GREENING CITIES

A REVIEW OF GREEN INFRASTRUCTURE

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Summary

This report is a review of the published literature available on green infrastructure (GI) and GI developments. We have identified procedures, functions and benefits to establish the ways in which GI may be utilised to enhance liveability of urban environments. The authors have reviewed a broad range of GI practices, highlighting the ecosystem services provided by each and the state of current research concerning each. The GI assets and procedures reviewed at the macro scale include nature reserves, parks and wetlands; and at the micro scale, living roofs, green walls, green streets, permeable paving, rain gardens, bioswales and ponds.

We have reviewed the literature pertaining to the function of various GI procedures and identified their benefits as they have been used in cities around the world. Overall, incorporating green infrastructure into urban settings has improved human and environmental health, reduced air pollution, helped to mitigate climate change, increased biodiversity and native species, moderated urban temperatures, mitigated stormwater runoff quantity and quality, reduced flood risk, assisted in local food production and generally increased quality of life.

Numerous international developments were reviewed as case studies and we have identified the functionality, liveability and value of the GI procedures included in the developments. We have considered the application of GI in 10 cities in order to understand their experiences including costs accrued by projects undertaken. We chose the case study cities according to the availability of literature and data for review as well as how representative they are of a class of GI initiative (e.g. heat island effect mitigation, water management and biodiversity conservation). We reviewed Chicago, USA (mitigation of heat island effect via living roofs); Philadelphia, USA (GI for stormwater management); New York, USA (bluebelts, green streets, green parking, living roofs and other Best Management Practices); Copenhagen, Denmark (transportation); Stockholm, Sweden (eco-districts and green belts for integrating nature with the city); London, UK (multiple examples of GI); Singapore (GI used to manage water and land); Curitiba, Brazil (transportation, waste management); Vancouver, Canada (considered to be one of the world's most liveable cities); and Brisbane, Australia (transport and also for its similarities to Auckland). Overall, the case studies demonstrate how cities around the world have implemented GI for multi-functionality, often providing solutions to global issues (e.g. emission of greenhouse gases) whilst focusing on local issues (e.g. pollution mitigation or stormwater management).

We conclude by considering Auckland's current infrastructure issues and some possible future issues as they have an impact on liveability. We discuss the potential of GI, based on available data from research conducted in New Zealand as well as successes from the international case studies. Our findings show that many GI procedures are already being utilised in Auckland. For example, Auckland Council provides guidelines on procedures involving the use of site-scale GI such as living

roofs and bioretention for stormwater management. Likewise, practices such as tree planting and street trees are well-established procedures in many cities including Auckland. Table 1 describes some of the widely used GI procedures internationally. We recommend the widespread use of such GI procedures, designed for Auckland conditions at different scales, to green Auckland City.

Table 1 Green infrastructure assets or procedures recommended for Auckland

GI asset or procedure	Explanation
Permeable paving	'Permeable pavements are hard surface paving systems that reduce stormwater runoff flows and improve runoff water quality. The porous surface of permeable pavement allows stormwater to soak through to an underlying coarse gravel layer, before slowly draining away. They are used in low traffic areas such as car parks, driveways and footpaths' (Auckland Council, Permeable Pavement Operation and Maintenance Guide: 2).
Living roofs (green roofs)	Living roofs are 'vegetated roof covers, with growing media and plants taking the place of bare membrane, shingles, tiles or other roofing materials.' (Fassman-Beck and Simcock, 2013). The roofs utilise vegetation for numerous functions including stormwater management, air pollution reduction, reduced heat island effect and biodiversity support.
Bioretention systems (including rain gardens and bioswales)	Bioretention systems can be applied to small sites including parking lots, residential swales and highway medians. A rain garden is 'a man-made depression in the ground that is used as a landscape tool to improve water quality' (Virginia Department of Forestry, 2012). An engineered media is used to achieve primary functions that include reducing runoff pollution, peak flows and total volumes. Bioretention can also provide significant amenity value.
Urban forests	Auckland City Council (2008) defined urban forests as all vegetation, including habitats and ecosystems, on the Auckland isthmus. This includes vegetation in private properties, parks, reserves and street trees. Urban forests serve multiple functions including pollution amelioration, temperature regulation, carbon sequestration and storage, as well as providing aesthetic appeal.
Green streets and alleys	'A green street is defined as a streetscape designed to: integrate a system of stormwater management within its right of way, reduce the amount of runoff into storm sewers, make the best use of the street tree canopy for stormwater interception as well as temperature mitigation and air quality improvement' (Odefey et al., 2012: 2). Similarly, Chicago's Green Alley Handbook defines a green alley as 'an alley designed and constructed incorporating best management practices (BMP) of environmentally sustainable design' (Chicago Department of Transportation, 2010: 41).
Street trees	According to Odefey et al. (2012: 2), 'When properly designed, traditional tree plantings along street and road edges can capture, infiltrate and transpire stormwater. These virtues can be expanded by incorporating trees into more extensively designed 'tree pits' that collect and filter stormwater through layers of mulch, soil and plant root systems, where pollutants can be retained, degraded and absorbed.' Additional functions provided by street trees include air pollution reduction, climate change mitigation via carbon sequestration and storage.

Table 1 Green infrastructure assets or procedures recommended for Auckland (cont.)

GI asset or procedure	Explanation
Cycle lanes	Lanes that are separated from traffic (not shared with public transport vehicles such as buses) and supported by crossing facilities, parking space and other structures. Encouraging cycling via provision of appropriate infrastructure could lead to health benefits (issues with obesity and related ailments), reduced traffic pollution and congestion, reduced greenhouse gas emissions and other benefits.
Wetlands, rivers, lakes	Existing wetlands, rivers, lakes and waterways provide numerous functions and benefits (e.g. habitat for biodiversity, stormwater management, provision of food and water resources) and should be maintained and preserved where possible.
Constructed wetlands	According to Dzurik and Theriaque (2003: 318), constructed wetlands are 'designed complex of saturated substrates, emergent and submerged vegetation, animal life and water that simulates natural wetlands for human use and benefits'. Constructed wetlands provide numerous functions and benefits including stormwater management, wastewater treatment and enhanced biodiversity.

With regard to stormwater management, a combination of GI assets and procedures, such as permeable paving, living roofs and bioretention and grassed swales have already been adopted in parts of Auckland. Their successful application in the case study cities suggests that they should be used far more widely. Such procedures fit with the micro-scale potential of the urban environment where individual properties may utilise appropriate practices to manage stormwater more effectively. In addition, we recommend that studies investigating the impact of rainwater tanks on stormwater management be carried out for Auckland.

Macro-scale GI assets such as parks, reserves, corridors, rivers and wetlands (natural and constructed) are significant for Auckland although current research does not completely quantify all the benefits they provide. Nevertheless, parks, reserves and corridors confer numerous benefits to recreation, biodiversity and climate change mitigation and adaptation. Urban forests, urban parks reserves and gardens should be maintained and enhanced wherever possible. We recommend that further research be done to quantify the benefits specific to Auckland of parks, reserves and corridors.

Due to the complexities involved in the systems in which GI exists, trade-offs can be expected. Success depends on the careful application of the different GI procedures so that the benefits of GI outweigh the negatives. In most cases, GI procedures have superior performance compared to the conventional engineered techniques that are currently employed ('grey infrastructure'). Overall, we recommend the widespread application of appropriately designed micro- and macro-scale GI procedures, taking into account the complex nature of the systems involved and their potential for change, as they are likely to improve the liveability of Auckland.

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Note:

The draft Auckland Unitary Plan has been released since the completion of this GI report. The Unitary Plan is the regional planning tool that outlines how the Auckland Plan is delivered. The Auckland Plan was reviewed as part of this GI report; however, the Unitary Plan has not been reviewed as part of this work.

ABBREVIATIONS

BMP	Best Management Practice
CSO	Combined sewer overflow
DEP	New York City Department of Environmental Protection
EEA	European Environment Agency
EPA	United States Environmental Protection Agency
GI	Green infrastructure
LCA	Life Cycle Assessment
LCCP	London Climate Change Partnership
LID	Low Impact Development
LIRRDD	Low Impact Rural Residential Design and Development
LIUDD	Low Impact Urban Design and Development
LEED	Leadership in Energy and Environmental Design
SUDS	Sustainable urban drainage systems
TDS	Total Dissolved Solids
TSS	Total Suspended Solids
UFP	Ultrafine particles

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1. INTRODUCTION

Increasing population pressures and limited land and resources are causing city authorities to shift their focus from a purely economic growth perspective to showcasing how they can make their city a more attractive and liveable place for all residents as well as attractive to visitors. City leaders eagerly await the listing of the top liveable cities, which are based on a variety of criteria that attempt to compare the wellbeing of residents and how well the city functions. The network of cities aspiring to become recognised as 'sustainable' is increasing and it is at the city level that actions to reduce greenhouse gas emissions and energy consumption, manage water more effectively and improve the urban environment are taking place (see, for example, ICLEI Local Governments for Sustainability: www.iclei.org).

Many of these cities' governing bodies see green infrastructure as critical to achieving liveable, sustainable cities of the future. The concept of green infrastructure has shifted from merely improving street trees and urban recreational parks for popular sports to 'engineered ecosystems' that assist in removing pollution, managing stormwater, providing biodiversity, cleaning the air, reducing CO_2 emissions and moderating urban temperatures. Green infrastructure is now being incorporated into architecture and engineering practices, although the full potential for its use within urban planning and the urban built environment has yet to be realised.

Auckland is, in many ways, a city with an abundance of natural green infrastructure – significant urban forests, green spaces and parks – used for recreation, flood control, stormwater management and to enhance the built environment. With the development of the Auckland Plan in 2011 and the Mayor's vision to make Auckland the most liveable city in the world, it is evident that green infrastructure needs to play an even greater role in the city's urban design and development. This report aims to extend our knowledge by identifying strategies and procedures that could lead to net benefits for the entire region of Auckland. We hope that our report will be of assistance to future infrastructure and community projects that aim to increase the resilience, sustainability and liveability of Auckland.

The objective of this research is to identify strategies and directions for the application of GI to urban spaces, transportation corridors and building footprints (parking areas, roofs/façades) in the city of Auckland. We set out to:

1. Review the literature on GI, including existing and proposed developments for cities in order to identify how GI has been developed elsewhere;
2. Identify procedures and, where possible, costs associated with the establishment and maintenance of GI;
3. Identify the benefits accrued by the developments reviewed; and
4. Assess how GI can be implemented in Auckland to achieve the goal of the world's most liveable city.

The literature was reviewed in two stages:

- Stage 1 identified GI assets and their functions including a brief background on their beginnings and an update on the current state of research, where applicable; and
- Stage 2 reviewed GI developments as case studies.

Primary sources of literature include:

- Published academic research in peer-reviewed journals;
- Published reports by independent organisations, such as the Millennium Ecosystem Assessment, United Nations Environment Program and the International Union for the Conservation of Nature; and
- Internet search of relevant websites.

The initial scope of the review was broad in terms of the programmes that involved the development of GI. The scope for the case studies was narrower, although we made some effort to include how cities incorporate GI holistically for multiple functionality. Given that there are innumerable GI projects at various stages of development throughout the world, we adopted two primary criteria to select case study cities:

- Availability of literature and data; and
- Representativeness of a class of GI initiative (e.g. heat island effect mitigation, water management, biodiversity conservation).

Using the above criteria, we chose the following 10 cities as our case studies:

1. Chicago, USA (GI for heat island effect mitigation via living roofs);
2. Philadelphia, USA (GI for stormwater management);
3. New York, USA (bluebelts, green streets, green parking, living roofs and other Best Management Practices);
4. Copenhagen, Denmark (transportation);
5. Stockholm, Sweden (eco-districts and green belts integrating nature with the city);
6. London, UK (multiple GI uses);
7. Singapore (GI used for limited water and land resource management);
8. Curitiba, Brazil (transportation, waste management);
9. Vancouver, Canada (identified as one of the world's most liveable cities); and
10. Brisbane, Australia (transport).

Key programmes from the United States are included in this report, due to the availability of recent data. Considering the high level of development among European countries, programmes within the European community were also included. Furthermore, we also looked at developments in densely populated regions such as Singapore to find about how such cities cope with a growing population and more intensive use of infrastructure with limited resources at low cost.

Considering the broad scope of this report, some topics were investigated in depth whilst others were sparsely reviewed. Although we tried to cover the various aspects of GI equally, water management appears dominant, reflecting the extent of research conducted in the field as compared to other functions of GI. Furthermore, while we identified quantified costs and benefits within the existing literature, our work did not extend beyond the existing literature to attempt quantifications for Auckland.

2. Review of GI

2.1 What is Green Infrastructure?

As with most other complex concepts, green infrastructure (GI) has numerous definitions, which include:

- 'An interconnected network of natural areas and other open spaces that conserves natural ecosystem values and functions, sustains clean air and water and provides a wide array of benefits to people and wildlife. Used in this context, green infrastructure is the ecological framework for environmental, social and economic health – in short, our natural life-support system' (Benedict and McMahon, 2002: 12);
- 'Strategically planned and managed networks of natural lands, working landscapes and other open spaces that conserve ecosystem values and functions and provide associated benefits to human populations' (The Conservation Fund, 2011: 5);
- According to the U.S. Environmental Protection Agency, GI is an 'adaptable term used to describe an array of products, technologies and practices that use natural systems- or engineered systems that mimic natural processes- to enhance overall environmental quality and provide utility services' (USEPA, 2011a);
- 'Our nation's natural life support system – an interconnected network of protected land and water that supports native species, maintains natural ecological processes, sustains air and water resources and contributes to the health and quality of life for America's communities and people' (Williamson, 2003: 4);
- 'Green infrastructure is a concept that aims at recreating a system, which is robust and enables species and their communities to move and adjust' (WWF, 2011);
- 'Green infrastructure: the physical environment within and between our cities, towns and villages. The network of open spaces, waterways, gardens, woodlands, green corridors, street trees and open countryside that brings many social, economic and environmental benefits to local people and communities' (TEP, 2005: 1);
- 'Green infrastructure is the physical environment within and between our cities, towns and villages. It is a network of multi-functional open spaces, including formal parks, gardens, woodlands, green corridors, waterways, street trees and open countryside. It comprises all environmental resources and thus a

green infrastructure approach also contributes towards sustainable resource management' (Davies et al., 2006: 2); and

- 'Green infrastructure is a network of multi-functional green space, both new and existing, both rural and urban, which supports the natural and ecological processes and is integral to the health and quality of life of sustainable communities' (TSO, 2008: 5).

Sylwester (2009) and the European Environmental Agency (2011) have compiled lists of GI definitions, including those by England's Community Forests, US Environmental Protection Agency Green Infrastructure Action Strategy, The Conservation Fund's Green Infrastructure Leadership Program and the European Commission. The two processes involved in forming definitions consist of examining common characteristics of definitions, identifying the most widely used definition and adapting it to suit. All of the above definitions reflect the idea of multi-functional networks with life supporting capabilities. The list by EEA (2011) has been characterised according to discipline, key benefits and scale.

The definition from Benedict and McMahon (2002: 12) seems to be the most widely used in literature (Erickson, 2006; American Planning Association, 2006). This definition was a result of the Green Infrastructure Work Group by the Conservation Fund and USDA Forest Services and incorporates GI at a landscape scale. The EPA definition is primarily based on disciplines associated with stormwater management and focused more at an urban scale. It should be noted that the terms 'green spaces' or 'green systems' are used to refer to GI by institutes such as the European Environment Agency (2011).

In this report, we define green infrastructure as: ***Natural and engineered ecological systems that integrate with the built environment to provide the widest possible range of ecological, community and infrastructure services***. This is a new definition of green infrastructure, which is broader than previous definitions and incorporates both the landscape and urban scale.

GI is a relatively new approach, although many concepts have appeared under different guises and, according to Benedict and McMahon (2006), have been in practice for over 150 years. GI differs from traditional 'grey infrastructure' as GI incorporates or mimics nature and natural processes to mitigate impacts associated with the built environment. Discourse on the grey-green continuum can be found in Davies et al. (2006) and is illustrated in Figure 1. GI does not imply an absence of technical design. For example, GI systems for urban stormwater runoff are often highly engineered to mimic nature and manipulate natural processes, but are not natural systems in their own right. This transition to GI may become more widespread with changes in the social infrastructure respective to land use (Olsenius, 2010). According to Pickett and Cadenasso (2008), there are three goals for urban areas when it comes to the improvement of landscapes and infrastructure:

1. To increase understanding of urban ecosystems (function and structure);
2. To increase the ecological function of cities; and

3. To increase benefits to humans resulting from ecological functions.

Benedict and McMahon (2006) outline 10 principles of GI, in which GI encompasses a system of hubs (e.g. community parks and public land), sites (e.g. smaller nature recreation areas) and links (e.g. floodplains, greenbelts), allowing for connectivity. A view of a network consisting of hubs (which include various natural elements) linked by corridors is shown in Figure 2. These hubs, sites and links can differ in terms of physical size as well as the extent of human interaction. For example, according to Heritage Conservancy (2008: 6), 'the rarity of ecological importance of the natural features within each component determines the level of conservation required to protect these resources, while the sensitivity of the environment to human activity determine how much interaction between man and nature is appropriate'. Therefore, hubs such as nature reserves and links such as conservation corridors require less human interaction due to their potential sensitivity.

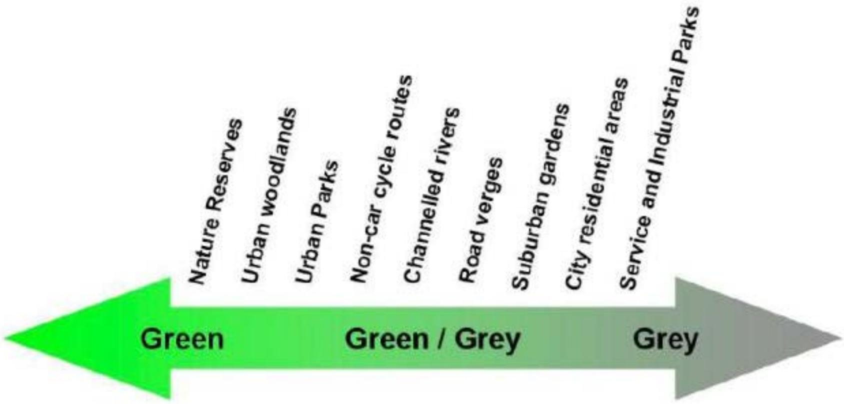


Figure 1 Grey-green continuum

Source: Davies et al. (2006)

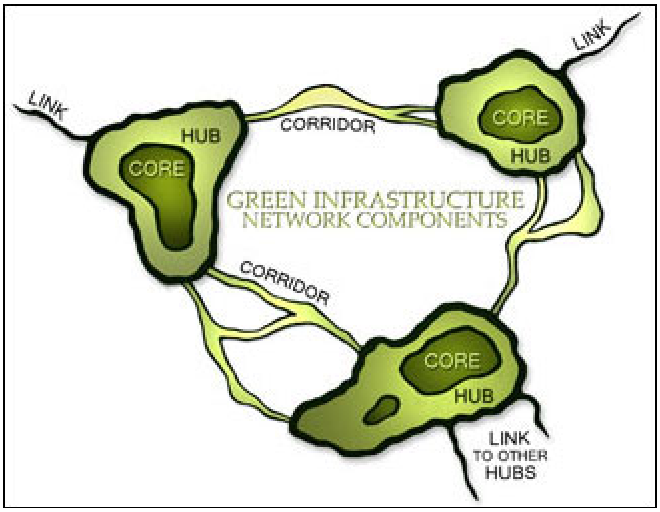


Figure 2 GI network components

Source: The Conservation Fund (2011)

In addition to the GI principles enumerated by Benedict and McMahon (2002), many other sets of GI principles have been developed as interest in GI and GI practice has increased internationally. Table 2 presents the principles by which GI is implemented.

The value of GI is closely associated with the purpose or use of the infrastructure. Its purpose can be defined as 'strategies actively seek[ing] to understand, leverage and value the different ecological, social and economic functions provided by natural systems in order to guide more efficient and sustainable land use and development patterns as well as to protect ecosystems' (PCSD, 1999: 64). GI can thus consist of numerous simple or complex ventures, ranging from tree planting to parks, living roofs, green corridors for pedestrians, porous pavements, nature reserves, stormwater systems, transport systems, erosion prevention, sediment control, wetlands creation and stewardship, urban design for watershed protection and so on. Whilst the more simple ventures are not considered to be true GI by hardcore GI practitioners, they are a good start to greening infrastructure at large. The European Environment Agency (EEA, 2011) classifies GI according to urban scale and landscape scale and notes the differences between the two: urban scale consists of built-up urban areas (for example parks, green streets, living roofs, agricultural land and woodlands inside towns) and landscape scale consists of built-up areas plus different types of ecosystems (for example, habitats and corridors, rivers and catchments).

Another similar way to classify the different types would be according to scale in terms of the macro- and micro-level procedures that contribute towards ecosystem services; complexity increases from the micro- to macro-levels aligned with the ecosystem services embodied in the infrastructure. Ecosystem services, such as clean air and water, are discussed by Daily (1997; 1999), Costanza et al. (1997) and Millennium Ecosystem Assessment (2005a). According to Dobbs et al. (2011), ecosystem services are defined according to the services, resources and enjoyment they contribute to human beings (e.g. climate regulation) and thus to human wellbeing. The components of GI at the micro level consist of trees or plants (vegetation). The function and benefits of trees have been discussed by numerous authors, including Nowak (2006). The role of vegetation in improving climate, air, hydrology and the quality of life was documented in the 1980s (e.g. Bernatzky, 1982 and Rowntree, 1986). Examples of the benefits of trees and vegetation include water uptake, filtration, infiltration, breakdown of pollutants and the absorption of nutrients and toxins. Macro-level components can incorporate numerous micro-level processes and lead to larger and more complex GI such as nature reserves, parks and landscapes.

Furthermore, GI appears to overlap with Low Impact Development (LID) and Water Sensitive Urban Design (WSUD), of which there are numerous works (e.g. stormwater management practices). Irrespective of the scale of a project, GI systems that simulate natural processes and cycles and are consonant with nature's own processes, are thought to be beneficial.

Table 2 Notable GI principles reflecting how to implement GI

Benedict and McMahon (2002)	National Association of Regional Councils (USA) (NARC, 2012)	European Environment Agency (2011)	Town and Country Planning Association (UK) (2008)
1. Connectivity is key; 2. Context matters; 3. GI should be grounded in sound science and land-use planning theory and practice; 4. GI can and should function as the framework for conservation and development; 5. GI should be planned and protected before development; 6. GI is a critical public investment that should be funded up front; 7. GI affords benefits to nature and people; 8. GI respects the needs and desires of landowners and other stakeholders; 9. GI requires making connections to activities within and beyond the community; 10. GI requires long-term commitment.	1. Identify and protect green infrastructure before development; 2. Engage a diversity of people and organizations in your green infrastructure initiative, obtaining input from representatives of different professions and sectors; 3. Recognise that linkage is key, for connecting natural areas and features and for connecting people and programmes; 4. Design green infrastructure systems that function at different scales, across political boundaries and through diverse landscapes; 5. Ground green infrastructure activities in sound science and land-use planning theories and practices.	1. Strategically planned and delivered network of high-quality green spaces and other environmental features; 2. Delivering multifunctional benefits; 3. Helping to deliver place making – recognising character and distinctiveness of different locations and ensuring policies and programmes respond accordingly; 4. Delivering 'smart' conservation – addressing the impacts of urban sprawl and fragmentation, building connectivity in ecological networks and promoting green spaces in the urban environment	1. A primary consideration in planning, developing and maintaining an eco-town; 2. Provided as a varied, widely distributed, strategically planned and interconnected network; 3. Factored into land values and decisions on housing densities and urban structure prior to land or development options have been agreed upon and prior to master planning; 4. Accessible to local people and provide alternative means of transport; 5. Designed to reflect and enhance the area's locally distinctive character, including local landscapes and habitats supporting local priorities and strategies for environmental management 6. Supported by a GI strategy; 7. Multi-functional; 8. Implemented through co-ordinated planning, delivery and management that cut across local authority departments and boundaries and across different sectors; 9. Able to achieve physical and functional connectivity between sites at all levels and right across a town, city or sub-region; 10. Implemented primarily through focused GI strategies and the spatial planning system of Regional Spatial Strategies and Local Development Frameworks formally adopted within these planning policy documents; 11. Established permanently, with financial support for continued maintenance and adaptation.

The following section reviews some of the prevalent GI techniques beginning with a comparison of GI, green building and LID techniques. A brief review of GI typologies is given to establish the systems by which the available techniques have been classified. The remainder of Chapter 2 is dedicated to outlining the individual procedures and the functions and values that GI procedures and assets contribute towards urban environments.

2.1.1 GI TYPOLOGIES

Notable typologies for GI include those by Ahern (1995), Davies et al. (2006), Tzoulas et al. (2007), Mell (2011) and Naumann et al. (2011). Davies et al.'s (2006) typology is based on the green value provided by the infrastructure (see Appendix A) while Ahern's (1995) is based on scale, goals, landscape context and planning strategies. Ahern's typology was developed for greenways (defined as 'networks of land containing linear elements that are planned, designed and managed for multiple purposes including ecological, recreational, cultural, aesthetic, or other purposes compatible with the concept of sustainable land use' (Ahern, 1995: 134)). Mell's (2011) typology is classified according to form, function and context whereas Naumann et al.'s (2011) typology was drawn up during research on case studies in Europe and is classified according to a different set of parameters such as objective, actions, green infrastructure elements, ecosystem, sectors affected, setting and geographic scale.

Another classification can be found in the conceptual framework by Tzoulas et al. (2007), in which living roofs, urban parks, green corridors, encapsulated countryside, derelict land, housing green space, domestic gardens, churchyards, cemeteries, school grounds and open standing and running water make up GI. Likewise, Natural England (2009a) presents a GI typology consisting of parks and gardens (e.g. urban parks), amenity green space (e.g. domestic gardens, living roofs), natural and semi-natural urban green spaces (e.g. woodland, wetlands, open and running water), green corridors (rivers and canals, road and rail corridors, cycling routes, pedestrian paths) and others such as community gardens, cemeteries and churchyards. The Town and Country Planning Association's 2008 typology of GI assets is similar to that of Natural England with the addition of existing national and local nature reserves, archaeological and historic sites and functional green spaces (drainage, flood control areas). Another typology based on scale has been developed by the Landscape Institute (2009) and adopted by the EEA (2011), wherein GI practices are classified according to:

1. Local, neighbourhood and village scale;
2. Town, city and district scale; and
3. City-region, regional and national scale (EEA, 2011).

GI assets classified according to the three scales are shown in Table 3.

Table 3 GI assets classified according to scale

Local, neighbourhood and village scale	Town, city and district scale	City-region, regional and national scale
• Street trees, verges and hedges • Living roofs and walls • Pocket parks • Private gardens • Urban plazas • Town and village greens and commons • Local rights of way • Pedestrian and cycle routes • Cemeteries, burial grounds and churchyards • Institutional open spaces • Ponds and streams • Small woodlands • Play areas • Local nature reserves • School grounds • Sports pitches • Swales (preferably grassed), ditches • Allotments • Vacant and derelict land	• Business settings • City/district parks • Urban canals • Urban commons • Forest parks • Country parks • Continuous waterfronts • Municipal plazas • Lakes • Major recreational spaces • Rivers and floodplains • Brownfield land • Community woodlands • (Former) mineral extraction sites • Agricultural land • Landfill	• Regional parks • Rivers and floodplains • Shorelines • Strategic and long distance trails • Forests, woodlands and community forests • Reservoirs • Road and railway networks • Designated greenbelt and strategic gaps • Agricultural land • National parks • National, regional or local landscape designations • Canals • Common lands • Open countryside

Source: Landscape Institute (2009)

2.1.2 GI, Green Building and Low Impact Development

Whilst there has been and indeed may still be, some confusion about the use of the various terminologies, it is now generally accepted that GI differs from green buildings and LID. Table 4 compares the three concepts in terms of their definition, major focus, example practices and expected benefits.

LID came into practice in the 1990s, pioneered by Prince George's County in Maryland, USA. Research by Lehner et al. (2001), Coffman (2002) and Braden and Johnston (2004) outlines the different services provided by LID. MacMullan and Reich (2007) reviewed the economics involved. LID seems to be primarily concerned with stormwater, as per definitions given by the US EPA (2011c). The concept is known as Water Sensitive Urban Design (WSUD) in Australia (Lloyd et al., 2001) and Sustainable Urban Drainage Systems (SUDS) in the UK. The former Auckland Regional Council introduced LID for the Auckland Region in Technical Publication 124 (Shaver, 2000), focusing on stormwater practices. While practices under LID can also be seen as GI, the focus of GI is broader, taking a region-to-site level perspective and extending beyond stormwater control. From a single site perspective, LID is similar to GI in terms of its practices and benefits.

In New Zealand, research conducted by the University of Auckland and Landcare Research Ltd. (van Roon and van Roon, 2005) developed the concept of Low Impact Urban Design and Development (LIUDD), which also appeared in practice during the

1990s. According to van Roon and van Roon (2005), LIUDD integrates ecological principles for development, green architecture, environmental economics, alternative wastewater system design, integrated three waters management, tikanga and mātauranga Māori, urban/regional planning, landscape restoration and design, management and maintenance of alternative stormwater management. In addition, Low Impact Rural Residential Design and Development (LIRRDD) was developed to cater for rural settings (van Roon and van Roon, 2005). Thus GI as both a concept and a process can incorporate or overlap with green buildings and LID/LIUDD.

Table 4 Comparison of GI, green buildings and LID

	Green Infrastructure	Green Building	Low Impact Development
Definition	'An interconnected network of natural areas and other open spaces that conserves natural ecosystem values and functions, sustains clean air and water and provides a wide array of benefits to people and wildlife. Used in this context, green infrastructure is the ecological framework for environmental, social and economic health – in short, our natural life-support system' (Benedict and McMahon, 2002: 12).	'The practice of creating structures and using processes that are environmentally responsible and resource-efficient throughout a building's life-cycle from siting to design, construction, operation, maintenance, renovation and deconstruction. This practice expands and complements the classical building design concerns of economy, utility, durability and comfort. Green building is also known as a sustainable or high performance building' (EPA, 2011b).	'A site design strategy with a goal of maintaining or replicating the predevelopment hydrologic regime through the use of design techniques to create a functionally equivalent hydrologic landscape' (EPA, 2000).
Focus	Macro-scale – i.e. in terms of regions and landscapes.	Buildings: efficient use of energy, water and resources.	Site-specific means of offsetting impacts from built environment. Water management as a specific focus in the United States.
Examples	Green open spaces such as parkland, forests, wetlands, greenbelts, floodways.	Renewable sources of energy for lighting, heating and other uses. Living roofs, rain gardens.	Bioretention facilities, rain gardens, vegetated rooftops, rain barrels and permeable pavements.
Expected benefits	Many depending on the type and scale of GI practice. For example, nature reserves can help protect wildlife whereas a practice such as living roofs can help minimise impacts from runoff.	Minimised environmental impact from buildings including impact on water use, energy and resources. Health and safety of inhabitants. Reduction in costs associated with water, energy and other resources.	Mitigation of impacts associated with grey infrastructure – e.g. rain gardens to reduce stormwater runoff. Site-specific contributions to conservation/ biodiversity outcomes through design criteria.[1]

[1] Note that design for ecosystem services does not necessarily result in biodiversity gains unless specifically included in the design.

Green building and GI are different in terms of the scope and focus of their activities. Green building is focused on the enhancement of buildings so that environmental impacts are minimised and the health of their inhabitants is safeguarded, whilst seeking economic benefits from lower operating costs (EPA, 2010b; Fischer, 2010). The scope of green building is associated with the building itself, which may be a new build or a retrofit. Whilst the term 'infrastructure' includes buildings, activities involved with buildings seem to be at the periphery rather than a major focus of GI. Nevertheless, activities associated with green buildings such as living roofs and green walls are also part of GI. Therefore, green buildings, LID and GI have commonalities in terms of micro-level practices, but are different in terms of their scale.

2.2 FUNCTION, SCALE AND VALUE

The function of GI can vary due to the different definitions given to GI, since the debate concerning the semantics and terminology continues (MacFarlane et al., 2005; Davies et al., 2006; Mell, 2010). Despite the different definitions, they share the idea that GI can help provide ecosystem functions to urban areas. The value of GI is closely tied to its multiple functions. The primary GI functions are as follows:

- Water and stormwater;
- Land use;
- Energy;
- Communications; and
- Transport.

Existing infrastructure catering to the above is highly engineered and comes under pressure as the human population increases and the impacts of climate change are felt. The inclusion of green strategies to modify engineered infrastructure such that the grey infrastructure becomes GI would be beneficial for numerous reasons. The primary benefit is the provision of ecosystem services (e.g. climate amelioration) contributing to improvements in human wellbeing. This would involve implementing GI practices that function within natural parameters to enhance the efficiency of engineered infrastructure. GI would contribute to reducing human-induced impacts occurring from the built environment as well as impacts from natural causes associated with climate change. It would also assist humans and the other species that cohabit urban environments. The functions of GI can be categorised according to the ecosystem services (clean air, water, food, energy, biodiversity) that are sought (EEA, 2011):

- Habitat services (protection of biodiversity);
- Regulating services, such as climate change mitigation and adaptation (lower impacts and costs due to impacts of climate change such as extreme weather events);
- Provisioning services (including mitigation of human induced impacts of the built environment, such as water and waste water management); and
- Cultural services (health and wellbeing, recreation, protection of landmarks, tourism).

Likewise, Davies et al. (2006) identifies the five interests of GI to provide context and function for GI: sustainable resource management, biodiversity, recreation, landscape and regional development and promotion.

Value, in the context of this review, considers not only the economic value of GI, but also its environmental, social and cultural benefits. As such, there are multiples values associated with the practices that provide the various functions listed above. Evidence of value is being gathered with some notable research by Crompton (2001), Williamson (2003), Blackman and Thackray (2007), Gill et al. (2007), Beatley (2009), Mell (2009) outlining potential values associated with the different types of GI. The UK National Ecosystem Assessment (2011) offers a way to estimate the UK's national wealth derived from the state of the natural environment and ecosystem services provided in the UK. The economic, social and environmental functions and values of GI according to the Town and Country Planning Association (TCPA, 2008) are shown in Table 5.

Table 5 Economic, social and environmental functions and values of GI

Economic value	Social value	Environmental value
• Water and flood risk management; • Water quality, supply and function of hydrology; • Sustainable energy use and production – saving energy and cost; • Sustainable waste management; • Sustainable food production; • Microclimate adjustment and adaptation to climate change; • High-quality environment to attract and retain a quality workforce; • Rising property values; • Boosts to the local economy; • Links between town and country.	• Recreation, enjoyment and health benefits; • Community development and cohesion; • Provision of space for public art, concerts, etc.; • Non-motorised transport systems; • Exposure to nature and increased awareness of environmental issues; • Education and training; • Visual screening of unsightly buildings or infrastructure; • Heritage preservation and cultural expression.	• Biodiversity protection and enhancement of habitat and species – preserving ecosystems; • Landscape restoration and the regeneration of degraded sites; • Protection of significant geological sites; • Reductions in the ecological footprint; • Carbon sequestration.

As mentioned earlier, value can range from economic value such as increased property values (Crompton, 2001), lower cost of treatment or impact mitigation such as flood control (EMDA, 2008), to the aesthetic quality of beautiful natural surroundings that instils a general sense of wellbeing and community. While some benefits may be quantifiable in monetary terms, others are not easily quantifiable (ECONorthwest, 2011). For example, the preservation of native species and wildlife adds environmental value although it cannot truly be quantified in the same manner. Gill et al. (2007) and Mell (2009), for example, advocate the use of GI for promoting and delivering sustainability to urban settings. Additionally, the protection of biodiversity can provide both functions as well as values. For example, biodiversity provides ecosystem services (a function) that can improve the quality of life for residents (a value), possibly more cheaply than engineered infrastructure (another value) (Bolund and Hunhammer 1999; McPherson et al 1997). However, it may be necessary to design for biodiversity goals separately from designing for ecosystem services, even though the two may overlap (Bullock et al., 2011). Separate goals may be necessary due to the ability to design for biodiversity goals without contributing to ecosystem services and vice versa.

The health benefits of green space have been considered by Kaplan and Kaplan (1989). Similarly, many researchers are investigating the health benefits of GI (Takano et al., 2002; de Vries et al., 2003; van Kemp et al., 2003; Nielsen and Hansen, 2007; Yang et al., 2008). The health benefits are associated with the removal of pollutants. For instance, the removal of air pollutants such as carbon monoxide (CO), ozone (O_3), nitrogen dioxide (NO_2), particulates (PM10) and sulphur dioxide (SO_2) can reduce respiratory ailments. Green spaces provide opportunities for physical activity (ultimately leading to the reduction of obesity and related ailments such as heart disease). The World Health Organization defines human health as 'a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity' (WHO, 1948: 100). Some dimensions of social wellbeing associated with GI are difficult to quantify (e.g. benefits associated with social interaction, inclusion and cohesion and benefits associated with aesthetic value (Forest Research, 2010)).

According to WWF (2011), EMDA (2008) and TCPA (2008), GI is fundamental for providing climate mitigation and adaptation. For example, increased resilience via the management of temperature in urban areas, water supply, surface water, river and coastal flooding, visitor pressure, the reduction of soil erosion and enabling the adaptation of diverse species may all assist in adapting to climate change (WWF, 2011). Additionally, as per WWF's specific focus, the WWF report (2011) discusses the impact that habitat fragmentation has upon biodiversity. Carbon sequestration is geared to play a crucial role in mitigation of and adaptation to climate change. GI such as urban forests is not only capable of pollution amelioration but is also able to sequester carbon. For example, Chicago's urban forests have a total carbon sequestration rate of 25,200 tons/year equivalent (Foster et al., 2011). The value of Chicago's urban forest totals $2.3 billion and the carbon sequestration rate is valued at $14.8 million/year (Foster et al., 2011). Research by Nowak et al. (2007; 2010) quantified carbon sequestration and storage in urban forests while Getter et al. (2009) investigated carbon sequestration potential of extensive living roofs. The results of these studies are given in later chapters (for instance, Section 4.2.6 considers rates of sequestration for trees in New Zealand).

