessible:* Rotterdam needs to remain accessible to people, goods and services. It is important that the vital urban networks remain robust, and that extreme weather events do not result in unmanageable situations.
- *The inhabitants of Rotterdam are aware of the effects of climate change and know what they can do for themselves:* Residents and businesses in Rotterdam need to be aware of the consequences of climate change, to become conscious of their own responsibilities and know what actions they themselves can take. The city administration will provide the framework within which they can assume their own responsibilities.
- *Climate change adaptation contributes to a comfortable, pleasant and attractive city:* Rotterdam must continue to be a city that is pleasant to live and work in and where climate change does not adversely impact the health and welfare of its inhabitants. Climate adaptation measures will directly contribute to making the city more attractive and improving the environment.
- *Climate change adaptation strengthens the economy of Rotterdam and its image:* Making the city climate-proof will benefit its economy. Specifically, climate adaptation will create new economic opportunities and strengthen the international image of Rotterdam as an ambitious and progressive delta city. This way, it will be able to promote itself as a role model for other cities.

Table 7.2 Adaptive approach in Rotterdam

Adaptation solutions	*Examples*
Robustness and resilience	Sewers and water plazas
Protection and living with water	Levees and adaptive building and design
The Delta Works Programme and small-scale measures	Storm surge barriers and permeable pavement (removing tiles, planting greenery)
Technology and nature	Pumping stations and green embankments

7.3.2 Rotterdam Climate Adaptation Strategy Principles

There are four core principles in the Rotterdam Climate Adaptation Strategy:

1. *Robust system:* To ensure the city is climate-resilient, it will continue to rely on the current robust system of storm surge barriers, dikes, canals, etc., which in the future will be strengthened to prevent the loss of vital public utilities and facilities.
2. *Adaptation:* The existing system for managing heavy precipitation or periods of drought will, in time, reach its limits, resulting in the need for the application of small-scale measures throughout the entire urban area to create resilience. The ability of the city to absorb excess water will be restored with measures that keeps rainfall where it falls, stores it and drains it away slowly (Table 7.2).
3. *Cooperation and linkage with other activities:* Climate change adaptation in the city requires cooperation with other partners; for example, the majority of the city's buildings are on private property, requiring public–private cooperation in implementing adaptation solutions. Residents, businesses, housing associations, developers, institutions and interest groups will all need to be involved in the process of making the city climate-proof, with local government acting as facilitator, initiator and supporter. Raising awareness on climate change is key to spurring small-scale adaptive measures throughout the city. Furthermore, these measures will be linked with other urban developments and projects, for example, regular maintenance of the roads and public areas.
4. *Added value for environment, society, economy and ecology:* In addition to environmental benefits, climate change adaptation offers numerous

opportunities to make living in the city more attractive, by ensuring that residents benefit from community initiatives, thereby adding value to the economy and increasing biodiversity and water quality.

7.4 Implementing BGI in Public and Private Spaces

The Climate Adaptation Strategy will be implemented by the City of Rotterdam, in partnership with the Port Authority, municipal services, other government departments and utilities (e.g. water boards), private organisations (including housing corporations and project developers) and last but not least, the city's residents. The key aspects of implementation are listed below:

- *Implementation is in tune with the 'rhythm' of the city:* Climate adaptation is a slow process, with its effects only gradually visible. At the same time the city is developing, with urban utilities and infrastructure being maintained, houses renovated, outdoor areas redesigned and the city extending and compacting, all of which is long lasting. Passively waiting for climate change to determine which measures need implementing is very costly and therefore, linking climate adaptation measures with other city development and maintenance projects is key to implementing adaptation measures.
- *Implementation is area-specific:* The vulnerability of different parts of the city has already been determined and there are adequate levels of knowledge on what measures and activities are available to make areas more climate-proof. Parties responsible for specific areas will have to determine which measures are most appropriate and feasible as in most cases the city administration will not be in charge; instead it will define the framework, provide advice and stimulate other parties to act.
- *Implementation will create added value:* Activities will be devised that make Rotterdam more climate-proof, reinforce the city's aims and create added value for the physical city, the economy and the community. Added value will be created by linking adaptation measures to construction and development projects.
- *Implementation involves working together:* It is impossible for the city administration to create a climate-proof city on its own. Instead, all stakeholders must become involved in the climate adaptation strategy.

7.4.1 Implementing 'No Regret' BGI Actions

Rotterdam will continue to maintain and improve the sewer system by increasing its drainage capacity, thus making the city less vulnerable to flooding. However, this measure alone will not be sufficient in ensuring a climate-proof city. As such, Rotterdam is implementing large-scale implementation of small-scale 'no regret' BGI actions that embed climate adaptation into the urban fabric of the city and increase the resilience of the urban water system. These measures also support community learning, specifically in respect to understanding the urgency of the need to take action on climate change. Measures range in their type and scale, and include:

- A large number of small-scale projects that are led by citizens and businesses under the motto 'many small actions make a big difference'.
- A small selection of key projects specifically designed to inspire and create publicity.
- Effective large-scale projects that run quietly in the background to deepen understanding and support research.[7]

7.4.2 Specific BGI Measures

Specific BGI goals include: (1) increasing the capacity of public areas to temporarily store water without causing any damage; (2) greening of open spaces; (3) creating water squares (water plazas), and (4) using bioswales and porous pavements to reduce flooding damage. In addition, the construction of underground water storage areas will be implemented in areas of limited space. BGI solutions are also implemented on private property with 'blue roofs', replacing paving in gardens with greenery and constructing green facades. Where possible, BGI measures will be linked with other projects, for example, existing road, park and sewage maintenance programmes, thereby limiting and spreading the required additional investments. Over time all parts of Rotterdam will gradually become greener and more climate-proof through BGI solutions.

7.4.3 One Size Does Not Fit All

The types of BGI measures implemented across the city vary depending on the area and its specific characteristics, including: (1) the relationship between paving, water and vegetation; (2) the type of ground; (3) the depth of the water table; (4) the type of sewage system, and (5) the functioning of the current water system. In the older, densely built-up areas of Rotterdam, where there is limited public space, the focus is on implementing a combination of BGI measures, for instance, underground water storage and water squares. In addition, promoting green roofs and greening of the streets and open areas contributes to increased resilience. In contrast, post-war districts are more suitable for implementing BGI measures that include the creation of additional stretches of open water, i.e. canals and lakes. The additional benefit of tailoring BGI solutions to districts is that they can increase resiliency to droughts and UHI effects.

7.4.4 Public Sector Cooperation

With regard to climate change adaptation there is strong cooperation between the city's Department of Public Works, which is responsible for the maintenance of infrastructure, and the Urban Development Department. This is because the fundamental aspect of developing a climate adaptation strategy and implementing it is strong cooperation between the designers and the city planners and the water managers. They have to develop integrated water and and climate adaptation plans because most of the solutions are to be found in spatial planning and in the design of build. So there needs to be close cooperation between these two departments. Increasing cooperation also means that the integration of climate adaptation solutions can be upscaled. For example, one department working on solar panels may not be cooperating with another working on green roofs; however, as research evidence shows that efficiency of solar panels positioned on green roofs is higher, the benefits of cooperation are established. In addition, as the city adopts measures that combine climate resilience with social resilience, this will involve departments working on infrastructure cooperating with the Social Affairs and Employment Department. As a consequence, the city will be looking to focus not only on climate resilience but also on resilience within a broader perspective.

7.4.5 Importance of Public–Private Partnerships

To date the focus has been on BGI projects that have been set up and organised by the city itself. However, there has been a shift towards greater cooperation with local entrepreneurs and citizens. In addition, the city is starting to see BGI initiatives developed by the citizens themselves independently. The city administration has two explanations for this. First, there is greater awareness with regard to the impacts of climate change, especially following significant flooding in the southern parts of the Netherlands as well as parts of Germany, Belgium and France in 2016; this has increased awareness of the threat of flooding. The second reason is that in the Netherlands many local governments have become smaller, along with reduced budgets. So there is greater awareness that all sectors of society have to cooperate together and play a role in reducing flood risks. This cooperation is important because while the local government implements BGI projects in public spaces to ensure the city becomes climate-resilient, 70 percent of land is privately owned. Therefore, the implementation of BGI in public spaces alone will not be sufficient to ensure the city is climate-resilient.

7.4.6 Results to Date

By 2013, total water collection capacity had increased to 45,000 m^3, resulting in 11 percent of the total target by 2025 being achieved.[8]

7.5 Implementing BGI: Fiscal Tools

To encourage the implementation of BGI, Rotterdam has relied on a green roof rebate in the past.

7.5.1 Green Roofs

Between 2008 and 2014, Rotterdam provided a subsidy scheme to promote the creation of green roofs on municipal as well as housing association and business properties. The subsidy of up to EUR 30 per m^2 was provided, of which EUR 25 was provided by the City of Rotterdam and EUR 5 by the Water Board. However, due to budget cuts the water board cancelled the subsidy for disconnecting rainwater pipes. To date the grant scheme has led to 150,000 m^2 of green roofs being developed across the city.[9]

7.6 Implementing BGI: Non-Fiscal Tools

Non-fiscal tools include a series of awareness programmes and knowledge tools to promote increased stakeholder participation.

7.6.1 Neighbourhood Programme: Paving Out, Plants In

Rotterdam's 'Paving Out, Plants In' programme encourages residents to replace paving in their own gardens with plants and vegetation. In addition to contributing towards climate adaptation the programme promotes cooperative action by residents, thus improving social cohesion.[10]

7.6.2 Rotterdam Delta City App

The Rotterdam Delta City app available on App Store and Google Play enables users to explore Rotterdam and discover the measures the city takes to protect itself from water: sea, river, rain and groundwater. It guides users to hotspots throughout the city to let them discover the broad network of innovative solutions, including multifunctional dikes and water plazas. Additional information is provided on each hotspot including how and why these measures work and how they are part of an integrated strategy for the entire city. Overall, the app aims to educate users on how smart spatial design and multifunctional solutions contribute to a more attractive and economically strong city.[11]

7.6.3 Interactive Climate Atlas

The interactive climate atlas provides a digital overview of the effects of climate change on Rotterdam. Specifically, the atlas is a collection of diagrams and graphs providing information about climate change, climate scenarios and the impacts on Rotterdam and vulnerable areas and buildings. The atlas allows users to compare the impacts of various climate scenarios both generally and in specific areas of the city, providing stakeholders with the information they require to arrive at solutions regarding both planning and prioritisation.[12]

7.6.4 Climate Adaptation Support Toolbox

This Toolbox is an aid for spatial designers and project managers; it provides an overview of potential adaptation measures at various spatial levels (region, city, district/street, building) and their aims, for example, limiting the likelihood of adverse consequences of climate change (prevention), limiting damage during flooding or accelerating recovery afterwards.

7.6.5 Rotterdam Climate Societal Cost Benefit Analysis

The Rotterdam Climate Societal Cost Benefit Analysis (SCBA) provides insights into the long-term social costs and benefits of various combinations of BGI measures that can be selected to make Rotterdam more climate-proof. The tool involves comparing two scenarios: the first shows what would happen if the project was not implemented ('zero' alternative) and the second what would happen if it was ('project' alternative). In its current form the tool supports strategic decision-making and shows how linking BGI measures with other construction projects or maintenance programmes nearly always leads to a positive cost-benefit outcome.[13]

7.6.6 Rotterdam Climate Game

This is a computerised game that was developed to make players aware of the challenges involved in making a city climate-proof. The modernisation of the Feijenoord district is used as an example in the game. Feijenoord is a partially outer-dike area where EUR 120 million will be spent over the coming years to create a more climate-proof environment. The district has a number of stakeholders, each with their specific interests. The game teaches players how to divide the roles and get everyone to work together to implement adaptation measures. The game gives a realistic visualisation of the interdependencies, advantages and necessities of working together. Issues in the game are universal and apply to a wide range of area development processes in which insights are needed on climate change adaptation, the effects of various measures and the interests of all parties involved.[14]

7.6.7 3Di

The 3Di computer program uses high-speed calculations to create an immediate visual representation of the effects of a disaster on Rotterdam, providing users with insights into the vulnerabilities of Rotterdam's public areas to extreme weather events. The model can also be used to visualise the effects of implementing BGI measures in urban spaces, for example, the impact of installing a green roof. This enables users to identify BGI measures that have the greatest effect at the district, street and even building levels. The City of Rotterdam can also use the program to proactively work towards preventing flooding and limiting damage from flooding as much as possible.[15]

7.7 Implementing BGI: Examples

Rotterdam has initiated and facilitated the implementation of a variety of BGI projects on both public and privately owned lands, including a water square and climate-proof district as well as multifunctional dikes, waterway restorations and a multifunctional recreational space.

7.7.1 Water Square, Benthemplein

The City of Rotterdam, in partnership with the architectural practice De Urbanisten, has developed the large, multifunctional Benthemplein water square that combines the collection of rainwater with a public outdoor area. The project involved the participation of a number of stakeholders, including Zadkine College and the Graphic Lyceum, a church community, a youth theatre, a sports school and local residents; they met over three workshops to discuss the square's potential usage, desired characteristics and the influence of rainwater on the area. The outcome was a square designed to prevent floods, relieve pressure on the sewers and improve the quality of water and the living environment of city. The square functions as a recreational and green space, providing opportunities for activities such as skateboarding. When it rains heavily the square functions as a water storage reservoir. Water flowing from the schools and the church located on the square is collected in two shallow basins. Water from the areas surrounding the square flows into the deepest basin via wide gutters; during extreme rainfall it pours into the basin over a wall. The water does not stay in the basin for long; instead it is absorbed into the ground or drained into the nearby Noordsingel (canal) within 24 hours. Agreements have been made with the municipal health service regarding the time by which water must be cleared from the square, ensuring the water does not pose any risk to public health.[16]

7.7.2 *Zoho: First Climate-Proof District*

The Zomerhofkwartier (Zoho) district was built shortly after World War II, mainly to accommodate businesses and schools. The housing association, Havensteder, wanted to turn the district into a quiet and attractive residential area. However, when plans to demolish and build new housing did not go ahead, the housing association decided to step back for a period of 10 years to let the district consider initiatives for further development. Havensteder then invited Stipo, an urban strategy and city development company, to move into one of its buildings. Stipo did so provided other collaborating partners could join them in the same building and implement the concept of 'slow urbanism' in partnership with the housing association. Since then a large number of companies and institutions have moved into the district, enabling collaborative efforts to adapt it to climate change. With Havensteder supervising the process and the municipality providing funding of EUR 100,000, workshops were held in which parties identified climate projects, including replacing superfluous parking spaces and excessively wide roads and pavements in public spaces, installing three 'summer gardens' with rainwater collected for food production and converting the Hofbogen, a former railway track to The Hague, into a green route.

7.7.3 *Multifunctional Terraced Dikes*

Rotterdam has developed the multifunctional terraced dike, a heightened dike that can be used for different purposes while protecting residents and infrastructure from flooding events. It will be constructed in South Rotterdam as part of a spatial development plan to connect the Afrikaander and Kop van Zuid districts. The dike has wide terraces on both sides that can be used for road construction, landscaping and even building construction, enabling it to generate revenue and add value to the districts.

7.7.4 New Parks on the Banks of the New Meuse

Ten collaborating parties are working together on the banks of the New Meuse River to create new parkland areas. Outside of the city, tidal parks have been created, with landscaped areas containing reeds, willows and rushes. The parklands located in the city have a more urban design.

7.7.5 Blue Corridor

In 2012, construction began on the Blue Corridor, a blue-green link between the Zuiderpark in Rotterdam, the future landscape park Buijtenland in Rhoon and the Zuidpolder in Barendrecht. The Blue Corridor project, involving eight government organisations, will provide a recreational, navigational route for leisure activities, clean water supply to the area and act as a water storage facility in addition to forming an ecological link between the various natural areas. The project will take over a decade to complete and has been divided into six sub-projects.[17]

7.7.6 Willem-Alexander Baan Rowing Course

In 2013, Rotterdam opened this rowing course as part of the new recreation area of Eendragtspolder. The area acts as a large water storage basin which can store 4 million cubic metres of water, preventing the Rotte from overflowing in times of heavy rainfall. Overall, the area combines sport, recreation, nature conservation and water storage.[18]

7.8 Monitoring of BGI Implementation

Rotterdam has developed a climate adaptation monitor, designed to provide insights into whether climate change is taking place more quickly or slowly than expected or whether the objectives of the Climate Adaptation Strategy have to be adjusted upwards or downwards. It also reviews the progress of the various adaptation measures.[19]

Meanwhile, a Climate Adaptation barometer has been developed to follow the progress of the development of the Strategy. A key aspect of the barometer is that new insights, extreme events, other funding options or experiences with measures may result in a re-evaluation of priorities and/or other measures and implementation schemes. While the barometer helps the city structure the adaptation plan and enables the tracking of progress, it is not suitable for tracking progress of individual projects. Tools for this purpose will be designed n the near future.[20]

7.9 Case Study Summary

Rotterdam will implement BGI as part of its stated aim to become '100 percent climate-proof', while at the same time strengthening the economy, improving the environment, enhancing natural resources and increasing the involvement of inhabitants in climate change adaptation. It has already determined the vulnerability of different parts of the city to climate change and identified the most appropriate measures and activities to protect them.

The city is initiating the implementation of numerous 'no regret' BGI measures that embed climate adaptation into the urban fabric and increase the resilience of the water system. These measures include a large number of small-scale projects that are led by citizens and businesses, a small selection of which are specifically designed to inspire and create publicity; there are, in addition, large-scale projects to help deepen understanding of BGI. Where possible, these measures will be linked with other projects, for example, incorporating BGI within existing road, park and sewage maintenance programmes.

The implementation of BGI in public spaces requires that the Department of Public Works, responsible for the maintenance of infrastructure, liaise closely with the Urban Development Department. Cooperation between designers, planners and water managers is fundamental to developing and implementing a successful Climate Adaptation Strategy.

Until recently Rotterdam provided a subsidy scheme to promote the creation of green roofs on municipal as well as on housing association and business properties. However, the city now relies on a variety of non-fiscal tools to encourage the implementation of BGI. For instance, the 'Paving Out, Plants In' programme encourages residents to replace paving in their own gardens with plants and vegetation. Meanwhile, the Rotterdam Delta City app enables users to explore the multifunctional BGI measures the city is taking to become climate-proof. In BGI hot spots around the city users can learn about how and why these measures work and how they are part of an integrated strategy for the entire city.

To provide enhanced awareness on the impacts of climate change, the city has developed an interactive climate atlas that provides information about climate change, climate scenarios and the impacts on Rotterdam as well as vulnerable areas and buildings. Users can also compare the impacts of various climate scenarios.

To enhance capacity of stakeholders to implement BGI, the city has developed the Climate Adaptation Support Toolbox as an aid for spatial designers and project managers to understand potential adaptation measures at various spatial levels. Meanwhile, the 3Di computer program visualises the effects of implementing BGI measures in urban spaces. This enables users to identify measures that have the greatest effect at the district, street and even building level. In addition, the city has developed the Rotterdam Climate Societal Cost Benefit Analysis (SCBA) tool that shows how linking BGI measures with other construction projects or maintenance programmes nearly always leads to a positive cost–benefit outcome.

To encourage cooperation between various stakeholders, both public and private, Rotterdam has developed a computer game that teaches players how to allocate roles and get everyone to work together to implement adaptation measures. It provides a realistic visualisation of the interdependencies, advantages and necessities of cooperation.

In order to track the progress of BGI projects, Rotterdam is developing a climate adaptation monitor to provide insights into whether climate change is taking place more quickly or slowly than expected and whether the objectives of the Climate Adaptation Strategy should be modified. The city has also developed a climate adaptation barometer that tracks the progress of the development of the Strategy.

7.10 Adaptive Management

To increase resilience to climate change, reduce environmental degradation and become a Blue-Green City, Rotterdam has implemented an adaptive management decision-making framework that involves planning, designing, implementing and monitoring the design and implementation of BGI to achieve multiple social, environmental and economic objectives (summarised in Table 7.3).