Combining green and grey infrastructure can sometimes add more value than relying on either alone. Furthermore, the benefit and hence the value of GI also depends on the context, especially in terms of geography, climate, user behaviour and other factors. The act of linking or integrating GI practices may lead to increased connectivity and thus offer greater benefit in terms of environmental systems. The following section outlines practices that are part of GI. The practices are included in the order of their physical magnitude, since it is not yet possible to rank them in terms of importance. A selection of practices for New Zealand and specifically for Auckland, will be presented in later chapters.

Additionally, EEA (2011) has reviewed the benefits provided by GI from a number of literature sources including Environment DG (2010), United States Environmental Protection Agency (2009), Landscape Institute (2009), Natural England (2010), Ahern (2007) and Benedict and McMahon (2006). The benefits are categorised according to significant aspects of the various ecosystem services such as biodiversity protection, climate change adaptation and mitigation, water management, food production, recreation and wellbeing and health, as shown in Table 6. It should be noted that energy or waste does not appear to be a focus in this report although the security of energy supply for Europe as well as land use impacts for waste are both mentioned.

Table 6 Benefits of green infrastructure

Topic area	Benefits	Reference					
		Environment DG (2010)	US EPA (2009)	Landscape Institute (2009)	Natural England (2010)	Ahern (2007)	Benedict and McMahon (2006)
Biodiversity/ species protection	Habitat for species			●	●	●	
	Permeability for migrating species	●		●		●	●
	Connecting habitats	●				●	●
Climate change adaptation	Mitigating urban heat island effect with evapotranspiration, shading and keeping free corridors for cold air movement			●	●	●	
	Strengthening ecosystems' resilience to climate change	●		●			
	Storing flood water and ameliorating surface water run-off to reduce the risk of flooding	●	●	●	●	●	●
Climate change mitigation	Carbon sequestration	●		●		●	
	Encouraging sustainable travel			●			
	Reducing energy use for heating and cooling buildings			●			
	Providing space for renewable energy like ground source heating, hydroelectric power, biomass and wind power			●		●	
Water management	Sustainable drainage systems – attenuating surface water run-off		●	●		●	●
	Groundwater infiltration		●			●	●
	Removal of pollutants from water (e.g. reed beds)		●	●			●
Food production and security	Direct food and fibre production on agricultural land, gardens and allotments			●			
	Keeping potential for agricultural land – food security (safeguarding of soil)						
	Soil development and nutrient cycle					●	●
	Preventing soil erosion	●		●			
Recreation, well-being and health	Recreation			●	●	●	●
	Sense of space and nature				●	●	●
	Clean air						●
Land values	Positive impact on land and property			●		●	●
Culture and communities	Local distinctiveness			●			
	Opportunities for education, training and social interactions			●	●	●	

Tourism opportunities	●

Source: EEA (2011)

The following section reviews GI components/assets in terms of their general benefits and the issues encountered. The review is aimed at giving some indication of the progress of research associated with the GI asset. With respect to GI systems specifically aimed at stormwater management, some performance data are presented. The International Stormwater BMP Database (www.bmpdatabase.org) provides a freely accessible repository for performance monitoring data, which includes over 530 studies (as of 2013) and statistical data summaries.

2.2.1 Nature reserves and preserves (protected areas)

As human populations increase, greater demand for resources exerts pressure on ecosystems. Ever since human needs and activities were prioritised over wildlife and nature, development, agriculture and industry have replaced forests with cities, towns and roads. Agriculture draws on water resources to grow food for human populations at the expense of wildlife, claiming wildlife habitats, fragmenting biodiversity and ultimately degrading land (Dobson et al., 1997a). Nature reserves and preserves are an effort to safeguard what is remaining, protect endangered species and allow the enjoyment of nature in its untamed forms. Nature preserves are thus defined as 'places where naturally occurring features are protected within the context of their natural environment' (Pearsall, 1984: 3). However, the concept of nature reserves is not entirely novel, with forests having been preserved from ancient times. For example 'Forbidden forests' and 'Royal hunting areas' areas were established to prevent public access. According to Margules and Pressey (2000), the role of reserves is to separate elements of biodiversity from activities and processes that threaten their existence. Margules and Pressey (2000) outline two main objectives for nature reserves:

- Representativeness of a full variety of biodiversity; and
- Persistence in terms of long-term survival of species/biodiversity.

Currently, the International Union for the Conservation of Nature (IUCN, 2012) classifies protected areas into six categories, each of which affords a different level of protection with different consequences for breaches:

Category Ia — Strict nature reserve: areas set aside to protect biodiversity and geological/geomorphic features, where human visitation, use and impacts are strictly controlled and limited to ensure protection of the conservation values;

Category Ib — Wilderness area: large unmodified or slightly modified areas, retaining their natural character and influence without permanent or significant human habitation;

Category II: — National park: large natural or near natural areas set aside to protect large-scale ecological processes, species and ecosystems characteristic of the area, which also provide a foundation for environmentally and culturally compatible, spiritual, scientific, educational, recreational and visitor opportunities;

Category III: Natural monument or feature: set aside to protect a specific natural monument, which can be a landform, sea mount, submarine cavern, geological features, or other features;

Category IV: Habitat/species management area: protected particular species or habitats;

Category V: Protected landscape/seascape: area where the interaction of people and nature over time has produced an area of distinct character with significant, ecological, biological, cultural and scenic value;

Category VI: Protected area with sustainable use of natural resources: protected areas conserve ecosystems and habitats together with associated cultural values and traditional natural resource management systems.

Nature reserves can consist of forests, wetlands, mangroves, grasslands and other vegetation types, all of which can have significant impact on the ecosystem services. The Convention on Biological Diversity Work Program on Protective Areas called for effective conservation of at least 10% of the world's ecosystems by 2010. While progress was made in terms of increased protected areas, the 10% target was not reached (Jenkins and Joppa, 2009). Nevertheless, according to the IUCN (2012), there are now over 180,000 protected areas worldwide including national parks and nature reserves cover over 12% of the world's land area and 7.2% of coastal waters. Additionally, the World Database on Protected Areas (WDPA), compiled since 1981, is considered to be the largest database on terrestrial and marine protected areas (UNEP-WCMC, 2008). There is potential for increased protection areas as a result of climate policy, where evidence of the lack of deforestation may lead to tradeable credits (Joppa and Pfaff, 2011).

Ando et al. (1998) noted that past efforts at conservation in the USA have been for the most part opportunistic and uncoordinated, with systematic approaches emerging only recently. Research on choosing the right site to protect has continued, with researchers providing principles for making systematic choices. For example, Pressey et al. (1993) proposed three principles to assist in identifying priority regions for conservation: complementarity, flexibility and irreplaceability. Margules and Pressey (2000) acknowledged that it is difficult to identify priority areas for conservation, pointing to the need for resource extraction as a barrier that hinders proper site selection. Other competitive ventures such as housing developments also hinder appropriate site selection (Dobson, 1997b).

Table 7 presents the potential functions, benefits and issues associated with nature reserves and preserves as GI assets. However, research on nature reserves as GI components is somewhat limited, perhaps due to nature reserves being located far from urban areas and thus lacking the necessary connectivity to become integral to urban areas. Research on biogeography is regarded as relevant to GI (Benedict and McMahon, 2006). According to Benedict and McMahon (2006), conservation biologists investigated and evaluated internationally-based nature reserves with respect to what does and does not work. Using this knowledge, they developed a number of principles, including:

- Larger reserves are better than smaller ones;

- One large reserve is better than many smaller ones;
- Reserves in close proximity are better than those far apart;
- Rounded reserves are better than long, thin ones;
- Reserves compactly clustered are better than those in a line; and
- Reserves connected via corridors are better than those not connected.

While there is some debate over their universality, the principles have been adopted in the IUCN World Conservation Strategy (1980) as generic guidelines. The principles are valuable, as they strive to prevent further fragmentation of habitats, giving biodiversity a better chance of long-term survival. Further to research on what makes a better reserve, there is research on the benefits of protected areas. For example, Andam et al. (2010) discuss how protected areas can help reduce poverty, using Costa Rica and Thailand as case studies.

The UK has developed national standards whereby nature reserves are evaluated in terms of accessibility, facilities, links to local communities, links to the wider countryside, management, activities and information and interpretation (Natural England, 2009a). The application of standards appears to be an effort to involve visitors. The UK also has the Green Flag Award Scheme, which is aimed at improving the quality of the reserve and the visitor's experience. While the UK is attempting to encourage human interaction in reserves, Zhang et al. (2009) cautions against human interaction such as ecotourism, referring to the devastated Ordos Relict Gull Reserve in China as an example. In other parts of the world, such as the USA, many cities are attempting to improve and utilise nature reserves for the benefit of both wildlife and humans. An example is Chicago Wilderness, a programme intent on preserving undeveloped natural ecosystems (Chicago Wilderness, 2004). Furthermore, some countries such as China appear to be reversing policies that exploited nature for the sake of economic development (Zhang et al., 2009), implementing measures such as the Regulations of the People's Republic of China on Nature Reserves (MEP, 1994) and creating new policies for the preservation of forests and habitat including joint intergovernmental efforts (e.g. USA and China (Bureau of Public Affairs, 2012)).

Table 7 Functions, benefits and issues associated with nature reserves and preserves

Functions and benefits	Issues
• Protection of biodiversity; • Carbon sequestration – forests acting as carbon sinks; • Opportunity for recreation, education, scientific research; • Opportunities for tourism; • Ecosystem services; • Mitigation of climate change impacts; • Provision of flood protection; • Replenishment of water catchments; • Stops avalanches in alpine regions; • Preservation of a country's heritage.	• Potential for human-wildlife conflict; • Poaching; • Invasive species.

Source: Sylwester (2009); Forest Research (2010)

2.2.2 WETLANDS, RIVERS AND STREAMS

The Ramsar Convention on Wetlands (article 1.1) defines wetlands as 'areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres' (Ramsar Convention Secretariat, 2006). Wetland ecosystems such as rivers, lakes and marshes provide numerous ecosystem services to society, including the provision of food and fresh water; regulation of climate; recreation; soil formation; nutrient cycling; support of aquatic and terrestrial biodiversity; and storm surge buffering (Millennium Ecosystem Assessment, 2005b) (Table 8). According to Wadzuk et al. (2010), wetlands improve water quality, specifically via removal of phosphorus, nitrogen, lead, copper and suspended solids. According to the Millennium Ecosystem Assessment (2005b) report, there are over 1.2 million km^2 of wetlands globally. However, over 50% of wetlands in North America and Europe have been converted (Millennium Ecosystem Assessment, 2005b). The percentage for converted wetlands in New Zealand is approximately 90% (Auckland Regional Council, 2010a). Human actions have led to reduced resilience, affecting the ability of the land to recover from disturbances such as heavy storms (Postel and Richter, 2003). The destruction of wetlands can occur due to:

- Draining of wetlands for agricultural and industrial land;
- Draining of wetlands due to urban sprawl (Hass and Lathrop, 2003); and
- Industrial, residential, or agricultural pollution being emitted into wetlands.

Table 8 Functions, benefits and issues associated with wetlands, rivers and streams

Functions and benefits	Issues
• Protection of biodiversity; • Opportunity for recreation, education, scientific research; • Opportunities for tourism; • Ecosystem services – provision of water, food; • Flood control mechanisms; • Climate regulation; • Water regulation; • Erosion regulation; • Soil formation and nutrient cycling; • Replenishment of water catchments; • Transport; • Aesthetic, cultural and spiritual value.	• Potential for human-wildlife conflict; • Water pollution; • Pest species; • Flooding, if not managed.

The draining of wetlands and pollution of waterways destroy ecosystem services such as the maintenance of environmental quality and support of biodiversity. The impacts of the degraded ecosystem includes contaminated drinking water, increased risk and severity of flooding, loss of wildlife habitat, reduced fish stocks and thus reduction of food sources, loss of unique natural features and loss of aesthetic function to society. Activities that reduce or remove wetlands can increase risks from climate change and there is ample evidence that wetlands are being inundated or eroded in many regions worldwide. Wetlands and waterways are protected by legislation in many nations with compensatory mitigation required where damage has occurred. For example, the

Clean Water Act 1972 protects wetlands in the United States. New Zealand has the Resource Management Act (RMA) 1991 which includes river-specific protection measures such as water conservation orders. In addition to legislation, stormwater management measures can help protect waterways by minimising pollutant discharge into receiving waterways, reducing the impact of storm events and flooding, reducing soil erosion and maintaining habitat (Kloss and Calarusse 2006; Richards, 2009; EPA, 2011d). Stormwater management practices such as living roofs, green walls, bioretention, permeable pavement, wet and dry ponds and green streets are reviewed in the following sections. It should be noted that while these practices are primarily for management of stormwater and thus the protection of wetlands and rivers, they also have additional functions related to other ecosystem services such as biodiversity and carbon sequestration. Furthermore, other GI assets such as nature reserves and nature corridors also have significant impact on wetland and river ecosystem health. The connectivity of these bodies is discussed in the final section of this chapter. Constructed wetlands and Living Machines™ are discussed in section 2.2.11.

River restoration is an emerging area of research (Palmer and Bernhardt, 2006) where attempts to restore polluted waterways and re-establish habitat are being carried out in order to reverse damage and restore ecosystem services (Baron et al., 2002; Clifford, 2007; Palmer et al., 2007). Palmer et al. (2007) reviewed data and experiential knowledge on river restoration programmes, noting the lack of data due to administrative mishaps and the lack of monitoring of restoration efforts. They call for a database consisting of restoration projects as well as strategic monitoring of these projects so as to adopt a proactive approach for restoring rivers and hence ecosystem services.

Currently there are many projects throughout the world aimed at restoring wetlands and rivers. A significant goal of the projects was to provide measures for climate change mitigation associated with changed precipitation in the region, e.g. Yangtze River floodplain in China (Yu et al., 2009; CCICED, 2010; Pittock and Ming, 2011) and the Four Major Rivers Project in Korea (Shin and Chung, 2011). Some projects have been controversial, such as the Four Major Rivers Project (Normile, 2010), which has been criticised for a number of reasons including the construction of dams and a host of issues concerning the destruction of habitat and loss of biodiversity. Other goals associated with the projects involve biodiversity protection and the desire to bring wildlife back to a region.

2.2.3 Urban forests, community parks and botanical parks

Traditionally, parks were considered only as open spaces for recreation (Ulrich and Addoms, 1981). However, according to Walker (2004), this view, while still prevalent, has developed to include the idea that parks confer broader potential benefits, from the provision of employment (entry level, involving physical labour), child and youth activities that encourage social and physical interaction, participation in park management, to health and wellbeing. Research has focused on gaining an understanding of the broader perspective by attempting to understand the intentions of park visitors.

According to Little (1990), urban parks gained popularity through the work of Frederick Olmsted, whose projects in New York (Central Park) and Boston (Emerald Necklace) were focused on forming networks to connect different socio-economic backgrounds via urban landscapes. However, after World War II, parks in the United States fell on hard times, with more focus on the enhancement of private backyards as a substitute for visiting parks (Harnik et al., 2006). At the same time, there was population loss from central cities and consequent economic decline, while new low-density housing areas were developed. The result was a lack of interest in public parks for half a century, from 1950 to 2000. Established parks deteriorated due to neglect, lack of maintenance and decline in safety and increase in crime. Nevertheless, research and interest in urban ecology gained pace in the 1960s (Spirn, 1984; Platt et al., 1994) and the Trust for Public Land (TPL) was founded in 1972 as an attempt to revive public parks. As urban areas regenerated with a subsequent quest for urban vitality many cities began to incorporate practices that now fall under the umbrella of GI. TPL initiated research on what makes the best parks. Harnic et al. (2006) give an account of the rise of urban parks and measures to plan and improve them for the benefit of cities. The functions, benefits and issues associated with urban and community parks are given in Table 9.

Table 9 Functions, benefits and issues with urban parks, community parks and botanical parks

Functions and benefits	Issues
• Favourable micro-climates; • Reduction of the ‘urban heat island’ effect; • Space for socialising; • Cleaner air – trees and vegetation filtering out pollutants; • Cleaner water, as roots trap silt and contaminants before they flow into local water bodies; • Reduced health costs through opportunities for physical fitness; • Improved learning opportunities from ‘outdoor classrooms’; • Increased urban tourism with resulting increased commerce and sales tax revenue; • Increased business vitality based on attraction of good parks; • Natural beauty and respite from traffic and noise; • Biodiversity.	• Possibility of crime in areas of poor visibility; • Dangers from getting lost (specially for children); • Diseases (e.g. Lyme’s disease) and allergies; • Combats heat island effect though only on micro scale – i.e. effects are not localised to whole city; • Pests such as insects, mammals (rats, mice, etc.), birds; • Pest plant such as poison ivy; • Increasing dust and debris such as leaves which increase costs for cleaning; • Tree canopy may trap pollution at ground level (specifically in street canyons).

Source: GRaBS (2010); Forest Research (2010); University of Washington (n.d.)

Current research ranges from studies concerning aspects of the biodiversity of individual parks and which variety of trees to plant in parks, various uses of parks, to the function of tree roots for stormwater management purposes. For example, Bartens et al. (2008) investigated different tree species and their root’s ability to penetrate compacted soil and assist in infiltration. The study showed an average infiltration rate increase of 153% for black oak and red maple compared to control sites with no trees. At a larger scale, Hirokawa (2011: 233) outlines the functions and benefits of urban forests in terms of the ecosystem services provided and their potential for promoting civic awareness and identity of the urban setting – i.e. how to enhance the understanding of urban forests and how this can help local governments to 'become ecosystem beneficiaries by effectively bringing nature into their communities'. Research has also been carried out on quantifying the benefits of urban parks. For example, according to Bowler et al. (2010) urban parks are approximately 1°C cooler than 'non-green' areas of the city such as roads and buildings. Nevertheless, since the cooling effect is based on observational studies, empirical research is necessary in order to establish whether the greenery is solely responsible for the cooling and to identify measures on how to incorporate greenery for best results.

Additionally, recent research has been attempting to quantify the benefits of urban forests on a per tree basis (McPherson et al., 2006; NRDC, 2009) in terms of reduced demand for energy (cooling and heating), carbon dioxide reduction, improvements in air quality, reduction of negative health impacts due to heat and stormwater retention. Research carried out by Nowak et al. (2007; 2010) for the United States Department of Agriculture (USDA) employs the Urban Forest Effects (UFORE) model to assess the effects and values of urban forests for USA cities. The UFORE model (Nowak and Crane, 2000) uses field data (an inventory of trees), meteorological data, air pollution concentration data and boundary layer height measurements to calculate the urban forest structure; hourly urban forest volatile organic compound emissions; hourly pollution removal by the urban forest and associated per cent improvement in air quality; the effect of trees on energy use in buildings and their consequent carbon dioxide emissions; the relative ranking of species' effect on air quality; total carbon stored and net carbon sequestered annually by urban trees; insect and disease potential for gypsy moth and Asian longhorned beetle; pollen allergy rating for the species composition; exotic species composition; and tree transpiration. In Chapter 3, we discuss the research findings of Nowak et al. (2007; 2010) on assessing GI for Philadelphia, New York and Chicago. Recently, the UFORE model was applied to Perth for estimating vegetation function (Saunders et al., 2011). The study concluded that UFORE is a straightforward method for estimating urban vegetation functions, so it could also be used in New Zealand.

Research on the health benefits of urban parks is emerging. For example, according to Younger et al. (2008), green spaces such as urban parks provide access to nature. Access to urban parks encourages physical activity (Sherer, 2006) with potential significant benefits for reducing levels of obesity and other ailments such as stroke, sleep apnoea and hypertension. Research by Dadvand et al. (2012) investigated the link between green spaces and pregnancy outcomes and found that exposure to green spaces is associated with increased birth weight for those in low socioeconomic groups (with low levels of education). Such findings could be useful for improving health of residents in poorer urban areas.

2.2.4 Conservation corridors

According to the literature (Hess and Fischer, 2001; MacDonald, 2003), conservation corridors have been useful tools for conserving biodiversity and preventing the fragmentation of species due to human encroachment on natural habitat. Fragmentation is defined as 'breaking up of large patches of native vegetation into smaller and increasingly isolated patches' (USDA, 2004: 613-8). As landscapes become fragmented, habitats are lost or shrink, edges increase (which favours species inhabiting edges such as invasive colonisation and pest species, whilst putting stress on species that require large and relatively intact interior areas), biodiversity is isolated into patches and natural regimes are disturbed. Fragmentation is considered to be one of the major threats to biodiversity (Wilcox and Murphy, 1985; Wilcove et al., 1986; Beier and Noss, 1998; Zwick, 1992; Fahrig, 2003; USDA, 2004; Kettunen et al., 2007).

According to USDA (2004: 613-12), conservation corridors (natural and introduced) are a 'realistic opportunity to begin to rebuild functional ecosystems and conserve biodiversity' so as to 'knit the landscape back together'. There is some confusion about the goals of conservation corridors and contradictory uses of the term 'corridor' (Hess and Fischer, 2001). However, there are numerous types of corridors (e.g. environmental, remnant, introduced, disturbance and regenerated corridors), each functioning in a different manner but for similar purposes. According to ADB/BCI (2005), as cited in IUCN (2012), corridors have three primary purposes:

1. Conserving habitat, allowing for species movement and the maintenance of viable populations;
2. Conserving and enhancing ecosystem services; and
3. Promoting and enhancing local community welfare through the conservation and use of natural resources.

In addition to the above, conservation corridors may also be an entire habitat.

The protection of biodiversity is considered to be vital in maintaining ecosystem resilience (Walker et al., 2004). Kettunen et al. (2007: 21) state that 'Ecosystem resilience is closely linked to the assessment of the role of biodiversity within ecosystems and the ability of ecosystems to cope with human-induced impacts. Consequently, it is important to understand the role of biodiversity within ecosystems, not merely assess species richness.' According to the Millennium Ecosystem Assessment (2005c) report, research on the relationships between biodiversity and ecosystem services and human wellbeing was somewhat limited. However, as Bullock et al. (2011) point out, there is renewed interest and research pertaining to the complex links among between biodiversity, ecosystem services and human wellbeing. Their paper, which was based on restoration of ecosystem services and biodiversity, concluded that the economic benefits of restoring ecosystems can can outweigh the costs. It further reported that, while restoration can enhance both biodiversity and ecosystem services, there is potential for conflict according to the priorities or goals of the restoration project; consequently restoration requires a participatory process in order to minimise conflicts and trade-offs (Bullock et al., 2011). Therefore, greater understanding of the complexities involved is necessary to reap the benefits of ecosystem services whilst enhancing biodiversity.

Historical developments from game management to association with island biogeography (MacArthur and Wilson, 1967) and metapopulation (Levins, 1970) theories were documented by Hess and Fischer (2001), together with a review of corridor functions. That review resulted in the following list of possible functions of corridors as: conduits, barriers, habitats, filters, sinks and sources. Functions and benefits, according to Simberloff et al. (1992) andrews (1993), Forman (1991) and USDA (2004), are outlined in Table 10. Most of the benefits and issues are similar to those for urban and community parks (see Table 9 above).

Table 10 Functions, benefits and issues associated with conservation corridors

Functions and benefits	Issues
• Protects threatened species and biodiversity; • Assists the movement of species (migratory) between habitats according to lifecycles and dispersal of species; • Acts as greenbelts and buffers; • Allows colonisation of new sites and spread of biodiversity; • Allows wildlife to leave unsuitable sites; • Enhances water resource management and quality protection; • Reduces risk of flooding and allows groundwater recharge; • Allows recreation, wildlife watching, hiking and other physical outdoor activities; • Engages community and cultural cohesion; • Acts as windbreaks and thus reduces soil erosion and resists desertification; • Provides economic benefits via environmental services, increased crop yields, increased crop quality, increased livestock production, improved livestock health, reduced energy consumption, increased property values and recreation revenue.	• Possible spread of pests; • Improper design can lead to fragmentation and loss of species; • High maintenance costs; • Poor vegetation quality. Spread of pests but also infiltration of pests into corridors, thereby degrading flora and fauna quality.

According to Anderson and Danielson (1997) and MacDonald (2003), the value of conservation corridors depends on spatial configuration, context in terms of the landscape, the type and quality of habitat, the species involved, as well as the nature of areas connected by the corridors. A key conclusion from the MacDonald (2003: 48) literature review was that 'designing and assessing the corridors for biodiversity conservation is difficult because of the large number of potential influences', such as species type and behaviour. Furthermore, there are questions about and criticisms of the effectiveness of corridors, though this depends on the type of corridor and the general structure and area involved (Bennett, 2003). For example, Noss and Daly (2006) argue that if efforts are put into creating or protecting corridors that are not in the right place, these efforts will prove ineffective in the long run, resulting potentially in populations becoming locally extinct, funds being wasted and a loss of credibility for the conservationists. In terms of specific types of corridors, Davies and Pullin (2007) show that narrow corridors may be effective in providing habitat but may be limited in terms of providing connectivity. Thus there is a need for research on assessing functional importance of landscape features and their ability to provide connectivity (Kettunen et al., 2007). This is an example of the need for clarity when establishing project priorities or goals to ensure that the goals are in harmony rather than conflictory, leading to trade-offs between goals.

Additionally, research considering the interaction of species is limited. Haddad and Tewksbury (2006), for example, point out that the effects of corridors on population viability are not well studied. Considering that the species of an area are region-specific, in-depth knowledge of local species and behaviours is fundamental for successful development of conservation corridors. Bennett (2003: 5) outlines the issues facing conservation corridors as follows:

- 'Whether sufficient scientific evidence is available to demonstrate the potential conservation benefits of corridors;
- Whether the potential negative effects of corridors may outweigh any conservation value; and
- Whether corridors are a cost-effective option in comparison with other ways of using scarce conservation resources'.

In addition to the above issues, USDA (2004) warns that the state of corridors in the USA have been deteriorating, perhaps due in part to an indifference in perceptions and attitudes (Cooperrider, 1991). Shadie and Moore (2010) provide an outline of initiatives undertaken in different regions in the world and reflect on the lessons learnt from those initiatives, but the state of corridors internationally still needs to be assessed in order to provide sufficient literature. It should be noted that despite issues and criticisms, there are some success stories such as the conservation of the great panda via development of bamboo corridors to aid connections between isolated habitats (WWF, 2012). In terms of protecting biodiversity, current conventions, directives and agreements (e.g. Habitat Directive and Bird Directive in the European Union (IEEP, 2007); Convention on Biological Diversity, 1992) are likely to assist in improving the state of corridors. More research is necessary to address the issues identified and to assess the benefits of corridors as a GI mechanism.

2.2.5 GREEN TRANSPORT

UNEP (2011) summarised issues with the transport sector as:

- Transport is responsible for the consumption of more than half of global liquid fossil fuels;
- The combustion of fuels is responsible for nearly a quarter (23%) of the world's energy related carbon dioxide emissions;
- More than 80% of outdoor air pollution in developing cities can be attributed to transport;
- Transport is responsible for more than 1.27 million traffic accidents in developing countries; and
- Traffic congestion is responsible for time loss and productivity loss as people wait on roads.

Research has already established the extent of transport-related air pollution (e.g. Michaelis, 1997; Schwela and Zali, 1999) and water pollution (e.g. Foreman et al., 2003; Nixon and Saphores, 2003; Han et al., 2006). Air pollution via emissions of carbon dioxide, particulate matter, lead, nitrogen oxides, sulphur oxides and volatile organic compounds and their negative impacts on both human and environmental health have been investigated and documented (e.g. Theakston, 1992; Graham, 2002). Road ecology research assists in the quantification of ecological impacts from roads in order to avoid or mitigate negative impacts (Forman et al., 2003). Research suggests many ways to ameliorate pollution including reducing the source of pollutants (i.e. vehicles) and applying GI procedures such as green streets, street trees, green walls and green roofs. Pugh et al. (2012) investigated the use of GI (street trees and green walls) for air pollution amelioration in 'street canyons'. They stressed the importance of accounting for ventilation rather than merely concentrating on the number of street trees: 'By not considering the adverse effects of tree planting on canyon ventilation, urban greening initiatives that concentrate on increasing the number of urban trees, without consideration of location, risk actively worsening street-level air quality while missing a considerable opportunity for air quality amelioration' (Pugh et al., 2012: 7697). The authors' findings pertaining to green walls are discussed in section 2.2.8.

The impacts on ecosystems associated with agriculture and waterways are due to the effects of acidification, eutrophication and migratory ozone (Graham, 2002). UNEP (2011) thus calls for reducing the need to travel, shifting to more environmentally efficient modes of travel and improving fuels and vehicles for higher efficiency. In addition to the above issues, transportation also leads to pollution of waterways via stormwater runoff, increased urban heat island effect and the loss of biodiversity when new roads are built that further fragment habitats. Additionally, social conflict may arise as the cost of fossil fuels continues to increase due to the depletion of conventional sources coupled with the increased demand for energy to meet the development needs of a growing urban population. This calls for an integrated effort, more efficient and adequate connectivity in urban areas, improved roads and a more fuel-efficient vehicle fleet, as well as the ability to mitigate unavoidable effects so that people are able to access markets, employment and basic services without causing detrimental impacts to either themselves or the environment. GI can contribute to the greening of transportation via provision of green streets that promote greener modes of travel (such as walking and bicycling) and 'green alleys', parking and paving for more vibrant access routes and parking spaces that provide for multiple functions. Green alleys, parking and paving are all discussed in section 2.2.6.

Green streets are people-oriented streets (rather than vehicle-oriented), or streets that take socio-environmental concerns into account. According to a report of the City of Portland (2012), green streets are streets that maximise the permeable surface, tree canopy and landscaping elements. Sousa and Rosales (2010: 105) states that 'a green street should both meet transportation need and apply environmental stewardship to improve the natural, built and social environments'. The objectives of a green street include reducing stormwater runoff and associated pollutants, mitigating air pollution from motorised traffic, incorporating natural elements into streets and improving access for pedestrians and bicycles. The benefits and issues associated with green streets are outlined in Table 11. There are numerous types of green streets that each incorporate numerous LID techniques such as curb extensions, street planters, permeable pavements, swales and rain gardens (Zhang, 2010).

Unfortunately, current research on green streets is relatively limited. More attention has been paid to the individual practices that integrate to form green streets than to comprehensive studies of green streets. However, there has been a substantial amount of background research carried out to provide the case for green streets based on aspects such as: driver safety and roadside design where drivers tend to drive faster on wider lanes than on narrower lanes (Potts et al., 2007); driving speeds and crashes where faster driving speeds were associated with higher rates of crashes and fatalities (Richter et al, 2006); the effect of roadside trees on driver speed where trees planted closer to the road result in lower speeds than when trees are planted further from the road (Dumbaugh, 2006; Van der Horst and de Ridder, 2007); driver perception that streets with trees are perceived as safer than those without (Naderi et al., 2008); and involvement of trees in crashes where it was found that roadside trees posed no significant risk to safety (Dixon and Wolf, 2007). Additionally, work on developing performance measures for complete green streets was carried out by Macdonald et al. (2010). This work established a new performance measure framework for the California State Department of Transportation (CALTRANS) to remove barriers to the application of approaches such as green streets. Those performance measures expanded upon existing goals (safety, mobility, delivery, stewardship and service) to include non-motorised forms of transport. In addition to research on safety associated with green streets, there is evidence of positive impacts on health, including older people living longer (Takano et al., 2002). Frank et al. (2007) found improvements to health due to increased walking that was encouraged with safer and more aesthetically pleasing green streets.

Table 11 Functions, benefits and issues associated with green streets, highways and motorways

Functions and benefits	Issues
• Reduced or slower stormwater runoff from urban areas into streams, rivers, etc.; • Diverted stormwater from sewer system to reduce backups and overwhelming of sewers; • Reduced impervious surfaces to encourage infiltration for groundwater recharge; • Reduced soil erosion; • Reduced polluted water entering rivers and other waterways; • Reduced demand for pipe systems and costs thereof; • Reduced air pollution from vehicle traffic; • Reduced air temperature; • Improved safety for pedestrians and cyclers; • Enhanced aesthetic quality of streets and motorways; • Enhanced pedestrian experience; • Encouragement of green transport (cycling) and walking; • Safety for biodiversity; • Increased urban green space and wildlife habitat; • Enhanced neighbourhood liveability; • Increased community and property values; • If narrowing of streets is considered, safety benefits due to reduced speeds and reduced vehicle accidents; • Reduced commuter stress; • Increased environmental awareness.	• Initial cost of development is high; • Potential for biodiversity loss due to increased access to roads; • Safety concerns when sharing roads with automobile traffic (cycling).

One of the issues facing green transport and green street design is the integration of different modes of transport that encourage non-motorised modes such as cycling and walking. However, research on cycling and the design of urban arterials is not yet robust, according to Macdonald et al. (2009). Nevertheless, there is research on a number of issues related to cycling, specifically concerning safety. For example, Parkin et al. (2007) found that the volume of traffic on a road increases the perceived risk of cycling; adding separated cycle lanes can reduce that perception of risk. Litman (2008) found that high volumes of traffic act as a barrier to cyclists, discouraging them from cycling. Dill and Gliebe (2008), Lee and Vernez Moudon (2008) and Buehler and Pucher (2012) discussed the correlation between the availability of cycle lanes and the amount of cycling undertaken, finding that when there are cycle lanes, there are more cyclists. Birk and Geller (2005) analysed Portland's investment in cycling infrastructure and found that a 215% increase in the cycling network led to a doubling of overall cycling commuter share and a 210% increase in number of cycling trips. A number of studies have found that cyclists are even willing to travel longer distances to ensure that their commute is on a cycle lane (Hunt and Abraham, 2007; Tilahun et al., 2007; Dill and Gliebe, 2008). This research also shows a preference for cycling in areas of low traffic and presents a marked preference by women for low-traffic cycling routes. According to Dill and Gliebe (2008), bicycle boulevards and paths may be more effective than bike lanes located on arterial roads.

Several research studies (e.g. Pucher and Buehler, 2006; Dill and Voros, 2007; Xing et al., 2008) show an obvious connection between cycling and the availability of cycling infrastructure. These include studies in which the cycling performances of countries such as the United States, Canada and Germany (Pucher and Buehler, 2006; Buehler, 2008) have been compared in order to determine the differences and possible reasons for the extent of cycling in those countries. Findings reveal that a combination of factors such as transportation policies (ones that favour car travel over cycling), spatial development patterns (more roads allowing more vehicles) and socioeconomic and demographic factors all play a part. Other research considers the impact of activities such as cycling on human health. For example, Cavill and Davis (2007) have documented how cycling can reduce the risk of obesity and related diseases. Frank et al. (2007) studied how walking and cycling can contribute to the daily exercise needs for human health. With the cost of fuel increasing, upgrading cycling facilities may help alleviate much more than environmental concerns due to pollution. In Auckland, studies by numerous researchers have quantified the impacts and benefits of shifting mode of transport from cars to cycles for travel within the urban environment (e.g. Lindsay et al., 2011; Tin et al., 2011; Macmillan et al., 2014). The impacts and benefits are discussed in more detail in Chapter 4.

Mass public transport is another area where GI can influence greater connectivity and reduce adverse impacts. Similar approaches to that of green streets may be implemented with respect to GI for railway systems (referred to as 'railway lineside management'), although there does not appear to be much literature associated with GI for railways. Nevertheless, the practice of tree planting along rail corridors has been documented by a few, including Frith (1998) and NUFU (2002) and there are plans to plant trees along railways in the UK (e.g. The Telegraph (2012), although in this case the tree planting was to mitigate the felling of trees due to the development of high speed rail in the area). A cautionary approach seems to be applied with respect to tree planting in order to avoid the risk of accidents due to felled trees on tracks and also due to maintenance costs. Other research areas include work on the impact of rail transit such as evidence of reduced air pollution associated with rail transit (e.g. reduced carbon monoxide levels in Taipei found by Chen and Whalley (2012)). In cases where renewable energy drives the rail network, the benefits are likely to be greater.

2.2.6 Green alleys, parking and paving

Alleys usually provide access to parking garages, loading bays or rubbish bin collection. As such, they were not originally designed for vibrant social activity or environmental benefits. The typical use of impermeable surfaces has led to flooding of property, pollution of waterways and overflow of stormwater/sewage managements systems in stormy conditions. Green alleys are hailed as the sustainable solution to the multiple issues that plague conventional alleys. The city of Chicago's *Green Alley Handbook* (Chicago Department of Transportation, 2010: 41) defined a green alley as 'an alley designed and constructed incorporating best management practices (BMP) of environmentally sustainable design'. These BMP practices involve four techniques that are outlined in the Handbook (Chicago Department of Transportation, 2010):

1. Alley drainage improvement through proper pitching and grading;
2. Permeable pavement;
3. High albedo (high reflectivity) pavement; and
4. Recycled construction materials.

The multiple benefits of green alleys are outlined in Table 12. Other associated benefits (for permeable paving) can be found in Table 13.

Table 12 Functions, benefits and issues associated with green alleys

Functions and benefits	Issues
• Stormwater managed on-site and need for additional storm sewer infrastructure prevented; • Reduced flooding of adjacent property; • Reduced pollution of waterways; • Reduced heat island effect in urban areas; • Recycling of material resources (recycled construction materials) promoted; • Outdoor space provided (gardens, farmer's markets, etc.); • Stormwater mitigation promoted while doubling as walking, driving or parking area.	• Cost (for initial clean up and construction); • Regular maintenance and commitment for regular maintenance required (depends on whether the alleys are publicly or privately owned); • Unsuitable for use where there is overhanging vegetation or in developing or unstable catchments (drainage areas), which generate very high sediment loads and can accelerate clogging; • Unsuitable in areas with high water table or previously contaminated soils.

According to EPA (2006), 'green parking refers to several techniques that applied together reduce the contribution of parking lots to total impervious cover'. Paved surfaces, such as parking areas, contribute to a number of environmental effects in urban areas such as the facilitation of pollutants to waterways via stormwater runoff, increased peak flow in waterways thus increasing soil erosion, potential overwhelming of sewage systems, exacerbated heat island effect and, furthermore, such surfaces tend to look barren and unsightly (Horner et al., 1994; Konrad et al., 2002; Nelson and Booth, 2002). The functions, benefits and issues concerning permeable paving are outlined in Table 13. The use of permeable materials for green parking and paving are alternatives to impermeable asphalt and concrete surfaces (Bean et al., 2004). In many instances, the use of permeable pavement reduces or eliminates entirely the need for costly conventional stormwater ponds or wetlands.

Permeable paving has been in use since the Roman Empire (Knapton, 2003). Germany developed it further and permeable paving is now used more extensively in Europe than in many other parts of the world. Considering that drainage needs differ according to the local climate (Dawson, 2009), research in individual countries is likely to be prioritised according to the significance of runoff and sewage overflow issues facing them. Accordingly, different kinds of permeable paving that uses various types of materials have been developed. For example, there are permeable interlocking concrete pavers (sometimes called porous pavers, typically used in driveways and walkways), porous asphalt (used in parking lots), porous concrete (used in light traffic roads, parking lots or pedestrian walkways) (Rowe et al., 2010), concrete grid pavers, plastic reinforced grid pavers, pervious concrete and more. It should be noted that the terms 'permeable', 'pervious' and 'porous' are used interchangeably, although there are slight differences in meaning.

Table 13 Functions, benefits and issues associated with permeable paving

Functions and benefits	Issues
• Reduced stormwater runoff volume and peak flow by exfiltration to the ground and/or capture and slow release; • Stormwater managed on-site; • Reduced pollution of waterways; • Reduced heat island effect (large parking complexes); • Multiple functionality: stormwater management within footprint of trafficable area is provided; • In some cases, developable area can be increased.	• Cost (can be more expensive than conventional pavement); • Requires regular maintenance to maintain surface infiltration capacity (i.e. reduce clogging); • Structural concerns due to incorrect sub-base design; • Unsuitable for use where there is overhanging vegetation and in developing or unstable catchments (drainage areas), which generate very high sediment loads and can accelerate clogging; • Unsuitable in areas with high water table; • Must be lined if used over contaminated soils, which may reduce effectiveness.

Research has been conducted on permeable pavement in four areas: runoff reduction and long-term hydrology, clogging and water quality (Bean et al., 2007b; Hunt and Collins, 2008; Fassman and Blackbourn, 2010, 2011). The use of permeable pavement reduces or eliminates surface runoff, lowers peak discharge and reduces runoff volume, according to many researchers, including a study in Auckland (Boving et al., 2008; Hunt and Collins, 2008; Fassman and Blackbourn, 2010; International Storm Water Best Management Practice Database, 2012). Permeable pavement acts as a filter for pollutants such as lead and automotive oil (Brattebo and Booth, 2003). The study by Brattebo and Booth (2003) also investigated the long-term effects of permeable pavement including its infiltration capabilities over time and the resulting water quality. The study found that the performance of permeable paving may not be uniform everywhere and would depend on the permeability of the underlying soil of the area. The results were variable for water quality according to the constituent. For example, it was found that the concentrations of zinc increased while that of copper decreased (Brattebo and Booth, 2003).

Investigations on permeable modular pavement (PMP) were carried out in Auckland, New Zealand, by Fassman and Blackbourn (2010, 2011). Concentrations and loading of non-point source (NPS) contaminants such as total suspended solids (TSS), pH and dissolved zinc and copper were monitored. This study concluded that 'PMP is an effective tool for minimising NPS discharges from transportation-related land uses' (Fassman and Blackbourn, 2011: 728). Asphalt surfaces are a source of sediment in stormwater runoff as the surface deteriorates and asphalt is washed away, continually releasing sediments that are picked up by runoff. Permeable pavements, on the other hand, often do not show this characteristic; however, the materials comprising the system itself have the potential to act as contaminant sources if not properly specified. Additionally, studies in Auckland by Fassman and Blackbourn (2010) indicated significant mitigation of peak flow and runoff volume, despite being installed over clay soils that are generally considered to preclude infiltration.

Fach and Geiger (2005) conducted laboratory tests to determine the effective pollution retention capacity of permeable pavement and found that the capacity for retaining pollutants varied according to material and specific reactive surface of the pavers. Several studies on permeable pavement (e.g. Brattebo and Booth, 2003; Bean et al., 2007b) have demonstrated decreased concentrations of pollutants such as heavy metals, motor oil, sediment and some nutrients, compared to asphalt pavement. These studies also indicate lower total pollution loadings compared to standard pavement, attributed to the hydrologic control also provided.

Boving et al. (2008) found that clogging by sand (brought in from the outside) was more prominent in heavy traffic areas. According to Bean et al. (2007a), clogging of permeable surfaces, whilst lowering infiltration rates, does not necessarily mean sealing which would prevent infiltration completely. The survey of permeable pavement surface infiltration rates indicated that the location of permeable pavements and their maintenance were critical for high infiltration rates (Bean et al., 2007a). Essentially, clogging of the surface voids and consequent loss of permeability can be minimised by maintenance and appropriate design. Fassman and Blackbourn (2010) indicated that the potential for clogging was dependent on the proximity of unstable catchments and the presence of overhanging trees or vegetation that drops litter.

During investigations to determine the potential for ground water contamination from the use of permeable paving on Rhode Island, USA, Boving et al. (2008) found that in areas that were still porous, asphalt removed both organic contaminants (e.g. polycyclic aromatic hydrocarbons (PAH) and petroleum hydrocarbons) and metal contaminants (e.g. copper, lead, zinc and cadmium) more effectively as compared to the removal of anions (e.g. Br-, Cl- and SO4-) and nutrients (nitrate and phosphate).

The study also found that no bacteria or BOD were found in percolating water; polycyclic aromatic hydrocarbons (PAH) were present in concentrations near the minimum detection limit; nutrients (nitrate and phosphate) were being leached into the ground via the permeable parking lot surface at annual flux rates of 0.45-0.84 $g/m^2/year$; and the retention capacity of the permeable parking lot structure was greater than 90% for metals and 27% for nutrients, via multi-species tracer test.

Additionally, Boving et al. (2008) found that contaminant concentrations in the percolated water varied with season (according to seasonal fertilisation and salting for de-icing, a phenomenon also discussed by Kwiatkowski et al. (2007)), with highly concentrated contaminants being attenuated as they percolate. With respect to potential ground water contamination, this study found that a layer of pavement (the geotextile layer) might have prevented deep infiltration to enable collection of water for sampling. Thus Bovine et al. (2008) hypothesised that there was potential for localised groundwater contamination since infiltration did not occur by design and there was potential for discrete points at which infiltration occurred where the capacity for retardation could be overwhelmed, causing contaminant leaching. However, research including that of Kwiatkowski et al. (2007) has dispelled fears of contamination, concluding that proper siting would prevent adverse impacts on groundwater. As such, it is generally accepted guidance to avoid installations within approximately 1 metre of seasonally high groundwater table (Tennis et al., 2004; Wang et al., 2006) or in stormwater hotspots that may already have contaminated soils that may be mobilised. Pitt et al. (1999) suggest that risks associated with potential groundwater contamination below infiltrating stormwater systems (e.g. permeable pavements, bioretention, infiltration basins) depend on the mobility of the specific contaminant, its prevalence in urban runoff, in-situ soil organic content and hydraulic conductivity (i.e. below the stormwater system) and the presence or absence of pre-treatment.

Starke et al. (2010) investigated the effects on evaporation rates from different permeable pavement designs and found that the evaporation rates of pervious concrete were 16% higher than impermeable pavements. Further studies by Starke et al. (2011) found that the rate of evaporation was dependent on the underlying soil as well as the type of paving and specifically that fine-grained particles were unsuitable for allowing permeability. Additionally, Starke et al. (2011) found that the colour of paving has an impact on the evaporation rate since the colour determined the amount of solar energy absorbed and thus the energy for evaporation. Karasawa et al. (2006) found that thermal pollution reduction of approximately 4°C to 12°C was achieved in Tokyo for permeable interlocking concrete pavers (PICP) when compared to conventional asphalt pavement. This reduction in temperature was largely due to the pavement colour and cooling due to evaporation. The capacity to decrease thermal pollution in other types of permeable pavement has not yet been established.

Research has also been conducted on different soils. For example, research by Dreelin et al. (2006) showed that pervious pavements may be used successfully in clay soils by using appropriate design. In terms of appropriate design, Tyner et al. (2009) conducted studies to determine the mechanisms to increase exfiltration from pervious concrete retention system and into an underlying subgrade in Tennessee. Treatments such as soil that has been trenched and backfilled with stone aggregate; soil ripped with a subsoiler and placement of shallow boreholes backfilled with sand were applied. It was found that the trenched treatment exfiltrated fastest, followed by the ripped and then the borehole treatments. Therefore, it was concluded that 'treating the clay subgrade beneath pervious concrete plots with boreholes, ripping and trenching greatly increased the infiltration rate' (Tyner et al., 2009: 2641).

Research on the application of permeable pavement in cold climates has been conducted by researchers including Drake et al. (2010), Henderson and Tighe (2012), Roseen et al. (2012) and Roseen et al. (2013). According to Kevern et al. (2008), the use of pervious concrete in colder environments (wet freeze) was limited due to poor durability. Freeze-thaw durability has been improved by substituting up to 7% of the coarse aggregate with sand, polypropylene fibres and air entraining agents (Kevern et al., 2008; Henderson and Tighe, 2012). Conversely, Roseen et al. (2012) found that the rapid drainage properties of a surface layer of porous asphalt and well-drained basecourse minimised issues associated with frozen media. No adverse affects of freeze-thaw on the pavement structure were noted over 4 years, nor was hydrologic performance compromised. Roseen et al. (2013) concluded that surface temperatures in permeable pavement were lower than that for porous asphalt, pervious concrete and standard asphalt. Henderson and Tighe (2012: 197) investigated construction methods, multiple mixes and maintenance for permeability performance of test pavements and concluded that 'freeze–thaw cycles are in general not the cause of distress development or failure'. According to the authors, attention needs to be given to site design, mix design and construction stages of the permeable pavement. A study by Tyner et al. (2009) monitored the internal temperature of pervious concrete and aggregate base during their research on exfiltration in Tennessee during the winter of 2006–2007. The coldest recorded air temperature was −9.9°C and the corresponding coldest recorded pervious concrete temperature was −7.1°C (Tyner et al., 2009). The temperature of the aggregate base did not drop below freezing (minimum temperature in the aggregate base was 0.7°C) despite the temperature of the pervious concrete dropping below freezing. Water within the pervious concrete was able to increase the specific heat capacity of the system and hence inhibit freezing; convective heating of water within the rock and concrete also contributed to the warmer temperature (Tyner et al., 2009). Further findings indicated that the temperature of the pervious concrete lagged behind the diurnal cooling of the air.

In the same study by Tyner et al. (2009), the highest air temperature recorded for the test period was 23.4°C and the corresponding maximum temperature in the pervious concrete was 23.8°C. The maximum temperature recorded in the aggregate base was 18.4°C. Direct exposure to air temperature and solar radiation are thought to be the reason for the high temperature in surface pervious concrete, as the temperature was clearly mitigated in the basecourse. Despite the results from this study, research shows that pervious concrete pavement can help mitigate urban heat island impacts. Research conducted in Iowa by Haselbach et al. (2011) showed that, despite the lower solar reflectance index (SRI) of 14 as compared with traditional concrete (SRI of 37), pervious concrete pavement could be considered a cool pavement option. Research conducted on traditional asphalt, porous asphalt, porous concrete and interlocking concrete paver car parks at EPA's Edison Environmental Center (EEC) monitored urban heat island effects amongst other objectives such as hydrologic performance and water quality performance (Rowe et al., 2010). When the surface air temperature reached a high of 17^{o}C, the corresponding temperature reached by the traditional asphalt paving was 33^{o}C. The porous asphalt was cooler than the traditional asphalt during the day, but both reached the same temperature when cooled at night. The porous concrete paving was found to be coolest during the night but attained a high of more than 30^{o}C during the day. The interlocking concrete pavement temperatures remained steady with a differential of 8 degrees (Rowe et al., 2010). Thus there is potential for permeable paving to mitigate heat island effect. More research is necessary to determine the types of paving to suit the particular climatic contexts of different cities.

In addition to research on the performance of pervious paving, there is a need for policy change to determine the appropriate use of permeable paving in a region. Litman (2011) provided a guide on how to reduce the amount of paved surface initially with the recognition that there is oversupply of road and parking spaces due to standards that facilitate oversupply. Litman (2011) also identified strategies for reducing parking space by, for example, educating decision makers on alternative strategies to oversupply of parking and thus paved surfaces; accurate and flexible standards that lead to reduction; mobility management; parking management; and efficient road and parking pricing. In Europe and the United States, there have been many projects to develop parking lots with permeable paving (e.g. City Mall, Stuttgart, Germany and USA Cellular Field, a major league baseball stadium in Chicago). The practice has been taken up in many states of the USA (e.g. South Percy Street, Philadelphia) (van Diemen, 2009).

2.2.7 Living (green) roofs

According to Landcare Research (2012), living roofs are 'vegetated roof covers, with growing media and plants taking the place of bare membrane, shingles, tiles or other roofing materials'. They are generally categorised under LID (Low Impact Design). Although vegetated roofs were used in ancient times (such as ancient Mesopotamia (Osmundson, 1999) and thirteenth-century France (Wark and Wark, 2003)), work on the modern day living roofs was published in 1961 by Reinhard Bornkamm from Berlin's Free University (Bornkamm, 1961). According to Oberndorfer et al. (2007), the first living roofs in Germany were developed to prevent damage to the roof via sun exposure. Köhler (2008) has undertaken an historic account in Germany, with current research on green façades (living roofs and green walls). Alexandri (2005) gives a broad account of the history of living roofs, including a review of thatched roofs around the world and the concept of 'tree tenants' by Hundertwasser in the 1970s. At present, the primary objective or most important function of living roofs seems to be the reduction of stormwater runoff (Peck and Kuhn, 2003; Liu and Baskaran, 2003; Monterusso et al., 2004; DeNardo et al., 2005; Schmidt, 2006; EPA, 2009) although there are many other uses associated with living roofs (Table 14), particularly the reduction of heat island effect in cities such as Tokyo and Singapore (Leng and Sia, 2002). According to Koppe et al. (2004), heat waves in urban centres increase the risk to the urban population and the cooling effect of living roofs may reduce the risk. Additionally, energy demand mitigation is the driver for living roof installation in Korea and Singapore (Fassman et al., 2010a).

The structural components of living roofs are shown in Figure 3. There are two main types of living roofs: 1. Extensive or low profile (substrate depth 20 to 150 mm); and 2. Intensive or high profile (substrate greater than 200 mm), with various modifications such as semi-extensive (with substrate depths between 100 to 200 mm) in between (EPA, 2008; Fassman et al., 2010a; Green Roof Guidelines, 2012). The difference between the two types is due to the depth of substrate: an extensive roof has shallower substrate for lower ground cover whilst intensive roofs have deeper substrate to allow for a conventional ground-level type of garden. Given that the two roof types differ in terms of substrate depth and thus the type of plants that can grow on them, they also have different functions and benefits. For example, whilst the extensive living roof is more functional in nature (stormwater capture, thermal insulation, fire protection), the intensive living roof strives to be aesthetically pleasing as well as functional and can also be considered as extra living space (Peck and Kuhn, 2003; Oberndorfer et al., 2007; Martin, 2008). The additional depth of substrate in an intensive roof does not necessarily provide better performance for stormwater retention (Fassman-Beck and Simcock, 2013), but may increase thermal insulation. However, the intensive roof costs more to install and maintain whilst the extensive roof may require less structural strengthening, uses less material and tends to require less maintenance.

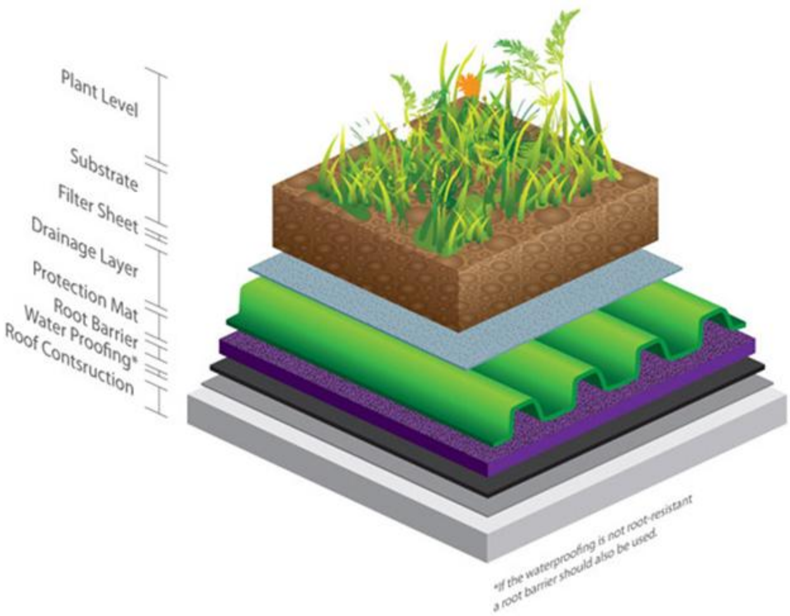


Figure 3 Structural components of a living roof

Source: Green Roof Guidelines (2012)

Research has been focused on quantifying the benefits of living roofs, such as the extent of stormwater runoff reduction (Köhler, 1989; Hutchinson et al., 2003; Carter and Rasmussen, 2006; Deutsch et al., 2007; EPA, 2009; Voyde et al., 2010b; EFB, 2012; Fassman-Beck et al., 2013). For example, according to research by Köhler (1989), living roofs in Berlin have the potential to absorb 75% of precipitation, reducing runoff to 25% of normal levels. Hutchinson et al. (2003) and Carter and Rasmussen (2006) demonstrated the variability in runoff retention noting that detention and thus reduction of runoff, is dependent on a number of variables such as size and intensity of storm events, the frequency of events, the saturation level of the living roof medium and climatic conditions where the living roof is situated.

Table 14 Functions, benefits and issues associated with living roofs

Functions and benefits	Issues
• Reduce or slow down stormwater runoff from urban areas; • Reduce risk of flooding, river/stream bank erosion; • Improve thermal insulation of building and reduce energy costs related to heating and cooling; • Reduce urban heat island effect; • Vegetation may filter airborne pollution; • Create habitat for birds, butterflies and insects; • Increase aesthetic appeal on hard built structures; • Noise insulation; • Increase property values; • Provides garden space, agriculture; • Increase roof durability from lack of sun exposure; • Fire resistance; • Although not very common, enables the use of recycled materials on roof.	• Initial cost of development is high; • Aesthetic appearance may change significantly with seasons depending on level of irrigation and type of plants; • Need for irrigation on some installations; • Primarily understood with respect to benefits at the site-scale; uncertainty of benefits associated with the lack of complete urban area coverage (i.e. what are the impacts if 100% of roofs are not green?).

Other research includes the effect of slope on stormwater retention (Getter et al., 2007), the role and quantity of evapotranspiration (Voyde, 2010b; Feller, 2011), thermal insulation (Getter and Rowe, 2006), reduction of ambient temperatures (Plumb and Seggos, 2007), impact on heat island effect (Alexandri and Jones, 2008), noise insulation with estimations of 8dB or more capacity for reduction by living roofs compared to conventional roofs (Lagström, 2004; Teemusk and Mander, 2006), modelling and simulation capabilities to assist quantification (Sailor, 2008), pollution mitigation (Clark et al., 2008; Currie and Bass, 2008; Rowe, 2011). Additionally, research on living roofs has focused on implementing and improving living roof designs (Fassman and Simcock, 2012; Getter et al., 2007; Durhman et al., 2007), roof materials (Dunnett and Kingsbury, 2004), the type of plants that can be planted as well as their effects (Köhler, 2003; Ip et al., 2010), the impacts or tolerance of plants (e.g. salt tolerance by Whittinghill and Rowe (2011) and the range of temperature they can survive in (Lagström, 2004)) and on retrofitting existing buildings (Castleton et al., 2010). Some comparative studies such as the comparison of life-cycle impacts of standard roofs and living roofs have also been undertaken (Saiz et al., 2006). Findings from comparisons of living roofs point out that not only do living roofs perform differently from conventional roofs, but they also tend to perform differently within a range of living roof examples (Simmons et al., 2008). This leads to the conclusion that not all living roofs are alike and are likely to function differently according to their various designs as well as the conditions to which they are exposed. Fassman et al. (2010b), Fassman-Beck and Simcock (2013) and Fassman-Beck et al. (2013) have begun to link design to performance for retention and water quality, based on research performed in Auckland.

A number of research projects on living roofs have been conducted in New Zealand. According to Peryman (2009), New Zealand cities have 80 to 100% drainage where 5% replenishes aquifers, 15% goes to the atmosphere and 75% is surface runoff. Extensive research has been conducted regarding living roof design and performance for stormwater mitigation in Auckland (Fassman et al., 2010a; Fassman et al., 2010b; Voyde et al., 2010a, Voyde et al., 2010b; Fassman and Simcock, 2012; Fassman-Beck and Simcock, 2013; Fassman-Beck et al., 2013). While day-to-day variation in performance is influenced by multiple parameters such as rain depth, rain intensity, climatic variables and antecedent dry days (Voyde et al., 2010b), long-term studies suggest that rainfall depth is an effective predictor of runoff retention for planning purposes (Carson et al., 2013; Fassman-Beck et al., 2013). Monitoring of five living roof substrates installed at depths of 50 mm to 150 mm at three different locations in Auckland showed substantial reductions in volume and peak flow rate. Long-term cumulative runoff volume was reduced by up to 67% compared to rainfall and up to 56% compared to a control roof (Fassman-Beck et al., 2013). Fassman et al. (2010a and 2010b) outlined the research project consisting of the design, retrofitting and performance monitoring of the extensive living roof constructed on the roof of the Faculty of Engineering, University of Auckland, 'mini' living roofs atop garden sheds located at Landcare Research in Auckland and the living roof atop the Waitakere Civic Centre. Fassman and Simcock (2012) described substrate design specifically for Auckland rainfall, using New Zealand-sourced materials and developed a method to link substrate design to stormwater retention performance. These sites have also been monitored for plant selection and performance. The Waitakere Civic Centre living roof was designed as a demonstration project to promote New Zealand native biodiversity (Simcock et al., 2006).

Further to the above, studies on evapotranspiration and the type of plants to use for Auckland have been conducted (e.g. Ignatieva et al., 2008; Voyde, 2010b; Voyde 2011). Ignatieva et al. (2008) suggest the following plants for use on living roofs in Auckland with a focus on enhancing biodiversity:

- *Crassula sieberiana***
- Sand convolvulus**
- *Oxalis exilis*
- New Zealand ice plant**
- *Epilobium brunnescens*
- *Epilobium nummulariifolium*
- Sea spurge
- *Haloragis erectus*
- New Zealand linen flax
- New Zealand groundsels
- *Cotula coronopifolia*
- Mazus spp.*
- *Acaena microphylla**
- Danthonias
- *Festuca coxii***
- *Poa anceps*
- Silver tussock
- *Pyrrosia eleagnifolia**

- Knobby clubrush
- *Lachnogrostis* spp.
- *Leptinella dioica*
- *Dichondra repens**
- New Zealand spinach
- Holy grass
- *Leptostigma/Nertera setulosa**
- *Libertia peregrinans***
- *Selliera radicans**
- Rice grass
- Mat pohuehue*
- Leafless pohuehue
- *Pimelea prostrata**
- *Coprosma petriei**
- Sand coprosma**

* Plants that have survived up to 2 years with minimum substrate depth of 100 mm.
** Plants that can tolerate thin and dry substrates.

Whilst not all of the above plants have been tested, Voyde et al. (2010b) investigated the evapotranspiration potential of *Sedum mexicanum* (Mexican stonecrop) and *Disphyma australe* (New Zealand ice plant) in stressed and unstressed states. Voyde et al. (2010b) concluded that 50% of total evapotranspiration was contributed by the two plant species in their unstressed conditions (daily peak evapotranspiration of 0.29 mm/h). The study revealed that the two species of plants behaved differently when they were stressed (drought conditions) with daily peak evapotranspiration of 0.05 mm/h by New Zealand ice plant and 0.02 mm/h by Mexican stonecrop. Transpiration by Mexican stonecrop contributed to 48% of total evapotranspiration (2.19 mm/day) while evapotranspiration of New Zealand ice plant contributed to 47% of total evapotranspiration (2.21 mm/day). In drought conditions, plants tend to reduce evapotranspiration to conserve water and in this case, the Mexican stonecrop was more efficient (faster) at conserving water via reduction of evapotranspiration (0.02 mm/h compared to 0.05 mm/h by New Zealand ice plant). This research illustrates an interesting complexity – if the plants are stressed, their chance of survival diminishes but if they are frequently irrigated, the capacity to retain stormwater during rain events is diminished. Voyde (2011) determined that common agricultural evapotranspiration models are not appropriate when water is limited (i.e. during dry periods common to non-irrigated living roofs). More research on the effects of different native plants is needed in order to establish efficient living roofs that are able to thrive during harsh stressful conditions while also catering to biodiversity goals.

While much work has already been conducted on the improvement and quantification of benefits, work on further quantification and investigation of impacts continues. For example, there are gaps in research with respect to the classification of living roofs as impervious or non-pervious (Köhler et al., 2001; Martin, 2008); the levels and impacts of nitrogen and phosphorus leaching from the roof substrate (Moran et al., 2005; Fassman et al., 2010b); the benefits on air quality; and the role of biodiversity (Oberndorfer et al., 2007). Additionally, comparative studies, comparing living roofs with alternative technologies (e.g. different roofing material), would be beneficial taking into account the particular requirements of different regions. This review reflects Rowe's (2011: 2100) conclusions regarding the need for research on 'plant selection, development of improved growing substrates, urban rooftop agriculture, water quality of runoff, supplemental irrigation, the use of grey water, air pollution, carbon sequestration, effects on human health, combining living roofs with complementary related technologies and economics and policy issues'. In terms of carbon sequestration, Getter et al. (2009) conducted studies to identify potential sequestration by extensive living roofs. The study involved 12 roofs in Michigan and Maryland populated with *Sedum* species. The study revealed an average sequestration above ground of 162 g C/m^2. The carbon sequestered ranged from 73 to 276 g C/m^2, showing high variability among roofs. In total, the extensive roof system sequestered 375 g C/m^2 comprising of 168 g C/m^2 in above ground plant biomass, 107 g C/m^2 in below ground plant biomass and 100 g C/m^2 in substrate carbon.

Although they are popular in some European countries (e.g. Germany (Herman (2003)) and North American cities (e.g. Chicago and Toronto) where living roofs are legislated for or subsidised, the uptake of living roofs has been slow in other regions (e.g. London and Australian cities) despite the availability of the technology (Greater London Authority, 2008; Williams et al., 2010). It may be that gaps in understanding are affecting the uptake of living roofs. However, there are incentives via the green building sector including accreditation via Leadership in Energy and Environmental Design (LEED) (e.g. SS 7.2 Heat Island Effect – Roof) as well as government subsidiaries for converting roofs, especially in Europe.

As more living roofs are installed throughout the world, there is greater need for standards and guidelines for building living roofs in many countries (Wark and Wark, 2003; Dvorak and Volder, 2010). However, according to the International Green Roof Association (IGRA, 2012), only a few countries have regulations and guidelines for living roofs. 'Guidelines for the planning, execution and upkeep of Green Roof sites' developed in the 1990s (updated in 2002 and 2008) by The Landscaping and Landscape Development Research Society in Germany is said to be the oldest regulation available. Codes of practice based on the German regulations are available in UK (GRO, 2011). Whilst there are no specific standards for America, the American Society for Testing and Materials (ASTM) has developed standard testing methods applicable to living roofs. For example, E2396: Standard Testing Method for Saturated Water Permeability of Granular Drainage Media for Green Roof Systems; E2397: Standard Practice for Determination of Dead Loads and Live Loads Associated with Green Roof Systems; E2398: Standard Test Method for Water Capture and Media Retention of Geocomposite Drain Layers for Green Roof Systems; E2399: Standard Test Method for Maximum Media Density for Dead Load Analysis; E2400: Standard Guide for Selection, Installation and Maintenance of Plants for Green Roof Systems. Peryman (2009) notes the lack of incentives for living roofs in New Zealand. The long-term research programme supported by local government in Auckland has resulted in the publication of a freely available guide specifically focussed on living roof design for stormwater management (Fassman-Beck and Simcock, 2013).

2.2.8 Green or living walls

A green wall, or living wall, is essentially a vertical element of a building where vegetation is partially or fully applied to provide significant benefits (Table 15). Green walls, much like living roofs, have their origins in Europe (Köhler, 2008). Green Roofs for Healthy Cities (2008: 1) identified two distinct types of technologies for green walls: green façades and living walls. Living walls have been defined as wall systems 'composed of prevegetated panels, vertical modules or planted blankets that are fixed vertically to a structured wall', while green façades are a 'type of green wall system in which climbing plants or cascading groundcovers are trained to cover specially designed supporting structures' (Green Roofs for Healthy Cities, 2008: 1). Pérez et al. (2011) presented a green wall typology where the first differentiation separated green façades (consisting of traditional green façades, double-skin green façade/green curtains and perimeter flowerpots) from living walls (made with panels and geotextile felts).

Table 15 Functions, benefits and issues associated with green walls

Functions and benefits	Issues
• Filters out dust and pollution; • Assists insulation; • Provides shading; • Protects wall surfaces from damage from the sun, wind, rain and other natural elements; • Assists in cooling (in hot climates) via evapotranspiration; • Energy savings for cooling; • Slows stormwater runoff due to canopy depending on green wall design; • Potentially adds to visual enhancement; • Provides resting areas for birds, insects and invertebrates; • Dampens noise; • Allows increased biodiversity and urban agriculture.	• Initial cost of development is high; • Potential issues if decay sets in; • Most effective at cooling in tropical climates; • Timeliness: it may take years for some systems to get established; • Requires significant maintenance; I • Requires irrigation in most climates; • May interfere with light penetration for some residents.

Source: Johnston and Newton (2003); Sheweka and Magdy (2011)

The second differentiation, based on the nature of the systems, ranges from extensive, semi-intensive, intensive, to free-standing. Extensive green walls (equivalent to green façades) consist of vines or self-clinging plants able to climb up existing structures (Dunnett and Kingsbury, 2008). Semi-intensive green walls require support in the form of wire mesh or cables for the climbing plants used. Intensive green walls have purpose-built planter cells with pockets of soil arranged in a grid-like formation along the building walls (Johnston and Newton, 2004), whereas free-standing green walls are independent of any structure for support (for example, a hedge). Intensive green walls require significant levels of irrigation and the most maintenance overall and are usually considered to be a form of 'green art' rather than contributing ecological benefits.

The uptake of green walls has been slow due to the expense and difficulties associated with construction and maintenance. In addition, there is the perceived danger of plants damaging building walls. According to Johnston and Newton (2003), the damaging effects of plants on walls (especially of façades where plants are directly on the wall) has been exaggerated. They found that plants can damage walls but only when decay has already set in. Nevertheless, practical implementation of the technology has not been successful in some cases. One such case was the living wall commissioned by Islington Council (Paradise Park Children's Centre in Holloway, UK) where a 230 m^2 living wall, built in 2005 to enhance biodiversity, withered and died in 2009 (Blunden, 2010), resulting in a large replacement cost. It is possible that the installation was not appropriately designed for the climatic conditions in the region, but there has been no research conducted to investigate the causes of the failure.

Utilising different types of green walls may alleviate issues with wall deterioration and may in fact protect walls by providing a barrier against the elements, comparable to living roofs. According to Alexandri (2005), there are three types of green walls:

1. Creepers and climbers directly on the wall (façade);
2. Creepers and climbers on a structure adjacent to the wall (living roof); and
3. Plants loosely hanging in front of the building with no structural support (green curtain).

Research on the cooling effects of green walls has been carried out since the 1990s. For example, Di and Wang (1999) studied the cooling effect of ivy on walls and found a 28% reduction in temperature for the west-facing wall of a brick building in Beijing. They also found that the building was warmer at night. Current research is still based on the various effects that different plants have on the surface and ambient temperatures of buildings. For example, Schumann (2007) worked on green walls where a lightweight structure was used to support and suspend vines over the roof and walls of a building in Maryland, USA. This research found that the green cloak over the building cooled the building by 11.3°C which led to 73% saving in the cost of energy for cooling. Alexandri and Jones (2008) modelled and compared the effect of green walls and roofs on urban canyons around the globe. Their findings show that vegetation cover applied in hotter and drier climates would have a greater impact on urban temperature. For example, in Riyadh (Saudi Arabia), air temperature decreases of up to 26.0°C maximum and 12.8°C daytime average were achieved as a result of introducing vegetation cover throughout the city. Additionally, decreases of up to 11.3°C maximum and 9.1°C daytime average were achieved while inside the canyon. In humid climates such as Hong Kong, applying vegetation to both roofs and walls can yield substantial temperature decreases (maximum temperature decreases of up to 8.4°C were achieved in Hong Kong) where temperature decreases are dependent upon the amount and geometry of the vegetation cover. With respect to canyons, the study found that temperature decreases due to vegetation were not affected by wind direction and that temperature decreases due to vegetation from green walls and roofs were weaker when the canyons were wider. The study concluded that using green walls and roofs in combination would prove more effective in lowering urban temperature (particularly for hot climates), with greater impact occurring where vegetation cover is at the city scale rather than at localised block scale. This city scale application of vegetated roofs and walls could potentially reduce energy for cooling requirements from 32% to 100%.

Wong et al. (2003a) investigated thermal effects on high-rise buildings in Singapore and found that when completely covered by vegetation, a 74% reduction in energy for cooling was achieved. With windows, they found a 10% reduction in energy for cooling. Eumorfopoulou and Kontoleon's (2009) work on the cooling effect of climbing plants found that there were significant interior and exterior reductions in surface temperature when climbing plants such as Boston Ivy were added to the east wall of a building. Research also shows that different walls lead to different effects when greenery is added. For example, Kontoleon and Eumorfopoulou (2010) found that the exterior surface temperature was most reduced on the west side, followed by east, south and north. Price (2010) investigated the impact of green walls on residential buildings in North America and found that on sunny days, south- or west-facing walls were able to reduce the interior air temperature, exterior surface temperature, exterior ambient temperature and heat flux through the walls. All of these studies show that there are marked cooling effects when the temperatures are higher, thus regions with high temperatures (such as tropical regions) are bound to reap more benefits from green walls than those in cooler climates.

In addition to looking at the cooling properties of green walls, research has also been undertaken on their thermal insulation capabilities in cooler climates. For example, Baumann (1986) found that convectional heat loss is reduced due to evergreen species trapping air against the façade, leading to energy savings. However, the energy savings are less significant when the building walls are made of materials that allow for good insulation. Doernach (1979) found out through experiments that an insulating effect of up to 30% was possible when temperatures fell close to zero. In a more recent study, Köhler (2007) measured the insulating effect of ivy, which accounted for cooling in summer and approximately 5°C insulation in extreme winter. Research by Dinsdale et al. (2006) show that a 25% reduction in heating demand was achieved at Queen's University Campus (Canada) by the use of vegetation to insulate buildings from cold winds.

Additionally, there is a growing body of research on the type of plants suitable for green walls in order to maximise the benefits of ecosystem services and to determine the impacts. For example, Stemberg et al. (2010) investigated dust particle absorption by ivy and found that vegetation acts as a sink for fine dust particles. Utilising research on tropical forests, Blanc (2002) suggested that using tropical plants as vertical vegetation would be beneficial given the similarities in climatic conditions between urban canyons in warmer climates and tropical forests. Plants that already have adaptive capacity for living with less light and high winds would fare best in such areas, depending on climate.

Recent research by Pugh et al. (2012) investigated the potential for air pollution mitigation by street-level GI procedures such as green walls and street trees in street canyons. Studies on nitrogen dioxide (NO_2) and particulate matter (PM_{10}) showed that street-level reductions of up to 40% for NO_2 and 60% for PM_{10} could be achieved via application of green walls. Pugh et al. (2012: 7697) went on to state that 'of the green infrastructure options available in a densely populated urban area, in-canyon vegetation offers by far the biggest benefits for street-level air quality, much greater than, for example, green roofs.' Green (living) roofs are nonetheless a successful GI procedure for stormwater management, so the appropriateness and purpose of GI installations must be assessed on a case-by-case basis to obtain the best possible results.

Life-Cycle Assessment (LCA) has been used to quantify and compare the impact of different green walls. For example, in The Netherlands, Ottelé et al. (2011) compared the life cycles of conventional brick wall, a façade greened directly, a façade supported by steel mesh, a façade consisting of planter boxes and a façade made of felt layers. The study concluded that it is 'not clear if these systems are sustainable, due to the materials used, maintenance, nutrients and water needed' (Ottelé et al., 2011: 3419). Green façades and walls can fail due to numerous factors such as irrigation system failure, poor plant selection, plant quality, container substrate issues and problems in installation and establishment (Rayner et al., 2010). Indeed, irrigation needs of some green walls, specifically the intensive ones, are more demanding and require further investigation. As mentioned previously, intensive green walls are more likely to be considered as works of art requiring significant water resources to keep the plants alive depending on the climate in which they are used. Green walls should thus be designed in conjunction with an irrigation scheme – preferably one that utilises captured stormwater. Therefore, in addition to the need for more life-cycle research, there is a need to develop appropriate irrigation schemes according to the type of green wall applied and the climate in which it is applied. More life-cycle research is required in order to establish the long-term viability of green walls.