Table 7.3 Rotterdam's adaptive management decision-making framework

Developing a plan for implementing BGI	
Define a vision	The Climate Proof Programme aims to make Rotterdam '100 percent climate-proof' by 2025. The Climate Adaptation Strategy outlines the course of action to achieve a climate-proof city, while maximising economic, environmental and social benefits
Identify the geospatial extent of the project	The vulnerability of different parts of the city to climate change has already been determined and there are adequate levels of knowledge on what BGI measures and activities are available to make areas more climate-proof
Establish cross-cutting steering groups	The Climate Adaptation Strategy will be implemented in partnership between the City of Rotterdam, municipal services and other government departments including water boards
Promote collaborative working across different stakeholders	The city recognises that it is impossible to create a climate-proof city on its own. Instead, the city administration will act as a facilitator, initiator and supporter of community-led BGI initiatives
Identify multifunctional benefits of BGI	BGI projects aim to enhance social cohesion in addition to providing a number of other benefits. The Rotterdam Climate SCBA provides insights into the long-term social costs and benefits of various combinations of BGI measures
Identify local issues, challenges, risks and community needs	The city follows a 'one-size-does-not-fit-all' mantra for implementing BGI. Measures implemented across the city vary depending on each area and its specific characteristics. These include the relationship between paving, water and vegetation; type of ground; depth of water table; type of sewer system; and the functioning of the current water system. Parties responsible for specific areas will have to determine which BGI measures are most appropriate and feasible as in most cases the City of Rotterdam will not be in charge; instead it will define the framework, provide advice and stimulate other parties to act
Establish resources for successful implementation	The cost of making Rotterdam climate-proof will result in investments totalling between EUR 4 and 5 billion

Table 7.3 (continued)

	Designing BGI
Prepare and communicate a draft strategy/plan/design incorporating the vision and objectives	BGI projects are initiated that are: (1) in tune with the rhythm of the city; (2) area-specific; (3) of value to the city, economy and community; (4) designed to foster collaboration between stakeholders, and (5) supportive, when appropriate, of other stakeholders' projects
Use responses to refine and improve the plan, strategy or design and its delivery	The city is implementing a broad programme of 'no-regret' BGI measures that support community learning, deepen understanding, support BGI-related research, and enhance the development of a rigorous cost-benefit analysis system
Ensure the plan/strategy/design meets requirements for function, durability and beauty	Projects are chosen that reinforce the city's vision that climate change adaptation enhances the environment, encourages community participation, adds value to the economy and increases biodiversity and water quality
	Implementing BGI
Set design and management standards by establishing locally relevant criteria	BGI measures implemented across the city vary according to each area and its specific characteristics, including (1) the relationship between paving, water and vegetation; (2) the type of ground; (3) the depth of the water table; (4) the type of sewer system, and (5) the functioning of the current water system
Ensure the provision of adequate funding mechanisms for ongoing management and maintenance costs	Funding for BGI projects comes from multiple sources, with investments made by the municipality as well as businesses and community organisations
Build the project, launch the strategy and adopt the policies	Rotterdam in the past had a green roof subsidy. Today the city concentrates on raising awareness on the need to adapt to climate change through education and the development of smartphone apps and interactive computer modelling for professionals
Set milestones, targets and programme	By 2013, total water collection capacity had increased to 45,000 m^3, resulting in 11 percent of the total target by 2025 being achieved.

(*continued*)

Table 7.3 (continued)

Managing/maintaining BGI	
Monitor the strategy's delivery against its objectives regularly, using key performance indicators and stakeholder consultation	A climate adaptation monitor is being developed to: (1) provide insights into whether climate change is taking place more quickly or slowly than expected; (2) assess whether the objectives of the Climate Adaptation Strategy have to be adjusted upwards or downwards; and (3) review the progress of the adaptation measures that have been taken

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CHAPTER 8

Singapore Becoming a Blue-Green City

8.1 Introduction

Singapore is a sovereign city state, situated on one large island and around 60 islets, lying 1.5° north of the Equator. It has a tropical rainforest climate and experiences around 2,400 mm of precipitation per annum. Storms occur in the form of monsoon surges, Sumatra squalls and sea breeze-induced thunderstorms. Singapore has 32 major rivers, more than 8,000 km of waterways and 17 reservoirs, all within a space of around 700 km^2. Currently, 67 percent of the land area is water catchment, with the aim of increasing this to 90 percent.

Singapore is vulnerable to flooding events due to the abundant rainfall and to the fact of its being relatively low-lying, with limited space for drainage infrastructure. Over the past 30 years the government has accordingly invested over $2 billion in extensive drainage infrastructure, including drains, rivers and canals to channel rainwater into reservoirs or out to sea. In addition, Singapore uses two separate systems to collect rainwater and used water.

With nearly two-thirds of Singapore as water catchment, rainwater that falls in these areas is collected through an extensive network of drains, canals, rivers, stormwater collection ponds and reservoirs before being treated for drinking water supply. This makes Singapore one of the few locations in the world that harvests urban stormwater on a large scale for its water supply.

R.C. Brears, *Blue and Green Cities*,
https://doi.org/10.1057/978-1-137-59258-3_8

8.2 Challenges to Traditional Stormwater Infrastructure

Singapore faces multiple challenges to its traditional stormwater infrastructure from urbanisation and climate change.

8.2.1 Urbanisation

Singapore's population has increased in recent decades, from 1.6 million in 1960 to 5.31 million in 2012. Over time the construction of high-density satellite towns and residential and commercial developments has increased the city's impervious surface area, leading to higher peak runoffs during storm events.[1] Furthermore, it is a challenge to expand the city's drainage system, as drains and canals usually lie close to urban infrastructure such as buildings and roads.

8.2.2 Climate Change

In 2011, an independent panel was appointed to review rainfall records over the period 1980–2012. Named the Expert Panel for Drainage Design and Flood Protection Measures, it produced a report the following year. It found an upwards trend of increased frequency and magnitude of intense rainfall events. Maximum hourly rainfall increased from 96 mm in 1980 to 117 mm in 2012; meanwhile, the frequency of rainfall events with more than 70 mm of rain in one hour increased at an average rate of 1.5 days per decade from 1980 to 2012.[2,3]

8.3 The 'City in a Garden' Strategic Vision: ABC Waters

In 2006, as part of its City in a Garden master plan, Singapore's Public Utilities Board (PUB) launched the Active, Beautiful, Clean Waters (ABC Waters) Programme that aims to integrate the city's abundant blue spaces with parks and gardens to create beautiful and clean streams, rivers and lakes with community spaces for all to enjoy. The aim of the ABC Waters Programme is to integrate the environment, water bodies and the community, in order to create new community spaces and encourage lifestyle activities in and around the waters.

8.3.1 Key Strategies of the ABC Waters Programme

The three key strategies of the ABC Waters Programme are the following:

1. *Development of ABC Waters master plan and project implementation:* Launched in 2007, the master plan guides the overall implementation of projects devised to transform the city's drains, canals and reservoirs into vibrant, clean-flowing streams, rivers and lakes. Over 100 potential projects have been identified for island-wide implementation in phases, by 2030. As of 2015, 24 projects had been completed and 26 are underway.
2. *Promotion of the ABC Waters concept:* As the benefits of implementing the programme's design features became increasingly clear, PUB launched the ABC Waters design guidelines in 2009 to encourage the public and private sectors to consult them in order to integrate waterways in their development projects.
3. *The 3P (people, public, private) partnership approach:* The vision of achieving sustainable stormwater management would not be possible without buy-in from the wider community. PUB constantly encourages residents to adopt and take ownership of water bodies.

In the future, climate change, rises in sea level and increased rainfall intensities will make it necessary for drainage infrastructure to be upgraded to protect developments from flooding. However, the traditional approach of widening and deepening drains and constructing diversion canals would place competitive pressure on land use in land-scarce Singapore.[4] Recognising the limitations of implementing 'pathway' solutions – the means or routes through which stormwater is conveyed – PUB will work with developers to put in place source solutions to better manage stormwater runoff onsite and receptor solutions to protect developments from flooding (Table 8.1).

8.3.2 Benefits of ABC Waters Designs

ABC Waters design features introduce additional flexibility to the system in coping with intense rainfall that exceeds what it was originally designed to cope with. In particular, they can be coupled with other stormwater detention systems (i.e. tanks, surface ponds) to reduce peak flows

Table 8.1 Source, pathway and receptor solutions

Type	*Description*	*Solutions*	*Examples*
Source	Where stormwater runoff is generated, i.e. origin of stormwater flows	Slowing down and capturing stormwater runoff on site	Green roofs, porous pavements, rain gardens, decentralised detention/retention ponds, detention tanks
Pathway	Means or routes through which stormwater is conveyed	Enhancing the capacity of the conveyance system	Diversion canals, canal improvements
Receptor	Where stormwater flows may propagate and affect infrastructure	Measures to protect areas where the stormwater may end up	Flood barriers, urban flood plains, minimum platform and crest levels

PUB. 2013a. Managing urban runoff. Available: https://www.pub.gov.sg/Documents/managingUrbanRunoff.pdf.

generated by intense rainfall events. This in turn reduces the risk of flooding at the development site and within the larger catchment area. The design features also improve water quality through natural means by channelling stormwater through components that remove pollutants, enhancing the biodiversity of the landscape. As a result, sites developed according to the design criteria can potentially enhance the involvement of communities with their local water resources (what PUB describes as 'bringing people closer to water'). In doing so, they produce the following benefits:

- Increased community safety and financial risk management by reducing the risks of urban flooding.
- Increased social benefits and improved/enhanced liveability, as (1) multifunctional spaces not only slow down runoff and improve stormwater quality but also provide educational and recreational opportunities, and (2) developers can demonstrate their commitment to the environment by incorporating sustainability features and environmental best practices.
- Stormwater can be stored on site for a range of non-potable uses, e.g. irrigation, general washing.

8.4 Implementing BGI in Public and Private Spaces

The ABC Waters Programme incorporates a variety of Blue-Green Infrastructure (BGI) in buildings, roads and pedestrian walkways, open spaces and large spaces along waterways. This is summarised in Table 8.2.

8.5 Implementing BGI: Fiscal Tools

To encourage the implementation of BGI, Singapore uses a couple of financial incentives to include BGI on buildings.

8.5.1 Skyrise Greenery Incentive Scheme

Since 2009, the National Parks Board (NParks) has run its Skyrise Greenery Incentive Scheme that funds up to 50 percent of installation costs of rooftop greenery and vertical greenery, including extensive green roofs, edible gardens, recreational rooftop gardens and lush verdant green walls, across the city. Both residential and non-residential (e.g. commercial, industrial) developments are eligible.[5]

8.5.1.1 Rooftop Greenery

NParks will issue a grant equal to 50 percent of installation costs for rooftop greenery with the reimbursement capped at $200 per square metre of planted area within the green roof.[6]

8.5.1.2 Vertical Greenery

NParks will issue a grant equal to 50 percent of installation costs for green walls or vertical greenery with the reimbursement capped at $500 per square metre of planted area within the green installation.[7]

8.6 Implementing BGI: Non-Fiscal Tools

To encourage the implementation of BGI, Singapore uses a variety of non-fiscal instruments including developing a code of practice (COP) and a certification programme, as well as engaging and raising awareness of BGI in both the public and private sectors.

Table 8.2 ABC Waters design features incorporating BGI

Design features	*Type*	*Description*
Buildings	Intensive green roofs	Intensive green roofs are green spaces on rooftops that are designated as recreational spaces. The development of public recreational spaces and gardens on rooftops of commercial buildings has had a long history in Singapore.
	Extensive green roofs	Extensive green roofs are low-maintenance vegetated roof systems that use lightweight plants with shallow drainage/storage layers to store stormwater that could be supplied to plants when there is no rain. In addition to conserving potable water for irrigation and improving air quality, extensive green roofs cool down buildings, reducing the urban heat island effect.
	Balconies, planter boxes and vertical green	Cleansing biotopes and bioretention planter boxes can be implemented in a tiered or multi-level and sequential system to capture stormwater that can be used for watering plants and water features.
Vehicular roads and pedestrian walkways	Bioretention swales and basins	Bioretention swales and basins can be installed for detention (to slow down the flow of runoff into the drains and canals) and filter stormwater runoff before it is discharged into receiving waterways.
	Vegetated swales	For small catchments vegetated swales can be used as roadside drains to slow down the runoff and allow sediments to settle.
Open spaces	Vegetated swales	Vegetated swales are applicable to small catchment areas (e.g. small perimeter drains and roadside drains) near the summit point or for use with an overflow system).
	Bioretention swales	Applied to treat runoff from roads, car parks, residential areas and parklands etc. They are designed with gentle gradient and temporary ponding (extended detention) to facilitate infiltration. In addition, bioretention swales encourage habitat creation and biodiversity as well as beautify the landscape
	Bioretention basins (rain gardens)	Because of the high content of clay in the soil in Singapore, sub-soil pipes are installed

Table 8.2 (continued)

Design features	*Type*	*Description*
		in the drainage layer to discharge the filtered water into a nearby drain. If there is no suitable drain nearby, a soakaway rain garden can be used where the water is discharged into surrounding permeable soil.
	Underground systems	Underground detention systems can capture runoff and reduce peak flows into the drainage system. Their size varies depending on the availability of space. In addition, they can be combined with a rainwater harvesting system to provide storage for non-potable reuse.
Large spaces and greening of waterways	Sedimentation basins	Sedimentation basins provide temporary retention and a reduction of stormwater flow velocity to promote the settling of particles as well as to regulate flows entering downstream treatment systems to protect these systems from severe erosion and other damage during extreme high flows.
	Constructed wetlands	Constructed wetlands can be constructed on different scales, to service buildings, parks or larger areas, depending on the size of the contributing catchment. In Singapore, wetlands can perform very efficiently due to a tropical climate promoting faster plant growth and other biological activities.
	Cleansing biotopes	Cleansing biotopes are a form of artificially constructed vertical flow wetlands, usually with recirculation. They can be implemented in a variety of situations to encourage the revitalisation of lakes and the cleaning of urban water bodies or outdoor areas
	Greening of waterways	Creepers can be used to enhance the aesthetic appearance of concrete waterways that would otherwise be demolished; they are either planted directly in the canal walls or in gabions incorporated within them.

PUB. 2014. ABC design guidelines. https://www.pub.gov.sg/abcwaters/designguidelines.
PUB. 2013a. Managing urban runoff. Available: https://www.pub.gov.sg/Documents/managingUrbanRunoff.pdf.

8.6.1 Code of Practice

PUB has established a Code of Practice (COP) on Surface Water Drainage that specifies the minimum engineering requirements for the planning, designing and constructing of drainage systems to ensure their adequacy in developments. From January 2014, the COP requires developers/owners of new and redevelopment projects of land sizes 0.2 ha or more to implement source measures to slow down surface runoff and reduce the peak flow of stormwater into the public drainage system. Source measures can include building detention tanks, retention ponds and green roofs as well as incorporating ABC Waters design features, including bioretention swales, rain gardens and wetlands.[8,9]

8.6.1.1 Revision to COP

The ABC design guidelines state that from January 1, 2014, 'developers/owners must engage an ABC Waters Professional to design, oversee the construction of, and develop a maintenance plan for ABC Waters design features. Developers/owners then must submit to PUB the concept design and design calculations endorsed by an ABC Waters Professional. An ABC Waters Professional may also inspect and endorse a Certification of Inspection on the installed ABC Waters design features annually to certify the features have been inspected, are maintained satisfactorily and function well'.[10]

8.6.2 ABC Waters Certification

ABC Waters Certification was launched by PUB on July 1, 2010, to provide recognition to public agencies and private developers who embrace the ABC Waters concept and incorporate ABC Waters design features in their developments. The certification scheme also aims to ensure that these design features achieve a minimum design standard. Applications for certification are open year-round for developers of completed projects, projects under construction and projects at the design stage. No assessment fees are charged and the evaluation and assessment is carried out based on the information submitted. The certification is for three years, with random inspections conducted during the temporary permit stage. Under this scheme, certified projects can use the ABC

Table 8.3 ABC Waters point system

Category	*Points*
Active	30
Beautiful	30
Clean	30
Innovative	20
Total	110

PUB. 2016a. Certification criteria. Available: https://www.pub.gov.sg/abcwaters/certification/criteria.

Waters logo to promote their developments as 'ABC Waters Certified'. The certification scheme awards points based on the four qualities listed in Table 8.3: Active, Beautiful, Clean, Innovative. For a project to be certified it needs to receive a minimum of 45 points, with at least five points allocated to each of the first three categories.

8.6.2.1 Active Category

The aim of this category is to encourage vibrancy and activity at each site by providing new community spaces for people to enjoy recreational activities and bring people closer to water (Table 8.4).

8.6.2.2 Beautiful Category

This focuses on achieving integration between water and greenery to achieve scenic water-focused landscapes (Table 8.5).

8.6.2.3 Clean Category

This focuses on sustainable and holistic water management (Table 8.6).

8.6.2.4 Innovative Category

This category recognises creativity and innovation in incorporating ABC Waters design elements, together with other environmentally friendly features, into projects to minimise the impacts of urbanisation on the quality and quantity of rainwater. It also acknowledges designs that go beyond the standard criteria listed under the certification scheme (Table 8.7).

Table 8.4 Active Category: point system

Aims	*Description*	*Examples*	*Points*	*Total points*
Provision of facilities for new community spaces and public enjoyment, with possible educational values	Inclusion of facilities that bring people closer to water and promote waterside activities	Viewing decks, seating spaces	5	**20**
	Accessibility and safety considerations	Barrier-free designs	5	
	Maintaining of ABC Waters design features	Design features requiring minimal maintenance	5	
	Public education	Signage to explain facts about water/nature/ABC Waters design features	5	
Usage by stakeholders and community engagement	Formation of interest groups, organising activities	Plans to ensure sustainability of activities at project site	5	**10**
	Convenience of usage	Increased number of visits by members of the public	5	

PUB 2014. ABC design guidelines. https://www.pub.gov.sg/abcwaters/designguidelines

8.6.3 Implementing the 3P Partnership Approach

To convince the public to help keep Singapore's waters clean while enjoying various water-based recreational activities on the reservoirs and waterways, the 3P (people, public, private) approach is encouraged by conducting BGI educational activities in and around waterbodies.

8.6.3.1 People

ABC Waters: Bringing People Closer to Water

By creating new community, social and recreational spaces the ABC Waters Programme brings people closer to water in order to learn how to value it as a precious resource while enjoying it. By walking along ABC

Table 8.5 Beautiful Category: point system

Aims	*Description*	*Examples*	*Points*	*Total points*
Integration of water features within site architecture	Aesthetic improvements of surface water drainage	Use of vegetated swales/ bioretention swales, retention ponds, wetland plantings	10	**20**
	Aesthetic improvements to the sky terrace/roofs	Intensive or extensive green roofs to slow down runoff	5	
	Aesthetic improvements to the facade	Vertical greenery/planter boxes to treat rainwater	5	
Integration with greenery	Planting scheme with variety of plants that encourage habitat creation	Preferably native plants to develop habitat for butterflies/dragonflies and birds	10	**10**

PUB. 2014. ABC design guidelines. https://www.pub.gov.sg/abcwaters/designguidelines.

Table 8.6 Clean Category: point system

Aims	*Description*	*Examples*	*Points*	*Total points*
Incorporation of ABC Waters design features to treat surface runoff from site	Treatment or retention of runoff from more than 35 percent of the site's total area	Infiltration Retention ponds	20	**20**
	Treatment or retention of runoff from 11 to 35 percent of the site's total area	Infiltration Retention ponds	15	**20**
	Treatment or retention of runoff from up to 10 percent of the site's total area	Infiltration Retention ponds	5	
Holistic water management of the site	Rainwater harvesting	Integration with design features	7	**10**
		Irrigation	3	

PUB. 2014. ABC design guidelines. https://www.pub.gov.sg/abcwaters/designguidelines.

Table 8.7 Innovative Category: point system

Aims	*Examples*	*Points*
Incorporation of innovative ABC Waters designs in projects	Infiltration measures Creative drain cover designs Innovative irrigation systems using rainwater Gross pollutant traps Other natural drainage systems Grey water recycling	Up to 20

PUB. 2014. ABC design guidelines. https://www.pub.gov.sg/abcwaters/designguidelines.

Waters Learning Trails students also visit ABC Waters sites for experiential learning and geographical studies.[11]

Community Participation: Friends of Water Initiative
Over 280 individuals and organisations have taken ownership of ABC Waters sites and waterways throughout Singapore through the Friends of Water Initiative. They care for their adopted sites by conducting clean-ups; in the process they learn about the biodiversity in and around the sites and encourage other Singaporeans to enjoy them in a responsible manner.[12]

River Classroom Experiences
Two ABC Waters projects, Sungei Ulu Pandan and Sungei Pandan, have been conceptualised as 'river classrooms', with gathering decks that serve as outdoor learning spaces as well as vantage points to enjoy the views. ABC Waters design features, including a sedimentation basin and marshland, are showcased, showing students how these treat runoff from the catchment and improve the water quality before it is discharged into the rivers.[13]

8.6.3.2 Public

Government Collaboration on BGI: Skyrise Greenery Awards
PUB is working with NParks, developers and other stakeholders to develop a variety of green and blue spaces across Singapore. As part of this collaboration, NParks has developed the Skyrise Greenery Awards

programme that aims to promote and reward greening efforts in urban developments. The awards publicise the contributions made by architects who are incorporating green elements in their projects from the design stage onwards. The objectives of the awards are to:

- Promote awareness of the role of greenery in urban development.
- Recognise the architects/owners/designers/management teams that are actively prioritising greenery.
- Encourage innovative use of greenery and landscaping to create a positive environment in which to live, work and play.
- Encourage ownership and participation in greening of the high-rise urban built enviroment.[14]

To be eligible, projects are required to have been established for at least six months and enter their submission in one of the following categories: (1) commercial/industrial; (2) educational institution; (3) community facility; (4) residential (multi-unit); (5) residential (small-scale). Entries are judged based on the criteria of design, function, sensitivity to surroundings, engagement and sustainability. The awards for 2017 are as follows:

- *Outstanding Skyrise Greenery Project Award:* A cash prize of S$8,000, awarded to the most outstanding project/development overall.
- *Skyrise Greenery Excellence Awards:* Cash prizes of S$1500 for up to ten projects that demonstrate excellence in greenery design.
- *Skyrise Greenery Special Award:* Cash prizes of S$500 for up to four projects that deserve special mention.[15]

HDB Extensive Green Roof Programme

The Housing Development Board (HDB) has piloted extensive green roofs in existing HDB public housing blocks since 2006 to reduce heat build-up on exposed concrete roof surfaces in public housing estates. In addition to providing greenery, the green roofs slow down stormwater discharge. HDB has patented its own green roofing system, the Prefabricated Extensive Greening (PEG) Roof System, which is lightweight, modular, and designed to require minimal maintenance.[16]

8.6.3.3 *Private*

ABC Waters Professional Programme

To increase the number of ABC Waters projects throughout Singapore the Institution of Engineers, Singapore (IES), with support from the Singapore Institute of Architects (SIA), Singapore Institute of Landscape Architects (SILA) as well as PUB, NParks, HDB and the Land Transport Authority (LTA) launched, in 2011, the ABC Waters Professional Programme. The programme aims to build up expertise in the area of design and increase the competitiveness of professionals in the local market and region. The objective of the programme is to enhance awareness of ABC Waters design concepts and their application in Singapore and train professionals in the design, implementation and maintenance of ABC Waters design features. Participants who complete the programme, comprising four core modules and four electives, are eligible to be registered as an ABC Waters Professional (PUB, ABC Waters Professional). The core modules are: (1) understanding ABC Waters design guidelines and certification; (2) stormwater quality management – planning and designing ABC Waters design features; (3) design, construction and maintenance of swales and buffer strips; and (4) design, construction and maintenance of bioretention basins and swales.