In addition to methods to assess the impacts of green walls, there are programmes such as LEED (Leadership in Energy and Environmental Design) that support and incentivise the use of green walls. Up to 18 LEED credits also can be gained by installing green walls for new buildings (Green Roofs for Healthy Cities, 2008). However, despite the incentives it should be noted that it is possible that the practices encouraged by organisations such as the Green Building Councils (e.g. LEED) may not necessarily be conducive to sustainability (Byrd and Leardini, 2011). Overall, this review echoes conclusions by Perini et al. (2011): while there are interesting developments in green wall technology, green wall concepts have not yet been sufficiently investigated to draw clear conclusions.

2.2.9 BIORETENTION

Bioretention systems can be applied to small sites such as car parks, residential swale and highway medians. Bioretention is an engineered system of filtration media and plants that is used to improve water quality and replicate pre-development hydrology. From the surface, it appears as a depression in the landscape that is designed to allow for the retention and treatment of pollutants (Roy-Poirier et al., 2010; EPA, 2012b). Bioretention is often commonly referred to as rain gardens (this is the term preferred in New Zealand). A distinction is sometimes made in North America whereby bioretention is the engineered system as described above, whereas a rain garden may incorporate the landscape depression and plants but without specific engineered fill media or other associated technical components related to stormwater management. According to the Virginia Department of Forestry (2008), bioretention can be developed to suit the climate and thus are practical solutions to stormwater issues in many parts of the world. Table 16 outlines the functions, benefits and issues associated with bioretention systems. Note that some or most of the issues can be managed through good design.

Table 16 Functions, benefits and issues of bioretention systems

Functions and benefits	Issues
• Reduces volume of stormwater runoff through storage in media for subsequent evapotranspiration and by exfiltration to surrounding soils (where conditions allow); • Although not designed for flood control, they control hydrologic impacts from the most frequently occurring rainfall events; • Reduces pollution of waterways via detaining and filtering pollutants and reducing total runoff volume discharged to waterways; • May satisfy landscaping requirements in parking lot applications; • Increases groundwater recharge; • Can improve biodiversity; • Can be aesthetically pleasing; • Cost effective.	• Overflow due to incorrect design (permeability of soil not tested); • Proper siting requires minimum separation from building foundations and seasonally high groundwater elevation; • Cannot be used to treat large drainage areas; • Requires annual maintenance – maintenance requirements may declining with time; • Should not be installed in catchments with active construction or significant amounts of exposed soils due to the potential to clog the media; • Fertiliser addition for plant growth compromises runoff water quality treatment.

The primary function of bioretention and rain gardens is to control stormwater runoff. In particular, research has been focused on outflows and inflows, pollution concentrations and reductions (Dietz and Clausen, 2005; Hunt et al., 2006; Davis et al., 2009). Numerous studies have found the practice to be efficient at pollution removal, though the results varied among studies. For example, Hunt et al (2006) studied pollutant removal and hydrological performance of three bioretention field sites in North Carolina. Their findings show high annual total nitrogen mass removal rates (40% reduction), variable nitrate-nitrogen mass removal rates of between 75 and 13% and annual mass removal of zinc, copper and lead of 98%, 99% and 81% respectively. Davis (2007) investigated water quality improvements of parking lot runoff at the University of Maryland and found event mean concentrations of 47% for total suspended solids (TSS), 76% for total phosphorus (TP), 57% for copper, 83% for lead, 62% for zinc and 83% for nitrate-nitrogen. The studies note that removal/reduction coefficients depend on factors such as attenuation of flow. Rusciano and Obropta (2007) conducted simulations to model performance of bioretention systems for New Jersey. The study resulted in a range of reduction coefficients for faecal coliform (FC) (mean, median and range of 91.6%, 98.6% and 54.5% to 99.8%, respectively), total suspended solids (TSS) (mean, median and range of were 91.5%, 91.9% and 81.0% to 99.4% respectively) and pH (influent pH of 6.87 and average leachate pH of 4.61).

In a substantial literature review of bioretention, Fassman et al. (2013) found that media composition heavily influences nutrient removal or release but heavy metals and TSS seem well controlled by bioretention regardless of the media composition.

EPA (2012f) presented the following pollutant removal efficiencies from two rain gardens in Maryland, USA:

- 43-97% removal of copper;
- 70-95% removal of lead;
- 64-95% removal of zinc;
- 65-87% removal of phosphorus;
- 52-67% removal of total Kjeldahl nitrogen (TKN);
- 92% removal of ammonium (NH_4^+);
- 15-16% removal of nitrate (NO_3^-);
- 49% removal of total nitrogen (TN);
- 27% removal of calcium.

According to Anderson (2011), there is a paucity of research on residential rain gardens as well as research on the hydrological performance in arid regions. Furthermore, Davis et al. (2009) has reviewed the literature on bioretention concluding that although the various techniques are able to manage pollutants including pathogenic bacteria and thermal pollution, more research is necessary for the benefits to be quantified. They also noted that 'BMPs [such as bioretention] can be problematic because of the variability in conditions experienced during runoff events' (Davis et al., 2009: 112). Additionally, research has been carried on the type of plants that would survive in the conditions that rain gardens are subjected to (Liebsch, 2011).

Other GI bioretention technologies include bioswales that provide a shallow depth of engineered media beneath the surface of a swale, such that flow is primarily through the media. A variety of plant species may be incorporated providing functions sought after for stormwater management, improving water quality and amenity value. According to Novotny and Olem (1994), bioswales differ from grassed waterways (or swales), which are essentially for conveying runoff rather than focusing on treatment. Nevertheless, despite the differences, the term 'bioswale' is used in some cases to describe other types of vegetated swales. This linear type of bioretention system can be utilised in lieu of curbs, gutters and stormwater sewer systems in residential, some industrial, or commercial areas (EPA, 1999).

Fassman and Liao (2009) found grassed swales were successful at peak flow volume control (storms less than 25mm), runoff control (storms less than 13mm) and pollutant removal (TSS, copper and zinc). This study showed that grassed swales were not effective at controlling Total Dissolved Solids (TDS). Yu et al. (2001) investigated pollutant removal efficiencies of grassed swale tests in Taiwan (agricultural test farm) and Virginia (highway median swale). The results for total suspended solids (TSS), chemical oxygen demand (COD), total nitrogen (TN) and total phosphorus (TP) varied from 14% to 99%; the authors note the significance of design parameters such as length and slope as factors contributing to the wide range of results. Bioswales and grassed swales are able to slow and retain runoff from storm events and remove pollutants in runoff. Pollution removal efficiencies of vegetated swales, according to EPA (1999), are as follows:

- 81% removal of total suspended solids;

- 67% removal of oxygen demanding substances;
- 38% removal of nitrate;
- 9% removal of total phosphorus;
- 62% removal of hydrocarbons;
- 42% removal of cadmium;
- 51% removal of copper;
- 67% removal of lead;
- 71% removal of zinc.

Other studies reviewing performance show variability due to differences in context, design and conditions (e.g. storm events). Schueler (1997) estimated that 81% of total suspended solids, 29% of total phosphorous, 38% of nitrate nitrogen, 14% to 55% of metals and 50% of bacteria can be removed by grassed channels. Performance measures from numerous studies conducted prior to 1993 were presented in EPA (2012e). A review undertaken for Seattle Public Utilities by Herrera Environmental Consultants (2006) found that, in the Pacific Northwest, bioswales removed 64% of influent total suspended sediment, 18% of total phosphorus and 47% of total zinc. The local bioswales were found to perform poorly for removal of bacteria (-8%) and hydrocarbons (-10%) (Herrera Environmental Consultants, 2006). Recent research on engineered media (with high porosity) by Xiao and McPherson (2011) reported reduced runoff by approximately 89% and total loading by 95.4%, with reduction rates for iron and nitrogen of 86% and 97% respectively. Furthermore, 95% of minerals, 87% of metals, 95% of organic carbon and 95% of solids were removed. Overall, vegetated swales, bioswales and grassed swales are recommended by numerous studies for improving water quality (Barrett et al., 1998; EPA, 2004; Matteo et al., 2006).

In a comparison of grassed swales with other stormwater BMPs, Barrett (2005) evaluated 42 storm events for six grassed swales and found that, on average, they removed 54% of zinc, 24% of copper and 48% of suspended solids. This study found high export of nutrients: -28% nitrate and -242% orthophosphorus. Other studies such as Dietz and Clausen (2008) and Hunt et al. (2006b) are consistent with export of total phosphate. The issue is linked to phosphorus from planted areas and fertiliser (Dietz, 2007).

While bioretention plants may provide significant amenity value, the system's primary purpose is for stormwater management. Fassman et al. (2013) describe the role of the plants in terms of contributing to performance aspects such as sedimentation and surface erosion control, microbial processes (particularly in the rhizosphere) for contaminant cycling, nutrient and heavy metal removal and stormwater volume and attenuation through evapotranspiration. Bioretention hydraulics (surface infiltration and media hydraulic conductivity) are maintained by shoot and root growth, active invertebrate activity and reducing the potential for compaction. There is potential conflict between the amenity and pollutant removal functions of bioretention, whereby fertiliser additions to enhance amenity are likely to contribute high nutrient concentrations in "treated" bioretention discharge. Lewis et al. (2010) provide New Zealand-specific planting suggestions for various vegetated stormwater systems to promote amenity and ecology without compromising stormwater functions. Barrett et al. (2011) found that compared to unvegetated systems in the laboratory, vegetated systems improved total nitrogen, total phosphorus and dissolved phosphorus removal, but did not affect suspended solids removal.

Bioretention function is strongly influenced by the physical and chemical characteristics of the engineered fill media. Fassman et al. (2013) established locally-relevant performance objectives related to media hydraulic conductivity, response to compaction and chemical properties that influence the ability to support plant life and contribute to water quality improvement. Combinations of materials readily accessible to the Auckland region were investigated for potential compliance. Bratieres et al. (2008) and Hatt et al. (2008) determined that low organic content or predominantly sand-based media was more successful for retaining nitrogen and phosphorus, while Hunt et al. (2006b) established limits on the phosphorus "P-index" for bioretention media to prevent phosphorus leaching. Soil amendments that increase cation or anion exchange capacity, the addition of aluminium oxides, zeolite and wood chips may improve pollutant retention (Ergas et al., 2010; O'Neill and Davis 2012a, 2012b; Tarkalson and Ippolito, 2010; Lucas and Greenway, 2011).

2.2.10 Dry and wet ponds

The primarily purpose of both dry and wet ponds is the management of stormwater. According to EPA (2012a), 'Dry detention ponds (also known as dry ponds, extended detention basins, detention ponds, extended detention ponds) are basins whose outlets have been designed to detain stormwater runoff for some minimum time (e.g. 24 hours) to allow particles and associated pollutants to settle'. These ponds are vegetated basins, which fill up during storms and slowly release water over a number of hours. Their functions, benefits and issues are outlined in Table 17. Current research considers improvement of design and pollution monitoring.

Table 17 Functions, benefits and issues of dry ponds

Functions and benefits	Issues
• Reduces peak rate of stormwater runoff by detaining water; • Controls floods; • Can perform well in cold climates; • Area can be used for recreation when dry.	• Only low to moderate pollutant removal capabilities; • Large land areas required; • May increase water temperature (which may affect temperature sensitive biodiversity); • May encourage mosquito breeding during rainy periods; • Potential issues with clogging; • May be unsightly and thereby contribute to reduction in property values; • Limited capacity in highly urbanised areas; • May require fencing for public safety.

According to EPA (2012c), 'wet ponds (also known as stormwater ponds, wet retention ponds, wet extended detention ponds) are constructed basins that have a permanent pool of water throughout the year (or at least throughout the wet season)'. Their functions, benefits and issues are listed in Table 18. As with dry ponds, current research focuses on improvement of design and pollution monitoring.

Table 18 Functions, benefits and issues of wet ponds

Functions and benefits	Issues
• Reduces peak rate of stormwater runoff by water detention; • Pollution control; • Can be aesthetically pleasing; • Can lead to increased property values.	• Limited capacity in highly urbanised areas; • Can be impractical in arid areas; • Can cause stream/river warming due to increased water temperatures; • Can pose as safety hazards if not properly fenced; • Mosquito breeding; • Increases water temperatures; • Sediment saturation leading to leaching of contaminants as system ages; • Algal blooms.

Ponds should almost always be the last choice due to their limited protection function (EPA, 2012a). In terms of satisfying the definition of GI presented in this report, ponds provide limited ecosystem services. As technology has developed, other forms of stormwater GI (i.e. bioretention, living roofs, permeable pavements) have been shown to provided superior performance, while providing multiple additional benefits (e.g. drivable surfaces, amenity and recreational space on rooftops, or landscaping).

2.2.11 CONSTRUCTED WETLANDS

Constructed wetlands are defined as 'designed complex of saturated substrates, emergent and submerged vegetation, animal life and water that simulates natural wetlands for human use and benefits' (Dzurik and Theriaque, 2003: 318). They are essentially constructed basins with a permanent pool of water (at least during the wet season). Constructed wetlands differ from wet ponds due to characteristics such as shallow depth and having greater vegetation (e.g. macrophytes such as *Typha latifolia* in the USA (Scholz and Lee, 2005) and *Phragmites australis* in Europe (Vymazal, 2011)). According to Brix (1994) constructed wetlands are classified according to the dominant macrophyte in the wetland: free-floating, emergent and submerged systems. The emergent system, which is the most common system used worldwide, is classified further into free water surface flow, subsurface horizontal flow and vertical flow. Other systems such as the tidal wave Living Machine®, a hybrid of the vertical flow and subsurface flow system, also fall under GI applicable for wastewater treatment. The four types are briefly compared in Table 19.

Similar to natural wetlands, constructed wetlands are complex systems. Constructed wetlands can be considered as GI, providing multiple benefits similar to natural wetlands, such as cost effective flood protection, flow attenuation, water quality, aesthetic appeal of landscapes, recreational amenity as well as wildlife habitat (Wong et al., 1996). They are also instrumental in offsetting loss of natural wetlands and producing food via aquaculture (Kadlec and Knight, 1996). Constructed wetlands are also used for wastewater treatment, combined sewer overflow control and groundwater remediation where the overall design of the wetland (including parameters such as size, depth and plant species) can differ according to the function fulfilled. Furthermore, it is possible to combine different types of constructed wetlands to achieve enhanced treatment. For example, popular hybrid constructed wetlands include a combination of vertical and horizontal flow systems. Table 20 outlines functions, benefits and issues associated with constructed wetlands. Due to the complexities involved, there is an extensive body of literature based on numerous research topics (e.g. design and construction, hydrology, vegetation, operation, performance and maintenance), some of which are reviewed in this section.

Table 19 Comparison of constructed wetland systems for wastewater treatment

Wetland system	Method of treatment
Free water surface	Wastewater treatment occurs via bacterial, physical and chemical processes as the water flows through the wetland. This type of wetland emulates nature (a passive system) in treating wastewater with water surface exposed. The wetland is planted with emergent wetland vegetation and flooded. These wetlands can be planted with vegetation that attracts native species. The system is relatively inexpensive and allows for moderate levels of wastewater treatment. This type of treatment takes advantage of the high surface area on which UV rays from the sun are able to act thus effective on removal of pathogens. Mosquito breeding can become a concern due to the surface waters and the system's effectiveness can be subject to seasonal conditions.
Subsurface horizontal flow	Wastewater treatment occurs via a combination of bacterial, physical and chemical processes as water flows through the gravel or sand media. The water surface is below the media surface and the media is planted with emergent wetland vegetation. There are no issues with mosquito breeding due to the lack of surface water. However, the cost of the media can be an issue.
Vertical flow	Wastewater treatment occurs as the influent is distributed to the surface and percolates down through the pea-gravel media planted with emergent vegetation. Multiple ponds, vertical filtration and high levels of biological activity make this process reliable and highly effective as influent is let in intermittently and as the media is continuously drained. Some of the effluent is re-circulated for better treatment. Vertical flow systems do not treat total nitrogen effectively. In fact, treatment is efficient at nitrification than the free water surface and subsurface horizontal systems. The system is energy intensive compared to the passive free water surface system and does not provide sufficient area for providing species habitat and biodiversity.
Tidal wave Living Machine	The system utilises a series of Tidal Flow cells connected by small basins and pump stations to form multiple wetland cells. Multiple fill and drain cycle mimic natural tidal flows taking advantage of the biological process of wetland plants as well as metabolisms of microorganisms to treat wastewater (Worrell Water Technologies, 2007). The system is applicable to small wastewater flows but can be energy intensive due to the need for pumps.

Source: City and County of San Francisco (2009)

Water quality and the pollution attenuating ability of constructed wetlands, particularly related to treatment wetlands, is well researched. Nevertheless, the underlying microbial processes that facilitate the treatment is less understood and researched and is generally treated as a black box (Faulwetter et al., 2009). Despite this gap in research, constructed wetlands have been used for treatment of sewage (i.e. domestic sewage, industrial wastewater and agricultural runoff) for at least two decades (Zang and Hong, 2006). According to Hammer and Bastian (1989), constructed wetlands were developed four decades ago to exploit the ability of plants to facilitate biodegradation. There is a wealth of information and directions for future research. Brix (1994), for example, presented a database of results on wastewater treatment by subsurface flow wetlands. Later, Vymazal (2002) presented findings from 10 years of experience in constructed wetland use for wastewater treatment in the Czech Republic. In the USA, constructed wetlands have been used for treating municipal wastewater, stormwater runoff, industrial wastewater and agricultural runoff. The treatment wetland database (TWDB) contains system descriptions and performance data for a multitude of pilot and full-scale projects including data from the revised EPA sponsored North American Database (NADB). The EPA has also published *Handbook of Constructed Wetlands* (EPA, 1995) which acts as a general guide for the Mid-Atlantic Region. Since then, a number of works reviewing various aspects of constructed wetlands have been published (e.g. a review of hydrological, physical and biochemical processes within natural and constructed wetlands by Scholz and Lee (2005); a review of constructed wetlands for stormwater management by Mungasavalli and Viraraghavan (2006); a review of organic and metallic pollutants in water treatment and natural wetlands by Haarstad et al. (2012)).

Table 20 Functions, benefits and issues associated with constructed wetlands

Functions and benefits	Issues
• Provides fish and wildlife habitat; • Opportunity for recreation (e.g. bird watching), education, scientific research; • Provides flood control mechanisms; • Treats stormwater (urban and highway runoff); • Treats wastewater (municipal and domestic grey water); • Treats industrial and agricultural wastewater; • Pollution attenuation; • Erosion regulation; • Aesthetic value – pleasant natural landscape; • Low-cost, low energy process requiring minimal operational attention; • Depending on design, high ability to tolerate fluctuations of flow and water quality; • Effective removal of pathogens.	• Pest species; • Flooding, if not designed and maintained appropriately; • Fears regarding potential pharmaceuticals, endocrine disruptors, persistent organic pollutants in recycled wastewaters – research is available on constructed wetland performance (given below); • Space requirements; • Technical issues such as progressive clogging near inlet; • Influence of temperature on treatment; • Slow start-up treatment (requires time for establishment); • Inadequate hydrology precludes establishment of wetland conditions.

Source: California Stormwater Quality Association (2003); EPA (2006); Zhang and Hong (2006); Töre et al. (2012)

Scholz and Lee (2005) reviewed the literature in order to evaluate hydrological, physical and biochemical processes within natural and constructed wetlands. While most of the review focused on natural wetlands, they identified two types of constructed wetland systems (horizontal flow and vertical flow), noting that vertical-flow constructed wetlands have higher removal efficiencies for removing organic pollutants and nutrients although they are less efficient at denitrification. Additionally, Scholz and Lee (2005) identified gaps in knowledge and understanding of wetlands in the tropics as well as arid areas of South America, Africa and Asia.

Nevertheless, densely populated countries such as China have been using constructed wetlands (i.e. vertical flow, subsurface flow and surface flow) for treating sewage from numerous sources such as cesspits, nurseries, paper mills, oil and coal mines, a eutrophic lake and the urban environment (Zang, 2011).

A review by Mungasavalli and Viraraghavan (2006) provided a broad overview of constructed wetlands, reviewing the literature on design, performance, operation and maintenance for stormwater management. Their findings indicated that constructed wetlands have 'excellent pollutant removal ability in treating stormwater runoff, with a few exceptions' (Mungasavalli and Viraraghavan, 2006: 1366). Whilst it is challenging to compare the performance of different constructed wetlands due to the complex variability of conditions and contexts (e.g. design considerations, vegetation and climatic conditions) they found that, on average, constructed wetlands were able to remove 80% of faecal coliforms, 80% of organic material and suspended solids, 50% of heavy metals and 60% of nutrients from urban stormwater runoff. The review concluded that with proper design and maintenance, constructed wetlands can be efficient means of stormwater management for the long term.

Early research has established that, despite treatment from conventional wastewater treatment plants, organic pollutants (such as pharmaceuticals, personal care products, pesticides, surfactants, plasticisers) can be found in effluent discharged to water bodies (Töre et al., 2012). As such, there have been concerns over the existence of pharmaceuticals, endocrine disruptors and persistent organic pollutants in recycled waters. Research on performance measures for the efficacy of constructed wetlands in treating these pollutants has been underway. For example, it has been found that reed beds are effective in the removal of phthalates, alkylphenol ethoxylates, oestrogens, polycyclic aromatic hydrocarbons (PAHs), as well as several types of pesticides (Masi, 2005; Fontoulakis, 2009; Agudelo et al., 2010; Töre et al., 2012). However, according to Töre et al. (2012), there is currently no consensus on the thresholds for pharmaceuticals and personal care products. The review of literature conducted by Töre et al. (2012) contains numerous removal efficiencies for endocrine disrupting chemicals, pesticides, pharmaceuticals and personal care products, suggesting high potential for removing a wide range of pollutants via constructed wetlands.

Haarstad et al. (2012) recently compared organic and metallic pollutants in water treatment wetlands and natural wetlands. The review found that there are more than 500 organic and metallic pollutants in wetlands. The results of the review indicated that heavy metal removal was in the order of 30% to 60% with a maximum efficiency of 90%; that aerobic conditions are required for effective hydrocarbon removal; 50-100% hydrophobic organic compounds were removed; microbiological processes and plants made the removal of explosives more efficient as compared to relying on adsorption processes; 40-99% of pesticides were removed; and pharmaceuticals and personal care products were removed in a similar manner to that of conventional activated sludge wastewater treatment plants. Furthermore, since metals require stable redox conditions, the study cautioned against the use of subsurface flow-constructed wetlands to treat metal contamination from industrial wastewater, to prevent shifting of contaminants to different environmental compartments (Haarstad et al., 2012).

In recent years, constructed wetlands have been utilised successfully for water quality from urban stormwater runoff. Current literature ranges from topics such as thermal pollution and the impact on fish species such as trout (Jones and Hunt, 2008), to the removal of toxic pollutants such as arsenic (Lizama et al., 2011). The former study, reporting on the monitoring of a stormwater wetland in North Carolina, found that the effluent was warmer than the influent during summer and thus proposed design changes to counter temperature due to warm surface water, radiation and convective heat transfer. The latter study, carried out by Lizama et al. (2011), found that pH, alkalinity, temperature, dissolved oxygen, the presence of other chemical species such as iron, sulphur, phosphate, a source of carbon and the wetland substrate were important factors affecting arsenic speciation and called for studies to obtain better understanding of the function bacteria in treatment wetlands play in removing arsenic.

Jenssen et al. (1993) investigated the performance of constructed wetlands in treating wastewater in colder climates such as in Norway, Denmark, Sweden and North America. They concluded that 'winter performance is not significantly reduced as compared to other seasons, but in order to obtain high removal of organic matter and nitrogen in cold climates, aerobic pretreatment is probably a prerequisite' (Jenssen et al., 1993: 149). This was based on findings that 'significant biological activity occurs at temperatures between 0 and 5°C and that high removal rates of nutrients and organic matter are achieved in ponds and soil amended with wastewater at these temperatures' (Jenssen et al., ibid.). Scholes et al. (1998) investigated climatic conditions for treating stormwater with constructed wetlands. Their findings indicate that the effective volume of the wetland will be reduced as water freezes during winter. Due to increased growth of plants in warmer weather, removal of phosphorus and nitrogen is enhanced in summer (Mungasavalli and Viraraghavan, 2006). Therefore, efficacy of constructed wetlands would depend on the season as well as other parameters such as design, plant species and the kind of effluent treated.

Other research areas associated with constructed wetlands are vegetation and issues such as pest species. There are numerous works based on aquatic vegetation suited for maximising the effectiveness of treatment in constructed wetlands (Bachand and Horne, 1999; Scholz and Lee, 2005; Worman and Kronnas, 2005). Research covers the appropriate species and conditions for plants, their tolerance with respect to the effluent released into the constructed wetland, their pollutant removal capacity and their ability to propagate and establish themselves (Tanner, 1996). Vegetation should be selected depending on its effectiveness, availability and pollution tolerance capacity (Revitt et al., 1999).

Constructed wetlands and their associated vegetation provide habitats that assist wildlife conservation as well as enabling recreation for communities (Hawke and José, 1996). Concerns over mosquito breeding and the potential for the spread of disease have led to numerous studies (e.g. Knight et al., 2003; Hunt et al., 2006a; Yadav et al., 2012). The studies have found that factors such as physicochemical water quality parameters, temperature, sunlight water depth, vegetation type and predator abundance all influenced mosquito breeding. Knight et al. (2003) found that constructed wetlands had lower mosquito larval density compared to ponds and smaller scale stormwater-fed constructed wetlands. In recent research, Yadav et al. (2012: 509) found that 'created wetlands had lower mosquito larval density compared to the pond and newly constructed smaller-scale stormwater-fed wetland,' where the outflow region of the wetlands provided a conducive environment for mosquitoes with vegetation that had a higher propensity to support mosquitoes. Earlier, Hunt et al. (2006a) investigated the occurrence and abundance of mosquitoes in stormwater retention facilities such as constructed wetlands. This particular study compared standard wet ponds, innovative ponds and wetland ponds in North Carolina. The study found a significant association between mosquito larvae or pupae and the absence of mosquitofish in wetland stormwater retention facilities when compared to standard retention facilities. It should be noted that predators of mosquito larvae and pupae are context specific; native fish species (such as whitebait in New Zealand) are effective in combating mosquitoes. Introduced species such as the mosquitofish can threaten native fish species (e.g. by aggressive behaviours and consumption of native fish eggs). A significant insight from the research by Knight et al. (2003) was that the risk of disease and inconvenience due to pests needed to be offset by the economic savings, enhanced water quality and thus reduction of pollution. Additionally, ecological risks associated with chemical control of mosquito populations needs to be offset against the benefits of constructed wetlands. Carefully designed, context specific constructed wetlands would help offset issues and provide multiple benefits.

As mentioned above, there are many types of constructed wetland systems. The Living Machine® is a patented technology for wastewater treatment that mimics the treatment function of natural coastal wetlands (EPA, 2001). The tidal flow Living Machine system is an improved version of the Living Machine concept of 1996. It has a small footprint – much smaller than any of the other constructed wetland systems. This enables it to be constructed in urban and suburban scale sites. Furthermore, its aesthetic appeal allows it to be part of the design of buildings and act as an atrium (Lohan and Kirksey, n.d.). According to the USA EPA (2001), the advantages of the Living Machine system were associated with the ability to treat wastewater to BOD5, TSS and total nitrogen to less than 10 mg/L, nitrate to less than 5 mg/L, ammonium to less than 1 mg/L in a case study in South Burlington, USA, treating wastewaters of 80,000 gpd (gallons per day). The disadvantages, according to USA EPA (2001), were ineffective phosphorus removal and the need for greenhouses in temperate climates.

Since then, numerous case study projects have been carried out, including a comparison of performance for decentralised wastewater treatment systems in North America and Australia (Lohan et al., 2011.). Lohan et al. (2011) found that all the technologies surveyed (including treatment technologies based on membrane bioreactors by Aquacell and GE, re-circulating textile filter from Orenco Systems Inc. and wetland design by Natural Systems International) met reuse requirements with variations relating to footprint, energy use, operational requirements, capital and life cycle costs. The authors pointed out that the level of treatment depends on the reuse application. They provided the following recommendations for decentralised wastewater treatment systems in general:

- The technologies should be tailoured to expected influent quality and selected according to the reuse application (mindful of public safety);
- The technologies should become beautiful site amenities or be invisible with respect to visual pollution or odour.

Furthermore, Lohan et al. (2011) stated that calculation of costs is made difficult due to variability in application, regulations, maintenance requirements and project-specific factors including building costs. They identified numerous barriers to the adaptation of decentralised wastewater management systems, including the regulatory environment (lack of or outdated legislation) and politics (concerning opposition by those who have vested interests in centralised water and wastewater treatment systems).

2.2.12 NATIVE FLORA

Plants are at the heart of GI, for they are agents of numerous ecosystem services. They can be used as part of stormwater management systems, to reduce the heat island effect in dense urban areas, to assist biodiversity by providing habitats, to sequester carbon, provide food for humans and other creatures, as well as purify air, water and land. Additionally, plants give aesthetic appeal to LID projects and thus have an impact on health and wellbeing. The use of native flora for landscaping has many advantages over introduced plant species (see Table 21), primarily because native plants have evolved over time in their respective environments and have developed an adaptive capacity to survive in that particular native habitat. The rationale for encouraging native plants is based on a combination of science, culture, design and a desired aesthetic. For example, certain native species have evolved with a capacity to absorb more water as their natural surroundings are wetlands, while some plants may not require as much water given their biological evolution in arid conditions (Helfand et al., 2006; Sovocool et al., 2006; St. Hilaire et al., 2008). This explanation is generally accepted by organisations such as the Ladybird Johnson Wildflower Center, the Peggy Notabaert Nature Museum and New York City's Greenbelt Native Plant Center. However, it is not clear whether native plants are adapted to the altered conditions of urban environments, despite being native to the region. For example, while some native plants may flourish at ground level, they may not necessarily adapt well to being relocated to a rooftop.

Irrespective of their origin, plants need to be matched to the site conditions or they will not survive, leading to the failure of the GI. Thus a plant species thriving in GI in North America may not be well suited for conditions in New Zealand and vice versa. Similarly, plants that thrive in one city of New Zealand may not thrive in another due to climatic or other regional differences (such as soil type). Therefore, seeking local knowledge on what grows best for local environments is recommended when populating GI projects with plants and trees; local horticulturalists may be consulted to provide advice on plants suitable for GI specific to their locale. Furthermore, research is necessary when trying to relocate plants into uncommon sites, such as rooftops and walls.

Table 21 Functions, benefits and issues of native plants

Functions and benefits	Issues
• Assists in stormwater management; • May not require as much water; • Adapts to survive in local environments.	• Maintenance needs to apply to all forms of plants.

2.2.13 Green energy

Since the industrial revolution, society's need for energy has been increasing. Energy is required for all human activities including heating, cooling, lighting, electricity for appliances and machinery, transport, among other uses. Since transportation was discussed previously, this section will concentrate on energy for urban areas in the form of electricity. Humanity's main source of energy currently comes from fossil fuels. There are many issues associated with the release of pollutants from combustion, ranging from anthropogenic global warming to respiratory disease.

Attempts to reduce impacts of energy related issues include efforts to conserve energy and to set up renewable energy generation. The World Economic Forum (2009) recognises that while fossil fuel is likely to continue to be a primary source of energy, eight renewable sources are emerging: 1. Onshore Wind; 2. Offshore Wind; 3. Solar Photovoltaic (PV); 4. Solar Thermal Electricity Generation (STEG); 5. Municipal Solid Waste-to-Energy (MSW); 6. Sugar-based Ethanol; 7. Cellulosic and Next Generation Biofuels; and 8. Geothermal Power. While GI strategies are expected to involve the use of renewable energy as well as decentralised mechanisms to generate energy to meet local needs, they do not fall under the scope of GI. However, they can be used in conjunction with GI – for example, there are cases where living roofs have solar panels installed on them (e.g. The Ballard Library in Seattle). Research by Köhler et al. (2002) found a synergetic relationship between photovoltaic (PV) panels and plants on living roofs where PV panels functioned better due to the cooler temperature afforded by the living roof while the shading offered by PV panels improved growth of plants and increased the number of species that can survive on the roof.

While there is an extensive body of literature on decentralised and renewable energy sources, research associated with GI tends to focus on how LID techniques such as living roofs and green walls can lower energy needs for buildings rather than taking into consideration the energy generation aspect. Both solar and wind energy technologies can be incorporated into building structures and infrastructure in general. Incorporating them under the umbrella of GI may provide means of connecting technological solutions with natural ones. However, it should be noted that there are both benefits (e.g. no carbon dioxide production during use) and issues (e.g. life cycle impacts of component production) associated with current renewable technologies such as PV (Tsoutsos et al., 2005; Gunerhan et al., 2009).

2.3 Barriers to greening

Barriers to GI can occur in many forms, including economic, social, institutional and environmental barriers. EPA categorises barriers to GI according to barriers encountered by municipalities (e.g. perception that performance is unknown, perception of higher costs, conflicts with law, codes and ordinances, resistance within regulatory community, unfamiliarity with maintenance requirement costs), developers (e.g. perception of higher costs and scepticism about long term performance) and design challenges (e.g. perceived limitations to application in different soil types, performance in different weather conditions) (EPA, 2012d). The Clean Water America Alliance's report, *Barriers and Gateways to Green Infrastructure* (2011), provides a comprehensive set of barriers, which are listed in Table 22 under four categories: technical and physical, legal and regulatory, financial and community and institutional.

Table 22 Barriers to GI

Type	Barrier
Technical and physical barriers	• Lack of understanding and knowledge of what green infrastructure is and the benefits it provides; • Deficiency of data demonstrating benefits, costs and performance; • Insufficient technical knowledge and experience; • Lack of design standards, best management practices, codes and ordinances that facilitate the design, acceptance and implementation of green infrastructure;
Legal and regulatory barriers	• Local rules can be lacking, conflicting, or restrictive; • State water and land-use policies and property rights can be complicating factors; • Federal rules can be conflicting, overly prescriptive, without needed flexibility, or silent in key aspects;
Financial barriers	• Not enough data about upfront and continuing maintenance costs and economic benefits; • Perceived high cost over short and long term; • Lack of funding at all levels coupled with poor coordination or integration of programs and funds; • Too much risk – not enough incentives;
Community and Institutional Barriers	• Insufficient and inaccessible information about green infrastructure and its benefits for political leaders, administrators, agency staff, developers, builders, landscapers and others, including the public; • Community and institutional values that under-appreciate green infrastructure aesthetics and characteristics; • Lack of inter-agency and community cooperation.

Tabulated from Clean Water America Alliance (2011)

Together with research on the overall barriers to GI application, there is also research investigating the barriers to the individual GI procedures. For example, Stockwell (2009) and Tian (2011) investigated barriers to the application of LID procedures for stormwater management. Furthermore, research such as that carried out by Zhang et al. (2012) focused on a single LID procedure such as barriers to green roofs. Thus there are many levels at which barriers to GI are investigated and it is generally accepted that there are multiple barriers involved.

A significant barrier is related to the proximity and accessibility to green spaces (Croucher et al., 2007; Kaczynski and Henderson, 2007; Neuvonen et al., 2007). Weldon et al. (2007: 6) broadly categorises barriers to accessibility as: 'lack of knowledge; negative perceptions, fears and safety concerns; lack of motivation; lack of time; physical accessibility; lack of physical fitness; feeling unwelcome; lack of reasonable facilities; and conflicts of use'. Forest Research (2010) cites UK's Urban Green Spaces Task Force's (2002) social barriers to GI use as follows:

1. Lack of or poor condition of facilities, especially seats, toilets and play opportunities for children;
2. The incidence of anti-social behaviour. The potential for conflict between children and adults is often cited, but there are increasing concerns over the presence of drug and alcohol users, undesirable characters and 'stranger danger';
3. Concerns about dogs and dog mess;
4. Safety and other 'psychological' issues including feelings of fear and vulnerability based on real experiences and perceived concerns. This applies not only to people's own personal fears, but also especially to fears for their children;
5. Environmental quality issues such as litter, graffiti and vandalism; and
6. Loss of variety and too much 'old hat', especially for young people for whom Victorian parks do not always represent an exciting or attractive environment.

Barriers could be overcome in multiple ways including via research and provision of technical guidance for designing GI systems. Research on performance measures should indicate that there are multiple benefits to applying GI, including potential cost savings with respect to avoided impacts. More information on maintenance procedures and costs as well as adequate technical support and guidance with communication among professionals, practitioners and the public would benefit the uptake of GI. Additionally, recognising that GI application can add value to properties may also help overcome some of the barriers faced.

2.4 SYNOPSIS: CONNECTIVITY AND MULTI-FUNCTIONALITY

The built environment of urban centres exists within the complex systems of the Earth's environment. Therefore, it is to be expected that human actions result in impacts on ecosystems. For example, as urban centres increase in size, the amount of paved surfaces also increases. These paved surfaces reduce permeability, which results in increased volume and energy of runoff. This runoff can impact upon land and wetlands, leading to issues such as pollution, erosion, loss of biodiversity and each consequence reflects a risk to human wellbeing via the loss of ecosystem services. With the research undertaken and knowledge gained on the various impacts of human activities, it can be seen that there are intrinsic connections among the systems that provide ecosystem services. Therefore, familiar reductionist approaches to solving issues related to human activities should be avoided as the transfer of problems from one ecosystem to another can easily occur without intention or knowledge. Similarly, risks are transferable from environmental, social and economic systems due to the multiple interdependencies and connectivity of these systems, as illustrated in Figure 4.

According to the literature, the growing understanding of the consequences associated with infrastructure that supports urban centres and the awareness of imperfectly engineered environments drives GI research and development. Although there are numerous definitions for GI, the ideas of connectivity and the involvement of nature (greenery) to solve problems in the built environment of urban areas is a common theme. The primary functions/objectives of GI are:

- Water management;
- Human health and well-being;
- Conservation of biodiversity;
- Sustainable land management; and
- Climate change mitigation and adaptation.