ABC Waters Professional Registry

The ABC Waters Professional Registry was launched in May 2013. The registry aims to enable the industry to recognise the quality design work of accredited ABC Waters Professionals who have successfully completed the accredited four core and two elective modules under the Programme. In addition, ABC Waters Professionals will be assisted in improving higher quality standards of design through continuous education and training. Professionals who complete the programme are eligible to be registered as ABC Waters Professionals with IES, SIA or SILA if they also meet the respective registration criteria of the professional bodies. To date over 40 participants have completed the required number of modules and registered as ABC Waters Professionals.[17]

Raising Professional Awareness

In 2013, PUB published, in collaboration with the IES, the *Handbook on Managing Urban Runoff*. The handbook provides developers, architects and engineers with an overview of PUB's holistic stormwater management approach, including ABC Waters design features that can be adopted to ease surface runoff and reduce the peak flow of stormwater into the public drainage system.

ABC Waters: Recognition
The implementation of ABC Waters designs is also recognised by several government agencies including the Building and Construction Authority (BCA). The BCA Green Mark Scheme is a benchmark scheme that incorporates internationally recognised best practices in environmental design and performance, with the scheme including ABC Waters design features as a means of best stormwater management practice.[18]

8.7 Implementing BGI: Examples

PUB has initiated and facilitated the implementation of a variety of BGI projects on both public and privately owned land including schools, residential buildings, multifunctional recreational spaces, waterways and large public spaces.

8.7.1 *Rain Gardens and Education: Soakaway Rain Gardens in Local Schools*

PUB, in partnership with the National University of Singapore (NUS), has implemented three new rain gardens in local schools. The soakaway rain gardens are designed to overcome one of the main limitations to installing green gardens in Singapore, namely the high clay content of soil. NUS designed and installed three test-bed soakaway rain gardens in three local schools: Nanyang Junior College, Anglo-Chinese Junior College and Dunman High School. The test beds not only provide detention and treatment of stormwater runoff but also improve the aesthetics and biodiversity of the school grounds.[19] Key ABC Waters features include the following:

- *Simple design:* Soakaway gardens only have one filter layer, dispensing with the need for sub-surface drainage pipes, promoting ease of widespread implementation of and community participation in such projects in the future.

- *Engineered soil:* Comprising raw and recycled materials, engineered soil provides consistent soil properties, with the use of recycled materials reducing reliance on sand as a raw material.
- *Native plant species:* Plants can act as effective filters of pollutants and also sustain the hydrologic conductivity of filter media. Using native species helps support local biodiversity.
- *Engaging communities:* The gardens provide students with learning opportunities. Students are also engaged in the designing of signages allowing them to better understand how the ABC Waters features function. Teachers and students are also involved in the monitoring of plant health, water quality and hydraulic conductivity of the rain gardens.

8.7.2 BGI Buildings: The Peak @ Toa Payoh

The Peak @ Toa Payoh is an executive condominium under the HDB's Design, Build and Sell Scheme. The residential estate integrates ABC Waters features into its drainage and landscape design. The Peak features an intensively planted rooftop garden above its multi-storey car park, and is surrounded by green spaces and bioretention swales along with social and recreational activities. Key ABC Waters features include:

- *Bioretention swales:* These allow for extended detention and biological uptake of nutrients. The swales are interspersed with social and recreational features enabling residents to interact more closely with stormwater treatment green features.
- *Roof garden at multi-storey car park:* The roof garden is intensively planted with seating areas and pathways, providing social benefits as well as lowering ambient temperatures and helping slow down stormwater runoff.
- *Vertical greening on multi-storey car park:* Vertical greening with creepers helps soften the facade, as well as remove airborne pollutants and filter stormwater as it flows over the vertical green surface.
- *Planter at balcony:* Planters are placed on every balcony improving the estate's aesthetics and helping intercept and detain stormwater.

8.7.3 Education and Stormwater Management: Telok Kurau Primary School

The Ministry of Education is converting Telok Kurau Primary School's existing green sports field into an indoor sports hall. As a consequence of this development, the site will increase stormwater runoff. PUB will use this opportunity to incorporate ABC Waters design features that help manage the runoff. This will also provide opportunities for the school to carry out experimental learning. Educational posters and signage will accompany the various features. The school's teachers will also be encouraged to actively contribute ideas during the detailed design stage on how features can be incorporated as teaching tools to complement the teaching syllabus. The school will also educate nearby residents on their benefits. Key features include a stormwater detention tank, rainwater harvesting system, rain garden and roof garden.[20]

8.7.4 Stormwater Management and Recreation: Firefly Park @ Clementi

Firefly Park in Clementi has been specifically designed to harmonise with its immediate surroundings and provide the community with a 1.5 ha space for relaxation and recreation. Bioretention swales, designed by the HDB, detain and treat stormwater runoff from up to 35 percent of the park's total area. Underground tanks below the bioretention systems retain treated rainwater, allowing it to percolate slowly into the surrounding soil, reducing the need for irrigation.[21] The bioretention systems support a range of native plants and fruit trees that engage residents and support biodiversity. The park includes a jogging track that meanders around existing trees and open lawn with part of the bioretention swales running along the track to give park users a closer view of the ABC Waters designs. To educate the public and promote community involvement in stormwater management, signages are displayed to inform residents and park users on the functionalities and ecological benefits of the park's bioretention process.

8.7.5 Precinct-Wide Stormwater Management: Waterway Ridges @ Punggol East

This ABC Waters Precinct is a joint collaboration between PUB and HDB. It is the first housing project that integrates large-scale ABC

Waters design features within a public housing precinct. These include bioretention basins and vegetated swales that collect and treat stormwater runoff from roofs, roads, playgrounds and green areas in the precinct. Sediment, nutrients and other contaminants in the runoff are removed while flowing over a vegetated channel. Eventually, the filtered clean water will flow into the reservoir via the nearby Punggol Waterway. The new system will detain and treat runoff from around 70 percent of the precinct's area. A barrier-free broadwalk and viewing deck have been incorporated in the design to provide an amenity for residents, while seating areas will surround the bioretention basin, allowing them to enjoy the aesthetic appeal of the treated water before it flows into the waterways. To increase awareness, informative signs educating residents and visitors on ABC Waters design features are located around the precinct.[22]

8.7.6 Restoration of Waterways: Kallang River at Bishan-Ang Mo Kio Park

PUB and NParks have collaborated to transform a concrete canal into a meandering stream. During dry weather the water flow is confined to a narrow stream. During heavy storm events the adjacent park becomes a series of water channels that guide water downstream gradually. In addition, plants have been introduced to create habitats for a variety of aquatic and bird life. Today there are over 20 species of dragonflies and damselflies.[23] Additional features include a riverside gallery, suitable for events, community gatherings and festive celebrations, and three new playgrounds. Key ABC Waters design features include:

- *Soil bioengineering techniques:* These combine traditional civil engineering and natural materials, including rocks and vegetation, with aesthetic and ecological considerations. They were employed to transform the concrete canal into a natural river with landscaped banks.
- *Cleansing biotope:* Located upstream, the cleansing biotope replaced an existing pond. Comprising 15 cells in four terraces, water is pumped into it and filtered before the clean water is returned to the ponds, eventually cascading back into the river. Part of the treated water undergoes UV treatment and is supplied to a water playground.

- *Green roofs and vegetated swales:* Green roofs on top of the park structures and vegetated swales in place of concrete drains convey stormwater runoff from the park and upstream catchment into the river.

8.7.7 Large-Scale Water Gardens: Gardens by the Bay

Developed by NParks, Gardens by the Bay is a key component of Singapore's City in a Garden Vision. Covering 101 ha of reclaimed land in the southern part of Singapore, it consists of three waterfront gardens – Bay South, Bay East and Bay Central. Key ABC Waters design features include:

- *Ecological lake system:* Dragonfly and Kingfisher Lakes are part of Bay South and have a natural eco-filtration system that enhances water quality and biodiversity by providing aquatic habitats for fish and dragonflies. The lakes collect runoff from the gardens before discharging it into the Marina Reservoir. The built-in garden irrigation system also uses the naturally treated water from the lake system.
- *Reed bed and wetland filtering system:* Filter beds comprising aquatic reeds are located where water enters and discharges from the lake. Flow velocity is reduced and sediments are filtered out through islands of filter beds and floating wetlands. These islands absorb nutrients including nitrogen, ensuring better water quality by minimising algal bloom.
- *Bringing people closer to the water:* A 440 m-long boardwalk next to Dragonfly Lake brings people closer to the reed beds and filter beds. Storyboards provide information on how the plants clean water naturally.
- *Maintaining an aquatic ecosystem:* With a wide range of aquatic plants, good water circulation and aeration, the lake system is an ideal habitat for fish and dragonflies. The healthy water minimises the risk of mosquito breeding.

8.8 Monitoring of BGI Implementation

While PUB has the goal of implementing over 100 ABC Waters projects, the monitoring of BGI performance is conducted through the Certification scheme that ensures BGI design features incorporated into developments achieve a minimum design standard. PUB has collaborated with NParks to develop the Skyrise Greenery Awards programme to promote and reward greening efforts in urban developments. The implementation of ABC Waters designs is also recognised by BCA's Green Mark Scheme.

8.9 Case Study Summary

Singapore aims to integrate the city's abundant blue spaces with parks and gardens to create beautiful and clean streams, rivers and lakes with community spaces for all to enjoy. Singapore's PUB has identified over 100 potential ABC Waters projects for island-wide implementation in phases by 2030.

To increase the potential number of projects, PUB is collaborating with public agencies and the private sector institutions to develop the ABC Waters Professional Programme, which aims to build up expertise in the area of design and increase the competitiveness of professionals both locally and in the wider region. PUB is also working with NParks to develop a variety of green and blue spaces across Singapore. Other public agencies, including HDB, incorporate BGI into their new developments. In particular, HDB has piloted extensive green roofs in existing HDB public housing blocks since 2006 to reduce the urban heat island effect from roof surfaces in public housing estates.

To facilitate the implementation of BGI, NParks has proposed a Skyrise Greenery Incentive Scheme that funds a portion of the installation costs of BGI features, with the scheme open to residential and non-residential buildings. Meanwhile, PUB's COP requires developers/owners of new and redevelopment projects of certain sizes to implement BGI to slow down surface runoff and reduce the peak flow of stormwater into the public drainage system. They must also engage an ABC Waters Professional to design, oversee the construction of, and develop a maintenance plan for ABC Waters design features. Developers/owners then must submit to PUB the design and calculations endorsed by ABC Waters Professionals who are on the ABC Waters Professional Registry.

To raise awareness of these projects, PUB has developed the Certification programme to recognise the efforts of public agencies and private developers who embrace the ABC Waters concept and incorporate its design features in their developments. The Certification scheme also aims to ensure that design features incorporated into developments achieve a minimum design standard. NParks has also developed the Skyrise Greenery Awards programme that aims to promote and reward greening efforts in urban developments. To further encourage the implementation of ABC Waters design features and integrate waterways within their developments to enhance the environment, PUB has developed design guidelines.

8.10 Adaptive Management

To increase resilience to climate change, reduce environmental degradation and become a Blue-Green City, Singapore has implemented an adaptive management decision-making framework that involves planning, designing, implementing and monitoring the design and implementation of BGI to achieve multiple social, environmental and economic objectives (summarised in Table 8.8).

Table 8.8 Singapore's adaptive decision-making management framework

Developing a plan for implementing BGI	
Define a vision	PUB's ABC Waters Programme aims to integrate the city's abundant blue spaces with parks and gardens to create beautiful and clean streams, rivers and lakes with community spaces for all to enjoy
Identify the geospatial extent of the project	Over 100 potentially appropriate projects have been identified in and around Singapore for island-wide implementation in phases, by 2030. New and redevelopment projects may require the implementation of BGI to slow down surface runoff and reduce the peak flow of stormwater entering into the public drainage system
Establish cross-cutting steering groups	PUB collaborates with IES, with support from SIA, SILA as well as NParks, HDB and LTA to implement BGI as well as promote professional expertise

(*continued*)

Table 8.8 (continued)

Promote collaborative working across different stakeholders	PUB has initiated the 3P (people, public, private) approach to encourage the implementation of BGI, which involves enhancing educational activities in and around waterbodies, collaboration with government agencies on implementing BGI and enhancing professional awareness and expertise
Identify multifunctional benefits of BGI	The ABC Waters design features introduce additional flexibility to the system in coping with intense rainfall. They also improve water quality and enhance the biodiversity of the landscape. In addition, ABC Waters sites create aesthetic and recreational spaces for people to enjoy
Identify local issues, challenges, risks and community needs	The ABC Waters design guidelines encourage the public and private sectors to implement appropriate design features within their developments
Establish resources for successful implementation	BGI will be implemented through public and private investments throughout the city
Designing BGI	
Prepare and communicate a draft strategy/plan/design incorporating the vision and objectives	PUB has developed the ABC Waters master plan and identified sites throughout the city for implementation. It has initiated the 3P approach, engaging all stakeholders to implement BGI and adopt and take ownership of waterbodies
Use responses to refine and improve the plan, strategy or design and its delivery	To increase the number of potential projects throughout Singapore and ensure quality, the ABC Waters Professional Programme has been established to train professionals in the design, implementation and maintenance of ABC Waters design features. Professionals who have completed the programme are listed on the ABC Waters Professional Registry
Ensure the plan/strategy/design meets requirements for function, durability and beauty	PUB's COP mandates that all developers/owners who disturb a minimum amount of land must engage an ABC Waters Professional to design, oversee the

Table 8.8 (continued)

	construction of, and develop a maintenance plan for ABC Waters design features. The site is then inspected post-development by an ABC Waters Professional
Implementing BGI	
Set design and management standards by establishing locally relevant criteria	The ABC Waters design guidelines encourage the public and private sectors to implement various design features and integrate waterways within their developments
Ensure the provision of adequate funding mechanisms for ongoing management and maintenance costs	PUB's ABC Waters master plan will implement around 100 projects. Meanwhile the public and private sectors will be encouraged to develop source solutions on their own land that meet minimum performance standards and therefore a mix of public and private funding will be used for maintenance
Build the project, launch the strategy and adopt the policies	The ABC Waters Programme is initiated on sites identified by PUB. It also encourages the public and private sectors to implement ABC Waters design features and integrate waterways within their developments to enhance the environment. This is done via: (1) greenery incentives; (2) the mandating of design features on certain new and redevelopment projects; (3) creating educational spaces in ABC Waters developments; (4) raising professional capacity and collaborating with government agencies to initiate BGI
Set milestones, targets and programme	The aim of the Programme is to integrate the environment, water bodies as well as the community to create new community spaces and encourage lifestyle activities in and around the waterbodies. As at the end of 2015, 24 projects have been completed and 26 are underway

(*continued*)

Table 8.8 (continued)

Monitor the strategy's delivery against its objectives regularly, using key performance indicators and stakeholder consultation	While PUB has the task of implementing the projects, the performance of BGI is recognised through certification and awards. ABC Waters Certification was launched by PUB to provide recognition to public agencies and private developers who embrace the ABC Waters concept and incorporate its design features in their developments. The certification scheme also aims to ensure that design features incorporated into developments achieve a minimum design standard. PUB has collaborated with NParks to develop the Skyrise Greenery Awards programme to promote and reward greening efforts in urban developments. The implementation of ABC Waters designs is also recognised by BCA's Green Mark Scheme

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CHAPTER 9

Washington D.C. Becoming a Blue-Green City

9.1 Introduction

In Washington D.C., there are two types of stormwater management system, each managed by a separate entity: in the older portions of D.C. the city has a combined sewer system, built in the mid-to-late 1800s, managed by the District of Columbia Water and Sewer Authority (DC Water), which is a separate entity from the Government of the District of Columbia. Meanwhile, the Department of Energy and Environment (DOEE), a District of Columbia organisation, manages stormwater in the newer, separate sanitary areas of D.C.

In the combined sewer system, which covers approximately one-third of the District (12,478 acres), sewage from homes and businesses during dry weather conditions is conveyed to the District of Columbia's Blue Plains Advanced Wastewater Treatment Plant (Blue Plains), which is in the southwestern part of the District on the east bank of the Potomac River. Here wastewater is treated before being discharged into the Potomac River. When the capacity of the combined system is exceeded during storm events the excess flow, which is a mixture of sewage and stormwater runoff, is discharged into the Anacostia and Potomac Rivers, in addition to Rock Creek and tributary waters through outfalls.

R.C. Brears, *Blue and Green Cities*,
https://doi.org/10.1057/978-1-137-59258-3_9

9.2 Challenges to Traditional Stormwater Infrastructure

Washington faces multiple challenges to its traditional stormwater infrastructure from climate change, meeting regulatory requirements of the Clean Water Act 1972 as well an increase in demand for Blue-Green Infrastructure (BGI).

9.2.1 Climate Change

Washington will likely experience an increase in average summer high temperatures, from 87°F to between 93°F and 97°F by the 2080s. Meanwhile, extreme heat days will increase in number and heat waves will last longer and occur more frequently. In 2012, the city experienced a record-breaking heatwave with temperatures above 95°F for 11 days. This previously unprecedented event could occur every one to two years by the 2050s. The number of days that will activate the city's heat emergency plan is likely to increase from around 30 days per year to 70– 80 days by the 2050s and 75–105 days by the 2080s. Regarding rainfall and flooding, the frequency and intensity of heavy rainfall events that can cause flooding and pollution from stormwater runoff will increase significantly: today's one in 100-year rainfall event could become a one in 25-year event by the 2050s and a one in 15-year event by the 2080s.[1]

9.2.2 Regulatory Framework

In 2005, the United States Environmental Protection Agency (EPA), DC Water and the District of Columbia entered into a Consent Decree that addressed the District's combined sewer overflows (CSOs). The agreement to address CSOs outlined two types of solutions, the first to build underground storage tunnels to store the combined sewage following intense rainfall and the second, to use green infrastructure.[2] Meanwhile, the EPA in 2011 approved new performance standards for controlling urban stormwater runoff in Washington.

9.2.3 Political and Institutional Framework

The political will that drove DC Water to implement green infrastructure came from the utility's current General Manager and CEO, George

Hawkins. When he came into the position one of his main initiatives was for more green infrastructure to be installed across the District through the DC Clean Rivers Project. That vision has trickled down throughout the organisation. Also, at the government level there is a desire to be sustainable and 'green'. DC Water believes that the marketplace has embraced sustainability to the point that there is real demand for sustainable solutions, as well as an interest from the public to see sustainability elements incorporated into infrastructure and buildings. The result is that green elements are becoming more commonplace. Multiple stakeholders in D.C. have understood the benefits of green infrastructure, which has turned into a desire for more sustainability, whether in the context of greener stormwater sites or energy conservation in buildings. A shift in thinking has occurred over the past 10 years or so, with green issues increasingly being embraced. Also, DC Water has taken a 'leading-by-example' role, with other communities looking towards the nation's capital for guidance.

9.3 Strategic Vision: DC Clean rivers Project and RiverSmart Program

There are two strategic visions for managing stormwater in the city: the DC Clean Rivers Project, run by DC Water, and the RiverSmart Program run by DOEE.

9.3.1 DC Clean Rivers Project

DC Water is implementing the $2.6 billion Clean Rivers Project to reduce CSOs into the District's waterways – the Anacostia and Potomac Rivers and Rock Creek – by 96 percent system-wide in an average year.[3] The first phase of the project involves constructing large underground tunnel systems to control CSOs to the Anacostia River. These overflows, which currently discharge around 1.3 billion gallons of diluted sewage into the river in an average year, will be reduced by 98 percent when the tunnel system is completed in 2022. Since 2011, DC Water has explored the use of BGI as a tool to reduce sewer overflows to the Potomac River and Rock Creek.[4]

9.3.1.1 Hybrid Grey-Green Project for Potomac River

For the Potomac River, DC Water will build an underground tunnel that can hold 30 million gallons of combined sewage and stormwater.