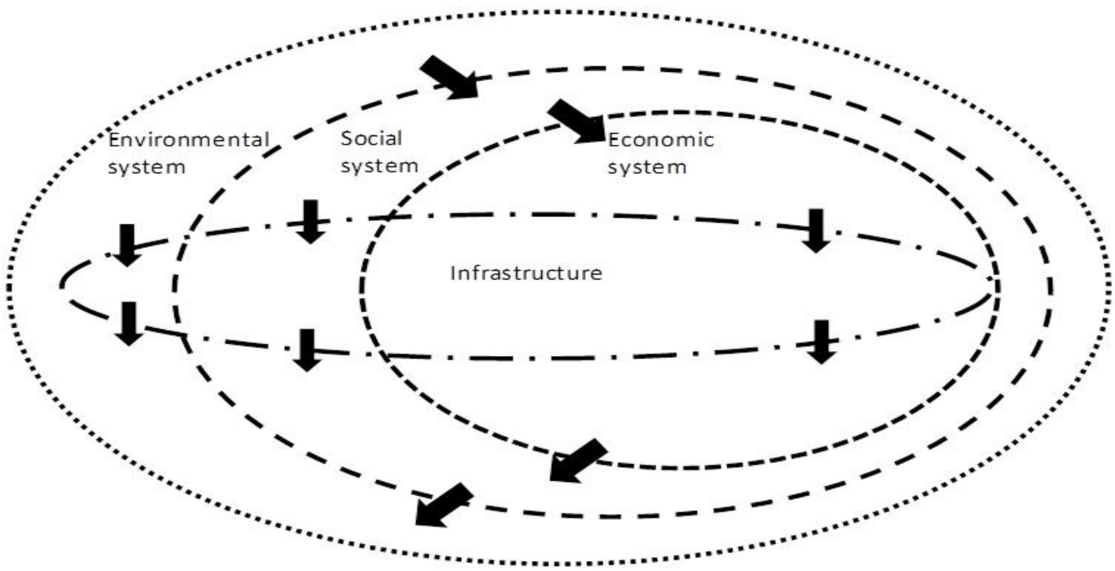


Figure 4 Distribution of risk across environmental, social and economic systems from infrastructure

There are many GI procedures that are able to assist in the amelioration of impacts associated with urbanisation and thus in preserving ecosystem services for the benefit of human beings and other species. These benefits can be further categorised according to their economic, social and environmental dimensions:

- Economic benefits: cost effective urban design (e.g. for stormwater management, reduction in urban heat island effect), job creation, reduced cost from natural hazards;
- Social benefits: recreation and cultural heritage, health and wellbeing, community and education; and
- Environmental: amelioration and preservation of ecosystem services (air, water, soil), preservation of biodiversity, pollution mitigation.

There are many assets and procedures that enable GI to be incorporated into urban areas. Some of these include urban parks, wetlands, conservation corridors, green streets, living roofs and green walls. All of these procedures and assets contribute to multiple functions and numerous benefits. For example, procedures and assets such as nature reserves and conservation corridors can assist in the conservation of biodiversity despite urban sprawl and encroachment on natural habitat. They can also encourage recreation activities and thus enhance human wellbeing. The multiple functions of GI assets are categorised in Table 23.

Table 23 Economic, social and environmental benefits by GI assets and procedures

	Regional			**Local**									**Local to national**	
Function/objective	Nature reserves	Wetlands, rivers	Conservation corridor	Constructed wetlands*	Urban parks	Green streets	Permeable pavement	Living roofs	Green walls	Rain gardens	Dry ponds	Wet ponds	Renewable energy	Green transport
Economic														
Water and flood risk management	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓		
Water quality, water supply and function of hydrology	✓	✓		✓		✓	✓	✓		✓	✓	✓		
Sustainable energy use and production		✓		✓				✓	✓				✓	
Sustainable waste management													✓	
Sustainable food production		✓		✓				✓						
Microclimate adjustment and adaptation to climate change	✓		✓		✓	✓		✓	✓					
Energy savings								✓	✓				✓	✓
High-quality environment to attract and retain a quality workforce					✓								✓	✓
Rising property values		✓		✓		✓		✓	✓	✓				
Boosts to the local economy	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Links between town and country			✓			✓								✓
Social														
Recreation, enjoyment and health benefits	✓	✓	✓	✓	✓	✓		✓	✓		✓			

Community development and cohesion					✓	✓								
Provision of space for public art, concerts, etc.					✓						✓			
Non-motorised transport systems						✓								✓

Table 23 Economic, social and environmental benefits by GI assets and procedures (cont.)

	Regional			**Local**									**Local to national**	
Function/objective	Nature reserves	Wetlands, rivers	Conservation corridor	Constructed wetlands*	Urban parks	Green streets	Permeable pavement	Living roofs	Green walls	Rain gardens	Dry ponds	Wet ponds	Renewable energy	Green transport
Social														
Exposure to nature and increased awareness of environmental issues	✓	✓	✓	✓	✓									
Education and training	✓	✓	✓	✓	✓									
Visual screening of unsightly buildings or infrastructure						✓			✓					
Heritage preservation and cultural expression			✓		✓									
Environmental														
Biodiversity protection and enhancement of habitat and species	✓	✓	✓	✓	✓	✓		✓	✓	✓				
Landscape restoration and the regeneration of degraded sites	✓	✓	✓	✓	✓	✓				✓				
Protection of significant geological sites	✓	✓	✓	✓	✓									
Reductions in the ecological footprint	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Carbon sequestration	✓	✓	✓	✓	✓	✓		✓	✓					

* Applicable to regional scale as well

There is abundant research on establishing GI procedures and assets including design as well as the quantification of benefits and impacts for the various GI assets/procedures concerned. Literature focusing on the mitigation of impacts from the built environment, such as water and stormwater management, appears to be far more extensive than the literature based on other types of GI. This is potentially due to the tangible effects in the form of financial loss and human suffering arising from issues concerning severe precipitation events (e.g. flooding and damage from storms). Nevertheless, the body of literature for GI such as living roofs, green walls and green streets is expanding with growing efforts to implement GI in various parts of the world. These attempts illustrate that the performance of GI procedures vary according to many factors, including:

- The design of GI procedure (where improper design can exacerbate issues rather than lead to amelioration); and
- The environmental conditions within which the GI functions.

Research has not yet identified all the variables that impact upon the function and performance of GI. The benefits are subject to GI design, which needs to suit the environment in which they function. This leads to the conclusion that GI procedures that function well in one region may not necessarily function well in another without some sort of adjustment. The uncertainty associated with performance can only be relieved via further research so as to cover all possible variables that may affect the function of GI. As such, there have been many initiatives, backed by research efforts, to incorporate GI in cities throughout the world. The next chapter reviews literature on international GI development case studies, outlining for each study the specific functions, benefits and costs accrued.

3. GI CASE STUDIES

The review of GI assets and procedures highlighted projects of current interest throughout the world. Germany is upheld as a pioneer for GI strategies with many advances in and implementation of technologies such as living roofs and green walls. Interest in GI for stormwater management in the United States of America appears to dominate much of the current research, but countries such as New Zealand and Australia are following suit with research to test the design and application of GI procedures. Many cities throughout the world already have or are in the process of applying GI to their urban environments for stormwater management, environmental quality, community liveability and so on. For example, the American Society of Landscape Architects (ASLA) released a database of 479 case studies that address stormwater management (ASLA, 2011); EPA (2010) provides case studies on USA local government efforts on stormwater management policy; the International Stormwater BMP Database contains over 400 performance monitoring studies for various technologies; and the Commission for Architecture and the Built Environment (CABE, Space, 2011a) provides numerous international examples of GI in practice including efforts by the former Waitakere City Council in New Zealand.

ASLA has the largest database of GI case studies gathered thus far. An analysis of the case studies shows the kind of projects conducted; their cost and the range of GI techniques and designs implemented (ASLA, 2011). The analysis is summarised in Table 24 showing the percentage per type of project; percentage of projects falling into different cost categories ranging from US$10,000 to $5 million; and the percentage use of the different GI procedures. The analysis also found that for 44.1% of the projects, the use of GI reduced overall costs, while for just 24.5% of the projects costs increased (noting that GI did not influence the cost of 31.5% of the projects) (ASLA, 2011; Odefey et al., 2012). It is not apparent which of the estimated costs in Table 24 contribute towards retrofits, new developments and redevelopment projects. However, according to Odefey et al. (2012), 50.7% of the total projects are retrofits of existing properties; 30.7% are new developments; and 18.6% are redevelopment projects.

Additionally, there are regional projects such as Reverse (Aquitaine Region, 2011), in which 14 European partners are focusing on biodiversity associated with agriculture, food production, tourism and land development, with a budget of 2.5 million Euros. Further case studies illustrating international efforts on biodiversity include those presented by the Convention on Biological diversity (CBD, 2012a). Other examples are green transport efforts in Curitiba, Brazil; Copenhagen, Denmark; and London, UK, where large-scale transport systems have been implemented for increased resilience.

Table 24 ASLA projects analysed according to project type, estimated cost and GI approach

Project Type	% of total	Estimated cost of GI	% of total	GI design approaches	% of total
Institutional/Education	21.5	≤ $10,000	3.5	Bioswale	62.1
Open Space/Park	21.3	$10,000-$50,000	12.2	Rain garden	53.2
Other	17.6	$50,000-$100,000	12.9	Bioretention	
Transportation		$500,000-$1,000,000	13.2	facility	50.8
Corridor/Streetscape	11.9	$100,000-$500,000	29.2	Permeable	
Commercial	8.6	$1,000,000-$5,000,000	22.1	pavement	47.3
Single Family Residential	5.5			Curb cuts	37.9
Government Complex	4.2			Cistern	21.2
Multifamily Residential	3.7			Downspout	
Open Space	2.9			removal	18.1
Garden/Arboretum	1.8			Living roof	16.5
Mixed Use Industrial	1.1			Rain barrels	5.7

Source: ASLA (2011)

Since different regions have their own distinct climates, the GI strategies correspondingly differ with respect to their intended aim. Mell (2011) categorised the respective focuses of GI planning in the UK, North America and Europe in Table 25. However, there are also many similarities in the focus of GI across the different regions, such as climate change mitigation and adaptation together with sustainable urban design. Many of the project aims would be applicable to the southern hemisphere and are likely to become more apparent as GI application is extended further in Australia and New Zealand.

Table 25 Focus of GI planning in UK, North America and Europe

UK	North America	Europe
i. Community forestry; ii. Sustainable urban design; iii. Urban renaissance; iv. Sustainable communities; v. Climate change adaptation; vi. Healthy lifestyles and landscapes; vii. Biodiversity and conservation.	i. Climate change adaptation; ii. Micro-climate control in urban areas; iii. Biodiversity conservation and assessments; iv. Sustainable urban design; v. Sustainable drainage systems; i. Smart Growth; ii. Water resource management.	i. High density urban development; ii. Mobility; iii. Climate change mitigation and adaptation; iv. Sustainable urban design.

Source: Mell (2011)

Given the increasing popularity of GI in practice, it is worthwhile focussing on specific cities in order to limit the scope of the literature review and provide a more indepth lens. Ten cities were selected as case studies, each regarded as pioneers in their respective GI strategies. These case study cities are:

1. Chicago, USA;
2. Philadelphia, USA;
3. New York, USA;
4. Copenhagen, Denmark;
5. Stockholm, Sweden;
6. London, UK;

7. Singapore;
8. Curitiba, Brazil;
9. Vancouver, Canada; and
10. Brisbane, Australia.

While the case studies cover a wide range of GI assets and applications to mitigate impacts and ameliorate a wide range of ecosystem services, we selected those GI projects where literature has been published in journals or is stored in a database such as the one by ASLA. Wherever possible, the latest data including quantifications have been included.

3.1 CASE STUDY 1: CHICAGO, USA

Chicago, situated on the coast of Lake Michigan, has an estimated population of 2.7 million (United States Census Bureau, 2012a) and is the largest city in the State of Illinois. The city was built on wetlands and faces the risk of flooding, which is aggravated during storm events. There are other water concerns too such as a decline in water quality (Lyderson, 2011), which is a significant issue associated with centralised stormwater and wastewater systems (i.e. combined sewer overflows) affecting their primary source of drinking water, Lake Michigan (NRDC, 2006). Chicago has a continental climate with four clearly delineated seasons. Daily average winter temperatures range from -4.7°C down to -18°C, while average summer temperatures range from 26 to 33°C. Precipitation ranges from an average winter snowfall of 970 mm and a yearly rainfall averaging 920 mm. Other factors that affect Chicago's climate include solar activity weather systems, urban areas and microclimatic conditions arising from its proximity to Lake Michigan.

Work on future climatic changes has been conducted by many researchers, including Vavrus and van Dorn (2010) projecting future temperature and precipitation extremes; Hayhoe et al. (2010) projecting heat waves and mortality for Chicago; Cherkauer and Sinha (2010) projecting hydrological impacts in the Lake Michigan region where the future climate of Chicago is expected to get wetter and more humid with potential increased frequency, intensity and duration of heat waves (Vavrus and van Dorn, 2010). In fact, observations and projections (e.g. by Vavrus et al. (2006); Peterson et al. (2008)) also point to increasing extreme heat, decreasing extreme cold and increasing precipitation over North America and much of the world (see also: Wuebbles and Hayhoe, 2004; Sun et al., 2007; Karl et al., 2008). The changes in climate and the resulting extreme events will impact human health, agriculture and energy resources with flow-on effects to the economy. For example, the heat wave experienced in Chicago during 1995 lead to 739 excess deaths (Semenza et al., 1999) and put additional pressure on health care systems with increased incidences of dehydration, heat stroke and heat exhaustion (an excess of 3,000 visits to emergency departments was recorded, according to Dematte et al. (1998)). According to Hayhoe et al. (2010), urban heat island effect may have exacerbated the heat wave.

Chicago has initiated efforts to reduce impacts of climate change and encourage adaptation via the Chicago Climate Action Plan in 2008 (Coffee et al., 2010). This initiative is based on quantifying greenhouse gas emissions, assessing economic risk for different levels (high and low) of emissions and prioritising potential impacts and risks to the region. Strategies for mitigation and adaptation considered under the Action Plan are shown in Figure 5.

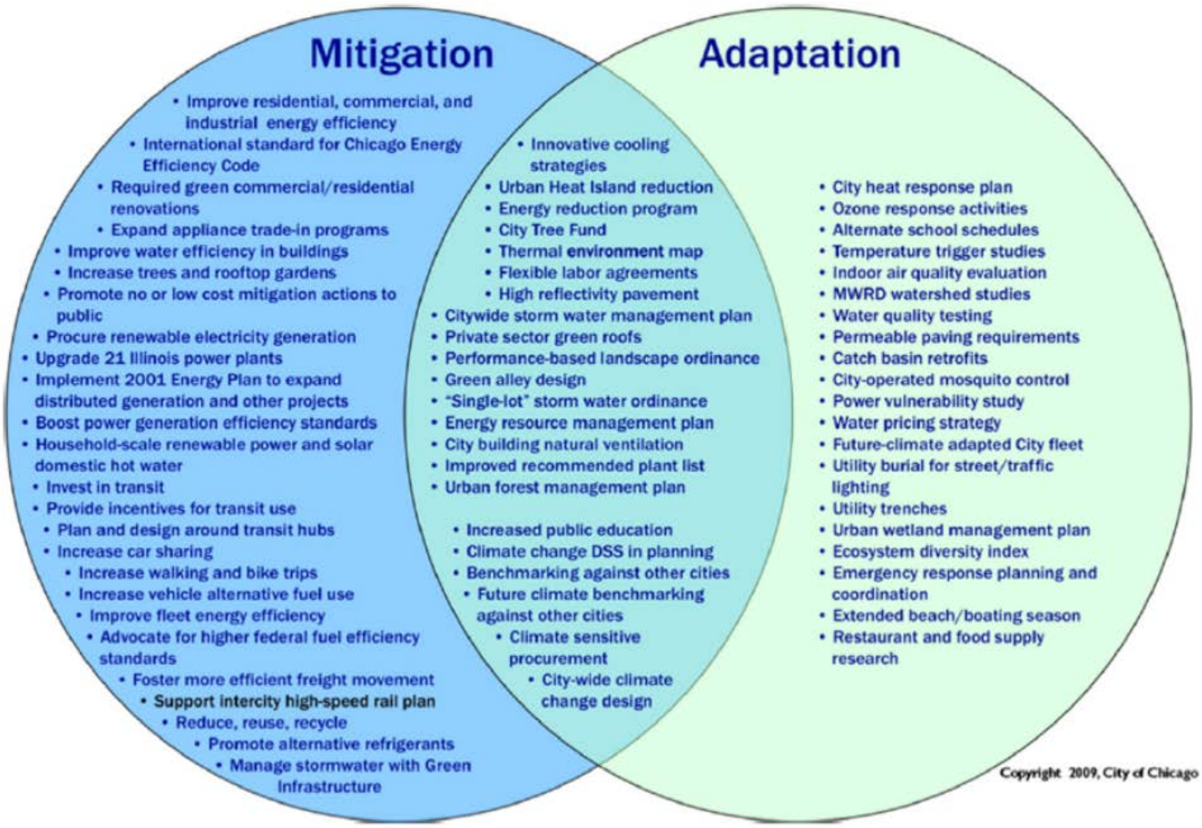


Figure 5 Mitigation and adaptation strategies – Chicago Climate Action Plan

Source: Coffee et al. (2010)

3.1.1 PROCEDURES, COSTS AND BENEFITS

Since the adoption of the Stormwater Management Ordinance in 2008, 'any new development or redevelopment that disturbs 15,000 ft^2 [1394 m^2] or more or creates a parking lot of 7,500 ft^2 [1394 m^2] or more must detain at least the first half inch [1.3 cm] of rain on site' (EPA, 2010a). This encourages the implementation of LID practices associated with stormwater management such as green streets, living roofs and green alleys. For example, Chicago's Green Alley Program utilises numerous BMPs and green infrastructure technologies such as permeable pavements to improve stormwater management.

In addition to stormwater management, the City of Chicago is also involved in numerous programmes such as Green Permit, Chicago Wilderness and Chicago Tree Initiative. City of Chicago's Department of Buildings initiated the Green Building

Permit Program in 2005 to encourage green technologies in new buildings. This incentive programme provides an expedited permit process and potential permit fee-waiver to projects that meet certain criteria, based on their utilisation of green technologies such as green roofs, renewable energy (e.g. solar panels, wind turbines), water management (e.g. rainwater harvesting), transit oriented development, affordability, innovation, LEED or Chicago Homes Certification, natural ventilation and other initiatives that minimise environmental impact (Kazmierczak and Carter, 2010). The highest reward from the Green Permit Program is expedited permit and waiver of the consultant review fee. Projects that consist of a combination of LEED Platinum or Gold with 75% green roof and two other criteria mentioned previously would be eligible for the highest reward (Kazmierczak and Carter, 2010). The Green Building Permits Program is part of Chicago's Green Building Agency and includes other programmes such as the Green Roofs Initiative, the Green Roof Improvement Program and Green Homes Program. Under the Green Roof Initiative, new developments that have been subsidised by the City of Chicago are required to include a green roof (Taylor, 2007). Incentives include a density bonus, allowing more units to be built provided a 50% or 186 m^2 (2,000 ft^2) roof is installed. The programme is credited for over 80 green roofs with the total area exceeding 232,257 m^2 (2.5 million ft^2) (Kazmierczak and Carter, 2010). The Green Roof Improvement Program is aimed at commercial projects and includes rewarding reimbursement grants of up to US$100,000. Criteria for receiving the grant include a highly visible green roof that covers more than 50% of the roof, use of drought resistant plants and plans to monitor performance for stormwater management and urban heat island mitigation. The Green Homes Program is aimed at the residential sector and the utilisation of green technologies and practices such as healthy indoor air quality and efficient water use.

The Chicago Wilderness Program is run by the Chicago Wilderness Alliance, which comprises over 260 organisations such as local, state and federal agencies, large conservation organisations, cultural and educational institutions, volunteer groups and others. They aim to 'restore nature to health, to protect green infrastructure, to mitigate climate change and to leave no child inside' (Chicago Wilderness, 2012). The green infrastructure component of the aim is based on mapping regional scale vision for biodiversity protection and restoration (Chicago Wilderness, 2004). The programme has identified 1.8 million acres (0.73 million hectares) of resource protection area of which 360,000 acres (146,000 hectares) is already protected natural open space. The Program also seeks to develop conservation efforts for identified areas. The Chicago Tree Initiative brings together government and non-profit agencies to work on tree planting and subsequent improvement of Chicago's Urban Forest. The initiative is aimed at achieving average tree canopy of 20% in the city by 2020 and is associated with other initiatives such as Chicago's Urban Forest Agenda at the macro scale and the Sustainable Backyard Program on the micro scale. The Urban Forest Agenda identified the following benefits of urban forests: better air quality, reduction in greenhouse gas emissions, reduction in urban heat island effect, improved wildlife habitat, stormwater management, noise abatement, greater psychological wellbeing, better energy conservation and higher property values. As such, it is a vital component of Chicago's GI (Chicago Department of Environment, 2009).

The GI procedures and assets implemented in Chicago contribute to flood alleviation, stormwater management, pollution management for clean water and air, reduction of the heat island effect and the protection of biodiversity. However, it should be noted that Chicago does not have a comprehensive plan to integrate its green infrastructure programmes and thus it is not possible to obtain a holistic view of their overall success. Nevertheless, there are many projects throughout the city, as illustrated by Figure 6, using the Centre for Neighborhood Technology (CNT, 2012) mapping tool for the state of Illinois. The green boxes indicate a GI project (some of which are outlined in Table 26) where the areas marked in green (in Figure 6) represent green spaces (e.g. parks and reserves).

Among the range of water management procedures implemented in Chicago are living roofs, rain gardens, vegetated swales, permeable pavement and downspout disconnection/rainwater collection. The 20,300 ft^2 (1,886 m^2) living roof on City Hall initiated the application of living roofs in Chicago (Greenroofs.com, 2010), leading to retention of 50-70% runoff from a one-inch (2.5 cm) storm event (WERF, 2009). The roof is also planted with 20,000 native plants comprised of 150 varieties. According to NRDC's *Rooftops to Rivers II* report (2011b), Chicago has nearly 500 living roofs amounting to 5.5 million ft^2 (0.5 million m^2) either constructed or in progress. The cost of living roofs reduces with increased application (Hawkins, 2009), dropping from $25 to $15 per ft^2 (NRDC, 2011a). Currently, Chicago requires new buildings in the city to have a partial living roof or 'cool roof', in order to be able to meet LEED certification (Silver).

The benefits of living roofs, in a broad sense, were previously discussed in Chapter 2. Benefits specific to Chicago are reported in a number of studies. For example, a study by Yang et al. (2008) quantified air pollution removal by living roofs in Chicago using a dry deposition model. This study found that 19.8 hectares of living roofs removed 1,675 kg of air pollutants within a year. The pollutants removed include ozone (O_3) (52% of the total), nitrogen dioxide (NO_2) (27%), particulates (PM10) (14%) and sulphur dioxide (SO_2) (7%). The study stated that, annually, living roofs remove 85 kg of pollutant per hectare per year. Furthermore, a study by Corrie et al. (2005) found annual NO_2 reductions of between 806.48 and 2,769.89 metric tonnes when 20% of roof surface was living roof with the variability in reductions due to the type of plant used. According to Clark et al. (2008), a building with roof area of 2,000 m^2 would absorb 530 kg of NO_2 per year resulting in estimated public health benefits between US$890 and $3390. However, the data was estimated from performance in greenhouses rather than on rooftops. Clark et al. (2008) estimates that greening 10% of roofs in Chicago (65,400,000 m^2) would lead to the uptake of 17,400,000 kg of NO_2 per year, amounting to benefits anywhere between US$29.2 to $111 million per year.

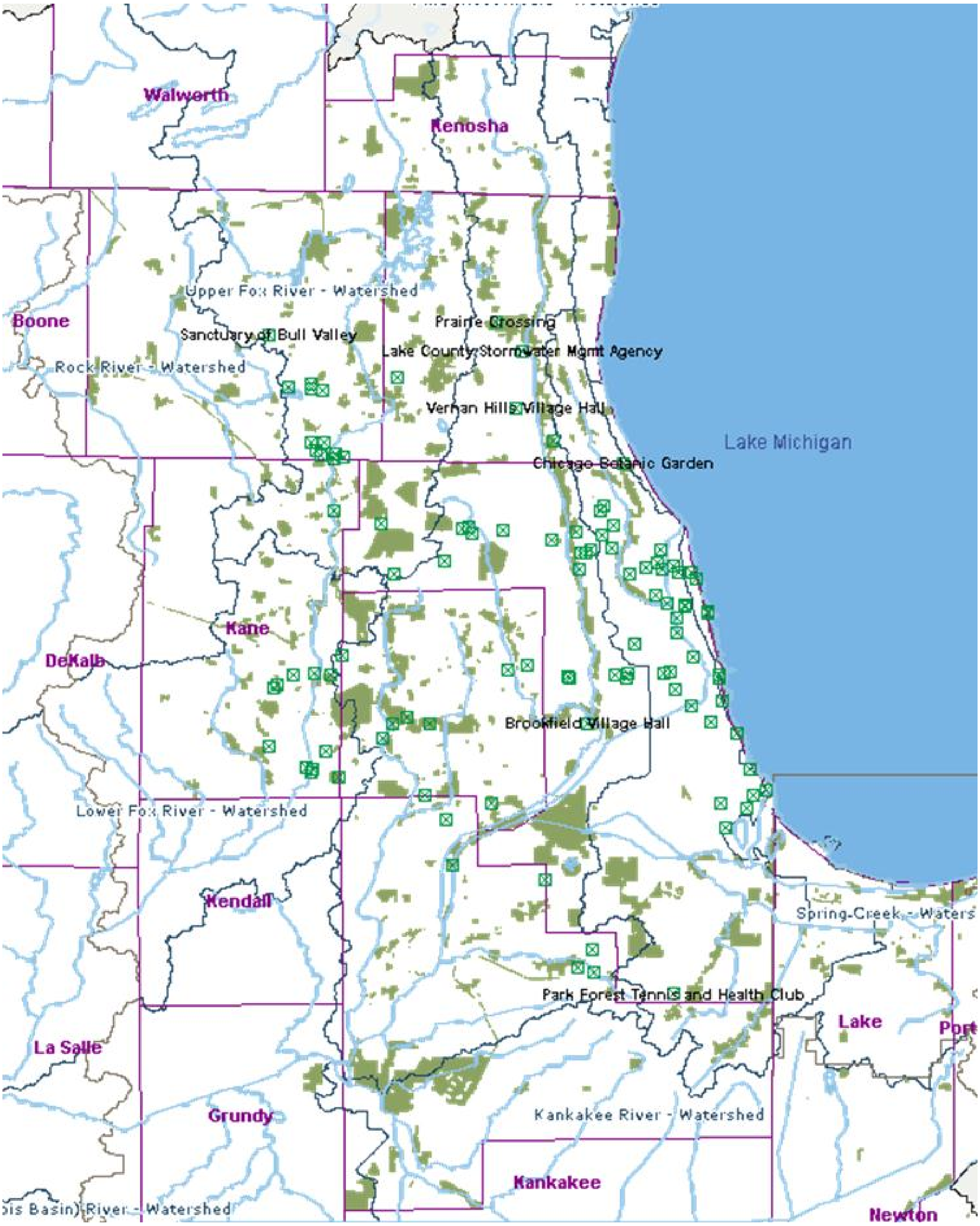


Figure 6 Chicago GI site inventory

Source: Centre for Neighborhood Technology (2012)

With respect to stormwater management, Chicago applies living roofs, green streets and other LID techniques. The American Society of Landscape Architects (ASLA) provides a number of case studies pertaining to stormwater management in Chicago (Ball Horticulture Inc., Cermak road sustainable streetscape and Fed Ex cargo sort building, as in Table 26). The Ball Horticulture Corporate Campus (40 acres, 16.2 hectares) was the subject of restoration efforts for improving water quality, stormwater control, erosion control and wildlife habitat (ASLA, 2012a). Chicago's Green Alley Handbook (2010) shares experiences of the Green Alley programme, illustrating 11 LID techniques and their benefits. However, whilst the benefits are provided in broad terms, no quantification has been carried out. For example, the report states that up to 80% of rainfall could percolate into the ground rather than being sent to water treatment plants, but there is no indication of the quantified savings made by such actions.

In 2011, Chicago launched the Sustainable Backyard Program, which is aimed at helping residents design and create more sustainable gardens. The programme provided 50% rebates for trees, native trees, compost bins and rain barrels (Chicago Centre for Green Technology, 2011). Likewise, Chicago's Green Streets programme is aimed at increasing tree canopy in the city. According to EPA (2010), there were more than 583,000 trees planted by 2006, which increased shading by 14.6%. According to Nowak et al. (2010), Chicago has approximately 3.59 million trees (canopy cover 17.2% of the area). This urban forest stores approximately 716,000 tonnes of carbon/year (value of $14.8 million/year) removing approximately 25,200 tonnes of carbon/year (sequestration) (value of $521,000/year) and 888 tonnes of air pollution/year (value of $6.4 million). Additionally, an annual residential energy cost reduction of $360,000/year is gained from trees in Chicago (Nowak et al., 2010). These gains are due to reduced energy consumption for cooling (via provision of shading of buildings and evaporative cooling) and/or heating (via blocking cold winds). Forest Research (2010) states that up to 10% improvement in air quality can be obtained by increasing tree cover. To that end, Chicago spends between $8 to $10 million annually to plant 4,000 to 6,000 trees (NRDC, 2006), which has increased the city's overall tree canopy from 11% (1991) to 17.6% (2008). Chicago aims to increase the percentage of tree canopy to 20% by 2020.

The Chicago Wilderness Program caters to the preservation of biodiversity in the Chicago area. Currently, Chicago's Wilderness spans over 370,000 acres (150,000 hectares) of natural areas (CWGIV, 2004). The GI vision (GIV) of the programme aims to increase connectivity at four levels: regional, community, neighbourhood and site-specific. GIV (2004) identified 1.8 million acres (0.73 million hectares) of areas that can be added to protected wilderness status. Additionally, by preventing the destruction of native habitat and forest, Chicago Wilderness (2011) is said to have prevented the emission of 53 million tonnes of CO_2 via carbon storage. The amount is equivalent to emissions by five million cars for a year or electricity from 7.1 million households/year or the operation of one coal-fired power plant for six years and seven months.

Table 26 Costs and benefits of GI projects in Chicago

Project/ Description	Benefits	Costs
Ball Horticulture Corporate Campus (ASLA, 2012b) – 40 acres (16.3 ha) of restoration for erosion, stormwater, air and water quality control. Wildlife habitat improvement. GI included: bioretention facility, rain garden, bioswale, wetlands.	• All stormwater retained on site; recreation and biodiversity.	$100,000 – $500,000.
Cermak Road Sustainable Streetscape (ASLA, 2012c) – 1.5 mile (2.4 km) long streetscape including rain garden, bioswale, porous pavement and curb cuts.	• Enhanced infiltration (80% of average annual rainfall); • Potentially benefit towards reduction of urban heat island effect.	<$5 million.
Fed Ex Cargo Sort Building (ASLA, 2012d) – living roof.	• 12 jobs created; • 90% of stormwater detained for 3 hours; • No irrigation needed for plants; • Air quality control.	$1-5million. $420,000 for components; $220,000 for drainage aggregate; $800,000 for labour; $1 million for sedum mat
City of Chicago's City Hall Rooftop Garden – 1858 m^2 (20,000 ft^2).	• Reducing the urban heat island effect – (approximately 14 to 44^{o}C cooler than nearby buildings). • Stormwater management – 75% of a 2.5 cm rainfall before there is stormwater runoff into the sewers (greenroofs.com, 2010); • Biodiversity consisting of 20,000 plants of more than 150 species; • Saves $5,000 a year on utility bills (including energy costs of US$3600 /year, amounting to a savings of 9272 kWh/year) – roof exhibits superior insulation properties, requiring as much as 30% less from City Hall's heating and air conditioning systems over the last four years (Clean Energy Awards, 2012).	$2.5 million.
Chicago's urban forest (Nowak et al., 2010)	• 3.59 million trees store approximately 716,000 t C/yr (value of $14.8 million/year) removing approximately 25,200 t C/yr (sequestration) (value of $521,000/year) and 888 tonnes of air pollution/year (value of $6.4 million). Additionally, annual residential energy cost reductions of $360,000/year are gained from trees in Chicago.	Chicago spends $8 to $10 million annually to plant 4,000 to 6,000 trees (NRDC, 2006).

3.2 CASE STUDY 2: PHILADELPHIA, USA

Philadelphia, located on the eastern border of Pennsylvania, is home to approximately 1.5 million people (United States Census Bureau, 2012b). There are multiple population projections, although the discrepancy is minor. For example, according to Espie et al. (2005: 5), 'the City of Philadelphia will likely continue to decline in population to reach approximately the 1.4 million level by 2050, reflecting an average decade decline of –1% which is more optimistic than the projected figures of nearly –3%'. Figures by the United States Census Bureau (2010) also show the population is declining and project it stabilising around 1.5 million in Philadelphia County. However, reports by Purcel (2010) state that Philadelphia's population is on the rise.

In terms of weather and climate, the city experiences average temperatures ranging from 0°C in January to 24°C in August with an annual average of 12°C (minimum temperature of -5°C and maximum temperature of 30°C). Annually, the city receives 116 cm of rain and 49 cm of snow (City-data, 2009). The city's proximity to the Delaware and Schuylkill Rivers as well as the Appalachian Mountains and the Atlantic Ocean moderate the climate. Current environmental issues facing Philadelphia include stormwater runoff, flooding, water pollution via combined sewer overflow, heat island effect and extreme storm events such as hurricanes, all of which are prone to intensification with climate change. Philadelphia has initiated a number of programmes, such as: green streets; green schools; green public facilities; green parking; green public open space; green industry, business, commerce and institutions; green alleys, driveways and walkways; and green homes. It should be noted that in addition to issues primarily focused on stormwater and water management, Philadelphia also faces numerous socioeconomic issues such as crime and failing educational facilities (Madden, 2010).

3.2.1 PROCEDURES, COSTS AND BENEFITS

With respect to climate change, Philadelphia has committed to the Cities for Climate Protection (CCP) Campaign of ICLEI-Local Governments for Sustainability, USA Mayors' Climate Protection Agreement of the USA Conference of Mayors and Large Cities Climate Leadership Group and the Clinton Climate Initiative (CCI) (City of Philadelphia, 2007). The aims of these commitments are focused around five elements:

1. Buildings;
2. Transportation;
3. Industry and waste;
4. Greening and open space; and
5. Policy, education and outreach.

In terms of 'greening and open space', the city aims to maintain its tree canopy at 15% and reduce energy demands from buildings through planning, designing and implementing green and open space (City of Philadelphia, 2007). Additionally, Philadelphia has been integrating GI as standard practice, especially for projects overseen by city agencies (NRDC, 2006). This effort includes policy initiatives such as Green Plan Philadelphia, the Green Roof Tax Credit and the Green Streets programme in an attempt to adopt GI throughout the city. The Greenworks Program (Greenworks Philadelphia, 2011) was designed to address multiple issues facing the city and its goals are to:

1. Lower city government energy consumption by 30%;
2. Reduce citywide building energy consumption by 10%;
3. Retrofit 15% of housing stock with insulation, air sealing and cool roofs;
4. Purchase and generate 20% of electricity used in Philadelphia from alternative energy sources;
5. Reduce greenhouse gas emissions by 20%;
6. Improve air quality toward attainment of Federal standards;
7. Divert 70% of solid waste from landfill;
8. Manage stormwater to meet Federal Standards;
9. Provide park and recreation resources within 10 minutes of 75% of residents;
10. Bring local food within 10 minutes of 75% of residents;
11. Increase tree coverage toward 30% in all neighbourhoods by 2025;
12. Reduce vehicle miles travelled by 10%;
13. Increase the state of good repair in resilient infrastructure;
14. Double the number of low- and high-skill green jobs; and
15. Ensure Philadelphia is the greenest city in America.

The city has numerous interconnected programmes that cater for each of the goals listed above. For example, the Philadelphia Water Department (2012) leads GI efforts related to the management of stormwater, as well as other GI projects on rain gardens (27), swales (9), living roofs (1), stormwater tree trenches (124), among others. Figure 7 illustrates the GI project map for Philadelphia. The Green City, Clean Waters Programme also undertakes activities such as tree planting on streets, which would ultimately act as a carbon sink – thus contributing to goal 5 as well as goal 11. The Green City, Clean Waters Programme's net present value (2009) is US$1.2 billion, representing $2.4 billion capital construction, operating and maintenance costs (PWD, 2011). Examples of benefits include savings made as well as improvements in the quality of ecosystem services. For example, according to the Centre for Clean Air Policy (Foster et al., 2011), Philadelphia's policies and pilot projects since 2006 have reduced combined sewer overflow (CSO) and improved water quality, resulting in savings of approximately $170 million. The costs and benefits of GI related activities are obtained from Greenworks Philadelphia (2011), PWD (2011) and EPA (2010) (Table 27). The costs, where available, consist of the expected value of the respective projects as well as valuations of completed projects.