The tunnel will direct this to Blue Plains and is scheduled to be completed by 2030. In addition, DC Water will construct BGI and targeted sewer separation to manage the volume of runoff produced by a projected 1.2 inches of rain falling on 133 impervious acres of land. The BGI in this area will be in place by 2027 and sewer separation by 2023.[5]

9.3.1.2 Rock Creek Going Fully Green

In 2015, DC Water, the District of Columbia, the Department of Justice and the EPA announced an agreement to modify a 2005 level settlement to allow large-scale BGI installations and other modifications to the Clean Rivers Project impacting the Potomac River and Rock Creek. Under this modified agreement DC Water will eliminate the previously planned underground tunnel for Rock Creek and instead build BGI and targeted sewer separation to manage the volume of runoff produced by 1.2 inches of rain falling on 365 acres of land that currently does not absorb stormwater. This portion of work is due to be completed by 2030.[6]

9.3.2 DOEE's RiverSmart Program

This programme seeks to reduce stormwater runoff pollution, which is harmful to the District's waterways and the Chesapeake Bay, by going beyond the activities required in the Municipal Separate Storm Sewer System (MS4) Permit. RiverSmart provides financial incentives to help District property owners install BGI, including rain barrels, green roofs, rain gardens, permeable pavement and shade trees, to reduce stormwater runoff.[7]

The District's modified MS4 permit supports sustainable stormwater management techniques including green roofs, tree planting and retaining rainfall onsite from redevelopment projects. It requires the District to take the following sustainable steps in promoting BGI:

- Providing a minimum of 350,000 square feet of green roofs on District properties.
- Planting at least 4,500 trees annually and developing a green landscaping incentives programme.

- Retaining 1.2 inches of stormwater onsite from a 24-hour storm for all development projects of at least 5,000 square feet.
- Developing a stormwater retrofit strategy that includes implementing retrofits over 18 million square feet of drainage of impervious surfaces.
- Developing consolidated implementation plans for restoring the impaired waterways of the Anacostia and Potomac Rivers, Rock Creek and the Chesapeake Bay.
- Preventing more than 130,000 pounds of trash from being discharged annually to the Anacostia River.[8]

9.4 Implementing BGI in Public and Private spaces

DC Water plans to implement BGI in public spaces, including rights of way (ROW), to manage stormwater runoff using natural processes including infiltration and evapotranspiration to slow down, clean and at times reuse stormwater to keep it from overwhelming sewer systems and polluting waterways. The goal of BGI in this instance is to mimic the natural environment within an urban setting, using various types of BGI tools including bioretention (tree boxes, rain gardens, vegetated filter strips), permeable pavements (porous asphalt, permeable concrete, permeable pavers) and rooftop collection (rain barrels, cisterns, green roofs and blue roofs).

9.4.1 How Are Green Infrastructure Projects Selected?

In order to determine which green infrastructure projects will be implemented across the Potomac River and Rock Creek area, DC Water conducts a detailed cost estimate from a capital improvement project standpoint so every time the utility develops a design plan it also develops a detailed estimate for the installation of BGI. However, this estimate does not include the long-term operational and maintenance costs associated with the BGI project. In addition, the estimate so far has not included additional triple bottom line benefits as these are difficult to quantify. Moving forward, the utility will aim to quantify the triple bottom line benefits of green infrastructure projects so a value can be assigned to each project.

9.4.2 Anticipated Benefits of Green Infrastructure Projects

Because DC Water will implement BGI to mitigate CSOs the utility will potentially receive numerous environmental benefits from managing stormwater runoff. The utility is interested in understanding how additional environmental triple bottom line benefits can be achieved from its green infrastructure projects, for example, reducing the urban heat island effect across D.C. and providing more habitat for wildlife. It is also investigating potential social benefits that include green jobs and other economic-related aspects related to green infrastructure. Overall, DC Water envisages the potential benefits of BGI as including the following:

- BGI provides water quality benefits sooner than traditional grey infrastructure, allowing the District to enjoy water quality and environmental and social benefits in 2017.
- BGI can increase property values, beautify neighbourhoods, cool down extreme summer temperatures, reinforce natural habitats, enhance public space and support local green jobs.
- DC Water has established a goal to have 51 percent of new jobs created by the BGI projects filled by District residents. DC Water will also engage professional service firms and contractors based in the District to perform work associated with BGI.[9]

Nonetheless, DC Water faces the challenge of maximising BGI's triple bottom line benefits while keeping the costs of development down. This is difficult, as the cost of implementing BGI typically increases when it involves more than one utility. DC Water therefore tries to ensure its efficiency at all stages of BGI project development and implementation to get the greatest value out of each project.

9.4.3 Public Sector Cooperation

Because DC Water's green infrastructure is located on District of Columbia-owned land and the success of implementing BGI projects involves coordination with other utilities, DC Water has developed a Memorandum of Understanding (MoU) with the District's DOEE that sets out the expectations on where the projects will be located, how they will be constructed, how they are designed, how outreach is performed and how they are maintained.

The MoU outlines the whole process, including: (1) how green infrastructure is implemented in the community; (2) the types of outreach that will be performed; (3) how the projects are technically designed; and (4) coordination on the preservation of green infrastructure after the projects are in place. Overall, the MoU is the main mechanism DC Water has to develop a clear understanding between the District of Columbia and itself and the processes and timelines for implementing green infrastructure. In addition, the Department of Transportation (DOT) as well as the Department of Parks and Recreation (DPR) have been attending the MoU development meetings and contributing to the process. This ensures DC Water will have in place the processes and approvals needed for green infrastructure to be successfully implemented on both DOT and DPR entity-owned properties.

Furthermore, DC Water has developed green infrastructure standards that require any other utility that is performing work in or around its green infrastructure facilities to restore the facilities to DC Water's standards, ensuring the green stormwater infrastructure (GSI) has the same level of performance post-repair.

9.4.4 In-house Maintenance

DC Water is required to maintain the green infrastructure under its Consent Decree. It either performs the maintenance itself or hires a contractor to do it. While DC Water recognises there are benefits of engaging the community in maintaining their local green infrastructure, the utility has seen many volunteer their services, only to see the GSI perform poorly due to inadequate maintenance.

9.4.5 Public–Private Partnership in Doubt

DC Water does not anticipate employing a public–private partnership model in implementing GSI. Instead, it envisages continuing with its current model of working through the design-build methodology. What the utility has found is that it is very efficient not only in terms of cost but also in terms of meeting the very strict guidelines imposed by the Consent Decree; the design-build approach has allowed the utility to be very competitive with its costs, not only with the projects but also with their scheduling.

9.5 Implementing BGI: Fiscal Tools

To encourage the implementation of BGI, DC Water and DOEE use a variety of fiscal tools including impervious area charges and stormwater fees.

9.5.1 DC Water's Clean Rivers Impervious Area Charge

DC Water has a Clean Rivers Impervious Area Charge (CRIAC), the computation of which is based on the amount of impervious surface on a property. The charge applies to all lots, parcels, properties and private streets in the District and is itemised on the monthly water and sewer bill. It is the funding source for the DC Clean Rivers Project. The charge is based on square footage of rooftop, pavement and other impervious surfaces on a property using a unit of measurement called the Equivalent Residential Unit (ERU), where one ERU equals 1,000 square feet of impervious surface. This means the utility can fairly distribute the cost of maintaining storm sewers and protecting area waterways, as it is based on a property's contribution of rainwater to the District's sewer system. All residential, multi-family and non-residential customers are billed for CRIAC; commercial properties are charged based on the actual amount of impervious surface while residential properties are assessed against a six-tiered approach (see Table 9.1). For FY 2017 the ERU is \$22.24 and in FY 2018 it will be \$25.18.[10]

9.5.1.1 Past Rate Increases

For the past 10 years, there has been a significant rate increase affecting all aspects of DC Water's bill. One of the fastest rising sections has been the CRIAC. As such, it has been a challenge to continue to persuade the public on an annual basis to accept rate increases. Ultimately all the rates must be approved by the Board of Directors, which has in the past generally approved the rate increases. However, it has become very difficult for some of the utility's customers to pay the water and sewage bill; it is becoming increasingly unsustainable over the long term for the utility to continue to increase rates to fund BGI projects. As such, it is looking at additional, creative ways of financing BGI. The alternative is to reduce the scope of BGI projects, while still providing the same level of service and value to the customers.

Table 9.1 Six-tiered stormwater fee rate structure for residential properties

Impervious area (square feet)	*ERU*	*ERU rate FY 2017*	*Monthly cost FY 2017*	*ERU rate FY 2018*	*Monthly cost FY 2018*
100–600	0.6	\$22.24	\$13.34	\$25.18	\$15.11
700–2,000	1.0	\$22.24	\$22.24	\$25.18	\$25.18
2,100–3,000	2.4	\$22.24	\$53.38	\$25.18	\$60.43
3,100–7,000	3.8	\$22.24	\$84.51	\$25.18	\$95.68
7,100–11,000	8.6	\$22.24	\$191.26	\$25.18	\$216.55
11,100 and more	13.5	\$22.24	\$300.24	\$25.18	\$339.93

DC WATER. 2016e. Impervious Area Charge. Available: https://www.dcwater.com/impervious-area-charge.

9.5.2 Clean Rivers Impervious Area Charge Incentive Program

Effective from October 1, 2013, DC Water customers can participate in the CRIAC Incentive Program. Customers who manage stormwater on their property using approved best management practices, for example, rain gardens, rain barrels, pervious paving, green roofs, bioretention practices and stormwater reuse methods, can receive up to 4 percent discount on the impervious area charge that appears on their DC Water bill.[11]

9.5.3 DOEE's Stormwater Fee

DOEE charges all District commercial and residential property owners a stormwater fee based on the amount of impervious surface area of each property. The fee provides a dedicated funding source to subsidise the cost of controlling pollution from stormwater runoff and pay for green roofs, rain gardens, tree planting and other activities that help keep waterways clean. It has adopted the principle of the ERU and is based on the average amount (1,000 square feet) of impervious surface on residential properties. Single family residences are assessed in terms of the number of ERUs, with each ERU charged at the rate of \$2.67 per month (Table 9.2). For all other properties, for instance businesses and large multi-family properties, the stormwater fee is charged at a rate of \$2.67 per month for each 1,000 square feet of impervious area on their lot, reduced to the nearest 100 square feet; for example, the monthly stormwater fee for a commercial property with 26,500 square feet of impervious area is calculated as follows: 26,500 square feet/1,000 square feet = 26.5 × \$2.67 = \$70.76 per month.[12]

Table 9.2 Tiered rate structure for single family residences

Square feet of impervious surface	*Number of ERUs*
100-600	0.6
700-2,000	1.0
2,100-3,000	2.4
3,100-7,000	3.8
7,100-11,000	8.6
11,000 and above	13.5

Department of Energy and Environment. 2016k. The District's Stormwater Fee. Available: http://doee.dc.gov/service/changes-districts-stormwater-fee.

9.5.4 RiverSmart Rewards Program

DOEE's RiverSmart Rewards helps to reduce stormwater runoff that harms the District's waterways and the Chesapeake Bay. The programme provides financial incentives to help District property owners install green infrastructure to allow rainwater to stay onsite and soak into the ground, where natural processes can help remove pollutants. The programme is funded through the stormwater fee that DC Water collects on the water and sewer bill on behalf of the RiverSmart programme, which is transferred to DOEE so they can administer their programme.

The programme provides all District residents, businesses and property owners with a discount of up to 55 percent of the stormwater fee for installing BGI practices including green roofs, bioretention, permeable pavement and rainwater harvesting systems that retain stormwater.

9.5.4.1 RiverSmart Homes

RiverSmart Homes is a District-wide programme that offers incentives of up to $2,400 to homeowners interested in reducing stormwater runoff from their properties with BGI enhancements. To become a RiverSmart homeowner the DOEE conducts an audit to assess what features – rain barrels, shade trees, rain gardens, bayscaping or pervious pavers – are appropriate for the property. Following the audit the homeowner receives the auditor's report for the property, with recommendations on which RiverSmart Homes features can reduce runoff from the property. After reviewing the report, the homeowners can contact the auditors to let them know what features they would like to have installed on the property. Installation will be conducted by DOEE partner organisations including local non-profit organisations and contractors. DOEE conducts random site inspections to verify and assess quality of installation and maintenance for 10 percent of all RiverSmart Homes installations, with homeowners given advance warning of the inspection.[13]

RiverSmart: Rain Barrel Rebate Program

The RiverSmart Homes Program offers two rain barrels per property for a $50 co-payment per standard barrel. To receive the rain barrels homeowners must sign up to receive a stormwater audit. DOEE also offers the Rain Barrel Rebate Program for homeowners who do not wish to wait for the audit or want a different type of rain barrel from the one offered through the programme.

From January 15, 2016, District homeowners who install rain barrels are eligible for a rebate based on the volume of stormwater that is captured and stored from rooftops. Rebates are issued as a direct reimbursement to homeowners at a rate of $2 per gallon; for example, homeowners with a 50-gallon rain barrel will receive a $100 rebate after installation. The maximum rebate amount is $1,000 per property and rebate amounts may not exceed the cost of the barrel.[14]

RiverSmart: Tree Rebates

Casey Trees, a non-profit organisation, in partnership with DOEE, provides a tree rebate programme in which private property owners – residential or commercial – who wish to add a tree to their property can receive a tree rebate to offset the cost by up to $100 per tree. There are two types of rebate:

- $50 rebates for any tree that is expected to achieve both height and width of at least 15 feet.
- $100 rebates for species noted for their large canopy and significant environmental benefits.[15]

RiverSmart: Landscape Rebate

This programme, established in 2016 and administered by the Alliance for the Chesapeake Bay on behalf of DOEE, offers a rebate for District homeowners who install landscaping projects that reduce and/or treat stormwater runoff from impervious surfaces on their property. The rebate amount is calculated based on the total square footage of the project (treatment area). The treatment area is determined by combining the project area with the impervious areas (rooftops, concrete or asphalt) that drain directly into the project. Rebates are issued as a direct reimbursement to homeowners at a rate of $1.25 per square foot treated. Projects eligible for the rebate must have a minimum square footage of 400 square feet, which would provide a $500 rebate. The maximum rebate is $1,200. Eligible projects include: (1) rain gardens, (2) replacement of impervious surface with vegetation and (3) replacement of impervious surfaces with pervious pavers.[16]

9.5.4.2 RiverSmart Rooftops

Over the period 2015–2016 the DOEE's Green Roof programme will provide base funding of $10 per square foot and up to $15 per square foot in targeted sub-watersheds with no cap on the size of projects eligible for the rebate. Properties of all sizes including residential, commercial and institutional are eligible for the rebate. For buildings with a footprint of 2,500 square feet or less, funds are available to defray the costs of a structural assessment.[17]

9.5.4.3 RiverSmart Schools

The Watershed Protection Division of the DOEE offers funding and training to schools selected through its RiverSmart Schools programme. These innovative school-yard greening projects focus on incorporating landscape design principles that create habitat for wildlife, emphasise the use of native plants, highlight water conservation and/or retain and filter stormwater runoff, while also providing an outdoor classroom that supports teaching and promotes student learning. The projects overall provide multiple benefits, including teaching students gardening and community service skills, providing wildlife habitat, improving the aesthetics of school grounds and building student and community pride.[18]

9.5.4.4 RiverSmart Communities

RiverSmart Communities is a District-wide programme that offers incentives to condominiums, co-ops, apartments, locally owned businesses and houses of worship who are interested in using BGI to reduce the amount of stormwater pollution entering the sewer system from their properties by installing BGI measures including rain gardens, pervious pavement and rain cisterns. There are two options for participating in the programme:

Option 1: Rebate (available city-wide). Rebates of up to 80 percent of project costs are available for specific BGI practices.

Option 2: Design/build (restricted to priority watersheds). Properties in designated high-priority watersheds will be considered for fully funded design/build of BGI projects.[19]

9.5.4.5 RiverSmart Innovation Grants

RiverSmart Innovation Grants provide short-term, start-up funding for community-orientated innovative projects across the District that educate residents on stormwater issues and achieve quantifiable outcomes. For example, planting ten trees can potentially reduce runoff by up to 1,000 gallons. The total amount of funding available is $140,000, with each project eligible for up to $20,000 with funds provided on a reimbursement basis. To be eligible for the grant, projects must promote the health of the District's watersheds and waterbodies in one or more of the following areas:

- Remove impervious surfaces, install BGI or plant/preserve trees.
- Create/promote green jobs.
- Restore native habitat.
- Clean up an area affected by high volumes of litter.
- Prevent litter.

Education is also a significant target of this grant; applications should clearly state the project's educational methods, including using media to reach a wider audience and partner with other community groups, District agencies, businesses, non-profit organisations or educational institutions to host one or more events, create signage or produce a work of art. To decide which eligible projects will receive grants, the DOEE has devised criteria to evaluate each project (Table 9.3).

9.5.5 Comparison of the Reward Programmes of DC Water and DOEE

All District properties receive a DC Water bill that includes DOEE's stormwater fee. These properties are then automatically enrolled in DC Water's CRIAC Incentive Program, which offers a discount of up to 4

Table 9.3 RiverSmart Innovation Grant project scoring

Scoring criteria	*Points*
Demonstrates an understanding of the project's link to stormwater issues	10
Benefits the Anacostia River, directly or indirectly	5
Benefits the District's MS4 area	5
Involves members of a specific community in a meaningful way	15
Is new and innovative	10
Will produce quantifiable outcomes	10
Is likely to serve as a model for future projects	5
Presents an achievable plan for executing the project	15
Presents a budget that is cost effective	15
Will manage funds and reporting properly	10

Department of Energy and Environment. 2016h. RiverSmart Innovation Grant – Project Examples and Scoring. Available: http://doee.dc.gov/service/riversmart-innovation-grant-project-examples-and-scoring.

percent on the CRIAC, which is also assessed on the DC Water bill. The differences between the two discounts are summarised in Table 9.4.

9.5.6 Stormwater Retention Credit Trading

The DOEE in 2013 created a Stormwater Retention Credit (SRC) trading scheme that catalyses green infrastructure retrofits and maximises cost-effective clean water benefits. The 2013 Stormwater Management Regulations require major land-disturbing (5,000 sq ft and over) and substantial improvement projects (up to 5,000 sq ft) to retain, respectively, the first 1.2 and 0.8 inches of rainfall following a storm. In the District, a downpour of 1.2 inches is categorised as a 90th percentile event – one greater than or equal to 90 percent of all 24-hour storms on an annual basis. A downpour of 0.8 inches is categorised as an 80th percentile event. Once these regulated projects retain 50 percent of their stormwater retention volume onsite they may meet the remaining volume by purchasing privately traded SRCs from other sites or pay an in-lieu fee to DOEE, which is $3.57 per gallon per year of required off-site retention. Each SRC achieves one gallon of retention per annum. Sites can generate SRCs by installing voluntary green infrastructure or by exceeding their regulatory requirements. Because off-site retention is an ongoing obligation that

Table 9.4 Comparison between the DC Water and RiverSmart rewards programmes

Areas for comparison	*RiverSmart Rewards*	*CRIAC Incentive Program*
Effective date	July 19, 2013	October 1, 2013
Maximum allowable discount	55%	4%
Offers a retroactive discount back to May 1, 2009, or the date of installation, whichever is later	Yes	No
Discount begins to be accrued on the date DOEE receives a completed application	Yes	No, under CRIAC Incentive Program, there is no discount accrual before the discount is awarded
Discount award period/expiration	3 years and renewable upon expiration	Up to 3 years, or at the end of the 3-year pilot programme, whichever is earlier

Department of Energy and Environment. 2016i. RiverSmart Rewards and Clean Rivers IAC Incentive Programs. Available: http://doee.dc.gov/riversmartrewards.

must be met on a yearly basis, the sales of SRCs can prove to be a reliable revenue stream to finance green infrastructure.[20,21]

9.5.6.1 Eligible Stormwater Retention Credit Projects

The DOEE is the sole SRC-certifying authority. To be eligible, projects must exceed existing retention requirements, be designed in accordance with an approved stormwater management plan, submit to a final construction inspection and ongoing maintenance inspections and document their ability to maintain the green infrastructure over the certification period. DOEE certifies up to 3 years' worth of SRCs at one time and will recertify projects every 3 years if eligibility requirements are met.[22,23]

9.6 Implementing BGI: Non-fiscal Tools

To encourage the implementation of BGI, DC Water and DOEE use a variety of non-fiscal tools including regulations, public–private partnerships, public awareness and educational initiatives, creating a BGI challenge for local firms, encouraging BGI-related jobs and skills as well as initiating community demonstration projects.

9.6.1 Green Infrastructure Regulations

DOEE administers all the stormwater runoff in D.C. through the permitting process. The stormwater management regulations stipulate that any person or entity – public or private sector – that disturbs 5,000 square feet or greater on their property, in terms of construction impact, is then required to implement green infrastructure to mitigate increased stormwater runoff.

9.6.2 Green Infrastructure Outreach Campaigns in Affected Neighbourhoods

DC Water has a rigorous public outreach approach where utility staff visit local Advisory Neighborhood Commissions, elected officials who attend meetings on a monthly basis. They also hold town hall meetings with various stakeholder groups and work with community groups that have an interest in green infrastructure. So as each one of DC Water's green infrastructure projects comes to a different area in D.C. the utility implements a significant outreach campaign with two primary aims. First, to educate the residents about green infrastructure, to make sure they understand why green infrastructure is necessary and how it can reduce CSOs as well as help them understand the construction impacts over the construction duration. Second, to help them be part of the process to achieving a solution and achieving reductions in CSOs, ensuring they feel empowered that this is their project just as much as it is DC Water's.

9.6.3 Raising General Awareness on BGI

DC Water has a rigorous outreach campaign on BGI that involves utility representatives attending neighbourhood meetings, distributing flyers and mailers and attending community festivals. During the summer months when there are many festivals the utility will often have a booth to provide information and distribute free giveaways. DC Water also visits schools to conduct educational presentations. Diverse approaches are employed to target the various stakeholder groups.

9.6.4 Green Infrastructure and School Education

DC Water has partnered with DC Greenworks to create an innovative green roof maintenance training programme and expand science, technology, engineering and maths (STEM) opportunities to students. The programme comprises classroom training followed by field-based, hands-on training that covers all aspects of maintenance including safety and fall protection, tool usage, plant identification, planting and weeding, operation of irrigation systems, pest and invasive species controls and repairing roof damage. Overall, the benefits of the training programme include:

- Providing real-world training for local students in a high-growth industry.
- Establishing a model for broad-based green infrastructure maintenance training that stands to support future job creation.
- Supporting local demand for a skilled 'green' workforce.[24]

In 2014, DC Water and Alice Deal Middle School began collaborating on expanding STEM opportunities for students through experiential learning, using the green roof that covers the Fort Reno reservoir as a real-world example. This provides students with the opportunity to bring the classroom outdoors into a learning/living laboratory and introduces them to future careers in engineering and other technical fields.[25]

9.6.5 Green Infrastructure Challenge

In 2013, DC Water launched the Green Infrastructure Challenge, encouraging firms to design innovative BGI practices that promote the absorption of rainwater. This is not only an awareness-raising activity; it also involves pushing the design community to provide designs and concepts that DC Water might use moving forwards. The focus of the Challenge is on the following goals:

- Advancing innovative BGI technologies in retrofit applications in the urban environment for CSO control, with the goal of increasing runoff capture from impervious surfaces and reducing the associated costs of these retrofits.

- Illustrating practicality by showing what is feasible and developing actual projects that will later be constructed in each area/design category.
- Accelerating the implementation of innovative BGI technologies that will support the development of DC Water's demonstration project.[26]

9.6.5.1 Green Infrastructure Challenge Categories

As part of the Challenge, each design team chooses one of the following categories for which to submit an entry: public space; commercial and private property; or governmental and institutional. The remit of the design concepts is limited to the Potomac and Rock Creek sewersheds.

- *Public space:* Over half the impervious area in the sewersheds is in public space, offering the potential to eliminate runoff into the combined sewers. Entries in this category are limited to ROW areas including roadways, sidewalks and alleys.
- *Commercial and private property:* Private property in the sewershed area makes up 40 percent of the impervious area. Entries in this category are limited to retrofitting existing properties (as redevelopment may complicate permission issues). Design teams are encouraged to consider neighbourhood enhancements and judged on their ability to collaborate with community organisations in BGI implementation and operation and maintenance agreements.
- *Government and institutional:* The District has a large number of government and institutional sites and buildings. The impervious surface in this category comprises nearly 10 percent of the total. Entries in this category are limited to government and institutional properties including federal and local government buildings, educational facilities and non-profit organisations. Design teams were also encouraged to consider collaborative and educational opportunities with institutions.

9.6.5.2 Green Infrastructure Challenge Criteria

All entrants are required to provide a narrative to the application that includes the following criteria, as summarised in Table 9.5.

Table 9.5 Green Infrastructure Challenge criteria

Challenge criteria	*Narrative required*	*Points needing to be addressed*
Innovative	All entries must document how the design incorporates innovative BGI technologies and implementation strategies	*Programmatic:* All entries need to describe how the entry addresses new strategies for BGI implementation at the site *New technologies*: This section should address specific new or innovative BGI technologies included in the design
Performance	All entries must document the site's performance in removing runoff volume in an effort to reduce CSOs	*Capture runoff:* A breakdown of the total runoff volume (in gallons) managed per acre *Cost effectiveness:* An outline of the cost per gallon of runoff managed per unique BGI feature and for the entire design
Practicality	Entries should focus on practical solutions that are constructible, cost effective and require less operation and maintenance than current technologies	
Triple bottom line and job creation benefits	All entries must address additional benefits (social, economic and environmental) beyond CSO control	*Multiple benefits:* This section should describe the design's benefits at multiple scales (street, neighbourhood, city) and categories (triple bottom line). Documentation of the total local jobs created due to the proposed design should be presented

DC Water. 2014b. Green Infrastructure Challenge – Briefing Document. Available: http://waterbucket.ca/gi/files/2013/05/Washington-DC_Green-Infrastructure-Challenge_Breifing-Doc.pdf.

9.6.5.3 Green Infrastructure Challenge Awards

A judging panel consisting of DC Water, EPA, DOEE, DOT, District Office of Planning and other industry experts is convened to select four design winners in each category, two of which are given construction awards in each category. In total, there are 12 planning and design awards and potentially six construction awards (Table 9.6). The winners are determined on ranking criteria and points possible per category (Table 9.7).

Table 9.6 Green Infrastructure Challenge awards per category

Category	*Planning and design*	*Construction*
Public space	4 awards at $10,000 each	2 awards at $300,000 each
Commercial/private	4 awards at $10,000 each	2 awards at $75,000 each
Government/ institutional	4 awards at $10,000 each	2 awards at $75,000 each
Subtotals	12 awards totalling $120,000	6 awards totalling $900,000
Total challenge	$1,020,000	

DC Water. 2014b. Green Infrastructure Challenge – Briefing Document. Available: http://waterbucket.ca/gi/files/2013/05/Washington-DC_Green-Infrastructure-Challenge_Breifing-Doc.pdf.

9.6.5.4 Kennedy Street Green Infrastructure Streetscape Project

In 2015, DC Water awarded contracts for final designs to two firms, including Nitsch Engineering, for the design of the Kennedy Street Green Infrastructure Streetscape Project. The winning team proposed improvements for Kennedy Street that integrate a variety of landscape and stormwater strategies, including additional street trees, permeable pavers, landscape infiltration gaps, stormwater curb extensions, grated landscapes and sub-surface storage/infiltration. This promotes 'complete street' concepts that use curb bump-outs, sidewalk crossings and broadwalks to create a streetscape that is safe and comfortable for pedestrians, cyclists and motorists. In addition to eliminating significant amounts of stormwater from entering the combined sewer system and improving water quality, the BGI will minimise urban heat island effects.[27]

9.6.6 DC Water and District of Columbia Supporting Local Green Jobs

DC Water and the District of Columbia have announced an agreement to help support local job creation associated with green infrastructure implementation. DC Water has established the goal that 51 percent of new jobs created by green infrastructure projects will be filled by District residents. It will also engage professional service firms and contractors based in the District to perform work associated with green infrastructure.[28]

Table 9.7 Green Infrastructure Challenge ranking criteria and points possible per category

Category	*Criteria*	*Description*	*Score (maximum points per category)*		
			Public space	*Commercial/ private*	*Government/ institutional*
Innovation	Programmatic	New strategies in BGI implementation		15	
	New technologies	New BGI technologies		20	
Performance	Capture volume	Total volume managed per acre		10	
	Cost effectiveness	Cost per gallon managed		15	
Practicality	Operation and maintenance considerations	Practical solutions to long-term operation and maintenance of BGI on a large scale		10	
	Constructability	Commitment to construction for this challenge. Adaptability to large-scale implementation		10	
Triple bottom line and job creation benefits	Community enhancement	Neighbourhood enhancement and revitalisation. Local job creation		20	
Total points				100	

DC Water. 2014b. Green Infrastructure Challenge – Briefing Document. Available: http://waterbucket.ca/gi/files/2013/05/Washington-DC_Green-Infrastructure-Challenge_Breifing-Doc.pdf.

9.6.6.1 Pilot 'Growing Futures' Program

The Pilot 'Growing Futures' Program was launched in 2014 to provide opportunities for young adults to work in green infrastructure. The training programme comprises traditional classroom training followed by field-based, hands-on training and covers all aspects of maintenance, including safety and fall protection; tool usage; plant identification; planting and weeding; operation of irrigation systems; pest and invasive species controls; and repairing roof damage.[29]

9.6.6.2 Green Infrastructure Mentor-Internship Program

This programme, set up in May 2016, encourages the participation of District residents in green infrastructure projects. Interns have specific responsibilities assigned to them by their mentors. Daily activities enable participants to experience processes and management methods first hand in field situations. This field experience will provide hands-on exposure to aspects of several types of green infrastructure, including bioretention, pervious pavement, green roofs and cisterns or rain barrels. The interns will also learn about the following: (1) construction/installation; (2) preventative and corrective maintenance; (3) landscaping; (4) inspection and site assessment; (5) equipment, operations and safety.

Under this programme, projects valued at $200,000 or greater involved in construction, inspection or maintenance on green infrastructure projects associated with the Consent Decree will operate a mentor-internship programme for District residents. Applicable contractors will be required to participate in the programme and take on a number of participants depending on project size (summarised in Table 9.8). As part of

Table 9.8 Green Infrastructure Mentor-Internship Program

Project size	*Number of participants*
Under $200,000	0 participants (no requirement)
Between $200,001 and $500,000	1 participant
Between $501,000 and $1,000,000	2 participants
Between $1,000,001 and $5,000,000	3 participants
Greater than $5,000,001	At least 4 participants

DC Water. 2016 h. Mentor-Internship Program Manual for Green Infrastructure Projects Implemented Under the 2016 Amended Consent Decree. Available: https://www.dcwater.com/sites/default/files/Green_Infrastructure_Mentor_Internship_Program.pdf.

the programme, contractors taking on interns will be reimbursed $0.80 per hour of training of the intern's salary, with interns paid no less than the District's living wage.[30]

9.6.7 Standardising BGI Across the Nation

In 2016, DC Water and the Water Environment Federation (WEF) launched the National Green Infrastructure Certification Program, to develop, nationwide, baseline standards for workgroups involved in the construction, inspection and maintenance of green infrastructure. Under the programme DC Water will provide certification to individuals in D.C. who receive green infrastructure training and pass an exam. This potentially provides a two-fold benefit for the utility. First, it will help increase the performance of its green infrastructure, as the utility will have greater assurance that it was installed correctly and is being maintained as intended. Second, DC Water will be in a better position to deliver economic and green jobs benefits to the community from its Clean Rivers Project.

The utility has also worked with other jurisdictions across the USA to have them formally participate in the programme. Currently there are eight partners: Milwaukee, WI; Montgomery County, MD; Kansas City, KS; Fairfax County, VA; Baltimore, MD; Louisville, KY; San Francisco, CA; and Harrisburg, PA. DC Water expects other jurisdictions to follow.

9.6.8 Community BGI Demonstrations

In 2014, to create wider awareness of BGI, the Project Green Infrastructure team, together with DOEE, co-hosted a workshop on rainwater harvesting at Wangari Gardens. The workshop included a presentation on the installed bioretention facilities at the Wangari Gardens site and along the Irving Street corridor, its purposes, benefits, plant types and maintenance plan. The workshop provided practical information to the community on how homeowners can get involved in BGI efforts by installing rain barrels and disconnecting downspouts in order to harvest rainwater for use around the home and reducing stormwater runoff entering the sewer system. The team also collaborated with DOEE to facilitate rain barrel distribution among the Wangari Gardens community.

9.7 Implementing BGI: Examples

DC Water has initiated and facilitated the implementation of a variety of BGI projects on both public and privately owned land, including Irving Street and its own reservoir.

9.7.1 Irving Street Green Infrastructure Project

This project includes the installation of bioretention at 14 sites in median islands and the roadside along the Irving Street corridor between Michigan Avenue and North Capitol Street including the Wangari Gardens site located at Irving Street and Park Place. Installing bioretention is part of the overall flood control solution for the area and is a component of the medium-term flooding mitigation. The bioretention consists of planted filter beds of native vegetation, specialised soil and stone aggregate that are slightly lower than the surrounding landscape.[31]

9.7.2 Green Roof at Fort Reno Reservoir

The green roof installed above the Fort Reno drinking water reservoir is one of DC Water's most notableBGI solutions. The 42,390-square foot green roof was installed in order to reduce stormwater runoff from the facility. DC Water converted the previous, traditional impervious roof into a green roof, constructed of layers of plants, lightweight soil and drainage and waterproofing layers that act as a natural filter by reducing and cooling stormwater runoff through absorption and evaporation. In addition, the green roof reduces the urban heat island effect, provides a habitat for birds and pollinators and helps insulate the buildings.[32]

9.8 Monitoring of BGI Implementation

DC Water will use an adaptive management approach to implementing BGI. This means BGI projects will be constructed in a sequential fashion. In between construction phases the projects will be monitored and assessed to evaluate their performance. Data collected and lessons learned during the monitoring phase will be used when planning and designing the next round of BGI projects. This will ensure that the BGI projects are practical and effective for CSO control and provide numerous benefits to the community.[33]

9.9 Case Study Summary

DC Water is implementing BGI to reduce the volume of CSOs into the District's waterways, while DOEE is implementing BGI to help reduce stormwater runoff that is harmful to the District's waterways and the Chesapeake Bay.

DC Water has developed an MoU with DOEE that sets out the expectations on where BGI projects will be located, how they will be constructed, how they are designed, how outreach is performed and how they are maintained. In addition, other public agencies have attended the MoU development meetings, ensuring that DC Water has in place the processes and approvals needed for BGI to be successfully implemented on their properties. DC Water has also developed BGI standards that require any other utility working in or around the utility's BGI to bring the restored facilities up to DC Water's standards, ensuring the BGI has the same level of performance post-repair.

DC Water has a Clean Rivers Impervious Area Charge (CRIAC) which is based on the amount of impervious surface on a property. The charge is included as a separate item in the monthly water and sewer bill.

Meanwhile, DOEE charges all District commercial and residential property owners a stormwater fee based on the amount of impervious surface area of each property. The fee provides a dedicated funding source to pay for controlling pollution from stormwater runoff and also pays for green roofs, rain gardens, tree planting and other activities that help keep waterways clean.

DC Water customers can participate in the CRIAC Incentive Program, where customers who manage stormwater on their property using approved BGI receive a discount on their stormwater charge. In addition, DOEE runs the RiverSmart Program, which offers discounts and incentives for District residents to implement BGI on their property.

DOEE has created a Stormwater Retention Credit trading scheme in which major projects that retain half of their stormwater volume onsite can meet the remaining volume by purchasing privately traded credits from other sites or pay an in-lieu fee to DOEE. Sites can also generate credits by installing voluntary BGI or by exceeding their regulatory requirements.

Regarding regulatory requirements of implementing BGI, any public or private sector development that disturbs a significant amount of land is required to implement BGI to mitigate increased stormwater runoff.

Prior to the commencement of a BGI project, utility staff will visit the local neighbourhood commission and hold town hall meetings with various stakeholder groups to educate the residents about BGI and the potential impacts during the duration of construction. This is done to ensure that residents feel empowered that this is their project just as much as it is the utility's.

DC Water has a rigorous outreach campaign on BGI that involves utility representatives attending neighbourhood meetings, distributing flyers and mailers and attending community festivals. During the summer months staff attend events and have a booth to provide information and distribute free giveaways. DC Water and DOEE have also co-hosted a workshop on rainwater harvesting at a community garden that included a presentation on the features, purposes and benefits of BGI, as well as the preferred plant types and plans for maintenance. DC Water also visits schools to conduct educational presentations. Furthermore, it has developed STEM courses with partners to educate students on BGI.

DC Water's Green Infrastructure Challenge, launched in 2013, involves firms submitting innovative plans involving the implementation of BGI in the categories of public spaces, commercial and private property and governmental and institutional property. The Challenge is not only an awareness-raising activity but has also involved pushing the design community to advance innovative BGI technologies and illustrate practical designs that can be implemented in actual projects.

As part of its agreement with the District of Columbia to help support local job creation associated with BGI, DC Water has launched an apprenticeship-style training programme for young adults to work in BGI. In addition, it runs a mentor-internship programme that requires projects of $200,000 and upwards to take in interns.

DC Water will use an adaptive management approach to implementing BGI. This means BGI projects will be constructed in a sequential fashion. In between construction phases the projects will be monitored and assessed to evaluate their performance. Data collected and lessons learned during the monitoring phase will be used when planning and designing the next round of projects. This will ensure that the BGI projects are practical and effective for CSO control and provide numerous benefits to the community.

9.10 Adaptive Management

To increase resilience to climate change, reduce environmental degradation and become a Blue-Green City, DC Water, along with DOEE, has implemented an adaptive management decision-making framework that involves planning, designing, implementing and monitoring the design and implementation of BGI to achieve multiple social, environmental and economic objectives (summarised in Table 9.9).

Table 9.9 DC Water and DOEE's adaptive management decision-making framework

Developing a plan for implementing BGI	
Define a vision	DC Water's Clean Rivers Project will use BGI to reduce CSOs, and DOEE's RiverSmart programme will reduce stormwater runoff pollution by encouraging District property owners to go beyond the activities required in the MS4 permit
Identify the geospatial extent of the project	DC Water will implement BGI to reduce the flow of CSOs into the Anacostia and Potomac Rivers and Rock Creek. DOEE will reduce stormwater runoff that is harmful to the District's waterways and the Chesapeake Bay
Establish cross-cutting steering groups	DC Water has developed an MoU with DOEE on where the projects will be located, how will they be constructed, how they are designed, how outreach is performed and how they are maintained. DOT and DPR attended the MoU development meetings. This ensures DC Water has in place the processes and approvals needed for BGI to be successfully implemented on both DOT and DPR entity-owned properties. DC Water has also developed a BGI certification programme for other jurisdictions to use to ensure quality of BGI
Promote collaborative working across different stakeholders	When BGI is installed in an area DC Water implements an outreach campaign to

(*continued*)

Table 9.9 (continued)

	educate the residents about BGI, the construction impacts and duration, and help them be part of the process to achieving a solution and achieving reductions in CSOs
Identify multifunctional benefits of BGI	DC Water is aiming to create new BGI-related jobs. In the future DC Water will aim to quantify the triple bottom line benefits of BGI
Identify local issues, challenges, risks and community needs	When BGI is implemented in a community, DC Water representatives visit local advisory neighborhood commissions as well as hold town hall-meetings with various stakeholder groups
Establish resources for successful implementation	DC Water's Clean Rivers Project will cost $2.6 billion of public funding. For each BGI project DC Water details cost estimates to ensure the efficient use of resources
Designing BGI	
Prepare and communicate a draft strategy/plan/design incorporating the vision and objectives	DC Water's strategy aims to ensure the implementation of BGI that mimics the natural environment. DOEE's RiverSmart strategy encourages the uptake of BGI on properties to reduce runoff and enhance the environment
Use responses to refine and improve the plan, strategy or design and its delivery	DC Water and DOEE incentivise the development of individual and community-led BGI projects, increasing the knowledge-base of BGI implementation
Ensure the plan/ strategy/design meets requirements for function, durability and beauty	DC Water faces the challenge of maximising BGI's triple bottom line benefits while keeping the costs of development down. It intends to ensure that it is efficient at all stages of BGI project development and implementation to get the greatest value out of each project
Implementing BGI	
Set design and management standards by establishing locally relevant criteria	DC Water has developed BGI standards that require other utilities performing work in/around the utility's BGI to restore the facilities to these standards. On private property, rebates are offered for a variety of BGI initiatives. Any public or private

Table 9.9 (continued)

	development that disturbs a significant portion of land must implement BGI to mitigate increased stormwater runoff
Ensure the provision of adequate funding mechanisms for ongoing management and maintenance costs	DC Water is required to maintain BGI under its Consent Decree. It either performs the maintenance itself using its own staff or contracts it out. The CRIAC charge is the funding source for the DC Clean Rivers Project. Meanwhile, DOEE's stormwater fee provides a dedicated funding source to pay for controlling pollution from stormwater runoff and paying for BGI to help keep waterways clean
Build the project, launch the strategy and adopt the policies	DC Water and DOEE have incentivised the private sector to implement BGI. They have also issued BGI challenges, demonstration projects and educational initiatives
Set milestones, targets and programme	DC Water plans to reduce CSOs into the District's waterways by 96 percent system-wide in the average year. DOEE will facilitate the construction of 350,000 sq ft of green roofing on District properties, encourage the planting of at least 4,500 trees annually, develop green landscaping incentives, mandate the retaining of 1.2 inches of stormwater on site for large developments, facilitate BGI retrofits over 18 million sq fr of impervious surfaces and develop plans for restoring the District's impaired waterways and prevent over 130,000 pounds of trash entering the Anacostia River
Managing/maintaining BGI	
Monitor the strategy's delivery against its objectives regularly, using key performance indicators and stakeholder consultation	BGI projects will be constructed in a sequential fashion. In between construction phases, the projects will be monitored and assessed to evaluate their performance. Data collected and lessons learned during the monitoring phase will be used when planning and designing the next round of BGI projects, ensuring that they are practical and effective for CSO control and provide multiple benefits

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CHAPTER 10

Mini Case Studies of Cities Implementing Blue-Green Infrastructure

10.1 Introduction

Many cities around the world are at various stages of implementing Blue-Green Infrastructure (BGI) to reduce stormwater runoff and improve surface water quality and capitalise on the multiple benefits that BGI provides. These cities include Chicago, Hamburg, Manchester, Melbourne and Seattle.