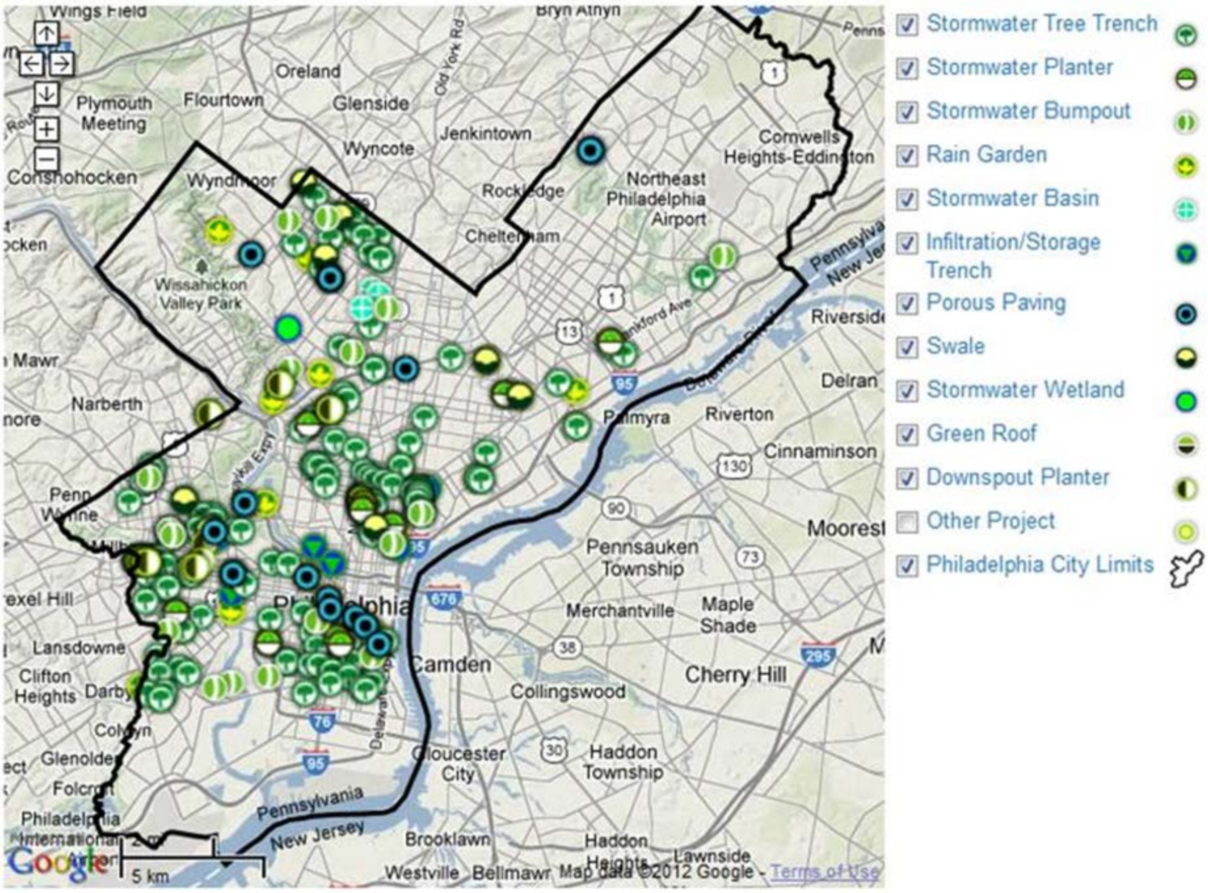


Figure 7 Philadelphia stormwater management related GI
Source: PWD (2012)

Table 27 Costs and benefits of GI projects in Philadelphia

Project/ Description	Benefits	Costs
Cliveden Park (ASLA, 2012e) – stormwater detention via rain garden and wetland	Stormwater detention – manage 1st inch (2.5 cm) of storm – performance measure of 1.8 acre-inches (185 m^3) achieved.	\$100,000 - \$500,000
Columbus Square Park (ASLA, 2012f) – rain garden and flow through planters	Stormwater management – 1st inch (2.5 cm) of storm – performance measure of 0.74 acre-inches (76 m^3).	\$100,000 - \$500,000
Heron park (ASLA, 2012g) consisting of bioretention, rain garden, bioswale, porous pavement and asphalt, native trees	• Retention of stormwater; • Increased permeability due to reduction of impermeable surface; • Creation of green space; • Increased biodiversity.	\$100,000 - \$500,000
Waterview Recreation center (ASLA, 2012h) consisting of porous concrete sidewalk, planters, etc.	Collection of runoff from street with associated benefits including bioretention and water quality management 0.31 acre-inches (31.8 m^3).	\$100,000 - \$500,000
'Green Cities Clean Waters' Plan (Philadelphia Water Department, 2011) expected to transform over 4,000 acres (1620 ha) (34%) of impervious areas within the City's Combined Sewer System to green space over the next 20 years through the use of GI.	• Reducing overflows in their CSO system; • Heat Stress Mortality Reduction (35%); • Recreation (22%); • Property Value Added (18%); • Water Quality and Habitat (14.5%); • Air Quality (4.6%); • Avoided Social Costs from Green Jobs (3.7%); • Energy Savings (1.0%); • Carbon Footprint Reduction (0.6%); • Reduction in Construction- Related Disruptions (0.2%). The above would lead to value of \$2.2 billion dollars as opposed to \$16 billion via conventional grey infrastructure.	Potentially \$1.6 - 2.4 billion dollar: \$1.67 billion allocated to green stormwater infrastructure; \$345 million allocated to stream corridor restoration and preservation; and \$420 million allocated to address wet weather treatment plant upgrades.
Living roofs total (Planned and Constructed) (Alarcón, 2007).	The annual benefits in energy savings and pollution reduction would be \$860,000 if 25% of the properties in a one $mile^2$ (1.6 km^2) area installed living roofs. A net benefit of \$640,000 may be accrued.	If 25% of the properties in a one $mile^2$ (1.6 km^2) area installed living roofs, the cost would be \$220,000.
Philadelphia's urban forest (Nowak et al., 2007a).	2.1 million trees (canopy cover 15.7% of the area) store about 530,000 tonnes of carbon valued at \$9.8 million removing about 16,100 tonnes of carbon/year (\$297,000/year) and about 802 tonnes of air pollution/year (\$3.9 million/year). Building energy reduction of \$1,178,000/year.	

3.3 CASE STUDY 3: NEW YORK CITY, USA

Located at the mouth of the Hudson River, New York City is home to approximately 8.2 million people (United States Census Bureau, 2012c). It is currently the most populous metropolitan city in the USA and its population is expected to rise to approximately 9.1 million by 2030 (City of New York, 2006). New York's humid subtropical climate contributes to wet cold winters with temperatures ranging from -12°C to 10°C. New York summers are hot and humid with temperatures ranging from 17°C to 38°C. The city's climate is regulated by its proximity to the Atlantic Ocean where climatic patterns follow the Atlantic Multidecadal Oscillation of 70-year warming and cooling. This cycle dictates the severity and frequency of storm events such as hurricanes. Precipitation includes snow in winter, averaging 71.4 cm and rainfall of 1,262 mm, with spring being the wettest season.

The issues facing New York City are similar to those of other USA cities. They include urban heat island effect, damage from extreme precipitation and storm events and rising sea levels – all of which are influenced by climate change. According to New York's Department for Environmental Protection (DEP, 2008), average temperature for the city region has increased by approximately 1.1°C during the 1900 to 2005 period (statistically significant). Rosenzweig et al. (2006) attributes the regional increase in temperature, which exceed that of global increases, to urban heat island effect. According to Rosenzweig and Solecki (2001), the warming occurs more in winter. Projections of the average regional temperature show increases by 1.7°C for the decade of 2020 and up to 3.3°C for the 1980s. Precipitation for the same period, 1900 to 2005, has increased by 9.9%; although, due to variably of the annual distribution, this is not considered to be statistically significant (DEP, 2008). Precipitation is expected to increase by 0.7% in the 2020s and up to 8.6% in the 2080s. Sea level rise could increase the severity of storm surges. According to DEP (2008), sea levels have risen by 0.85 ft (approximately 26 cm) for the period 1920 to 2005. Projections show sea level rising by 8.1 cm in the 2020s and up to 41.9 cm in the 2080s, although this does not account for the rapid rate of melting ice sheets in the polar regions. Therefore, increasing temperatures, increasing precipitation, more frequent and severe storm events, flooding, coastal flooding, sewage overflow and pollution are expected to place greater stress on New York's infrastructure and population in the future.

3.3.1 PROCEDURES, COSTS AND BENEFITS

In order to reduce the associated risks, New York has launched a number of programmes to green the city. The procedures involve construction of Bluebelts (e.g. wetlands designed and implemented at the catchment scale), green streets, green parking, green and blue roofs and other Best Management Practices (BMPs). Figure 8 illustrates GI in the New York region according to the City of New York's (2012) GIS tool. In 2007, a long-term sustainability plan (PlaNYC) targeted towards the year 2030 was announced. The goals of PlaNYC (2011) are outlined in Table 28. Efforts to incorporate GI are evident in the Green Infrastructure Plan where 'the City is prepared to spend up to $1.5 billion over 20 years and $187 million in capital funds over the next four years, for green infrastructure and other elements of the Green Infrastructure Plan' (NYC, 2010: 11). This plan is part of New York's overall plan to achieving a greener and greater New York (PlaNYC, 2011).

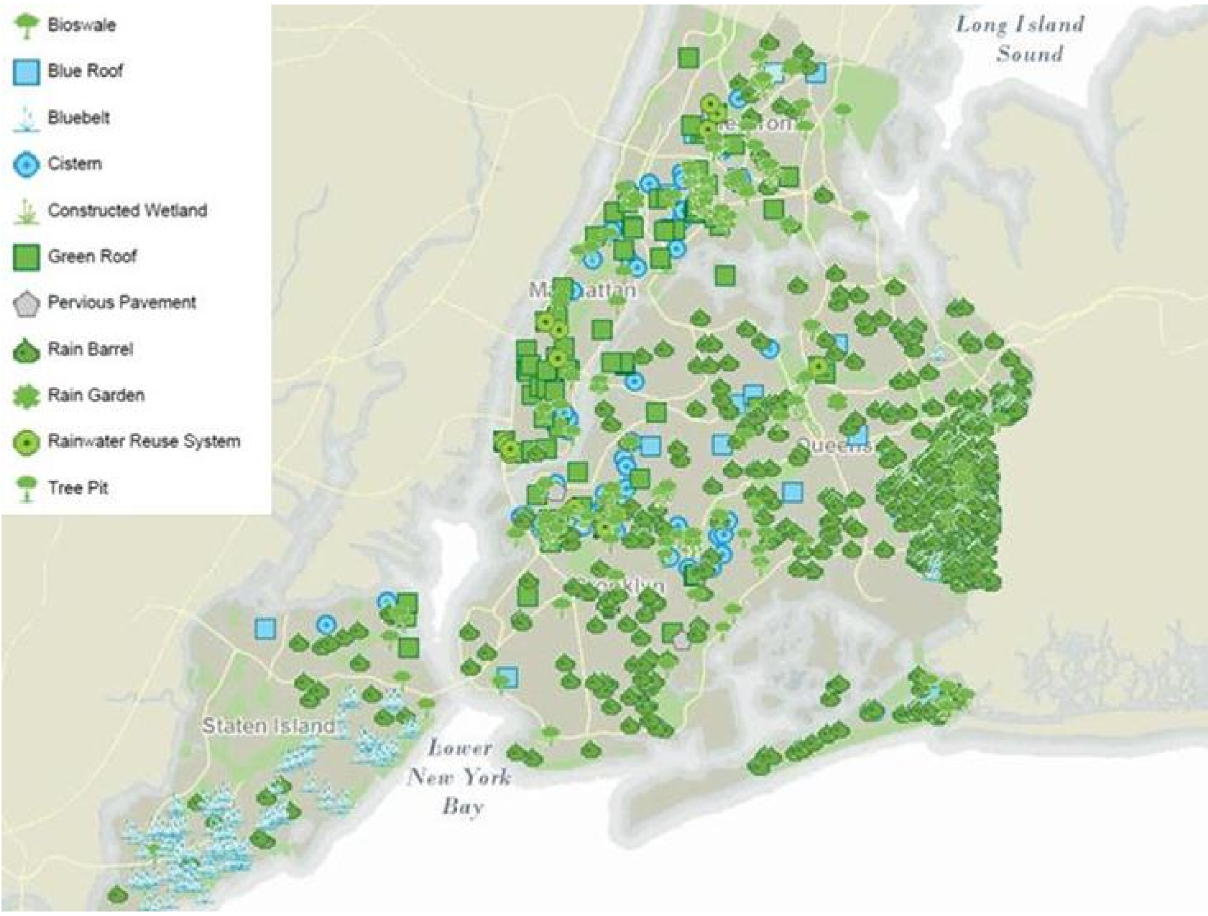


Figure 8 GI in the New York region

Source: The City of New York (2012)

While the strategy is outlined broadly in PlaNYC (2011), others such as NYC's (2010) Green Infrastructure Plan outline specific strategies for the different aims given below in Table 28. The Green Infrastructure Plan for water management has the following goals:

1. Build cost-effective grey infrastructure;
2. Optimise the existing wastewater system;
3. Control runoff from 10% of impervious surfaces through green infrastructure:
    a. Blue roofs and living roofs for rooftop stormwater detention and retention;
    b. Porous pavement for parking lots;
    c. Tree pits, streetside swales and porous pavement for roadways;
    d. Green streets, medians and kerbside extensions for roads;
    e. Constructed wetlands and swales for parks;
    f. A variety of these techniques for high density multi-family housing; and
    g. Rain barrels for low density single family housing.

4. Institutionalise adaptive management, model impacts, measure CSOs and monitor water quality; and
5. Engage and enlist stakeholders.

Table 28 Aims of PlaNYC

Project	Aim
Housing and Neighbourhoods	Create homes for almost a million more New Yorkers while making housing and neighbourhoods more affordable and sustainable.
Brownfields	Clean up all contaminated land in New York City.
Parks and Public Space	Ensure all New Yorkers live within a 10 minute walk of a park.
Waterways	Improve the quality of our waterways to increase opportunities for recreation and restore coastal ecosystems.
Water Supply	Ensure the high quality and reliability of our water supply system.
Transportation	Expand sustainable transportation choices and ensure the reliability and high quality of our transportation network.
Air Quality	Achieve the cleanest air quality of any big USA city.
Solid Waste	Divert 75% of our solid waste from landfills.
Climate Change	Reduce greenhouse gas emissions by more than 30%. Increase the resilience of our communities, natural systems and infrastructure to climate risks.

Source: PlaNYC (2011)

New York's Department of Environmental Protection is currently in the process of building, or has plans to build, over US$2.9 billion of grey infrastructure to reduce the combined volume of sewer overflow (NYC, 2010). The use of GI falls under the third aim, where DEP hopes to prevent the first inch (2.5 cm) of rain from contributing to CSO volumes. According to NYC (2010), the application of GI would result in costs of approximately $1.5 billion as compared with $3.9 billion required for investment in grey infrastructure. According to NRDC (2011b), New York City plans to invest over $1 billion in green infrastructure over the next 20 years in order to reduce CSO. Programmes such as those providing rain barrels to residents have already been initiated; 2,000 rain barrels were distributed in Brooklyn, Queens, the Bronx and Staten Island from 2008 through to 2011 (DEP, 2008).

Application of GI strategies such as the protection of wetlands (purchased for $1.5 billion) has been in practice since the early 1990s; and in this particular case, the city was said to have avoided spending $6 to $8 billion on new filtration and treatment plants (The Conservation Fund, 2012). There are plans for enhanced protection, remediation and protection of wetlands including the expansion of the Bluebelt programme within Staten Island over the next 25 years. PlaNYC (2011) has recognised the need for vegetation as a mechanism for stormwater management. New York City has over 52,000 acres (21,000 hectares) of parks, representing 25% of the New York area (NRDC, 2006), which provide additional benefits linked to ground water recharge, biodiversity protection and pollution control, among others. Other GI strategies include programmes to create enhanced tree pits and vegetated swales along parkways, as well as tax incentives to encourage the installation of living roofs (NRDC, 2011b).

As well as water management, the city is also focused on the reduction of greenhouse gas emissions. In addition to the application of GI to obtain lower sewerage management costs, the city estimates that 'every fully vegetated acre (0.4 hectares) of green infrastructure would provide total annual benefits of $8,522 in reduced energy demand, $166 in reduced CO_2 emissions, $1,044 in improved air quality and $4,725 in increased property value' (Foster et al., 2011: iv). Table 29 contains information on projects that have been, or are expected to be, undertaken in New York. The information has been assembled from numerous sources, including DEP (2008), NRDC (2011b), NYC (2010) and PlaNYC (2011). In addition to the benefits that have been quantified, there are other intrinsic benefits such as cultural/recreational value that cannot easily be quantified. For example, natural beauty may be enhanced by projects involving the addition of greenery and yet the aesthetic value cannot be quantified (other than perhaps through revenue from tourism).

Table 29 Costs and benefits of GI projects in New York

Project/Description	Benefits	Costs
New York City's 2010 Green Infrastructure Plan.	Reduce the city's sewer management costs by $2.4 billion over 20 years (Foster et al., 2011). The plan estimates that every fully vegetated acre (0.4 ha) of green infrastructure would provide total annual benefits of: • $8,522 in reduced energy demand, • $166 in reduced CO_2 emissions, • $1,044 in improved air quality and • $4,725 in increased property value. It estimates that the city can reduce CSO volumes by 2 billion gallons by 2030, using green practices at a total cost of $1.5 billion less than traditional methods (Foster et al., 2011). Using natural systems in place of traditional sewers has saved taxpayers $80 million in infrastructure costs, raised property values and restored damaged habitats.	GI to reduce stormwater from entering the system from over 10% of available impervious surfaces in combined sewer drainage areas by 2030 is expected to cost a total of $2.4 billion public and private investment over the next 20 years including $1.6 billion in traditional grey infrastructure projects (Cohen, 2011; NYDEC, 2011).
Bluebelt – Between 1997 and 2007, DEP created a bluebelt of 10,000 acres.	Saved the city an estimated $80 million in infrastructure costs while increasing nearby property values and saving homeowners flood damage costs (NRDC, 2011b).	
The Solaire (NRDC, 2012a) – 27-storey residential tower with 293 units.	Provides public transportation, hybrid rental cars for rent, bicycle parking and electric vehicle charging. 75% of roof is living roof with native shrubs, perennials and bamboo – lower heating and cooling loads. Aesthetic appeal from living roof. Use of recycled wastewater (50%) – low-flow toilets, irrigation, etc.	Construction Costs: $114,489,750 Greening Costs: $17,250,000 Photovoltaic system: $375,000 (4 year payback period) Low-e windows: $1,500,000 (7 year

	Energy savings of 35% due to automatic dimming fluorescent lights, high-performance windows, west-facing photovoltaic panels (5% of energy needs).	payback) Lighting control system: $125,000 (4 year payback).

Table 29 Costs and benefits of GI projects in New York (cont.)

Project/Description	Benefits	Costs
'5 Boro living roof' (ASLA, 2012i) 2694 m^2 (29,000 ft^2) transformation via living roof and cisterns.	371 m^2 (4000 ft^2) vegetable farm – food production; Stormwater retention.	$0.5 – 1 million
Bronx River Floodplain (ASLA, 2012j) consisting of floodplain restoration, stormwater management and habitat restoration.	Bioretention as stormwater management; Species habitat and increased biodiversity; Recreation, public health; 1-9% savings as compared to grey infrastructure; 10 new jobs created/year; Increased resilience for 2 year storms; Increased trees and ecological restoration.	$1 – $5 million
Queens Botanical Gardens Visitor and Administration Center (ASLA, 2012k) consisting of bioretention, rain garden, bioswale and living roof.	Allow the use of rainfall harvested on grounds Pollution reduction – on-site rainwater treatment; 100% detention for small rain events; Increased interest for cultural enjoyment and recreation.	$1 – $5 million
Gowanus Canal Pilot Streetend Sponge Park (ASLA, 2012l) consisting of bioswale and curb cuts.	Stormwater management via bioretention; Detention of stormwater for treatment.	$0.5 – 1 million
New York's urban forest (Nowak et al., 2007b).	5.2 million trees (canopy cover 20.9 % of the area) stores about 1.35 million tonnes of carbon valued at $24.9 million, removes about 42,300 tonnes of carbon per year ($779,000 per year) and about 2,202 tonnes of air pollution per year ($10.6 million per year).	

3.4 CASE STUDY 4: COPENHAGEN, DENMARK

Copenhagen, located on the Øresund coast, is the capital city of Denmark. The population of the greater Copenhagen region was 1.2 million people at 1 January 2011 (Statistics Denmark, 2011), but the Copenhagen municipality is 0.54 million. This population is expected to increase to 0.63 million by 2030 and 0.65 million by 2040 (Statistics Denmark, 2012). The city's climate can be described as temperate coastal, with average winter temperatures around 0°C and summer temperatures between 15°C to 21°c (Copenhagen City, 2006). Copenhagen can expect temperature increases of up to 3°C. The average precipitation ranges from 600 mm/year and sometimes includes snow, although snow is relatively rare compared with other Scandinavian countries.

Copenhagen's Climate Change Adaptation Plan (Copenhagen, 2011) acknowledges the potential risks to the city and outlines some of the initiatives in place to improve adaptation measures. The climate is expected to change, with precipitation increasing by 25-55% during winter and decreasing by 40% in summer (Copenhagen, 2011). Hallegatte et al. (2011) describe Copenhagen as a low-lying city (the highest ground being a mere 45 m above sea level), but explain that due to its surrounding topography, issues such as storm surges are rare. Nevertheless, expected increases in frequency and intensity of precipitation such as the heavy rains in summer can increase the city's risk of flooding. While reasonably sheltered, the city could face damage from storm surges of up to DKK 15-20 billion over the next 100 years (Copenhagen, 2011). Other concerns for the city involve heating costs in winter, cooling costs in summer, air pollution due to traffic, stormwater runoff and associated pollution, the need to upgrade sewer systems, among others.

3.4.1 PROCEDURES, COSTS AND BENEFITS

Copenhagen city is shaped like a hand extending its fingers, as shown in Figure 9. The palm and fingers represent urbanised areas and the fingers contain infrastructure such as roads and railway lines, spreading out like the patterns of blood vessels in the fingers. Green wedges separate the 'urban fingers' and residents are close to some form of green space (accessible by bicycle or on foot). According to Caspersen et al. (2006), the green wedges have assisted in constraining urban sprawl. In addition, the green wedges provide vital ecosystem services including climate change mitigation (Table 30).

The three priorities of the city's Climate Change Adaptation Strategy (Copenhagen, 2011) are to:

1. Minimise risk of damage (e.g. dykes, construction above sea level, expansion of sewers capacity, local management of rainwater);
2. Prioritise initiatives that reduce the risk of damage if the above is not possible due to technical or financial reasons (e.g. waterproof cellars rainwater storage); and
3. Implement measures that reduce vulnerability (e.g. water pumps in cellars).

The expansion of sewerage systems is an important issue for Copenhagen. This expansion and the laying of drains is expected to cost the city US$1.7-2.6 billion (DKK 10-15 billion) (conversion based on 1 Danish krone = 0.170419 US dollars, as at June 2012). Measures such as the local management of stormwater are given priority over the building of new networks so as to prevent stress on the city's existing sewerage systems. These initiatives include the use of sustainable urban drainage systems (SUDS), which are expected to cost approximately US$0.85 billion (DKK 5 billion). Additionally, Copenhagen is planning to take a proactive approach to potential damage from sea level rise at the cost of US$0.68 billion (DKK 4 billion) over the next 100 years, leading to potential savings of US$2.7 billion (DKK 16 billion) (Copenhagen, 2011). Copenhagen has been involved with cleaning its harbours and converting them from sewer and industrial waste dumps to attractive areas for swimming. As such, multiple benefits are expected, such as economic revitalisation along coastal areas and the reduced risk of urban flooding (Copenhagen City, 2006).

Urban heat island effect is not considered to be an issue of high risk as it is rare for heat waves above 25-28^{o}C to occur that far north (Copenhagen, 2011). Nevertheless, in preparation of future events, the city has initiated programmes to increase the number of trees, green and blue spaces such as green façades, parks, gardens and streams to help regulate possible future temperature fluctuations and to minimise costs related to healthcare and energy. As an early adapter, the City of Copenhagen already has many green spaces that provide multiple ecosystem services to the city. Additionally, residents are now able to reach a green or blue space within 10 minutes, thus allowing them recreational space for health and wellbeing (Copenhagen City, 2006).

Copenhagen is quite famous for its two-wheeled mode of transportation. The first bicycle lanes were established in 1896. However, their extensive use began in the 1980s. According to the report *Copenhagen: Solutions for Sustainable Cities* by the City of Copenhagen (2011), there were 369 km of cycle lanes in 2010 with two cycle bridges to allow cycle-only traffic. In addition, greenways (42 km) with unobstructed cycling were established, where cyclists could travel at a maximum speed of 20 km/h. The city transport system allows the integration of cycling and public transport and allows cyclists to change their mode of transport en route. For example, a cyclist can take a bicycle on the train if needed. Additionally, a 'cycling embassy' was created to teach and encourage safer cycling (City of Copenhagen, 2011). Benefits of the policies and strategies include reduction of CO_2 emissions (90,000 tonne reduction annually), reduced healthcare costs due to exercise (US$1/km cycled), provision of low-cost and relatively fast, congestion-free mode of transport and avoidance of external costs (from 1995 to 2010, the city avoided spending US$43,025,607) (City of Copenhagen, 2011). Integrated ticketing facilitates the integration of public transport systems. SMS ticketing has been introduced, reducing time loss via queuing as well as cutting operational costs. According to a City of Copenhagen (2011: 20) report, the integrated public transport system has encouraged people to opt out of using their cars and thus 'for every person using the Metro instead of travelling alone by car, carbon dioxide emissions drop by 83%'.

Waste management strategies by the City of Copenhagen have led to the reduction of waste going to landfill. The 2009 landfilled waste was 20 times less than that of waste landfilled in 1988. This reduction is partly due to separation and incineration of combustible waste. In order to provide incentives to prevent landfilling, the city charges a tax of US$10/tonne as opposed to the US$8.50/tonne for incineration. The incineration of waste is one means of providing energy for the city. Combined Heat and Power (CHP) technology allows the heat to be used in Copenhagen's district heating system for heating residential houses. In addition to producing energy from its waste, Copenhagen has also invested in wind energy, which is expected to contribute 50% of Danish electricity production by 2030. On top of benefits such as the reduction of emissions (e.g. nitrogen oxide, carbon dioxide), economic benefits in terms of employment have also been accrued. According to City of Copenhagen (2011), the wind energy industry employs over 25,000 people in Denmark.

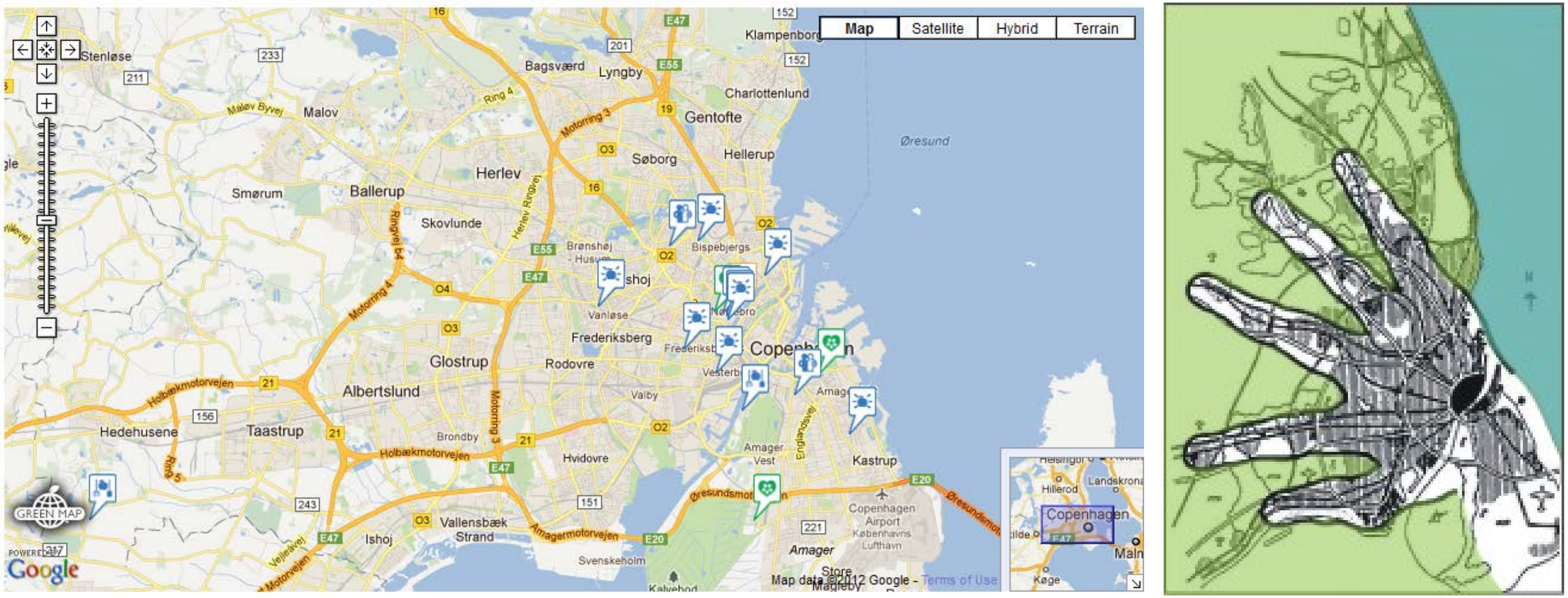


Figure 9 Green map showing GI features in Copenhagen city together with the concept of urban fingers

Source: Open Green Map (2012a)

Table 30 Costs and benefits of GI projects in Copenhagen

Project/ Description	Benefits	Costs
Cycling lanes (City of Copenhagen, 2012)	• Healthier citizens reduce health care costs at an estimated rate of US$1/km cycled. • Cycling provides a low-cost form of transport and by reducing journey times and congestion, increases economic productivity. • Reduced noise, air pollution and CO_2 emissions (90,000 tonne reduction annually).	It costs approximately US$1.3 million (DKK 8 million) to create 1km of cycle track and a further $82,125 (DKK 500,000) to mark 1km of cycle lanes. As a comparison, it costs $0.16 billion (DKK 1 billion) to create 1km of metro and $11.5-16 million (DKK 70-100 million) for 1km of wide motorway (City of Copenhagen, 2012).
District heating (City of Copenhagen, 2011)	• The District Heating system achieves lower carbon dioxide emissions than the individual gas (40% lower) and oil (50% lower) boilers it replaced. • Overall carbon dioxide emissions resulting from the consumption of heat and electricity have dropped from 3,460,000 tonnes in 1995 to 2,541,000 tonnes in 2005. • Cogeneration of heat and electricity use approximately 30% less fuel to produce the same amount of heat and power in separate heat and power plants. • Around 40% of the waste incinerated from the city is turned into electricity and heat. Combined with an extensive programme of waste management, prevention, separation and recycling, only 1.8% of waste in Copenhagen is deposited in landfills. • Conversion to biomass fuelled district heating is further decarbonising the energy supply. • 750 new jobs were created in developing the grid infrastructure required for the district heating system. • With high fuel efficiencies of up to 94%, by simultaneously generating heat and power the power plants need much less fuel per kWh generated. In comparison, conventional power plants have efficiency as low as 30-40%. • Costs around 45% less than oil heating and approximately 56% less than natural gas for a home of 130 m^2 and an average consumption of 18 MWh/year (based on 2009 figures). • Considered price competitive for household consumers. • Can be a competitive solution in new urban development areas, compared to alternatives like individual solar heating or individual heat pumps.	

3.5 CASE STUDY 5: STOCKHOLM, SWEDEN

Stockholm is the capital city of Sweden. With a municipal population of 0.9 million and urban population of 2 million in the County of Stockholm (City of Stockholm, 2012), the city is the most populous among the Scandinavian cities. Stockholm is located at the junction of Lake Mälaren and the Baltic Sea; inner Stockholm comprises 14 islands that are part of the Stockholm archipelago. Stockholm's climate is characterised by humid continental and oceanic zones allowing warm summers with temperatures ranging from 13°C to 22°C with variations up to 30°C; and cold winters with temperatures ranging from -5°C to 1°C with variations to -15°C. The report *Adapting to Climate Change in Stockholm* (City of Stockholm, 2007: 12) outlines the projected impacts of climate change as follows:

- 'An increase in mean temperatures of between 2.5 and 4.5 degrees until year 2100;
- Coldest winter days diminishing (all cold winter days with a mean daily temperature of below -10°C will essentially diminish);
- Less snow and a shorter snow and ice season;
- Spring floods 2 – 4 weeks earlier;
- Harvest season between 1 and 2 months longer;
- Rainfall amounts increasing, especially in the winter (5 – 10 per cent increase in rainfalls is forecasted for 2011 – 2040 while a 25 per cent increase is forecasted for 2071 – 2100 compared to the reference period of 1961 – 1990);
- High and low water levels in lakes will become standard at the expense of average levels (high water levels in the winter and low water levels in the summer);
- Rising sea levels;
- Reduced sea salt content;
- Rising sea and lake temperatures;
- Flooding along the coast and around lakes and watercourses more common;
- Dryer summers;
- Severe weathers such as torrential rain, storms, etc. more frequent.'

Armed with the awareness of the potential consequences, Stockholm has planned and implemented numerous initiatives to reduce risk to the population. Efforts to reduce greenhouse gas emissions, a combined effort by public, business and governing authorities, have led to a reduction from 5.3 tonnes of CO_{2e} per person to 4 tonnes of CO_{2e} per person from 1990 to 2005 (Suzuki et al. (2010) as per City of Stockholm, 2009). Some of these initiatives involve GI such as development of Hammarby Sjöstad, Green Wedges and The Royal National City Park.

3.5.1 PROCEDURES, COSTS AND BENEFITS

Green Wedges was initiated in the 1990s to safeguard urban forests that are threatened by urban sprawl. There are now 10 Green Wedges spanning rural to urban areas requiring the cooperation of multiple municipalities for their maintenance and protection. The wedges consist of forests, mixed stands, wetlands, agricultural land, parks and nature reserves. According to Åkerlund (2011), 20% to 30% of the wedges are protected, with the rest privately or institutionally owned. The Green Wedges are named after the services they provide (see Figure 10 where the solid green areas reflect the city's green spaces and the dotted areas show developed areas): 1. Climate balancing; 2. Links between town and country; 3. Promoting public health; 4. Promoting biological diversity; 5. Quiet areas; 6. Good access to countryside close to urban areas; 7. Contributing towards an attractive urban environment; 8. Ecosystem services; 9. Proximity to different experience values; and 10. Contact with the cultural landscape. The green wedges (which are essentially large green belts) foster connectivity via transport radial transportation networks.

Åkerlund (2011) also outlines the seven social values associated with the green wedges:

1. Untouched green space;
2. Woodland harmony;
3. Open views and open landscapes;
4. Biodiversity and lessons from nature;
5. Cultural history and living environment;
6. Activities and challenges; and
7. Facilities and meeting places.

According to Green Stockholm (2010), 95% of the population lives within 300 metres of green areas. Apart from the amenity value and other cultural benefits, green wedges play a role in the city's wastewater treatment, energy via forestry as well as nutrient recycling (Cardiff, n.d.). One of the major natural attractions of Stockholm, the Royal National City Park, which is part of the city's green wedges, spans over three municipalities encompassing an area of approximately $27km^2$. The park is considered to be the world's first city-based national park (Green Stockholm, 2010) and is also rich in social and cultural amenities: for example, 23 of Stockholm's 80 museums are located within it. In addition to social benefits, the Royal National City Park provides numerous biodiversity benefits. According to National Stads Park (n.d.), breeding grounds for approximately 1,200 types of beetles and 100 species of birds can be found in the park. Unfortunately, however, literature quantifying the benefits of Stockholm's Green Wedges is limited.

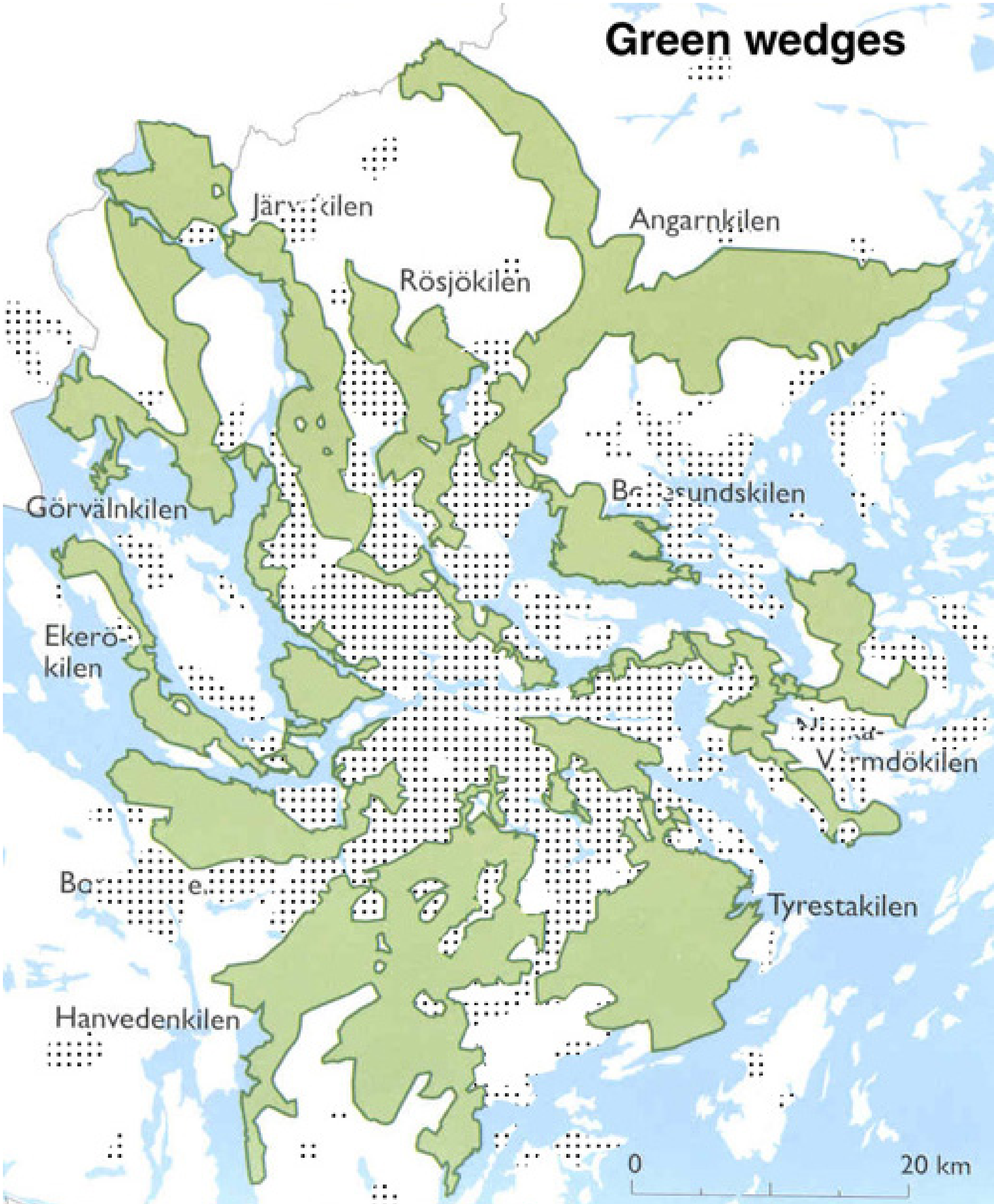


Figure 10 Stockholm's Green Wedges

Source: Cardiff University (n.d.)

Development in Hammarby Sjöstad is an example of the successful integration of ecological planning and goals at the outset of development (Pandis Iverot and Brandt, 2011). The programme was initiated in response to political interest in a bid to host the 2004 Summer Olympics. Ecological inspiration came from the Brundtland Report, Agenda 21 and UN-Habitat agenda and was backed up by the Olympic Committee, which paved the way for the project to be initiated in 1996. Goals of the project, according to Hammarby Sjöstad (1998) and as cited by Poldermans (2006), are as follows:

- Ensure the natural cycle operates at a local level;
- Minimise the consumption of resources;
- Reduce energy consumption and increase energy use;

- Reduce clean water consumption;
- Utilise sewage for energy extraction;
- Ensure building materials are to be renewable or recyclable;
- Ensure total soil decontamination;
- Restore the lake;
- Reduce transport needs;
- Stimulate community feeling and ecological responsibility for residents;
- Ensure that implementation is used as leverage for development of new solutions;
- Ensure that solutions used will not increase costs; and
- Ensure that the knowledge, experience and technology generated contributes to sustainable development in other areas.

According to Pandis Iverot and Brandt (2011), the development is near completion, with 11,000 apartments providing accommodation for 35,000 people. A remarkable feature of the project is that energy, water and waste (including sewage) is all either recycled or reused (eco-cycle shown in Figure 11). Furthermore, GI and green building (i.e. buildings that use materials non-toxic materials, have less embodied energy and are designed for less waste production and less energy consumption) have been integrated to yield multiple benefits, as outlined in Table 31. Over the years there have been numerous research studies undertaken on the various social, economic and environmental aspects of Hammarby Sjöstad (e.g. research on: wastewater treatment (Hellström, 2005); governance and management (Green, 2006; Engberg and Svane, 2007); the Environmental Load Profile (ELP) (Brick, 2008); decontamination of soil (Fryxell, 2008)). Poldermans (2006), Gaffney et al. (2007) and Suzuki et al. (2010) contain case study reviews of the Hammarby Sjöstad development. The quantification of benefits was carried out via ELP (Brick, 2008), which is based on life cycle assessment. However, quantification appears to focus on the combined effect of green buildings and infrastructure, so it does not permit a clear view of the specific benefits of GI implemented in the project.

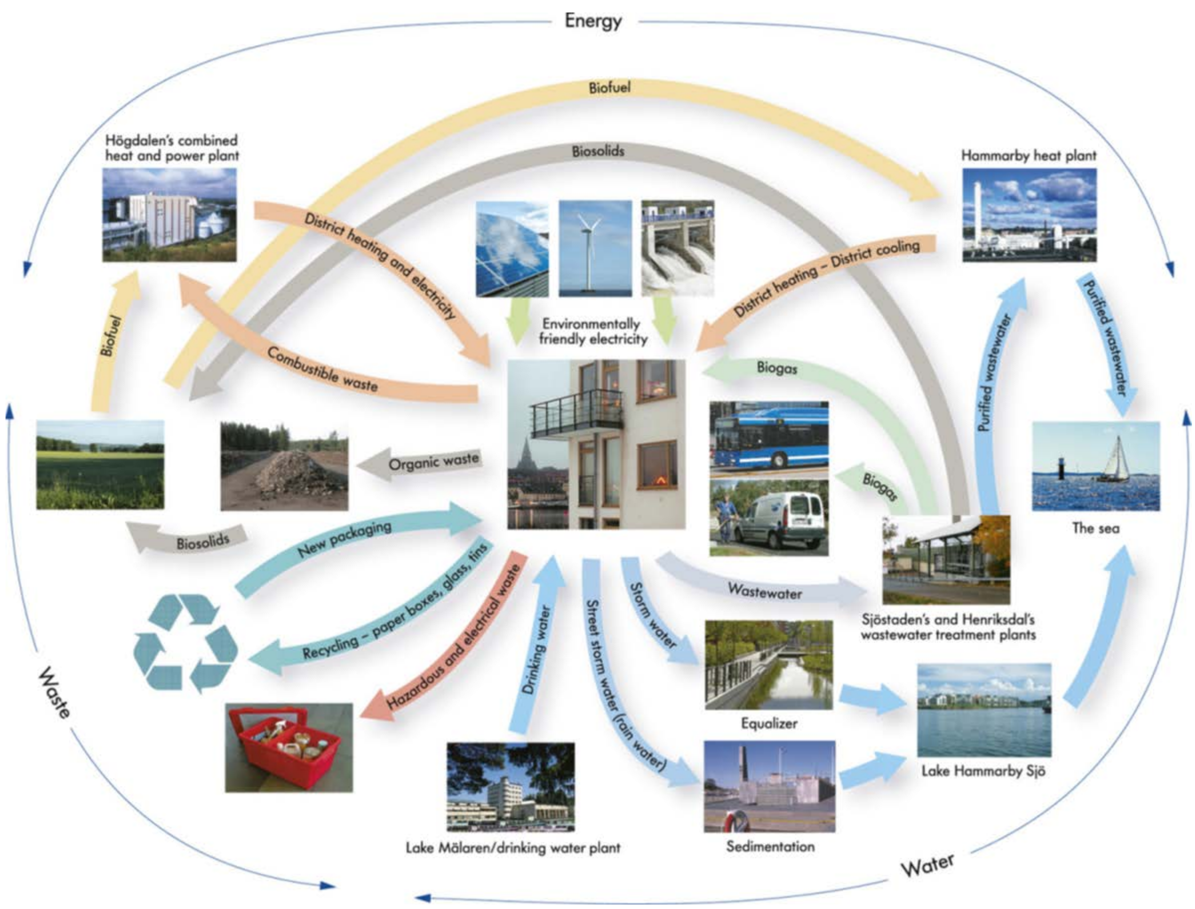


Figure 11 The Hammarby model showing the eco-cycle adopted

Source: GlashusEtt (2006: 15)

Biomass is a major source of energy for heating in Stockholm. Benefits such as a reduction in CO_2 emissions (593,000 tonnes/year since 1990) have been achieved, due to the shift from fossil fuel-based heating to district heating (Green Stockholm, 2010). In addition to the use of biomass, Hammarby Sjöstad also relies on hydropower, solar cells and biogas from sewage. According to Gaffney et al. (2007) citing City of Stockholm (2007), a solar cell module of 1 m^2 is able to provide approximately 100 kW/year, which translates to the energy requirement of 3 m^2 of housing. Nevertheless, Brogren and Green (2003) have argued that photovoltaic systems are currently not optimal in terms of their cost and performance.

Transportation options in Stockholm include trams (accounting for 33% of trips by residents (ITDP, 2011)), car sharing, cycling, public transport and walking. According to Fränne (2007), transport-related goals include:

- 80% of residents' and workers' journeys made by public transport, bicycle (with bike lanes separated from other traffic, bike sharing programme, docking stations) or foot (pedestrian pathways) by 2010;
- At least 15% of households having car-sharing memberships by 2010;
- At least 5% of workplaces having car-sharing memberships by 2010; and
- 100% of heavy transportation by vehicles meeting environmental zone requirements.

Table 31 Costs and benefits of GI projects in Stockholm

Project/ Description	Benefits	Costs
Royal National City Park – 27 km^2 of continuous park land	• Proximity to adjoining forests minimises fragmentation of species and protection of biodiversity (e.g. over 800 different flowering plants, more than 1,200 species of beetle and approximately 100 species of nesting birds); • Flood control and stormwater runoff control; • Pollution control; • Regulating microclimate of city; • Carbon sink for reduction of carbon emissions.	N/A
Hammarby Sjöstad	Energy savings: Sweden's average annual energy used per hour is 200 $kWhr/m^2$; Hammarby aims at a rate of 100 $kWhr/m^2$. According to Suzuki et al. (2010), preliminary evaluations for ELP (Brick, 2008) show: • 30% reduction in non-renewable energy use; • 41% reduction in water use; • 29% reduction in global warming potential (GWP); • 41% reduction in photochemical ozone creation production (POCP); • 36% reduction in acidification potential (AP); • 68% reduction in eutrophication potential (EP); and • 33% reduction in radioactive waste (RW). CO_2 emissions per apartment from personal transport by car is more than 50% lower in Hammarby Sjöstad than in the reference district. These savings alone would yield a reduction of approximately 2,373 tonnes of CO_2 per year (Brick 2008).	According to Suzuki et al. (2010), the programme lasted from 1998 to 2002 and allocated US$0.89 billion (SKr 6.2 billion = €671 million) to 211 local investment programmes involving 1,814 projects in 161 municipalities. This national investment leveraged $3.9 billion (SKr 27.3 billion = almost €3 billion) from municipalities, businesses and other organisations. Of this amount, $3 billion (SKr 21 billion = about €2.3 billion) were investments directly related to sustainability and the environment. It has been estimated that 20,000 full-time, short-term or permanent jobs were created (Swedish EPA and IEH, 2004).

Criticisms of the development are based on aesthetic functionality and environmental goals. For example, large windows are installed in order to obtain a nice view of the lake. However, large windows hinder energy conservation (Svane, 2005) since the building requires additional energy for cooling in summer and heating in winter. Gaffney et al. (2007) has criticised the project's lack of intra-generational equity and homogenous design, both of which are explained by the shifts in political power that have led to changes in the project goals, depending on the ruling political policies and views. Vestbro (2004) also observed that those who chose to live in Hammarby Sjöstad were more interested in living near the city centre than they were in the environmental aspects of the development. According to CABE Space (2012: 7), 'Hammarby Sjöstad has succeeded beyond expectations in attracting families with children. There are 981 children under 16 living in the area (approximately 16% of the current population).' More research is necessary to establish the extent to which green living has been a factor in choosing to live in Hammarby Sjöstad.

3.6 CASE STUDY 6: LONDON, UK

London is the largest metropolitan area in the UK, with a population of 7.8 million people in 2010 (Office for National Statistics, 2011). According to Natural England (2009b), London's population is expected to increase to 8.5 million by 2026. London has been settled since pre-Roman times, with intensive urbanisation in the last 200 years. London has a temperate oceanic climate, with cold winters (temperatures ranging from -4°C to 14°C) and warm summers (average temperature of 24°C). Extremes are experienced within the city and urban heat island effect increased temperatures by a few degrees. For example, according to Graves et al. (2001), there is a difference of 3°C between Langley Country Park and the British Museum in central London, 30km apart. Others, such as Kolokotroni and Giridharan (2008), have noted temperatures due to urban heat island intensity as high as 8.9°C. Furthermore, modelling work by Kolokotroni et al. (2012) illustrates the outcome of enhanced urban heat island effect; the potential for a five-fold increase in CO2 emissions associated with cooling requirements for city centre offices in London by 2050.

London can experience up to 7.6 cm of snow in winter and receives an average rainfall of 590 mm/year. Currently the city faces a number of environmental issues, including flooding (from rivers), photochemical oxidation (smog) and urban heat island effect, among other issues. Future climate projections indicate hotter summers with less precipitation, wetter winters, more intense rainfall and a rise in sea level over the coming century (Arkell and Darch, 2006; LCCP, 2012). This is expected to exacerbate current issues concerning water stress, flooding, stormwater runoff, erosion and heat island effect. For example, according to London Climate Change Partnership (LCCP, 2012), whilst issues concerning coastal flooding have been mitigated, river flooding continues to pose threats to the city. It has been projected that over the next 100 years, the average high tide of the Thames River and its tributaries may rise between 0.6 and 1.2m, thereby increasing the impacts of flooding (i.e. tidal, fluvial, surface and sewer) (LDA, 2010). Local authorities have taken greater interest in GI as part of the solution (e.g. tree planting projects (LCCP, 2012)), keeping in mind the potential for their intensification in the future due to climate change.

3.6.1 PROCEDURES, COSTS AND BENEFITS

In light of the issues and the increasing number of residents who would be affected, the governing body of London has initiated plans and strategies for sustaining London. Initially, recreation and protection of heritage appears to have been the main focus for GI in the past (Natural England, 2012). However, the city is currently planning for other services such as climate change, water quality, stormwater management (flood control) and the provision of green space for public health. Forest Research's (2010) report provides research on economic, social, environmental, land regeneration, hydrological and ecological benefits of GI including reviews of case studies based in the UK. The aims of Forest Research (2010) are similar to those of this report, although their scope was limited to UK case studies. The specific aims of Forest Research (2010) were as follows:

- Identifying and pulling together in one place, existing qualitative and quantitative evidence on the costs and benefits of green infrastructure in urban and peri-urban areas (including allotments, canals and other inland waters, community woodland and forests, green space around social housing, parks and city farms and community gardens), aligned to key government priorities particularly for mitigating and adapting to climate change; promoting regeneration and tackling deprivation; improving mental and physical health and wellbeing, conservation of biodiversity and improving the quality of place. Evidence on the specific benefits of different types of green infrastructure should be considered;
- Identifying and pulling together in one place existing evidence on the status and trends in the provision of green infrastructure (e.g. street trees, waterways, parks, community woodland and gardens, green linear routes);
- Identifying and pulling together in one place existing evidence on how and why communities should be engaged and empowered to realise those benefits; and
- Considering the feasibility of providing a toolkit for use in appraisal and evaluation of green infrastructure interventions.

The report presents a comprehensive review of case studies associated with economic, social, environmental, land regeneration, hydrological and ecological benefits. It brings together findings from various sources, such as reports by Land Use Consultants (2006), CSI (2008) and Regeneris (2009). The report emphasises the need for connectivity and the potentially greater benefits that flow from well-planned connectivity: 'with care given to planning, management and community involvement at the landscape, community and individual site levels, the benefits of green space can become additive and even synergistic, far outreaching the sum of benefits from each individual site' (Forest Research, 2010: 195).

Many GI projects have been initiated in the London area and, as such, there are numerous literature sources outlining the benefits to the city's residents (Table 32). One of the most extensive projects in the UK is the regeneration project called 'Thames Gateway', which is due for completion by 2016. London's contribution to the project is in the form of the East London Green Grid (ELGG) with a budget of over 110 million pounds, comprising 300 sub-projects in the area (LDA, 2010). Whilst London is considered to be a 'green' capital city, greenery is lacking in areas such as East London where 22% of the population have no access to regional parks (Natural England, 2009b). The ELGG project thus aimed to provide multi-purpose open spaces and to allow good networks and connections that link available green spaces to residential and work areas. Additionally, links to the Green Belt and the Thames were also made to facilitate better access in the region. What began as a simple strategy to regenerate East London has blossomed into manifold projects throughout London (Natural England, n.d.). The specific aims and implementation of projects are discussed in a series of reports according to the projects conducted in the following areas:

1. Lea Valley;

2a. Epping Forest;
2b. Roding Valley;
3a. Fairlop;
3b. Beam/Ingrebourne;
4. London Riverside;
5. Bexley, River Cray and the Southern Marshes; and
6. South East London Green Chain.

Figure 12 illustrates the location of the above areas and Table 33 outlines the opportunities per area. The GI projects carried out in area differ according to the variables influencing that particular area. For example, since London Riverside is likely to be affected by flooding, strategies to alleviate flooding and reduce erosion via stormwater runoff are likely to be of more importance.

As mentioned, there are some 300 projects involved in ELGG. Some of the smaller projects have been completed and thus can be quantified, at least in terms of costs (Table 32). Within the City of London, different districts illustrate the use of GI to solve issues that are specific to their respective region. For example, the project titled 'Greening for Growth in Victoria' aims to use various GI features such as living roofs, enhanced highway infrastructure, green walls and also increased tree cover in order to manage surface flooding. The GI is expected to provide other benefits such as the reduction of ambient heat, consequently reducing heat island effect in the business district in addition to providing a more aesthetically-pleasing working environment for local businesses. According to Land Use Consultants and Green Roof Consultancy (2010), the Victoria business district has 16,197 m^2 of trees with 5-15 m canopy size. The larger canopy sizes are said to contribute more towards reducing urban heat island effect.

A study associated with the East London Green Grid (ELGG) by Tiwary et al. (2009) illustrated the potential for pollution removal using green space. In particular, the study focused on the removal of PM10 (particle matter), which is responsible for health-related issues (Tiwary et al., 2009). Ongoing measures include the control of vehicle emissions, as well as the introduction of road tolls to discourage driving in central London. Tree planting has been suggested as another means for reducing the adverse impacts of particle matter, as trees provide surface area for the interception of particle matter and thus reduce the amount that is airborne. According to Tiwary et al. (2009), different species allow for different levels of particulate matter capture with one scenario of green coverage consisting of 75% grassland, 20% sycamore and 5% Douglas fir was estimated to remove 90.41 tonnes of PM10/year.

Table 32 Costs and benefits of GI projects in London

Project/Description	Benefits	Costs
The East London Green Grid (ELGG) identified around 300 projects with a total implementation value of £220 million.	Connection and provision of open space for formal and informal recreational uses; Promotion of healthy living via provision of areas for exercise; Increase of cultural and aesthetic value of surroundings; Adaptation measures for climate change: Reduction of flood risk; Enhancement of surface water management; Provision of habitat for biodiversity.	Design for London and the LDA have provided US$3.8 million (£2.4 million) revenue funding for project development and worked with partners have been successful in securing $170 million (£110 million) to deliver physical projects across East London.
Barking Riverside – incorporating GI into London's large housing development as part of Thames Gateway Associated with the Wetland Vision delivery, this includes river restoration.	Adapation measures for climate change; Biodiversity establishment and protection; Enhancement of community involvement.	
Olympic parklands.	Retention and restoration of natural environment of the Gateway's landscapes as well as the promotion of heritage. 'Improve 400 hectares of green space and 5.2 hectares of public spaces, 35.4km of foot and cycle routes including 14.9km of routes to the Thames waterfront. 10.9km of watercourses will be improved and restored, enhancing habitats and reducing flood risk for 1,070 properties. The programme will enhance the quality of life of the 118,700 residents who live within 300m of the projects and a further 298,000 living within 1km' (Design for London, n.d).	$54 million (£35 million) including $15.5 million (£10 million) capital funding toward five projects
Eastern Curve, Dalston, London (Landscape Institute, 2011) – restoration of 0.25 hectares of former railway land used as unofficial landfill site.	Trees planted for provision of shade, cooling and improvements to air quality, offsetting pollution associated with traffic; Provision of vegetable and herb growing areas for food production as well as promotion of horticultural skill development; Reconnection of local people with their natural environment.	US$310,188 (£200,000)
Lady Trower Trust open space – 7.5 hectares of land that will be transformed to allow community access to River Roding while enhancing and protecting biodiversity.	Aesthetic and functional improvements allowing public access and engagement with the environment – associated benefits to health.	US$310,188 (£200,000)

Table 32 Costs and benefits of GI projects in London (cont.)

Project/Description	Benefits	Costs
Greening for Growth in Victoria, London (Landscape Institute, 2011; Land Use Consultants and Green Roof Consultancy, 2010) – embed natural environment into business area.	Potential for 1.25 ha of new terrestrial green infrastructure, 1.7 ha of enhancements to existing green infrastructure and suitable space for 25 ha of living roofs; Solution to surface water flooding issues in the area – the 25 ha of living roofs is expected to assist with 80,000m^3 of rain water each year: Extensive living roof will attenuate between 45-55% of annual rainfall; A semi-intensive living roof will attenuate between 60-65% of annual rainfall; An intensive living roof will attenuate between 90-100% of annual rainfall.	Delivery of living roofs is expected to cost approximately US$78-233 per m^2 (£50 - £150 per m^2, plus cost of structural surveys, design advice and construction.
Barking Park and Loxford Water Link – consists of upgrading infrastructure by removing car parks, improving swimming areas and safe play areas for children while establishing vegetation, reed beds and wildlife cover.	Conservation and enhancement of vegetation; Upgrade to safety of children; Aesthetic improvement and community engagement; Enhancement of existing green space and connection to water.	$13.6 million (£8,800,000)
Tree Lined Streets (Greater London Authority, 2008) – consists of plans to plant over 1,139 new trees with the aim of forming a network of green streets (with existing tree lined streets and parks) so as to provide green space for pedestrians and cyclists.	Connection to parks increased; Provision of carbon sinks via trees; Water management and runoff control; Pollution control; Enhancement of aesthetic appeal for pedestrians and cyclists – improved health as a result.	US$3.9 million (£2,500,000) Maintenance of $271,000 (£175,000) per year for the first year, followed by a lifelong increased maintenance of $109,000 (£70,000).

The Olympic parklands, specifically the Queen Elizabeth Olympic Park, is another ambitious project for London (Neal, 2012). This development was completed for the 2012 Olympics. The park was constructed on derelict industrial land in the lower Lea Valley, north of London and was central to many of the venues where the 2012 Olympic Games were held. It serves multiple purposes including provision of cultural and recreational areas as well as contributing to climate change mitigation and adaptation. The following commitments of the Sustainable Development Strategy were relevant to projects such as the Olympic parklands:

- 'The reduction of carbon emissions through on-site renewables;
- Managing flood risk;

- Ensuring all buildings are completely accessible by public transport, walking and cycling;
- Meeting the biodiversity and ecology targets by creating a species-rich habitat of at least 45 hectares;
- Constructing the Parklands with recycled aggregates and certified and legally sourced timbers; and
- Conforming to all recognised inclusive design standards' (Neal, 2012).

While the initiatives are in place for development of the parklands, there is currently no quantifiable information on benefits arising from the development. However, a landscape view of the parklands development is evident by the efforts to connect with the wider region via networking through the Lea Valley, East London Green Grid and the Thames Gateway Parklands.

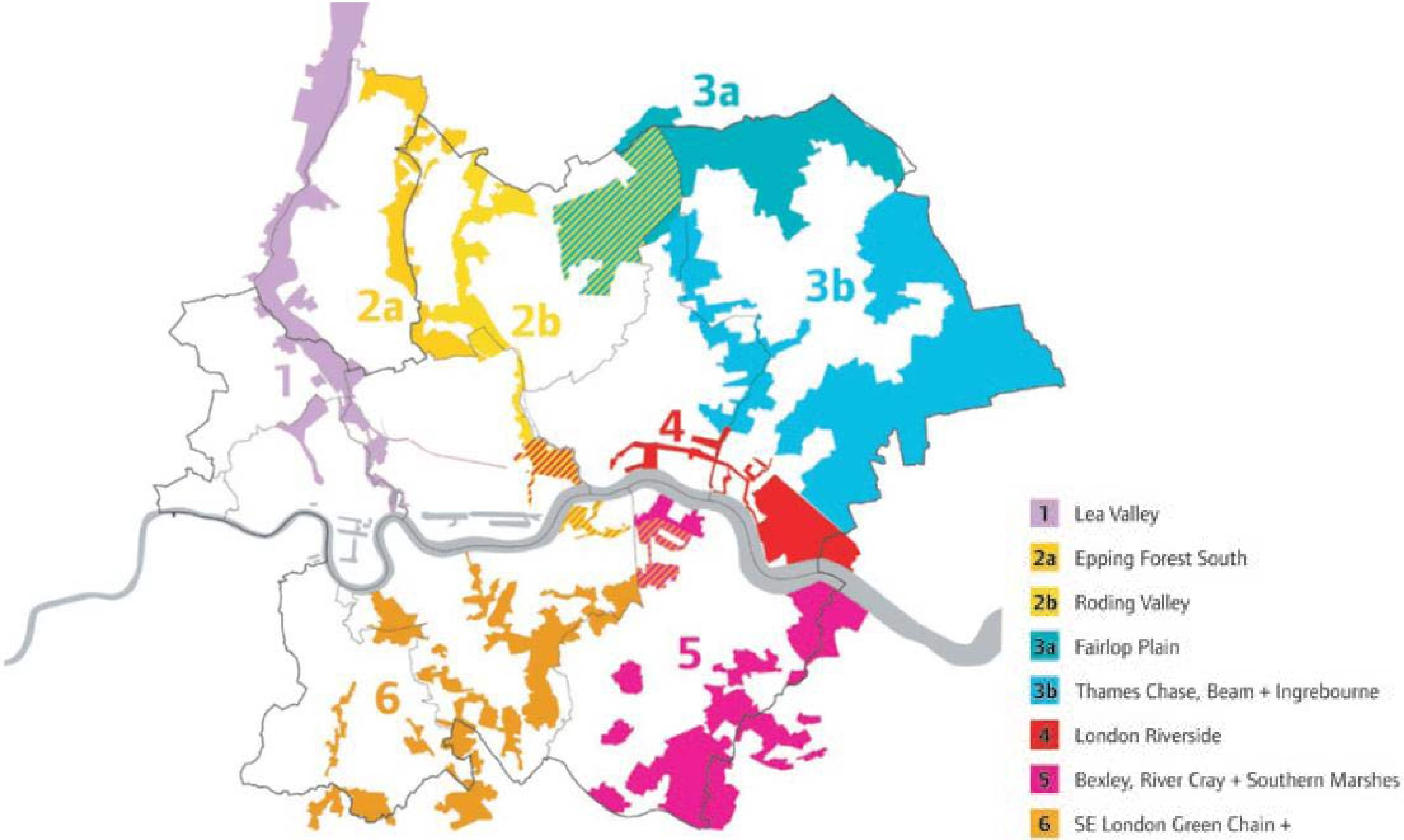


Figure 12 All London Green Grid areas

Source: Greater London Authority (2008)

Table 33 Strategies/aims (and thus GI opportunities) for the respective areas of London

Lee Valley	Epping Forest / Roding Valley	Fairlop / Beam / Ingrebourne Green Grid Area
• Provide at least 240-250 ha of new and improved public open space as a major new park through the Lower Lea Valley to the Thames, which includes the Olympic Legacy proposals. • Complete the strategic north/south recreational route through the valley to the Thames. • Create new access routes across infrastructure barriers, including waterways, railways and major roads. • Improve the ecological value of watercourses and water bodies, especially the heavily engineered flood protection channels. • Improve the value and connectivity of habitats, optimising appropriate access. • Refurbish and enhance the Northern Outfall Sewer Link and connect it with the Thames Gateway Bridge proposals. • Improve the heritage and community value and use of the Clissold Park Link.	• Restore the River Roding and its tributaries with natural river banks replacing the existing engineered concrete channels, incorporating flood storage and alleviating urban runoff. • Create a Metropolitan Park from Ilford to the Thames (including Cross River Park), linking the River Roding from Ilford to the Beckton Park Link, the proposed Thames Gateway Bridge and on to the south side of the river, maximising pedestrian and cycle connectivity and improving ecological value. • Improve the linkages between Mayesbrook Park and Goodmayes Park and Recreation Ground in order to address the Metropolitan Park deficiency. • Recreate natural habitats around Barking Creek to establish wetland habitats such as grazing marsh, reed beds, ponds and wet woodland, increasing accessibility with potential for productive uses. • Create a link between the Roding Valley, Claybury, Fairlop, Hainault Forest Country Park and Havering along the Redbridge Link. • Improve access to and awareness of rivers particularly in the lower part of the Green Grid Area without detriment to flood risk management and biodiversity. • Maintain the navigability of the lower Roding for commercial and leisure use.	• Improve the access to and the landscape quality of Fairlop Plain as part of the Redbridge Link. • Improve and protect the landscape value of the Ingrebourne valley, providing for informal recreation, reinforcing woodland planting, conserving and re-creating habitats. • Create an accessible open space network through the Dagenham corridor, linking Hainault and Fairlop with the Thames, providing long distance paths and strengthening east-west connections. • Create a mosaic of open spaces and woodland in Thames Chase, including for biomass, orchards for food production, allotments, wet woodlands and screening. • Restore previous mineral extractions and landfill sites with an accessible landscape structure of woods and hedgerows. • Naturalise river corridors, creating new habitats and flood water storage space. • Open up the culverted sections of the Goresbrook restoring naturalised riverbanks and floodplains, providing access along the Goresbrook Link from Parsloes Park through Goresbrook Park and the Barking Riverside development site to the Thames.

Table 33 Strategies/aims (and thus GI opportunities) for the respective areas of London (cont.)

London Riverside Green Grid Area	Bexley, River Cray and Southern Marshes	South East London Green Chain +
• Create the London Riverside Conservation Park as an exemplar sustainable regional park for the 21st century. • Create a Metropolitan Park from Ilford to the Thames (including Cross River Park), linking the River Roding from Ilford to the Beckton Park Link, the proposed Thames Gateway Bridge and on to the south side of the river, maximising pedestrian and cycle connectivity and improving ecological value. • Reopen the culverted Rainham Creek where it meets the Thames and to improve landscape, accessibility and wildlife value of the river corridor. • Create a linked network of accessible open spaces with a strong wetland character, along the London Riverside Link. • Open up the culverted sections of the Goresbrook restoring naturalised river banks and floodplains, providing access along the Goresbrook Link from Parsloes Park through Goresbrook Park and the Barking Riverside development site to the Thames. • Improve the London Loop long distance footpath linking Rainham village and the Thames and integrating other foot and cycle routes and destination points within the Green Grid Area. • Enhance access and connectivity across major east-west infrastructure corridors, including the A1306, A13 and railway lines.	• Conserve and improve the environmental and ecological value of Erith, Crayford and Dartford marshes and improve public access. • Conserve and enhance the rural character and intimate scale of the landscape between the A2 and A20, exploring opportunities to increase the flood storage capacity of the local floodplain. • Enhance the River Cray corridor and improve access between the A206 and A2 to create a high quality, accessible urban riverside environment. • Provide high quality open space links with the South East London Green Chain and improve other linkages within the area. • To enhance the river character and recreational use of the River Shuttle Link, improving public access. • Promote the educational value of the River Shuttle emphasising appropriate conservation management.	• Develop the South East London Green Chain regional park opportunity. • Maximise opportunities in relation to the proposed Thames Gateway Bridge, strengthening and enhancing the connections along the Tripcock Park (Cross River Park) to Plumstead Common Link, promoting habitat types characteristic of this part of the tidal river environment. • Create a connected park system along the Ravensbourne and Pool Rivers re-instating the natural channel, improving habitats, creating an exemplary green transport route, exploring opportunities for improving health and the local environment. • Restore the green infrastructure surrounding Eltham Palace and Charlton House. • Improve the relationship and connection between nature and housing across the Green Grid Area, including the use of nature trails and a green link between Woolwich Common and the Thames. • Reinstate a natural river course along the Quaggy River with natural banks and meanders, enhancing flood storage capacity and creating sustainable drainage schemes. • Promote and enhance the long distance South East London Green Chain footpath and links by improving accessibility into and through the area, particularly access from its edges. • Explore extensions of the South East London Green Chain including the Green Chain 'gateway' open spaces linking Avery Hill to Hall Place, Plumstead to the proposed Cross River Park, Sutcliffe Park to Greenwich Park, New Beckenham to Ladywell Fields and links west from Crystal Palace Park to Dulwich Park and Nunhead Cemetery. • Promote and enhance the existing woodland and heathland character of the Thames Barrier to Shooters Hill Link.

Source: Greater London Authority (2008)

3.7 CASE STUDY 7: SINGAPORE

The city-state of Singapore is home to 5 million people (Department of Statistics, Ministry of Trade and Industry, 2010). According to a Singapore government white paper, the population projection is between 5.8 and 6 million by 2020 and between 6.5 and 6.9 million by 2030 (National Population and Talent Division, 2013). The land area of Singapore is 700 km^2 – and the ground level does not rise more than 15 m above sea level. It is expected that the land area will increase as a result of land reclamation measures, merging some of the smaller (of the 63) islands in the future (although sea level rise may counter any gains made). Singapore has a tropical rainforest climate with uniform temperatures ranging from 23°C to 32°C. Singapore is humid with abundant rainfall averaging at 2,600 mm per year, with increases during the monsoon.

Issues facing the urban areas of Singapore include climate change impacts and heat island effect. Differences of up to 4°C have been observed between Singapore's urban and rural areas (Wong and Yu, 2005). In 2005, Singapore's CO_2 emissions amounted to 40 Mt (0.2% of global emissions) (SNCCS, 2008). In an attempt to reduce transport emissions, Singapore shifted from liquid fuel to natural gas. However, increased use of vehicles has reclaimed the gains made in lower CO_2 emissions, requiring numerous incentives to reduce emissions. Projections for climate change shows that Singapore would be vulnerable to the following impacts (SNCCS, 2008: 7):

- Increased flooding;
- Coastal land loss;
- Water resource scarcity;
- Public health impact from resurgence of diseases;
- Heat stress;
- Increased energy demand; and
- Impacts on biodiversity.

Mitigation and adaptation procedures have been initiated to limit damage to infrastructure and impacts on human wellbeing. Some of the initiatives include roof gardens to increase greenery in the city, a comprehensive water management strategy (e.g. tariffs, rain water collection, desalination techniques), transportation and land use planning to limit the use of vehicles and improvement of the City Biodiversity Index.

3.7.1 PROCEDURES, COSTS AND BENEFITS

Although Singapore is highly urbanised, much of it remains green due to optimised use of land. Given that parks and reserves make up 14% of Singapore's land area (Tanuwidjaja, 2010) (see Figure 13), Singapore has justifiably earned its reputation as 'Garden City'. The vision of enhancing Singapore's greenery and establishing it as a Garden City was initiated by Lee Kuan Yew, former Prime Minister of Singapore from independence in 1965 until 1990. This leadership provided sufficient political backing for the vision, which led to the creation of departments responsible for the gardens. Today Singapore has over 300 parks and four nature reserves, managed by the

National Parks Board. The programme was initiated with the idea of providing 0.8 hectares of park space per 1,000 residents (Tan, 2006). The parks serve multiple purposes, from recreational activities through to the protection of biodiversity. In addition to creating natural habitat, the parks also contribute to cooling, as illustrated by Chen and Wong (2006). Their study showed that a 1^{o}C reduction in air temperature resulted in a 5% reduction in energy required for cooling.

In order to establish connectivity between natural habitats and to encourage recreation, the Park Connector Network Plan was initiated in 1992. Park Connectors are essentially greenways that link existing parks, nature reserves and open spaces in Singapore (Tan, 2006). The linkages are important for improving human interaction and wellbeing (Briffet et al., 2004; Aldous, 2010; Tanuwidjaja, 2010). For example, according to research by Briffet et al. (2004), 77% of the 4,087 users per day visited the Park Connectors from nearby residences; and 85% were regular users, visiting at least once a week. Furthermore, it was found that of the users from UluPanan, 67% used the Park Connectors for physical exercise, 50% for environmental amenities, air quality and vegetation and 40% for recreation and relaxation.

In terms of biodiversity, Singapore has many urban parks containing numerous plant and animal species that have evolved to survive in the tropical conditions. The City Biodiversity Index (CBI), also known as the Singapore Index, was developed as a self-assessment tool to assist authorities in benchmarking conservation efforts in their cities (Chan and Djoghlaf, 2009). The index is useful for highlighting gaps in knowledge about biodiversity and its state in cities. CBI measures:

1. Native biodiversity in the city;
2. Ecosystem services provided by biodiversity in the city; and
3. Governance and management of biodiversity in the city.

Even though there are multiple benefits of parks (e.g. carbon sinks, alleviation of the heat island effect), it is not possible to increase green areas (such as forests) in Singapore due to severe limitations in land area. GI strategies such as living roofs (referred to as 'roof gardens' in Singapore) can contribute to solutions to multiple issues including water management. In fact, Singapore's tropical climate may offer advantages for living roofs by reducing maintenance costs. Although Wong et al. (2003a) note that research on living roofs in Singapore is in its infancy, countries such as Germany provide ample knowledge on a range of best practices. More recently, there have been increased research efforts to quantify thermal benefits and the costs associated with living roof design in cities such as Singapore. Research conducted by Wong et al. (2003b: 508) estimated the cost of extensive, intensive (shrubbery) and intensive (with trees) living roof types. They showed that the costs were '$89.86, $178.93, $197.16/m^2, respectively while the cost of exposed flat roofs was $49.35/m^2 and of built-up roofs $131.60/m^2'.

Figure 13 ABC water projects and parks in the Singapore region

Source: Onemap (2012)

In terms of the thermal benefits of living roofs in Singapore, studies by Wong et al. (2003a) confirmed the benefits on buildings and the surrounding area in terms of the reduced thermal loading (the study showed a maximum temperature decrease of 30°C in some cases). The cooling afforded by roof gardens with appropriate plant types (e.g. thicker foliage was found to be better) would be beneficial in lowering Singapore's energy costs and energy related emissions for cooling. However, unfortunately the change in annual energy demand did not appear in the Wong et al. (2003a) study. The costs and benefits of GI projects in Singapore are summarised in Table 34.