10.2 Chicago

In 1889, the Metropolitan Sanitary District of Greater Chicago was created to ensure safe drinking water for Chicago and determine an acceptable way to dispose of the city's waste. In 1900, the Chicago Sanitary and Ship Canal was constructed to reverse the Chicago River's natural flow from eastward to westward, preventing waste from entering Lake Michigan. In 1972 the Metropolitan Water Reclamation District of Greater Chicago (MWRD) began constructing the large-scale, multi-purpose Tunnel and Reservoir Plan (TARP), the 'Deep Tunnel', consisting of tunnels and surface reservoirs that capture, convey and store sewage and stormwater during storm events until it can be pumped to existing wastewater treatment plants when capacity becomes available. By 2006, MWRD had completed Phase I of TARP, comprising over 109 miles of tunnels with 2.3 billion gallons of

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capacity. Phase II will increase the TARP system storage volume to around 20 billion, with completion of this phase expected to be in 2029.[1]

Chicago's current stormwater infrastructure system comprises around 5,000 miles of sewers, with over 4,400 miles maintained by the city's Department of Water Management and over 500 miles maintained by MWRD. 99.5 percent of the city's sewer system is combined, with stormwater and sewage collected in the same pipe for treatment at one of MWRD's wastewater treatment plants before discharge. If MWRD does not have the capacity for treatment at its plants, the combined flow discharges into TARP. If TARP is full the combined flow is then discharged through one of 200 combined sewer outflows into the city's waterways.[2]

10.2.1 Challenges to Traditional Stormwater Infrastructure

Chicago faces two main challenges to its stormwater system: urbanisation and the impacts of climate change.

10.2.1.1 Urbanisation

In Chicago, one inch of rainfall city-wide generates around 4 billion gallons of stormwater, with the majority of the excess water flowing off impervious surfaces into the city's sewer system. This is a result of 150 years of development in Chicago that has seen permeable natural spaces converted into impervious surfaces including rooftops, roads, footpaths, parking space and driveways. Today, nearly 60 percent of the city's land area is either paved or covered with buildings, with most surfaces designed to drain stormwater away as fast as possible. Stormwater transported to the city's wastewater treatment plants is no longer available to be used for irrigation or groundwater recharge, and increases the energy and chemical costs associated with treating wastewater. During heavy rainfall events when stormwater overwhelms the system, the three main effects are combined sewer overflows (CSOs), basement flooding and backflow of water from the Chicago River into Lake Michigan:

- *Combined system overflows:* On dry days, Chicago's wastewater treatment plants have enough capacity to handle the city's sewage. During heavy storm events the combined flow is often more than the wastewater treatment plants and TARP can accommodate and treat. In Chicago a rain event of 0.67 inches of water in a 24-hour period is enough to trigger a CSO. Between 2007 and 2012, CSOs occurred on 314 days, averaging approximately once per week.

- *Basement flooding:* When too much water enters the sewer system and cannot flow fast enough to a wastewater treatment plant or combined sewage outfall, the water can back up into homes and buildings. Sewer backups occur when the level of sewer water rises to the level of openings including drains that are below street grade. Water will rise through openings in basements unless backwater valves are in place.
- *Lake Michigan reversals:* During extreme weather events that result in TARP being full and the rivers at risk of overtopping their banks, MWRD and the Army Corp of Engineers open the locks that normally separate the Chicago and Calumet Rivers from Lake Michigan. The event – Lake Michigan reversal – releases a mixture of river water, rainwater and sewage into Lake Michigan. These events can pollute the drinking water supply and contaminate the beaches along the lake.

10.2.1.2 Climate Change

It is projected that climate change will increase annual precipitation in Chicago by around 10 percent by mid-century and 20–30 percent by 2100. Most of this increase is expected during winter and spring, with little change in precipitation volumes over the summer and autumn months, although the magnitude of precipitation events is expected to increase significantly. Rain will fall more heavily but at fewer times, with long dry periods in between downpours.

10.2.2 Strategic Vision: Green Stormwater Infrastructure Strategy

The City of Chicago's Green Stormwater Infrastructure Strategy, announced in 2014, commits additional public funding to build green stormwater infrastructure (GSI) alongside traditional grey infrastructure to achieve four long-term stormwater management goals: minimise basement flooding in Chicago's most impacted neighbourhoods; reduce pollution of Chicago's rivers and Lake Michigan; enhance environmental quality through water infrastructure investments; and increase the city's resilience to extreme rainfall events and climate change.

10.2.2.1 Building Green Stormwater Infrastructure

The city has allocated $50 million during the course of 2014–2018 to fund GSI projects that deliver rapid benefits and improve knowledge and understanding of GSI, with priority given to communities at high risk of basement flooding. The projects aim to provide an additional 10 million gallons of stormwater storage that could reduce runoff in Chicago by 250 million gallons each year. Initiatives include the following:

- *Capital projects:* GSI will be incorporated into upgraded water pipes, repaired roads, and construction/renovation projects affecting parks, public facilities and schools.
- *Permeable streets:* Permeable pavement will be laid down in areas with low-traffic volumes following replacement of water and sewer mains.
- *Bioswales:* The city will construct a network of parkway bioswales that incorporate new tree plantings and capture and retain road runoff.[3]

10.2.2.2 Developing a Long-Term Stormwater Management Plan

The city will collect and analyse new information to determine how cost-effective GSI can be scaled up in the future. This information will then be incorporated into a long-term stormwater management plan that lays out a long-term vision and strategy for implementing both grey and green stormwater infrastructures. Initiatives include the following:

- *GSI:* The study will determine the costs and benefits of using GSI as a standalone strategy or in combination with traditional grey infrastructure investments.
- *Rainfall frequency analysis:* The city will develop rainfall frequency data that incorporate recent storms as well as the latest climate change projections for future rain patterns to inform the planning process and influence decision-making on GSI.
- *Citywide stormwater management plan:* The city will develop a long-term vision and implementation strategy for managing stormwater with green and grey infrastructure. At this stage the city does not know how large-scale investment in green infrastructure can supplement or serve as an alternative to sewer and tunnel projects.

10.2.3 Tools to Encourage Implementation of GSI

Chicago has, in recent years, implemented a variety of policies to promote the adoption of GSI measures throughout the city.

10.2.4 Chicago Stormwater Management Ordinance

In 2008, Chicago enacted the Stormwater Management Ordinance, which provides standards for and restrictions on developments that connect to the city's sewer system. The ordinance requires that any building with a footprint of 15,000 square feet or more or any parking lot over 7,500 square feet must detain at least the first half inch of rain onsite. Alternatively, the building or parking lot can meet this requirement by reducing its impervious surface area by 15 percent. To date the ordinance has resulted in the reduction of over 3 million square feet of impervious surface.[4]

10.2.4.1 Incorporating BGI into the City's Sustainable Development Policy

The Sustainable Development Policy, published in 2004 and updated in 2008, requires the implementation of GSI on new buildings and developments that receive special land use approval or public financing. This applies to all redevelopment agreements, planned developments and amendments to existing developments that are reviewed by the Department of Housing and Economic Development.[5]

10.2.4.2 Adding Green to Urban Design

The Adding Green to Urban Design: A City for Us and Future Generations plan provides direction to the Chicago City Council for regulating urban design and the Chicago Plan Commission for reviewing individual development projects. This plan promotes coordination among the city's agencies, including GSI in public projects.[6]

10.3 Hamburg

Hamburg Wasser invests EUR 60 million per annum in the maintenance and renewal of its approximately 5,500 km sewer network throughout Hamburg. In the inner city the network is a predominantly combined system while on the outskirts there is a primarily separate system (around 2,300 km for wastewater and 1,700 km for stormwater). The total sewer network encompasses an area of 360 km^2, of which around 175 km^2 can be classified as paved; around 105 km^2 is connected to the combined system.[7]

10.3.1 Challenges to Traditional Stormwater Infrastructure

10.3.1.1 Climate Change

Hamburg will be substantially affected by climate change, with potential sea level rises of up to 40 cm by 2050, while precipitation could increase by as much as 40 percent, with long dry periods in the summer. Studies provide evidence that climate change will lead to a significant increase in CSOs. Meanwhile, it is projected that the city will experience twice as many hot days due to a temperature increase of 1.2°C by 2050.[8,9]

10.3.1.2 Urbanisation

Hamburg's Senate is aiming to build 6,000 new low-cost homes per year in areas that are already quite heavily populated. This will result in an additional permanent increase in paved areas of approximately 0.4 percent. These areas produce runoff that places an increased burden on the city's drainage infrastructure (sewer network, water bodies and trenches). In addition, there is a potential risk to the drainage infrastructure from increased frequency of heavy rainfall.[10]

10.3.2 Strategic Vision: Hamburg's RISA Project

The city, in partnership with Hamburg Wasser and the State Ministry for Urban Development and Environment (BSU), has devised The Rain InfraStructure Adaptation (RISA) project. RISA aims to develop adequate responses to stormwater management in order to avoid flooding of streets and properties as well as reduce water pollution from sewer overflow and street runoff. Implementation has been allocated to a number of interdisciplinary working groups from the areas of environmental/sanitary engineering, urban and landscape planning, traffic planning and water-body planning. Pilot projects have commenced throughout the city and include the channelling of stormwater into green spaces. Overall, RISA's results and recommendations are summarised in the RISA Structure Plan

Rainwater 2030, which provide guidance for administrations, experts and property owners on the implementation of new stormwater management systems throughout Hamburg.

10.3.3 Tools to Encourage Implementation of BGI

10.3.3.1 Geographic Information Systems-Based Information for Rainwater Management

At the time of writing, a geographic information systems (GIS)-based analysis, planning and information system for rainwater management at the property level is being developed. The purpose is to be able to plan and implement appropriate measures, taking into consideration ecological and economic aspects. The foundation of the system is an Infiltration Potential Map (VPK). The VPK is based on hydrological, geological and topographical data in the RISA project and is combined with Potential Area Maps (FPK) that include paved area, area use, building structure and drainage area data to form a Decoupling Potential Map (APK).[11] The APK provides the ability to analyse the potential for rainwater management at various levels of detail. In addition, Inland Flood Protection Hazard and Damage Maps have been created to estimate the flood risk to infrastructure. This enables administrators, planners and property owners to cooperate in providing enhanced flood protection measures. In addition, it can enable a cost–benefit analysis to be conducted on the implementation of flood protection measures against associated costs. To reduce pollutant loads in the waterways Emission Potential Maps (EPK) have been developed. These maps provide information on yearly mean load pollutant removal rates (calculated with suspended solids) from developed areas, providing an improved detection of the main pollution area in settled regions of Hamburg. EPK maps will facilitate decision-making on the necessity, extent and expense of various stormwater treatment measures required to reduce pollution of waterways.[12]

10.3.3.2 Uniquely Designed Multifunctional Spaces

Multifunctional spaces including streets, parking spaces, green spaces, sportsgrounds and playgrounds will be used for short-term retention and/or transportation of runoff peaks during extreme precipitation events. However, they will not be used for every extreme weather event.

The use of public spaces will be limited to once-every-five-year events and streets once-every-ten-year events. Therefore the use of multifunctional spaces is not the rule but the exception. In addition, multifunctional spaces will be individually designed taking into account the extent to which each area is potentially at risk of flooding and the intensity of use.

10.3.3.3 RISA's Water-Sensitive Street Space Planning
The goal of the Water-Sensitive Street Plan is to direct stormwater runoff to open spaces, where it can be retained. The plan involves using the existing retention capacity of the street to store stormwater and create a 'flow path' that discharges the water to a nearby public park. The park provides the usual recreational and health benefits. During heavy rainfall, stormwater runoff is directed via a modified footpath to a permeable depression in the park's green area, allowing infiltration of water without causing damage to infrastructure. The maximum water level could be up to 30 cm for a once-in-thirty-year event with a retention/infiltration volume in the park up to 330 m^3. Meanwhile, the maximum water level of the street will be less than 10 cm with a retention volume of 12 m^3.[13]

10.4 Manchester

Manchester is served by a combined sewer system that accommodates both stormwater and sewage. However, increasing volumes of both, due to growth and development within the city, are placing increased pressure on the city's wastewater treatment works, particularly during periods of heavy rainfall. When the volume exceeds the capacity of the treatment works the untreated sewage is diverted into local waterways through CSOs, which is one of the main contributors to water pollution within the Manchester area. The sources of this pollution include: (1) urban diffuse pollution (runoff from roads, buildings and the built environment), (2) debris (including litter and vegetation) and (3) contaminated land (through which groundwater leaches into watercourses).[14]

10.4.1 Challenges to Traditional Stormwater Infrastructure

10.4.1.1 Climate Change
Manchester is likely to experience enhanced seasonal variation in precipitation levels, with summer rainfall decreasing and winter

rainfall increasing. It is projected that summer rainfall could decrease by 20 percent while winter rainfall could increase by up to 36 percent in the county of Greater Manchester, an area which comprises nine metropolitan boroughs in addition to Manchester itself.[15]

10.4.1.2 Population Growth

The population of Manchester grew from 423,000 in 2001 to 520,000 in 2014, a rate of increase that is at least twice the national average, and is projected to reach 587,000 by 2021.[16] Meanwhile, the population of Greater Manchester increased by over 180,000 between 2004 and 2014 to reach 2.73 million, and is projected to exceed 3 million by 2020.[17,18]

10.4.2 Strategic Vision: Manchester's Green and Blue Infrastructure Strategy

It is projected that by 2025 high-quality, well-maintained green and blue spaces will be an integral part of all the city's neighbourhoods, with communities living in healthier environments with increased provision for recreational activities that include walking and cycling. In addition, green and blue spaces will create high-quality and attractive surroundings that will attract businesses to invest in the city. In addition, new funding models will be in place ensuring that progress achieved by 2025 can be sustained and provide a platform for ongoing investments in the years following. To achieve this vision Manchester and its stakeholders will adopt the following measures:

1. Improve the quality and function of existing BGI, to maximise the benefits it delivers.
2. Use appropriate BGI as a key component of new developments to help create successful neighbourhoods and support the city's growth.
3. Enhance connectivity and accessibility to BGI within the city and beyond.
4. Promote a wider understanding and awareness of the benefits that BGI provides to residents, the economy and the local environment.[19]

10.4.3 Tools to Encourage Implementation of BGI

10.4.3.1 Objective 1: Improving Existing BGI

Currently around 58 percent of Manchester contains some form of BGI, varying in quality, functionality and benefits it provides. The strategy calls for projects that make best use of existing BGI, ensuring it has a designated function and use, has clear ownership and maintenance arrangements and delivers tangible and relevant benefits to the community and businesses. To achieve objective 1, the strategy lists a number of actions to be taken that are summarised in Table 10.1.

10.4.3.2 Objective 2: BGI in New Developments

The strategy provides initial guidance for developers on how high-quality green and open space that is appropriate for the location, well designed and well maintained, can be part of developments across the city. To achieve objective 2, the strategy lists a number of actions to be taken that are summarised in Table 10.2.

10.4.3.3 Objective 3: Improve Connectivity and Accessibility to BGI

The strategy seeks to ensure that all communities have access to high-quality BGI within and outside their own areas. This will be achieved by creating green linkages across the city, e.g. providing permeable, safe and attractive green routes between existing BGI to create ease of access, with recreational and health benefits. To achieve objective 3, the strategy lists a number of actions to be taken:

- *Enhancing river valleys and canals:* Manchester's river and canal network can be used to create linkages between green and blue spaces throughout the city. This will improve connectivity and promote sustainable transport options. In addition, high-quality permeable waterside pathways will link neighbourhoods with the city centre.
- *Creating green routes:* Creating and enhancing green routes will improve access to the city's green and blue spaces while contributing as multifunctional BGI.
- *Creating green boulevards and linkages:* Street trees and plants can provide attractive and safe routes adjacent to roads while existing transport corridors can incorporate multifunctional BGI.

Table 10.1 Actions to improve existing BGI in Manchester

Actions	*Description*
Investing in river valleys	Improving water quality, enhancing biodiversity, increasing access so that green and blue spaces can contribute to a healthy, liveable city
Enhancing existing parks and green spaces	Enhancing the vibrancy of the city's parks through active community participation
Increasing BGI within large estates	Large areas of green and blue spaces are owned or managed by organisations with large estates. Actions by housing providers can make change at significant scale
Enhancing school grounds	Actions by school and colleges can make change at significant scale
Effectively managing trees and woodlands	Maintaining and developing tree stocks will improve water/air quality and biodiversity
Creating community greening and community food growing areas	Community green and blue projects can create a unique sense of place, contributing towards the strategy's success
Protecting and enhancing private gardens	Gardens and courtyards make up a third of Manchester, providing potential for well-managed green areas for recreation, relaxation, food growing, wildlife watching, etc.
Increasing sites of biological importance (SBI)	Manchester can increase the number of SBIs as they play an important role in supporting a diverse range of species
Increasing local nature reserves	Sites that meet the needs of people and nature, have good management and are well maintained can be designated as local nature reserves
Improving health and well-being	Improving the quality and access of green routes and spaces increases activity pursuits (walking, cycling, jogging, etc.), enhancing health of residents and the workforce

Manchester City Council. 2015a. Manchester's 'Green and Blue Infrastructure' Strategy. Available: http://www.manchester.gov.uk/info/200024/consultations_and_surveys/6905/green_and_blue_infrastructure_consultation

- *Working with neighbouring authorities to improve access and connectivity:* Cross-boundary collaboration between local authorities, businesses and communities is essential for maximising the extent of BGI and connectivity.[20]

Table 10.2 Actions to implement BGI in new developments

Actions	*Description*
Retrofitting new BGI to existing buildings, particularly in the city centre	Major renovations provide an opportunity to increase access to nearby BGI, as well as to incorporate it into the building's design
Embedding BGI as part of the city centre's development	The greatest opportunities for new BGI in the city centre are provided by major new developments. Developers should consider how BGI can link to the wider city centre environment, providing residents, workers and visitors with access to green, blue and open spaces across the centre and outside
Establishing temporary BGI on sites awaiting development	Sites planned for development are often left vacant until the market is right for a scheme. Until then developers and the local community can initiate and create BGI projects to improve the local environment. Once development starts it may be possible to relocate the project to another area of the city or even incorporate it into the completed development
Embedding BGI as part of major refurbishments	Small-scale actions can increase BGI in parts of the city where space is limited. For example, green roofs and green walls are important for water management, biodiversity and climate adaptation
Embedding BGI as part of residential developments	A range of BGI can be considered in new residential developments; for example, gardens and balconies can provide areas for residents, new pocket parks and public open spaces provide community spaces; and areas designed for nature create space for humans and wildlife. In addition, linkages can be created to existing green and blue spaces
Embedding BGI as part of major employment developments	New employment developments located next to or near BGI spaces should look at linking with and encourage access to these areas. This provides staff with leisure, recreational and sporting opportunities. Developers should also enhance existing green and blue areas for staff to enjoy

Manchester City Council. 2015a. Manchester's 'Green and Blue Infrastructure' Strategy. Available: http://www.manchester.gov.uk/info/200024/consultations_and_surveys/6905/green_and_blue_infrastructure_consultation

10.4.3.4 Objective 4: Increasing Understanding and Awareness

Wider communication, education and awareness will solidify support for the strategy's core message that all stakeholders in the city have a role in contributing towards BGI and making the best use out of it for health, recreational, employment and other outcomes. Existing good practices include the following:

- *Manchester Town Hall green roof:* A 500 m^2 green roof was installed in 2013 on top of the Town Hall extension. This is one of eight green roofs that have been installed in the city centre in buildings including Manchester Metropolitan University, Whitworth Art Gallery and the University of Manchester Business School.
- *Multifunctional BGI:* Manchester Metropolitan University's Birley Fields campus contains a range of multifunctional infrastructure including a community orchard, sensory garden and landscaped student blocks with trees and stormwater management measures.
- *Renaturalisation of the River Medlock:* This collaborative project, involving the City Council, Environment Agency and the charity Groundwork MSSTT, has improved flood defences, water quality and biodiversity while at the same time providing the local community with an environmental asset.

10.5 Melbourne

Melbourne Water is responsible for managing more than 8,400 km of waterways and regional stormwater infrastructure. Under the Water Act 1989, Melbourne Water has been designated the caretaker of river health and is responsible for waterway, major drainage systems and floodplain management. Under the Environmental Protection Act 1979 and the State Environmental Protection Policy, Waters of Victoria, Melbourne Water is required to take action to help achieve water quality objectives for individual waterways and to protect environmental values and beneficial uses of waterways, by reducing nutrient, sedimentary and toxic loads delivered by stormwater. Meanwhile, councils are responsible for decisions made with reference to planning schemes that control land use and development. They are also responsible for managing local drainage infrastructure in catchments of less than 60 ha, including ownership and maintenance of drainage assets.

10.5.1 Challenges to Traditional Stormwater Infrastructure

10.5.1.1 Rapid Population Growth

The population of Greater Melbourne is projected to increase from 4.1 million in 2010 to 6.4 million in 2056, with 39 percent of that growth (930,000 people) occurring by 2026. Around 60 percent of Melbourne's growth is expected to take place in new urban areas. This will increase pressure on waterways, drainage and floodplains. In particular, new urban developments will increase volumes of stormwater and pollution loads, with downstream impacts on waterways and bays.[21]

10.5.1.2 Climate Change

Climate change is likely to result in Victoria facing more extreme heat-waves, reduced rainfall and more intense storms. The state will likely experience an increase in frequency of hot days (when the temperature exceeds 35°C) and hot spells (period of 3–5 consecutive days when the temperature exceeds 35°C). By 2070, Melbourne will likely see an increase in days above 30°C from the current 30 days to 42–62 days, while the number of hot spells could double. Regarding rainfall, the state is likely to become drier, with average rainfall decreasing by 4 percent by 2030 and 11 percent by 2070; most of this decrease will occur in spring. While overall rainfall for Victoria will decrease, extreme rainfall events are projected to increase in number by 5.9 percent by 2070.[22] Overall, Melbourne will most likely experience long dry spells interrupted by heavier precipitation events. This sudden, heavy localised rainfall may cause sewer overflows in waterways or more frequent overland flooding in some urban areas.

10.5.2 Strategic Vision: Melbourne's Stormwater Strategy

Melbourne Water has developed a Stormwater Strategy for 2013–2018 that articulates how the utility will support the city's transition towards a 'water sensitive city' that embraces community needs and values, and considers urban growth and climate variability. The Strategy is guided by the Government of Victoria's vision, articulated in *Living Melbourne, Living Victoria*, of creating a smart, resilient water system for a liveable, sustainable and productive Melbourne. The vision articulates the belief that sustainable stormwater management supports prosperous communities, thriving landscapes and healthy waterways and bays. To measure progress towards the vision, Melbourne Water has set a 20-year goal that 'stormwater is collaboratively managed to protect and improve waterways and bays, resulting in multiple outcomes for the community'.

10.5.3 Tools to Encourage Implementation of BGI

10.5.3.1 Education and Knowledge-Sharing Initiatives

Melbourne Water is developing its approach to stormwater management via partnership projects, knowledge-sharing events, and grant funding. Examples include the Water Smart City Model and the Healthy Waterways 10,000 Raingardens Program. It also has an extensive flood mapping and mitigation programme.

Water Smart City Model

To raise awareness of the issues of stormwater quality and surface runoff, Melbourne Water has developed the Water Smart City Model, an educational activity suitable for all ages which can be used at community events and festivals. The activity involves the audience building a model city with roads and buildings made from Lego building blocks. Food dye, representing pollutants, is placed on the city and rainfall is simulated over the model, carrying the pollution over the impervious surfaces and into the 'bay'. A variety of features including rain gardens, rainwater tanks, swales and rooftop gardens are then added. Pollution is again added to the model and rain simulated. The amount of surface runoff is significantly decreased due to the retention capabilities of the new features, reducing risks of flooding. Pollution is also captured in the features so the water flowing into the 'bay' is cleaner.[23]

Healthy Waterways 10,000 Raingardens

This programme aims to establish a change in thinking about stormwater. Melbourne Water is working with local government and the community to build rain gardens in public spaces including streets, parks and schools. It is also encouraging people to build rain gardens in their own homes; the aim is to install 10,000 and 5,000 have been registered to date.[24]

Flood Mapping

Flood mapping of Melbourne began in the 1990s, with the maps frequently updated to take account of improved modelling techniques, new catchment information and development, lessons learnt from actual flood events and long-term pressures created by urban renewal and climate change. The region has been divided into more than 700 catchments, with each individually assessed for flood risks. A catchment's flood risk is determined by the likelihood and consequences associated with the economic, safety and social impacts of flooding. In 2013 almost 23,000 properties were identified as being under threat from flood risk defined as 'extreme' or 'intolerable'.[25]

Flood Mitigation Programme

Since 2008, Melbourne's flood mitigation programme has aimed to reduce risks in catchments subject to intolerable flood risks. The programme prioritises flood-risk reduction options in these catchments based on feasibility, cost effectiveness, community vulnerability, and potential social impacts of flooding. It has involved consultation with stakeholders and affected communities. The programme also considers flood mitigation solutions in catchments where the risk of flooding is statistically lower but still unacceptable to the community due to the frequency of flooding events, or where solutions are relatively inexpensive and easy to implement. All flood mitigation solutions consider water quality, water harvesting, improving waterway health and providing best value for communities, examples of which include using existing open spaces and playing fields to store floodwater.[26]

10.6 Seattle

Prior to Seattle's industrial development in the later nineteenth and early twentieth centuries, the evergreen forest that covered most of the countryside surrounding Puget Sound slowed down runoff, allowing it to evaporate or infiltrate through the soil. As the city developed, the forest was replaced with impervious surfaces and runoff routed to either a combined sewage-stormwater system or discharged directly into the city's waterways. Today two-thirds of the city is served by a combined system while the remaining one-third employs an informal ditch and culvert system to manage drainage; there is no sewer infrastructure. Within areas served by the combined system, drainage basins under 1,000 square acres are operated and maintained by the City of Seattle, while drainage basins larger than 1,000 square acres are operated and maintained by King County Wastewater Treatment Division (WTD).[27]

10.6.1 Challenges to Traditional Stormwater Infrastructure

The main challenges that Seattle faces are as follows:

- In some areas of the city the combined system is now at or nearing capacity, resulting in CSOs at frequencies that exceed those permitted under the Clean Water Act. In 2014, 115.6 million gallons of combined sewage and stormwater overflowed into water bodies during 406 separate events.
- Basement backups of sewage and stormwater.
- Sewage backups onto city streets.
- Polluted stormwater runoff – estimated at 13 billion gallons annually – flowing directly into local water bodies.
- Localised flooding incidents.
- Degradation of creek, lake and near-shore habitats.

10.6.2 Strategic Vision: Seattle's Green Stormwater Infrastructure Implementation Strategy

In 2013, Seattle's City Council Resolution 31459 established GSI as a critical aspect of a sustainable drainage system. The Resolution encourages reliance on GSI to manage stormwater runoff wherever possible. The Resolution and associated Executive Order set a community-wide implementation target to manage 700 million gallons of runoff annually using GSI by 2025, with the Office of Sustainability and Environment charged with developing a GSI implementation strategy for Seattle. The 2015–2020 GSI Implementation Strategy sets a 2012 baseline and outlines a broad strategy for accelerating the adoption of GSI in Seattle across a range of project types.

10.6.2.1 Target: 700 Million Gallons

The total volume of stormwater runoff generated in Seattle each year is around 20 billion gallons. Managing 700 million gallons with GSI involves transforming 1,125 acres of impervious surfaces so that they function, in effect, like native forest. In Seattle, 1,125 acres represents approximately 3.6 percent of all impervious surfaces. with rights of way accounting for 10 percent and the city's fragile creek watersheds for a further 25 percent. By 2025, Seattle's population will be approximately

700,000; thus if every Seattle resident plays their part in managing 1,000 gallons of stormwater runoff annually with GSI, Seattle will reach its target. Managing 1,000 gallons involves managing runoff from around 70 square feet of impervious surface – half the size of a typical parking lot.[28]

10.6.2.2 Current GSI Projects

GSI projects are currently initiated for the following reasons:

- *Stormwater code requirements:* GSI is incorporated when public or private land is redeveloped. It is funded by the developer, which may be a public or private entity. Around 1 percent of Seattle's land is redeveloped per annum.
- *Retrofit projects led and funded by Seattle Public Utilities (SPU) or WTD:* These are typically retrofits of public rights of way to manage stormwater runoff from roads. Projects are designed to improve water quality, prevent combined system overflows or backups, prevent damage to creeks and/or improve conveyance. These projects are also designed with neighbourhood co-benefits.
- *Retrofit projects incentivised by SPU or WTD:* These voluntary projects are developed by property owners and incentivised by SPU or WTD via rebates or grants within high priority areas. The projects are funded by drainage rates.
- *Retrofit projects that are non-utility led and funded:* These voluntary projects on private or public land are developed and funded by entities other than SPU or WTD. Funding sources include private foundations, private developers, community organisations, state or federal grants and local agency funding.

10.6.2.3 2012 Baseline

Over the period 2000–2012 Seattle's GSI projects, mandated by the Stormwater Code and funded/incentivised by utilities or by other entities, have led to the city managing over 100 million gallons of stormwater per annum; a breakdown of the contribution of each project type is listed in Table 10.3.

Table 10.3 GSI implementation baseline, 2000–2012

Project type	*Description of action*	*Gallons managed (millions)*
Required by stormwater code	Single family, parcel-based, rights of way, trails, sidewalks	8.7
Utility-led and funded retrofit projects	SPU: SEAStreets, Carkeek Cascade, Broadview Green Grid	67.0
Utility-incentivised retrofit projects	SPU: RainWise, ReLEAF street tree planting	2.5
Non-utility led and funded retrofit projects	SDOT: street tree planting and retention permeable paved sidewalks	1.9
	SPARC: capital projects	10.0
	Community-led projects: voluntary green roof instalments projects led by community groups, businesses, non-profits	10.4
	Total	100.5

10.6.3 *Tools to Encourage Implementation of BGI*

To reach the interim goal of managing 400 million gallons of stormwater per annum by 2020, Seattle will accelerate the implementation of GSI through projects and retrofits triggered by the Stormwater Code, non-utility-led projects, non-utility-led and funded retrofits, utility-led retrofit projects, and utility incentives.

10.6.3.1 Stormwater Code-Triggered Projects

The Stormwater Code and Manual, first implemented in 2009 and updated in 2016, is expected to result in a 15 percent increase in GSI implementation. Code changes will accommodate the following stormwater management requirements: (1) the threshold for parcel-based projects will be lowered from 2,000 to 1,500 square feet of new or replaced impervious surface, or 7,000 square feet of land-disturbing activity; (2) single family projects of 1,500 square feet of new or replaced impervious surface will have to meet onsite management requirements; and (3) implementing GSI by following a pre-defined list of best practices or demonstrating compliance with a specified performance standard.[29]

10.6.3.2 Non-utility-led Project Areas

The Seattle Department of Transportation (SDOT) and Seattle Parks and Recreation (SPARC) have identified strategies for integrating GSI into capital transportation and Seattle parks respectively. SDOT will:

- Prioritise GSI features for traffic calming (retrofits to slow traffic speeds).
- Incorporate GSI into neighbourhood greenways, non-arterial paving projects, sidewalk projects, etc.
- Remove impervious surface in SDOT capital projects.

Meanwhile, SPARC will:

- Retrofit/convert existing landscaped areas adjacent to buildings or parking areas into rain gardens to manage roof and parking lot runoff.
- Invest in rainwater capture and reuse systems for irrigation.
- Utilise GSI retrofits to solve existing drainage issues and/or improve habitat value and aesthetic value of park land.
- Develop voluntary demonstration projects with interested community partners at park sites.
- Decommission and remove unnecessary impervious surfaces.
- Integrate GSI into future park development and land-banked sites.[30]

10.6.3.3 Non-utility-led and Funded Retrofits

These retrofit projects, on public and private lands, are developed and funded by entities other than SPU and WTD. To accelerate GSI implementation Seattle will review the following:

- *Facilitate city investments in integrated infrastructure:* The city will look into integrating GSI retrofits into non-drainage rate-funded capital infrastructure (e.g. roads, parks, other city-owned sites, electricity, water and communications when the cost per gallon is $0.50 or less). This requires the development of a GSI Opportunity Fund that can be operationalised via several approaches including: (1) cross-department prioritisation process run by an integrated infrastructure team; (2) community-grant process that considers and supports proposals from neighbourhood-based organisations; and (3) direct allocation to city departments for GSI retrofit integration.

- *Leverage external funding for strategic investment:* Develop and update a prioritised list of upcoming capital development projects that offer promising GSI retrofit opportunities and use the list to leverage available external funding from e.g. the EPA and private foundations.
- *Remove implementation barriers:* The city will endeavour to remove implementation barriers related to the planning, designing, constructing and maintaining of GSI in rights of way on public land and adjoining parcels. This includes offering clear guidance about partnering opportunities and dedicated budgets available for public–private partnerships.[31]

10.6.3.4 Utility-Led Retrofit Projects

These capital improvement projects are developed and funded by local drainage and/or wastewater utilities to proactively address high priority stormwater management challenges, including combined system overflows, creek protection and drainage system capacity issues. These projects typically involve retrofitting public rights of way to manage polluted stormwater runoff from the road system. To accelerate GSI, utilities can:

- *Increase efficiency via integrated infrastructure:* Utility-led GSI investments can be integrated into concurrent transportation, parks, waterfront, city sites or privately funded infrastructure investments in public rights of way.
- *Increase investment:* To be considered as part of the SPU strategic business plan for 2020–2025, with priority placed on increased investment in areas with constrained pipe capacity and/or creek watersheds that have been allocated funding under the Natural Drainage System Partnering programme.[32]

10.6.3.5 Utility Incentives

There are currently three utility-funded incentives to implement capital GSI retrofits:

- In high priority areas, RainWise rebates are available to install a rain garden or stormwater cistern to manage runoff from a roof or from paved walkways and driveways. RainWise offers a rebate of $2.35 per square foot of impervious surface managed.
- Green grants up to $50,000 are offered by WTD for community-based projects in the Duwamish watershed and can be used to develop GSI retrofit projects.
- SPU has budgeted over $3 million over the period 2016–2021 to develop public–private GSI partnerships in uncontrolled CSO basins.

Utilities will accelerate GSI throughout Seattle during the period 2015–2020, using the following three approaches:

- *Increasing investment in RainWise:* An increase in RainWise investments of $1 million per year over the 5 years is estimated to yield an additional 11.36 million gallons managed by 2020.
- *Increasing investment in public/private partnerships:* SPU's current funding of partnerships is expected to deliver 5.7 million gallons managed over the same period. This investment will, it is anticipated, be expanded.
- *Increasing efficiency:* The current cost/gallon managed via the RainWater rebate programme is around $0.45, or 2.3 gallons managed per dollar invested. However, increasing efficiency has the potential to shift the costs to property owners, impacting overall participation rates, particularly among low-income families.[33]

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CHAPTER 11

Best Practices

11.1 Introduction

Using the adaptive management framework stages of planning, designing, implementing and monitoring of the design and implementation of Blue-Green Infrastructure (BGI) the following best practices have been identified from the case studies of Copenhagen, New York City, Philadelphia, Rotterdam, Singapore and Washington D.C. in their attempts to become Blue-Green Cities. These best practices can be implemented by other cities around the world attempting to become Blue-Green Cities.

11.2 Recognising the Multiple Benefits of BGI

Blue-Green Cities recognise that the multiple benefits of BGI extend beyond improving water quality and enhancing resilience to extreme weather events. They have seen that it provides significant economic, environmental and social benefits; these include reduced pressures on the city's water supply and wastewater treatment system, a reduction in urban heat island effects, a greater focus on energy conservation, lower carbon emissions, improved air quality, higher property values, increased recreational areas and a higher quality of life for residents. Additional benefits include restored ecosystems and greater participation of residents in climate change adaptation activities. Cities also recognise the circularity of implementing BGI. For instance, one city's overall goal is to create a green identity that draws in more residents, which in turn increases

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revenues to support more greening, creating a positive feedback loop that helps the programme thrive.

11.3 Prioritising BGI Projects

Many cities attempting to become Blue-Green Cities face fiscal constraints in implementing large-scale city-wide BGI measures to reduce stormwater flow and improve water quality of waterways. As such, they are working out which aspects of BGI they need to prioritise. For instance, one city has been divided into catchment areas, each of which have been further divided into sub-catchments with their own detailed BGI plan; as a result, hundreds of projects have been selected for implementation over the next couple of decades. On an annual basis the city selects which projects will go ahead in that year. Meanwhile, another city has determined priority areas for BGI implementation that have the greatest impact on reducing combined sewer overflows (CSOs). By identifying priority areas, the city can then saturate these areas with BGI while achieving cost savings from efficiencies in design and construction. In another case, a city has ascertained which areas are most vulnerable; it then leaves it in the hands of various stakeholders to determine which specific BGI measures will be most appropriate and feasible. Finally, a couple of cities implement BGI city-wide via sector-targeted programmes such as Green Streets and Green Schools or public–public or public–private cooperation.

11.4 Integrating BGI with Other Projects

Many cities integrate BGI with other capital projects to capitalise on economic efficiencies. In one city, prioritised BGI projects are interlinked with other urban development projects. This is cost-effective as the BGI projects are implemented in places where construction projects have already begun. Moving forwards, the city aims to implement BGI projects in conjunction with stream conversion and road restoration, ensuring that urban renewal projects will include BGI in the planning stages. Another city reviews designs for public agencies initiating it in new projects and identifies opportunities to integrate it into planned public projects.

11.5 Interagency Cooperation on BGI

Because BGI is multifunctional, and often is a new concept to many city agencies, its implementation frequently requires interagency cooperation. One city recognises the implementation of effective BGI is a constant learning process which involves cooperation between the city and the utility that manages the city's stormwater system, as well as cooperation between different city departments and agencies to find the best possible BGI solutions for specific areas in the city. Another city recognises that the implementation of BGI in its public spaces requires cooperation between the public works department, which is responsible for the maintenance of infrastructure, and the urban development department, because the development and implementation of a climate adaptation strategy requires strong cooperation between designers, city planners and water managers. Commonly, public agencies in charge of implementing city-wide BGI cooperate with their city's respective parks and recreation agency to develop BGI on public green space, providing recreational areas that also manage stormwater runoff.

Meanwhile, a third city aims to capture efficiencies in construction and so its agencies work together to bid out construction of BGI projects. To enhance capacity on BGI, one agency in charge of implementing BGI funds job positions in other public agencies to ensure BGI is implemented in their programmes. This is in addition to the partnerships that have been established to implement BGI in housing projects, school playgrounds and streets. The same agency also collaborates with other agencies, including the Office of the Mayor, to encourage owners of properties with large impervious surfaces to implement BGI.

In order to formalise cooperation, one city's agency in charge of the combined sewer system has entered into a Memorandum of Understanding (MoU) with the agency in charge of managing its separate system. The MoU sets out the expectations on where BGI projects will be located, how will they be constructed, how they are designed, how outreach is performed and how they are maintained. In addition, other agencies have participated in the development of the MoU to ensure that the processes and approvals needed for BGI to be successfully implemented on their properties are in place. Furthermore, the agency in charge of the combined sewer system has developed a set of BGI standards that require any other utility that is performing work in or around the utility's

BGI to restore the facilities to its standards, ensuring the BGI has the same level of performance post-repair.

11.6 Public–Private Cooperation

Cities recognise that cooperation on implementing BGI not only occurs between public agencies but between the public and private sectors too. For instance, one city that aims to increase the number of BGI projects has developed a professional training programme; the agency in charge of implementing BGI collaborates with other public agencies and private sector associations and institutions to develop an accreditation programme for BGI professionals. The aim is to build up expertise in BGI design and increase the competitiveness of professionals in the local market and region. Meanwhile, another city is initiating the large-scale implementation of small-scale 'no regret' BGI actions that embed climate adaptation in design and planning and increase resilience to climate change, all of which will be led by citizens and businesses. This is in addition to a small selection of key city-initiated projects designed to inspire and create publicity as well as deepen understanding of BGI. Nonetheless, the city will ensure BGI measures will be linked in with other projects, for example, incorporating them within existing road, park and sewage maintenance programmes. Similarly, a third city has designed a set of BGI design guidelines to encourage both the public and private sectors to implement BGI and integrate waterways within their developments to enhance the environment.

11.7 Incentivising Stormwater Runoff Reduction

To encourage the management of stormwater on-site, several cities have stormwater pricing. For instance, in one city commercial and residential property owners are charged for the cost of treating stormwater runoff: for commercial customers the stormwater bill is based on the square footage of impervious area covering the property, while residential customers pay a standard amount based on the average surface area of impervious cover on residential properties throughout the city. One city is even trialling a pilot stormwater parking lot fee to encourage the reduction of stormwater runoff to its wastewater system.

11.8 Subsidies to Encourage BGI

To reduce stormwater bills and encourage the implementation of BGI on properties, cities have also developed a range of subsidies and grants. For instance, one city offers a stormwater grant programme that funds the design, construction and maintenance of BGI on private property. In particular, homeowners attend a workshop on BGI tools available and determine which are best for their home. After the workshop, the city's agency helps residents connect with a contractor to install subsidised BGI features. The agency even offers residents a subsidised stormwater assessment that involves determining the most appropriate BGI for a property. Meanwhile, a couple of cities offer subsidies for the installation of green roofs on both public and private properties. To encourage the widespread application of BGI on large parcels of land, one city provides funding for non-residential property owners to design and construct BGI retrofit projects, with project funding dependent on total volume of runoff managed, cost-competitiveness and environmental and educational benefits. To maximise efficiencies, the same city also provides funding to companies or contractors to construct BGI retrofit projects on private property across multiple properties in its combined sewer area. Another city offers an incentive scheme that funds a portion of the installation costs of BGI features, with the scheme open to both residential and non-residential buildings. Finally, in order to encourage innovative BGI designs, an agency has created a stormwater retention credit trading scheme in which major projects can install BGI as well as purchase privately traded credits from other sites or pay an in-lieu fee to the agency. Furthermore, sites can also generate credits by installing voluntary BGI or by exceeding their regulatory requirements.

11.9 Mandatory BGI on New Developments

A number of cities mandate the implementation of BGI in new urban projects or in any public or private sector development that disturbs a significant amount of land. For instance, one city mandates the incorporation of green roofs in new local plans to adapt to climate change, enhance biodiversity and create a greener city. In the near future, the same city will mandate the disconnection of downspouts to reduce the volume of stormwater entering the city's sewer system. Another city encourages developers to go beyond meeting minimum BGI standards on new developments by offering a fast-track review process if the design retains 95 percent or more of onsite stormwater.

11.10 Guidelines to Facilitate BGI

To guide the development and implementation of mandatory BGI, cities have developed guidelines. For instance, one city, which has developed a stormwater performance standard for new developments or major site expansions, has implemented a guideline that details BGI best management practices for meeting its requirements. Similarly, another city has developed a green streets design manual that provides BGI design details and specifications for both public and private entities implementing BGI in rights of way.

11.11 Oversight of BGI Construction

Several cities require that the design of mandatory BGI be approved by city agencies in charge of managing stormwater to ensure that it is effective. One such city has a code of practice that mandates that all new and redevelopment projects that disturb significant volumes of land must implement BGI and requires that the design and construction process be overseen by a registered BGI professional. Furthermore, the approved plans must be lodged with the agency in charge of stormwater management.

11.12 Engaging Stakeholders on BGI

Many cities have initiated stakeholder engagement programmes to encourage local residents to contribute to the design of BGI, develop community-led BGI projects, adopt BGI features in their neighbourhoods as well as implement them on their own properties. For example, when one city implements BGI in a neighbourhood, city staff visit the local neighbourhood commission and hold town hall meetings with various stakeholder groups to educate the residents about BGI and potential impacts during the duration of construction. This is done to ensure that residents feel empowered, that this is their project just as much as it is the utility's project. Another city invites residents to suggest how BGI projects located in their neighbourhood should look and what additional activities can be included in the project. A third city is seeking partnerships with community stakeholders across the city to develop BGI projects, with the city seeking community input on potential BGI projects at schools, recreation centres, parks, public spaces and parking lots. To facilitate the community-led projects, a dedicated website has been created where stakeholders can learn about BGI project requirements and selection priorities, project types that are eligible for funding, how to identify opportunities onsite and the steps required for project submissions. Furthermore, the same city runs a BGI adoption programme that provides grants to civic organisations to help maintain the beauty and functionality of BGI across the city's neighbourhoods, with adoptees assuming responsibility for the care of one or more BGI sites, including maintenance, monitoring activities on site and engaging the community on BGI. Finally, a fourth city has initiated a 'paving out, plants in' initiative that encourages residents to replace paving in their backyards with plants and vegetation.

11.13 Raising Public Awareness of BGI

To enhance public awareness of BGI, cities have implemented a variety of online and offline public education and outreach programmes. For instance, one city has developed an Internet-based BGI map that enables the public to search for BGI projects throughout the city. In addition, it has created a website that informs the public on the various types of BGI implemented throughout the city and whether any projects will be coming to specific locations. Social media and smartphone apps have become an important tool to enhance awareness of BGI too, with one city creating an educational YouTube video that describes the environmental challenges of CSOs and BGI measures to reduce stormwater runoff. Meanwhile, another city has developed a smartphone app that enables users to explore the multifunctional BGI measures the city takes to become climate proof. Specifically, users can learn about how and why these measures work and how they are part of an integrated strategy for the entire city. Cities have implemented traditional public outreach campaigns on BGI too that involve city representatives attending neighbourhood meetings, distributing door flyers and door mailers and attending community festivals.

11.14 Enhancing Professional Capacity and Awareness

One city has developed a raft of online interactive tools to raise awareness and knowledge of BGI among developers, planners and other professionals. For instance, it has developed an interactive climate atlas that provides visual impacts of climate change on the city and its vulnerable areas and buildings. Furthermore, users can compare the impacts of various climate scenarios. To increase knowledge on adaptation measures, the city has developed a climate adaptation toolbox for spatial designers and project managers to compute their impact at various spatial levels. Furthermore, it has developed a computer program that visualises the effects of implementing BGI measures in urban spaces. This enables users to identify those measures that have the greatest effect at the district, street and even building level. To enhance awareness of the multiple benefits of BGI, the city has developed a societal cost–benefit analysis tool that shows how incorporating BGI measures with other construction projects or maintenance programmes can provide a positive outcome. To enhance awareness of the significant amounts of cooperation required between public agencies as well as between the public and private sector to implement an effective BGI strategy, the city has also developed a computer game that teaches players how to allocate roles and get everyone to work together. Overall, the game gives a realistic visualisation of the interdependencies, advantages and necessities of working together.

11.15 Professional Recognition

Cities have initiated a variety of programmes to publicly recognise BGI projects as well as the professionals that implement them. One city holds BGI excellence awards to celebrate the best regional projects that not only reduce stormwater runoff but also provide multiple triple bottom line benefits, with awards given to both public and private projects as well as recognition of innovative research and leadership in BGI. Meanwhile, another city has developed a BGI certification scheme to recognise public agencies and private developers who embrace BGI and incorporate its features in their developments. The certification scheme also aims to ensure that design features incorporated into developments achieve a minimum design standard. Regarding professional recognition, one city has developed a BGI professional registry for the industry to recognise the quality design work of professionals who have successfully completed an accreditation certificate.

11.16 Innovative BGI Challenges

Cities have launched BGI challenges to drive private sector innovation in the development of BGI. For example, one city has launched a challenge to find innovative solutions to reducing the cost of implementing BGI. The challenge, which is open to anyone nationally and internationally, will lead to Requests for Proposals that will in turn lead to contracts issued for the construction of innovative BGI. Another city has launched a challenge to engage firms in innovative BGI practices in the categories of public spaces, commercial and private property or governmental and institutional property. The challenge has both raised awareness of BGI and pushed designers to develop innovative technologies as well as provide practical designs.

11.17 Workshops and Events

To enhance practical knowledge of BGI, a couple of cities have initiated public workshops for residents to understand how BGI works and how it can be maintained. For example, one city has created a bioswale maintenance programme that involves educational workshops for the public. In another, a couple of public agencies have co-hosted a workshop on rainwater harvesting at a garden that included a presentation on the features and benefits of BGI, appropriate plant types and maintenance programmes. Meanwhile, a third city hosts public events during the summer months that provide information on BGI along with free giveaways.

11.18 Classroom Education

Several cities run school education programmes to educate students on BGI and the various measures they have implemented to manage stormwater runoff. Their format varies from visits involving presentations to science, technology, engineering and maths (STEM) courses developed with various partners that not only educate students in a classroom setting on BGI but also provide practical experience on how it works and how to maintain it.

11.19 Green Jobs

The implementation of BGI strategies across cities has the potential to lead to new green jobs. One city has a goal that at least half of all new jobs created by BGI projects will be filled by local residents. To achieve this goal, it has launched an apprenticeship-style training programme for young adults to work in BGI that involves study both in the classroom and in the field. In addition, the city runs a mentor-internship programme whereby projects implementing BGI measures that are of a specific value are obliged to take in interns.

11.20 BGI Monitoring

Cities implement a variety of monitoring strategies to manage their path towards becoming Blue-Green Cities. For instance, at the strategic level, one city has created a climate adaptation monitor to provide insights into the speed of climate change and whether the objectives of its adaptation strategy should be modified as well as a climate adaptation barometer to track the progress of the development of the strategy.

At the operational level, a second city has standardised its designs and procedures to enable the systematic implementation of BGI, as well as measure and evaluate the benefits of BGI in reducing CSOs in specific locations. In addition, it is collecting and assessing performance data through a long-term monitoring programme. Furthermore, it is developing a Geographic Information Systems (GIS) based project tracking and asset management system for its BGI assets. Similarly, a third city has based its monitoring of BGI on how it performs during heavy storm events and whether the BGI projects increase the quality of life in the neighbourhoods in which they are located, with quality of life data provided by the city's 'urban life account'.

A fourth city is constructing BGI in a sequential fashion, enabling it to monitor and assess the performance of installed BGI as the programme is rolled out. This means data collected and lessons learnt during the monitoring phase will be used when planning and designing the next round of BGI projects, ensuring that they are practical and effective for CSO control while also providing numerous benefits to the community. Similarly, a city agency holds monthly meetings on the status of BGI projects in addition to monthly BGI maintenance meetings. At the other end of the spectrum, another city ensures the quality and performance of BGI through a certification scheme that mandates minimum design standards.

Conclusions

Cities around the world have to become more resilient to climate change and reduce their ecological footprints. Green Cities are concerned with how to design the whole city in a more sustainable, efficient, adaptive and resilient way. They recognise connections between different sectors and support development strategies that fulfil multiple functions and create numerous environmental, economic and social benefits. Moving this concept on a stage further, Blue-Green Cities use a variety of natural and man-made water features to manage water, wastewater and stormwater to ensure that their populations are resilient to extreme weather events while at the same time ensuring the health of aquatic ecosystems.

Traditionally, urban water managers have relied on grey infrastructural solutions to mitigate risks. However, this has led to numerous economic and environmental consequences, including increased downstream flooding risks and CSOs impacting the health of aquatic systems as well as drinking water quality. In addition, traditional stormwater systems are unable to cope with sudden large volumes of precipitation that are expected to increase in frequency with climate change. Furthermore, rapid urbanisation, as well as increasing environmental regulations, is challenging cities to simultaneously manage floods while also restoring the health of waterways. As such, cities are turning towards BGI to enhance nature's ecosystem services in the management of water resources while increasing resilience to climatic risks. In addition, BGI solutions also provide multiple environmental, economic and social benefits.

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Urban water managers are increasingly employing an adaptive management decision-making framework that guides the planning, designing, implementing and monitoring of BGI. In the planning stage of adaptive management, cities develop an overall vision of implementing BGI and identify the geospatial extent of applications across the city. Collaborative partnerships are established between public agencies as well as between the public and private sectors. The multifunctional benefits provided by existing BGI, as well as local issues and challenges, are identified to ensure successful implementation. Finally, resources are allocated to ensure the successful and sustainable implementation and long-term management of BGI. In the design stage, cities need to communicate the strategy, plan or overall design and ensure BGI is functional and durable, in addition to providing other various benefits. During the implementation stage, cities set standards to ensure that BGI functions well according to locally relevant criteria as well as ensure adequate funding and resources are available for the ongoing management and maintenance of BGI. Finally, in the managing and monitoring phase, cities monitor the delivery of BGI against the established objectives and ensure that BGI features throughout the city are functioning well.

In the implementation stage, cities can encourage BGI on both public and private properties, by using a variety of fiscal tools. Common fiscal tools include stormwater fees and rates that not only encourage sites to reduce runoff but also provide a funding mechanism for cities to cover the costs of implementing BGI. Cities also provide various stormwater fee discounts that provide the owners of all types of property with the opportunity to reduce their bills by implementing a variety of BGI measures. To encourage the incorporation of BGI in new developments, cities often provide financial incentives that include green roof subsidies and construction grants. Finally, cities offer rebates to properties that apply BGI retrofits such as installing rain barrels and developing rain gardens.

To further encourage the development of BGI on public and private properties, cities employ a variety of non-fiscal tools, such as information and publicity campaigns to raise awareness not only of the potential financial savings of BGI but also the numerous environmental and social benefits it brings. To encourage developments to manage stormwater runoff on-site, cities offer fast-track reviews of projects that include BGI, which can result in financial savings for site projects. Many cities implement pilot and demonstration projects to allow residents to experience the benefits of BGI first-hand while garnering public support for large-scale implementation. To ensure that BGI is implemented effectively, cities commonly develop performance standards. Other tools to encourage the implementation of BGI include awards and recognition programmes for BGI projects initiated by public and private sector actors, which encourage others to follow suit, as well as public education and awareness initiatives that aim to encourage residents to become stewards of the local BGI system.

Using the adaptive management framework stages of planning, designing, implementing and monitoring of BGI, the following best practices from the case studies of Copenhagen, New York City, Philadelphia, Rotterdam, Singapore and Washington D.C. have been identified for other cities around the world attempting to become Blue-Green Cities.

Many cities face fiscal constraints in implementing large-scale, city-wide BGI measures to reduce stormwater flow and improve water quality. A potential solution is to divide them into catchment or priority areas, allowing the process of implementation to be staggered. By identifying priority areas, cities can saturate them with BGI, while achieving cost-savings from efficiencies in design and construction.

Cities commonly integrate BGI with other capital projects to capitalise on economic efficiencies. This is cost-effective when the projects are implemented in places where construction has already begun, such as urban renewal projects and infrastructure upgrades. To ensure these BGI projects function well, guidelines have been prepared on how best to integrate BGI in public projects as well as restore them if utilities are performing work in and around BGI.

Because BGI is multifunctional, implementation requires interagency cooperation, whether it be between the city and the utility that manages its stormwater system or between the various departments and agencies. This is also important when applying BGI measures to specific areas in the city. To achieve efficiencies, city agencies can cooperate on the bidding of BGI contracts as well as form partnerships in developing BGI on public properties such as school playgrounds and housing developments. MOUs can be created that set out the expectations on where BGI projects will be located, how they are designed and constructed, how outreach is performed and how they are maintained. Cooperation is required between the public and private sectors when seeking to expand a BGI programme across the city, with the need to ensure that BGI installed in private developments is properly designed and effectively maintained. One city has implemented an accreditation programme for BGI professionals to ensure there is an adequately trained workforce for the widespread implementation of good quality BGI projects.

To encourage the management of stormwater on-site, several cities have introduced stormwater fees, determined by the impervious surface area of the property. For commercial and other large properties, the fee is often based on the actual impervious area, while residential properties pay a standard amount based on the average surface area of homes in that city. One city is even trialling a pilot stormwater parking lot fee to encourage the reduction of stormwater runoff to its wastewater system.

To reduce stormwater bills and encourage the implementation of BGI on properties, cities have developed a range of subsidies and grants. For instance, stormwater grant programmes can fund the design, construction and maintenance of BGI on private property. Other grants are distributed to homeowners who, after attending BGI workshops, determine which tools are most cost-effective, with a city-appointed contractor installing the BGI. Alternatively, the city offers a subsidised inspection of the homeowner's property to determine the best BGI solutions to manage stormwater on-site. Other cities offer subsidies for the installation of green roofs on both public and private properties.

Cities often provide funding for owners of non-residential property looking to design and construct BGI retrofits. The funding is dependent on total volume of runoff managed, cost-competitiveness as well as the potential environmental and educational benefits derived from installing BGI on large parcels of land. Similarly, one city offers an incentive scheme that funds a portion of the installation costs of BGI on both residential and non-residential properties. It offers funding to companies implementing BGI across multiple properties. To inspire innovation in BGI designs, another city has developed a stormwater retention credit trading scheme that allows companies to buy and sell stormwater credits to meet or exceed their regulatory requirements.

Several cities mandate the implementation of BGI in new developments on both public and private land. An example is one city requiring green roofs be installed on new developments to adapt to climate change, enhance biodiversity and green the city. Another encourages developers to go beyond meeting minimum BGI standards on new developments by offering a fast-track review process of the design if it manages nearly all its stormwater onsite.

Where BGI is mandatory, cities have developed stormwater performance standards for new developments or major site expansions, as well as guidelines that detail best management practices for meeting the cities' requirements. Similarly, green streets design manuals provide BGI design details and specifications for both public and private entities implementing BGI in rights of way.

To ensure BGI is effective and maintained well, cities often require mandatory BGI be approved by their respective city agencies in charge of stormwater management. Meanwhile, one city requires BGI design and construction processes be overseen by a registered BGI professional.

Many cities have initiated stakeholder engagement programmes to encourage residents to contribute to the design of public BGI, develop community-led BGI projects, adopt BGI features in their neighbourhoods as well as implement BGI on their own properties. Examples include: (1) a city inviting residents to suggest how BGI projects located in their neighbourhood should look and what additional activities can be included in the project; (2) a city agency holding town hall meetings to educate the residents about BGI and the construction impacts over the duration of construction; (3) a city seeking partnerships with community stakeholders across the city to develop BGI projects with a dedicated website created for the community to learn about BGI project requirements and funding opportunities; and (4) a programme that provides grants to civic organisations to help maintain the beauty and functionality of BGI across the city's neighbourhoods.

To further enhance public awareness of BGI, cities have implemented a variety of online and offline public education and outreach programmes. Examples include: (1) a map that enables the public to search for BGI projects throughout the city; (2) a YouTube video that describes the environmental challenges of CSOs and BGI measures to reduce stormwater runoff; and (3) a smartphone app that enables users to explore the multifunctional BGI measures required to become climate-proof. Offline, cities have implemented traditional public outreach campaigns on BGI including city representatives attending neighbourhood meetings, distributing flyers and mailers and attending community festivals.

To enhance knowledge of BGI among developers, planners and other professionals, cities can develop a range of online interactive tools that link BGI with climate adaptation and other benefits. For example, one city has developed an interactive climate atlas that provides visual impacts of climate change as well as a climate adaptation toolbox to understand potential adaptation measures at various spatial levels. In addition, it has developed a computer program that visualises the effects of implementing

BGI measures in urban spaces. To enhance awareness on the multiple benefits of BGI, it has developed a societal cost–benefit analysis tool that shows how BGI measures incorporated with other projects or programmes can provide positive cost–benefit outcomes. To enhance awareness of the significant amount of cooperation required between public agencies as well as between the public and private sectors to implement an effective BGI strategy, the city has also developed a computer climate game that teaches players how to allocate roles and get everyone to work together to implement adaptation measures.

To enhance practical knowledge of BGI, a couple of cities have initiated public workshops for residents to understand how it works and how it can be maintained. Examples of workshops include one on bioswales and another on rainwater harvesting.

Cities have initiated a variety of programmes to promote the public recognition of BGI projects as well as of the professionals implementing them, including: (1) excellence awards to celebrate BGI projects that provide multiple triple bottom line benefits; (2) a certification scheme to recognise public agencies and private developers who incorporate BGI features in their developments, and (3) the development of a registry for accredited BGI professionals.

Cities have launched challenges to drive private sector innovation in the development of BGI. Examples include solutions that reduce the cost of installing BGI, as well as new approaches in both public and private spaces that both raise awareness and accelerate implementation.

Several cities run education programmes to introduce students to the benefits of BGI and the measures used to manage stormwater runoff. The format varies from school visits to teaching courses that both educate students in a classroom setting and also provide practical experience on how BGI works and how it can be maintained.

Cities are aware that implementing BGI can be a driver for growing green jobs. One city will ensure that at least half of all new jobs created by BGI projects will be filled by local residents. To achieve this goal, it has launched an apprenticeship-style training programme for young adults to work in BGI. In addition, it runs a mentor-internship programme in which projects of a specific value performing a variety of BGI-related tasks will take in interns.

In the context of the adaptive management framework, cities implement a variety of monitoring strategies at both the strategic and operational level to manage their path towards becoming Blue-Green Cities. For instance, at the strategic level one city has developed a climate adaptation barometer that tracks its overall progress towards adapting to climate change. Another city is developing a GIS-based project tracking and asset management system for its BGI assets. Similarly, a third city measures how BGI projects increase the quality of life in neighbourhoods located using an urban life account.

At the operational level cities implement a variety of strategies to monitor the performance of BGI. For example, one city has standardised its BGI designs and procedures to ensure it can measure progress towards reducing CSOs in specific priority areas. Another city is constructing BGI in a sequential fashion, enabling it to monitor and assess the performance of installed BGI as the programme is rolled out, ensuring the BGI projects are practical and effective for CSO control while providing numerous benefits to the community. Similarly, another city agency holds monthly meetings on the status of BGI projects in addition to monthly BGI maintenance meetings.

In conclusion, becoming a Blue-Green City is not a static goal; instead it requires an adaptive management framework that involves planning, designing, implementing and monitoring of both the design and implementation of BGI. To encourage city-wide implementation of BGI, cities also need to develop a range of fiscal and non-fiscal tools to encourage the implementation of BGI on both public and private land.

Index

R.C. Brears, *Blue and Green Cities*,
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