Due to its high rainfall, Singapore is prone to flooding and the associated problems of stormwater runoff and water pollution. Nevertheless, it is considered to be a water-scarce region due its low capacity for water storage (i.e. there is not enough land to store water – 2,158 hectares of protected watershed in the middle of the island). These issues ultimately have flow-on effects and, combined with the water needs of the population, there is increased stress on water resources. According to Tortajada (2006), water consumption was approximately 1.36 billion litres per day. Singapore imports water from Malaysia under a long-term contract established in 1961/1962 (Long, 2001; Tortajada, 2006; Luan, 2010; Tortajada and Pobre, 2011). Because of uncertainties around future water supply and political priority on the critical nature of the issue (Ghesquière, 2007), Singapore has put in place numerous water management strategies, including enforcing tariffs on water take.

Table 34 Costs and benefits of GI projects in Singapore

Project/Description	Benefits	Costs
Braddell Road Campus – Zero Energy Building (4,500 m^2 in area) (Yudelson Associates, 2011).	Provision of photovoltaic panels for the purpose of energy generation and sun shading; Passive solutions for cooling; Minimisation of heat transmittance; Daylighting; Natural ventilation.	Cost: US$8.6 million; $1900/$m^2$ (S$11 million, S$2444/m^2).
Marina Bay (Landscape Urbanism, 2012) – a 30 acre (12 ha) development on Marina Bay Sands consisting of a 2.5 acre (1 hectare) Skypark, streetscape – triple allee of Roystonia palms interspersed with informal groupings of large canopy trees, permeable pavement	Tree canopy provides shade and reduces ambient temperatures; Aesthetic and recreational value; Permeable pavement reduces surface runoff.	
Four National Taps (CABE, 2011) – consisting of rainwater collection networks, stormwater ponds.	Allows management of water cycle to supply for growing demand: • 10% of fresh water supplied via water catchment; • Recycled water or NEWater (treated wastewater) is expected to provide 30% of water demand; • Other sources: desalinated and imported water.	

Singapore's water management strategy requires collection of rainwater, renewal of catchments, desalination (e.g. Tuas Desalination Plant at a cost of S$200 million), wastewater recycling (e.g. Bedok Water Reclamation Plant) and overall improved efficiency (Tortajada, 2006; Lee, 2010; Luan, 2010). To that end, the Public Utilities Board (PUB) manages the entire water cycle including the transfer of responsibility for sewage treatment (as opposed to its previous responsibilities, which entailed supply-based responsibilities). Tortajada (2006: 228) states that 'this transfer allowed PUB to develop and implement a holistic policy, which included protection and expansion of water sources, stormwater management, desalination, demand management, community-driven programmes, catchment management, outsourcing to private sector-specific activities which are not core to its mission and public education and awareness programmes.' Success of the water management strategy is based on the holistic perspective taken by PUB when managing supply and demand with respect to the Four National Taps: 1. Water from local catchments; 2. Imported water; 3. Desalinated water; 4. Reclaimed water from wastewater. Studies specific to the use of GI in wastewater management, control of runoff and catchment replenishment for Singapore were not available.

Singapore's main modes of transport are bus, Mass Rapid Transit (MRT), Light Rapid Transit (LRT) and taxi (Santos et al., 2010). According to May (2004), bus and train transport are not subsidised while the Area License Scheme (ALS) (later changed to Electronic Road Pricing (ERP)) and Vehicle Quota System (VQS) apply to private vehicles and taxis. VQS was established to limit car ownership while ALS targets vehicles entering the city (congestion reduction). Its status as a world-class transport system (Hasegawa et al., 1997) is due to the integrated nature of the network, allowing mass transit and demand management. This outcome was the result of the strategy proposed in the 1970s (UNDP, 1972), with goals that allow:

- 'Network of expressways;
- Comprehensive traffic management;
- Specific restraint on the use of cars in the Central Area;
- Restructuring the bus services; and
- Detailed investigation of a mass rapid transit network' (May, 2004: 86-87).

In addition to encouraging forms of public transport, Singapore initiated the Heritage Roads and Heritage Tree Schemes in 2001 to preserve and enhance the treescapes of the city (Figure 14). This attempt at preservation does not appear to be a direct attempt to incorporate GI but rather to balance the destruction of natural areas. According to Briffet et al. (2004: 56), 'Singapore's landscape was transformed from dense tropical forest to an equally dense built-up environment, entailing a sort of paradox. On the one hand, natural areas continue to be destroyed. However, on the other hand, policies and actions have been introduced to 'green' the city.' Although the goal of heritage roads and trees is conservation (National Parks Board, 2012), Singapore's urban trees (including street trees) are a significant source of carbon storage and sequestration (Tan et al., 2009).

Figure 14 Arcadia (left) and Mandai (right) Roads, illustrating Singapore's treescaped heritage roads

Source: National Parks Board (2012)

Whilst, from an economic, social and environmental perspective, Singapore is currently thriving, it is nevertheless compromised by a lack of alternative energy resources such as wind and hydropower. This leaves the city with the potential for expanding solar energy resources and options to increase efficiency in its fossil fuel use, which the city has been progressively moving towards.

3.8 CASE STUDY 8: CURITIBA, BRAZIL

The city of Curitiba is the capital city of the state of Paraná in Brazil. It is considered to be the largest city in southern Brazil, with a population of approximately 2 million. Curitiba has a subtropical highland climate and is located on a plateau with flooded areas. It has mild winters, with temperatures ranging from 0°C to 13°C and humid summers with temperatures ranging between 21°C and 32°C (CBD, 2012b). The city's altitude makes for lower temperatures than in neighbouring cities. However, Curitiba is known to experience heat waves during winter and cold periods in summer, with the variability resulting from the flat land and its proximity to the surrounding mountains. Furthermore, cold fronts from Antarctica or moving across Argentina contribute to tropical storms, while the warm dry air from mid-west Brazil creates dry conditions. Climate change is expected to increase the intensity and frequency of tropical storms. During Curitiba's establishment, urbanisation has caused fragmentation of natural habitat and consequent loss of biodiversity and numerous species are now under threat of extinction due to loss of food, reproductive capability and as a result of poaching; among them are the red howler monkey and panther.

Curitiba is known for its proactive approach to solving complex issues from urbanisation, using ecological strategies. For example, the Latin American Green City Index score for Curitiba showed that it rates highly among the 17 cities evaluated for sustainability by a programme initiated by Siemens (Sumner and Barchfield, 2010). Additionally, Curitiba was awarded the Globe Sustainable City Award in 2010, recognising its efforts to become a sustainable city. As such, there are many GI projects and related activities throughout the city.

3.8.1 PROCEDURES, COSTS AND BENEFITS

Since the adoption of the Curitiba Master Plan in 1968, numerous initiatives aimed at improving the connectivity and liveability of the city have been undertaken. The Master Plan was aimed at reducing urban sprawl, reducing traffic, preserving heritage and providing affordable transportation within and out of the city. Curitiba's attempt to integrate land use and mobility is evident in its increased connectivity via mass public transit (Rabinovitch, 1992; Smith and Raemaekers, 1998; Mell, 2011). Curitiba is known for its transport infrastructure, touting its efficacy as a city for people rather than a city for cars. Buses, trains and bicycles are given precedence over private vehicles and 'greenways' are designed to link residential and business sectors to provide integrated transport networks for commuters. Curitiba's Bus Rapid Transit (BRT) system is hailed worldwide as a successful means of improving speed and realiability of travel on public transport (Smith and Raemaekers, 1998) whilst also ensuring affordability. According to Menckhoff (2005), the buses used in the system can carry up to 260 passengers and are capable of fast travel times and lower fuel consumption (Deng and Nelson, 2011).

Studies conducted by Menckhoff (2005) report that 532,000 passengers use the BRT system per day, resulting in significantly fewer cars on the road. According to CABE

Space (2011b), 75% of the population travels via public transport. Lloyd-Jones (1996) states that 80% of private trips are by bus and that the city uses 25% less fuel than comparable cities, amounting to 30% less petrol per vehicle. BRT systems are viewed as cost effective alternatives to rail transport; however, there has been considerable lessening of investment in BRT systems for many reasons including the perception that buses are slow and polluting. This perception has influenced a greater investment in rail over bus transport (Flyvbjerg et al., 2006; Deng and Nelson, 2011). Moreover, the lack of research and knowledge regarding the land use impacts associated with BRT systems does not help investment decisions (Deng and Nelson, 2011). Nevertheless, the BRT system appears to make economic sense: it costs only US$8 to US$12 million/km to construct, while subways cost US$50 to US$100 million/km (Friberg, 2000).

In addition to the BRT system, Curitiba also has pedestrian-only streets in the central commercial areas. Nevertheless, pedestrians have been generally discouraged in other non-pedestrian friendly parts of the central city by the high speeds of vehicles, a lack of visibility and long streets that do not allow for crossing on foot. Furthermore, whilst Curitiba is internationally renowned for its sustainable strategies – particularly its transportation networks – there have been criticisms about the lack of poverty alleviation and the cosmetic nature of projects (Lloyd-Jones, 1996).

Curitiba utilises urban parks and forests as a means of flood control, rather than diverting stormwater to treatment facilities. Some 17.9% of the total land area has been classified as green urban areas, providing 51.5m^2 of green space per person (CBD, 2012b). Open stormwater management systems have also been utilised, with old quarries converted to lakes and parklands. Most of the parks have lakes that assist in flood control. Additional benefits include the ability to contain peak flows during storm events, avoidance of built impermeable facilities, aesthetically pleasing views and recreation. However, setting up open wastewater management systems may be costly to begin with and the need for maintenance could be high. In addition to benefits for water management, the increase in green spaces is also beneficial for cultural services as well as protection of biodiversity. Green areas, including parks, have been established to restrict land development.

In an effort to reduce landfilled waste and prevent littering, Curitiba has implemented programmes to recycle and compost residential wastes. This involves the separation of organic from inorganic refuse. Metals, glass, plastic and paper are salvaged to the cover the cost of the programme. The waste management programme not only prevents pollution by waste, but also provides a source of income or exchange of goods for the poor through a green exchange programme. Yet, despite these ambitious programmes, Melo et al. (2009) states that 40% of waste sent to landfill comprises recyclable material. Simulations carried out on alternative scenarios for waste management show that for the 2008–2020 period, a 20% reduction in recyclable waste from the waste stream could lead to an economic profit of R$2,410,000, diverting 535,000 tonnes of solid waste from the landfills (Melo et al., 2009). Whilst the link between waste management and GI is not readily apparent, waste management can take the form of composting and the compost can be applied to GI as a substrate or fertiliser. Furthermore, the potential for energy generation using waste can be explored to minimise land required for landfills.

Curitiba is considered to be an exceptional example of how developing countries can enjoy above average environments. According to Sumner and Barchfield (2010: 16), 'the key reason for Curitiba's outstanding performance is a long history [since the 1960s] of taking a holistic approach to the environment, which, as the Index demonstrates and experts confirm, is unusual in the rest of the region'. An increase in population is expected to challenge Curitiba's current systems (for instance, urban sprawl can threaten the protected parks and other green and blue space that now provide a rich variety of ecosystem services). Table 35 outlines some of the green initiatives planned for further improvement of Curitiba. Figure 15 shows the areas that currently cater to the natural, economic, social and cultural wellbeing of the city.

Table 35 Green initiatives in Curitiba

Project/Description	Initiatives and benefits	Costs
Transport – Rehabilitation of the Green Line (highway linking eastern and western Curitiba; Development of metro.	• 4 new exclusive bus lanes and three lanes for private vehicles in each direction, helping to cut down on commuting times and encourage use of public transport; • Half the buses on the line are driven by soybean based biofuel; • Expected to allow 500,000 commuters to travel between 22 metro stations.	Metro: US$1.2 billion.
Carbon emission reduction – studies to determine absorption of CO_2 by green spaces and plan for reducing emissions.	• Change all streetlights from incandescent to energy-efficient fluorescent bulbs; • Replace all diesel oil used in public transport with environmentally friendly, low-emission biofuels.	
Land use and building.	• Provide low cost housing in order to prevent urban sprawl, protect vulnerable ecosystems and allow for green space along river (squatter communities).	
Sanitation programme - From River to River – 2018.	• Improving sanitation and drainage and the quality of the state's water basins.	US$585 million.
Waste reduction	• Residents receive food baskets in exchange for each 8-10 kg of waste they hand over; • The city pays the neighborhood association 10% of the value of each food basket for community works or services; • 6,800 tonnes of waste are collected through this initiative each year.	

Source: Sumner and Barchfield (2010)

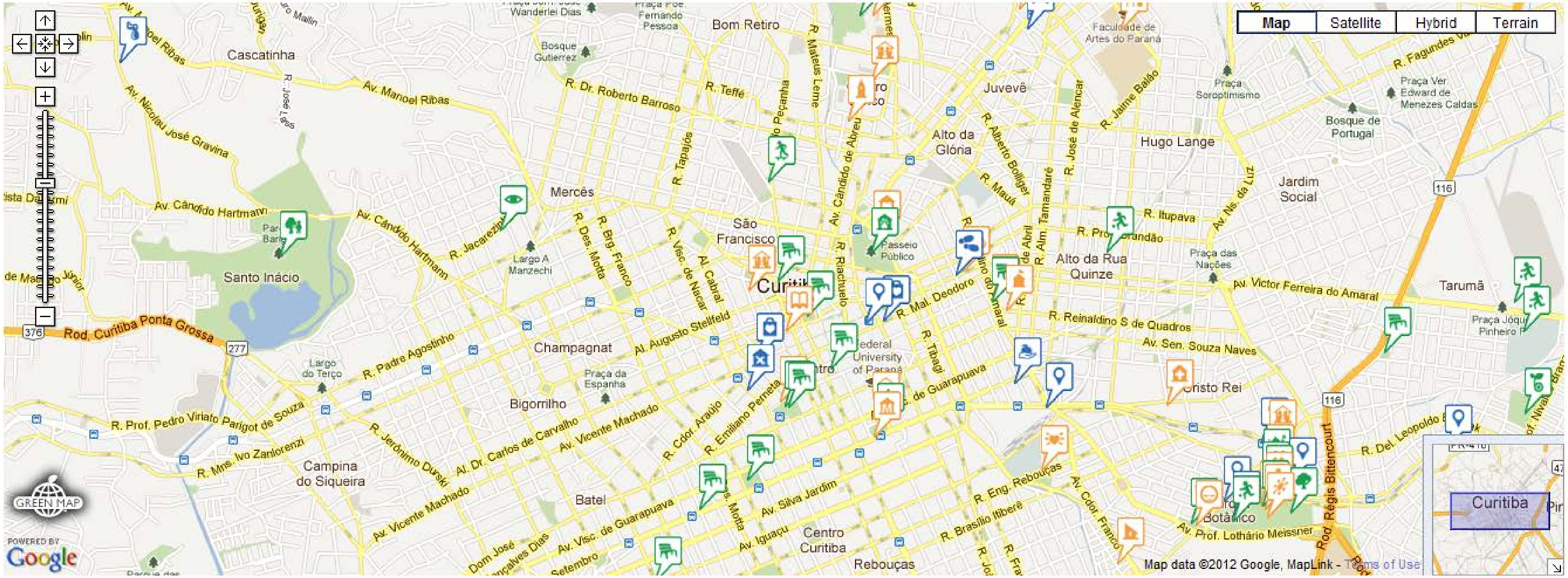


Figure 15 Green map of Curitiba

Source: Open Green Map (2012b)

(Legend on the following page)


Green Map Icons
Sustainable Living
Nature
Land and Water
Flora
Fauna
Outdoor Activities
Culture and Society
Green Map Icons
Sustainable Living
Green Economy
Technology and Design
Mobility
Hazards and Challenges
Green Map Icons
Sustainable Living
Nature
Culture and Society
Cultural Character
Eco-Information
Justice and Activism
Public Works and Landmarks

3.9 CASE STUDY 9: VANCOUVER, CANADA

The City of Vancouver, with a population of 603,502 (Statistics Canada, 2011a), is situated between Burrard Inlet (to the north) and the Fraser River (to the south). It is part of Greater Vancouver, which is home to approximately 2.3 million people (Statistics Canada, 2011b). The population of the city is projected to rise to 740,000 by 2041 whilst the population of Greater Vancouver is expected to rise to 3.4 million by 2041 (Metro Vancouver, 2009). The city enjoys a temperate climate, with dry summers and wet winters. The average summer maximum temperature is about 22°C, although highs of 34°C have been recorded (in 2009). The average annual rainfall is 1,199 mm and average annual snowfall is 48 cm. In the future, Beck and Crowe (2008) present climate projections tabulated by the Pacific Climate Impact Consortium (PCIC) showing rainfall and other precipitation increasing in amount and intensity during winter, with decreasing precipitation in summer. The PCIC also predicts a decrease in average snowfall, an increase in the incidence of extreme temperatures, rising sea level and intensification of storm surge. The report outlines the areas of infrastructure investment aimed at reducing the city's vulnerability to climate change:

- Sewers for managing water and wastewater – adapt for greater rain intensity, rising sea level and storm surge to limit the amount of water entering the city's sewerage systems;
- Parks and urban landscape – adapt to the impacts of higher rainfall (biofiltration), more Growing Degree Days (GDD) (economic costs of mowing), higher wind intensity and storms associated with sea level rise;
- Water utility – adapt to drier summers and the need for water storage; and
- Transport – adapt to rain intensity, higher temperatures, wind, etc.

To cater for the above and to reduce its greenhouse gas emissions, the city has developed the Greenest City 2020 Action Plan (GCAP) (City of Vancouver, 2012a). This plan consists of the following goals (City of Vancouver, 2012a):

1. Economic:
    - Double the number of green jobs over 2010 levels by 2020;
    - Double the number of companies that are actively engaged in greening their operations over 2011 levels by 2020;
2. Climate:
    - Reduce community-based greenhouse gas emissions by 33% from 2007 levels;
3. Green buildings:
    - Require all buildings constructed from 2020 onward to be carbon neutral in operation;
    - Reduce energy use and greenhouse gas emissions in existing buildings by 20% over 2007 levels;
4. Green transport:
    - Make the majority (over 50%) of trips by foot, bicycle and public transit;
    - Reduce average distance driven per resident by 20% from 2007 levels;
5. Waste:

- Reduce solid waste going to landfill or incinerator by 50% from 2008 levels;

6. Access to nature:
   - All Vancouver residents live within a five-minute walk of a park, greenway, or other green space by 2020;
   - Plant 150,000 new trees by 2020;
7. Lighter footprint:
   - Reduce Vancouver's ecological footprint by 33% over 2006 levels;
8. Clean water:
   - Meet or beat the strongest of British Columbian, Canadian and appropriate international drinking water quality standards and guidelines;
   - Reduce per capita water consumption by 33% from 2006 levels;
9. Clean air:
   - Always meet or beat the most stringent air quality guidelines from Metro Vancouver, British Columbia, Canada and the World Health Organization;
10. Local food:
    - Increase city-wide and neighbourhood food assets by a minimum of 50% over 2010 levels.

A number of these goals are associated with GI. For example, green streets that promote more cycling and pedestrian paths can be beneficial in limiting greenhouse gas emissions. They also act as carbon sinks (i.e. planting more street trees), assist in the management of stormwater, offer increased biodiversity and provide green space for physical activity. As well as climate change impacts, there are also issues such as water pollution, despite the city having good watersheds and ranking third in the world for quality of life (among 215 cities assessed). Together with stormwater runoff and combined sewer overflow, the quality of water in the city waterways has become degraded (NRDC, 2006). Pollution of waterways can have adverse impacts on species. The Fraser River is home to over 80 species of fish and 79 species of birds. In particular, the Fraser River is said to be one of the world's most productive salmon fisheries (Noakes, 2011). The further degradation of water would ultimately destroy habitat, pollute breeding grounds and lead to the extinction of species if left unchecked. The city implements a combination of GI assets and strategies such as living roofs, rain gardens, vegetated swales, landscape design, permeable pavement, wetlands, riparian protection and urban forests to help solve both issues related to climate change and urban pollution.

3.9.1 PROCEDURES, COSTS AND BENEFITS

Like the other cities reviewed here, Vancouver has multiple programmes and projects aimed at reducing adverse impacts and costs to the city, some of which incorporate GI practices (Table 36). Vancouver's Streets Department utilises permeable soils and vegetation for bulged sections (as shown in Figure 16) in order to transform them into green spaces and enhance their ability to collect stormwater (NRDC, 2009).

Bulged section

Figure 16 Bulged section along street

Source: City of Vancouver (2009)

Another means of using GI is in biofiltration for treating stormwater runoff. However, the perception of design difficulty and high cost may restrict the uptake of these LID techniques. Additionally, maintenance costs and vandalism can threaten the function of the techniques. One interesting finding from studies of Vancouver's GI is that retrofitting the stormwater infrastructure would cost marginally more than conventional upgrades (NRDC, 2009). However, for new developments, GI can be less costly than conventional systems, especially over the long term (NRDC, 2009).

Vancouver has set up collection and flare systems to manage landfill gas (LFG). Gas from landfills accounts for 5% of Canada's greenhouse gas emissions. The city's 1990 Clouds of Change programme resulted in 20% reduction in CO_2 emissions by 2005 (CSCD, 2004). The gases captured used to be flared off to control emissions and odour. However, since 2002, agreements have been made to increase the beneficial use of LFG. This includes sale of LFG to hothouse growers so they can produce and sell electricity. According to CSCD (2004), approximately 500,000 GJ of energy can be produced per year, accounting for the annual energy requirement of 3,000 to 4,000 homes. The heat generated is used in greenhouses. LFG was also used to provide heating for the administration building of the landfill only. According to the Landfill Gas Management Regulations of 2008, landfills must develop plans to capture 75% of LFG by 2016. A capture rate of 50% was reached in 2010.

Vancouver's green spaces consist of parks (over 200 diverse parks), woodland remnants, ravines, waterfront greenways, beaches, gardens, botanical gardens, golf courses and streetscapes (Figure 17). Vancouver has approximately 138,000 street trees; the result of planting 2,000 trees per year on average over the past 20 years. The City authorities aim to have 150,000 new trees planted by 2020. The overall effect is to create an urban forest within the city that is expected to provide multiple benefits, ranging from stormwater management to food production. Current priorities for increasing green space include the development of 'mini-parks' throughout the city. The City of Vancouver (2012a) states that approximately 92% of city residents live within a five minute walk of a park or green space. In addition to the creation of carbon sinks by tree planting, Vancouver has adopted strategies to provide safe pedestrian paths and encourage other forms of transport whilst reducing car ownership. This is expected to influence greenhouse gas emissions. Vancouver already has the lowest per capita emissions (4.6 tonnes/person) in North America. According to the City of Vancouver (2012a), about 40% of journeys within the city are made by mode of walking, cycling or rail: an increase of 33% since 1994.

One of the methods by which the City of Vancouver has attempted to solve or control the problem of stormwater runoff is by utilising permeable pavement; for example, the Crown Street redevelopment project. The project also serves to encourage pedestrian use of roads thus potentially discouraging transport via vehicles and thereby reducing greenhouse gas emissions. Other methods such as rain gardens, bioswales, planter boxes and tree cells are used along city streets to enhance their ability to manage stormwater runoff. Vancouver has implemented a rain barrel programme that provides a 50% subsidy to residents (City of Vancouver, 2012b).

Figure 17 Metro Vancouver green spaces

Source: Metro Vancouver (2007)

Table 36 Costs and benefits of GI projects in Vancouver

Project Description	Benefits	Costs
Crown Street redevelopment (NRDC, 2009) consisting of reduction of street width and development of swales for infiltration.	Retention of 90% of annual rainfall volume using swales with the remaining 10% treated via vegetated swales prior to discharge.	$707,000 (expensive means of managing stormwater due to additional design future developments may not incur as high a cost.
The Country Lane Program (NRDC, 2009) consisting of the replacement of impervious alleys and lanes with a permeable alternative as well as infiltration bulges.	• On-site infiltration of stormwater (structural grass and pavement made of permeable material); • Improved pedestrian paths; • Improved water quality and increased infiltration; • Improved wildlife habitat; • Reduction in the urban heat-island effect; • Reduction in peak flows in streams and rivers; • Increase of base flows in streams and rivers; • Improved traffic calming measures; • Aesthetic 'liveable' improvements.	$233/m (more expensive than conventional paving).
The Fairmont Waterfront.	The Fairmont Waterfront Hotel in Vancouver has been growing herbs and vegetables on its living roof since 1994. By cultivating their own produce they have saved in excess of $30,000 every year in food costs (City-Farmer 2005).	
Vancouver's living roofs – consisting of over 30 projects, one of which is the Vancouver Public Library (ASLA, 2012m) living roof with 14 inches (35.6 cm) of growing media spanning 934 m^3 (33,000 ft^3).	Controls runoff via retention: • 48% reduction in stormwater volume of the roof as compared to conventional roof (analysis over 8 months); • Peak stormwater flows reduced between 5% and 30% during wet winter months; peak flows were reduced by 80% in summer; • Based on data from Environment Canada, a grass roof with 2,000 m^2 of unmown grass could cleanse 4,000 kg of dirt from the air per year (2 kg/m^2 of roof).	$100,000 – $500,000
Biofiltration in Vancouver's parks – 167 acres (67.5 ha) of neglected paved land reclaimed and re-greened to create Hastings Park. Additionally, the 1,000 acre (400 ha) Stanley Park also provides biofiltration.	• Treats stormwater runoff from 300 acre (120 ha) residential area; • Aesthetic and environmental benefits by serving as valuable habitat for wildlife and birds.	
Vancouver gas collection and utilisation project (CSCD, 2004).	Capture of greenhouse gas emissions.	$10 million, invested by Maxim Power Corp.

3.10 CASE STUDY 10: BRISBANE, AUSTRALIA

According to the Australian Bureau of Statistics (ABS, 2011), Brisbane has a population of approximately two million (metropolitan population of 1,067,279), expected to grow to 2.9 million by 2031 (according to the medium-growth scenario). Brisbane is located on the southeast edge of Queensland on the banks of the Brisbane River. Although the region is hilly, Brisbane city is located on a floodplain, which increases the risk of flooding during storm events. Brisbane has a humid subtropical climate. Summer temperatures range from 21°C to 30°C, with extremes reaching as high as 40.7°C. Average lows range from 10°C to 22°C with variations down to 5°C. Brisbane receives 964.7 mm of precipitation per year on average. In recent decades the region has suffered from water stress, ranging from severe droughts to flooding (White, 2010). In addition, the city is also subject to hailstorms, dust storms, tropical cyclones and heat waves.

According to projections in a report by the State of Queensland's Environmental Protection Agency (State of Queensland, 2008), the following climatic changes are expected to impact the state and hence Brisbane city:

- Increased annual warming of about 0.9°C in coastal areas and 1.1°C inland by 2030 (under a high emissions scenario);
- Less rainfall;
- Severe droughts (increased evapotranspiration);
- Increase in extreme daily rainfall with changes in the frequency of El Niño events (17% increase in annual rainfall);
- Sea level rise (expected to be higher than the global average);
- Intense tropical cyclones – increased storm flooding;
- Increased wind speeds affecting coastal areas; and
- Increased risk of storm surge.

The awareness of these risks may be more apparent as a result of recent events, such as flooding events in Queensland exacerbated by La Niña and cyclones. For example, the river flood disaster in January 2011 (which peaked at 4.46m above sea level) damaged 22,000 homes and affected 7,600 businesses across 94 suburbs. The estimated cost of the flood repairs was estimated to be in excess of $440 million (Brisbane City Council, 2012). The Australian Institute of Architects (AIA) submitted a report to the Commission of Inquiry in response to the 2010/2011 floods, making a number of recommendations including a call to 'Investigate the use of green infrastructure for flood and drought resilience' (AIA, 2011: 3). Previously, Brisbane City Council (2010a) had initiated plans to address issues arising from climate change, increasing energy consumption, rising petrol prices and peak oil. The Council presented 31 plans to improve the sustainability of Brisbane including the following actions:

1. Immediately develop a discrete package of interim amendments to the City Plan that will upgrade the plan to address policy issues that are already well understood, such as:
    a. Upgrade the Q100 flood level;

   b. Lobby the State Government for mandatory rainwater tanks or stormwater capture for commercial and industrial development;
   c. Enhance stormwater and flood-related infrastructure requirements;
   d. Provide shade and weather protection;
   e. Encourage solar access for roofs and embedded electricity generation, especially cogeneration;
   f. Enhance attention to walking and cycling planning and infrastructure in development;
   g. Provide higher quality and mandatory footpaths for all new development;
   h. Provide bike lockers, showers and changing facilities;
   i. Promote greater integration of commercial development and public transport; and
   j. Recognise urban agriculture and living roofs.
2. Ensure that infrastructure charges plans incorporate the full costs of infrastructure development and then consider providing transparent incentives to encourage sustainable development (e.g. the Sustainable Development Incentives Policy);
3. Increase the provision of shade and weather protection throughout the city with direct Council works (such as improved bus shelters and public spaces) and introduce City Plan amendments to influence new development;
4. Encourage and actively promote urban agriculture and amend City Plan and Local Laws as necessary to reduce barriers to food production within the city;
5. Place greater emphasis on integration of public transport systems with key destinations including open space;
6. Establish a policy of no net loss of vegetation through development and require satisfactory compensatory planting for any clearing, including a net gain in vegetation cover, acknowledging that there may be some loss of existing vegetation, but that this should be offset;
7. Install solar PV and solar hot water panels on Council buildings and infrastructure, focusing on high-visibility locations;
8. Expand Council's involvement in energy from waste (landfill and sewage methane and green waste);
9. Explore with land owners and industry to have wind turbines installed in effective locations (e.g. coastal or elevated positions);
10. Partner with electricity retailers to assist them in promoting green power products (e.g. an option for households and businesses to sign-up to green power prominently on their rates notices);
11. Set an average fuel efficiency requirement for all City Fleet passenger vehicles, including executive vehicles (e.g. 10 L/100 km) and reduce to less than 5 L/100 km by 2026;
12. Build on the momentum of the current drought response to further drought-proof Brisbane for the long term including:
   a. Recycling 100% of wastewater by 2026 (as stated in the Brisbane 2026 Vision);

b. Phasing-in significant increases in water price for business and residential customers over a notified period;
c. Encouraging residents to remove all inefficient toilets, showers and washing machines from the city (in keeping with the Brisbane 2026 Vision that called for all households to be fitted with 5A water saving devices by 2026);
d. Making the most feasible components of the BCC water sensitive urban design guidelines mandatory; and
e. Actively promoting the use of grey water.

Numerous efforts involving GI have already been implemented, with more development and research in progress.

3.10.1 Procedures, costs and benefits

Whilst overall Australia has been slow to adopt green infrastructure practices, a few GI-related projects have been conducted in cities such as Brisbane. These include local projects such as the Mount Gravatt rooftop farm and the Brisbane City Hall rain garden. The Australian Green Infrastructure Council (AGIC) is currently developing a rating scheme for green infrastructure, much like the Green Building Council of Australia (GBCA). This will likely encourage a wider uptake of GI applications as awareness of its numerous benefits grows due in part to those authorities commissioning testing and pilot projects to determine potential outcomes for specific city contexts. The Brisbane Council is currently involved in a number of initiatives to transform Brisbane into a carbon neutral city by 2026. Using research conducted at Michigan State University, Wilson (2010) stated that 'extensive adoption of built-environment greenery in a two million-person city, like greater Brisbane, could capture at least 100,000 tonnes of carbon dioxide a year.' One programme that could assist with this is the Bushland Acquisition Program, which aims to purchase 500 hectares of bushland to increase green cover from 32% to 40% by 2026. This green cover will enhance biodiversity protection while providing sinks for greenhouse gas emissions, helping to mitigate heat island effect and improve stormwater management. Figure 18 illustrates the locations of land that would be added to Brisbane's Bushland.

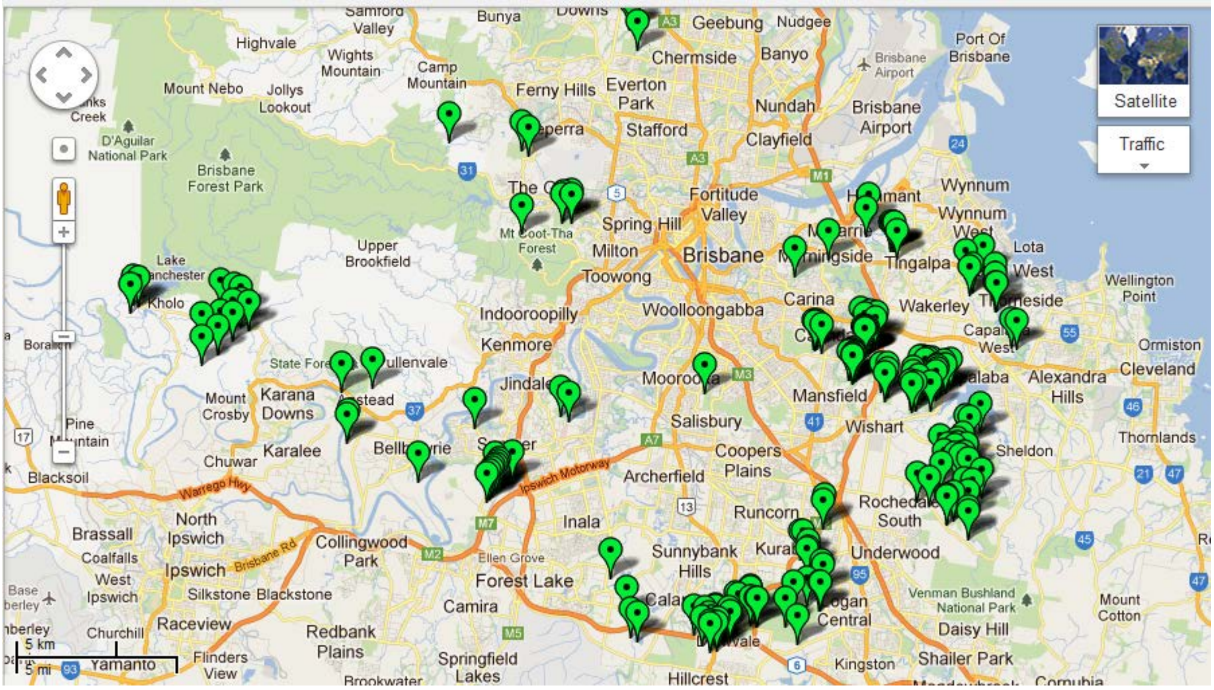


Figure 18 Bushland acquired by Brisbane City Council

Source: Brisbane City Council (2012)

As with most cities, Brisbane has plans to improve GI around the city. However, there does not appear to be a specific plan, unlike cities such as London or Philadelphia. Programmes that may be implemented in the future relate to water and stormwater management (e.g. South East Queensland Water Grid and water recycling plants), pollution, climate change, biodiversity protection, provision of transport (e.g. the Northern Busway and Airport Link which provide fast travel; the City Cats programme that encourages cycling via bike paths and walking via pedestrian bridges; reduction of traffic congestion). The pedestrian and cycling bridges are significant in linking the various parts of the city and GI. For example, Brisbane's Goodwill Bridge and Kurilpa Bridge (formerly Tank Street Bridge), which opened in 2009 at a cost of AU$63 million, provides uninterrupted cycling (a cycle loop) and pedestrian access through the city, allowing connections between areas of cultural importance (e.g. the Millennium Arts Precinct), parks and businesses. The City Cats cycling programme engages with the community to encourage cycling, which ultimately reduces traffic and traffic-related emissions and pollution.

Brisbane's WaterSmart programme alluded to the application of 'emerging green infrastructure standards to infrastructure projects and benchmark such projects against nationally and internationally recognised innovative water solutions' (Brisbane City Council, 2010b: 25). However, a database of examples applicable for the city does not currently exist, nor is there explicit mention of such projects. Nevertheless, there is educational material provided by the Council on GI practices such as rain gardens, permeable paving and bioswales. Brisbane also has programmes to help schools via the Green Schools programme whereby the Council encourages practices such as recycling and education on matters related to the city's health (e.g. water). The Council also provides 50 free trees to plant as a measure to educate and encourage participation by children. Other programmes, such as Green Heart, focus on engaging the community to achieve the city's sustainability aspirations. Some GI projects are described in Table 37.

Table 37 Costs and benefits of GI projects in Brisbane

Project/ Description	Benefits	Costs
Mount Gravatt rooftop farm – organic rooftop hydroponics and aquaculture (Nowak, 2004).	• After 17 months, the farm is expected to provide returns on invested capital of approximately 20% per year; • Jobs provided; • Other benefits not mentioned by Nowak (2004) could include those provided by conventional living roofs such as stormwater management, reduction in ambient temperature, etc.	AU$212,455
Brisbane City Hall rain garden, bioswale and downspout removal (ASLA, 2012n).	• Aesthetic landscape; • Runoff management via infiltration/bioinfiltration; • Pollution removal.	$100,000 – $500,000
Brisbane Botanic gardens – permeable paving.	Infiltration of water leading to reduced surface runoff, reduction in pollution, etc.	

3.11 SIGNIFICANT OTHERS

Other notable cities in which GI practices have been implemented include Toronto, Seattle, Barcelona, Munich, Milan and Kuala Lumpur. In Toronto, for example, living roofs have been mandated for new construction projects. Studies conducted for the living roof projects concluded that $37 million could be saved if 75% of the city's roofs were greened. In addition, the heat island effect of the city could be reduced by 2°C (Banting et al., 2005; Currie and Bass, 2010). Seattle's Green Factor system is a 'landscape requirement designed to increase the quantity and quality of planted areas in Seattle while allowing flexibility for developers and designers to meet development standards' (McIntosh, 2010: 8). The system was established to encourage GI practices and assets such as permeable paving, living roofs and walls, green streets and the protection of existing forests. In 2007, the city approved a $145 million Park Levy to fund park related infrastructure in the city. Barcelona, Munich and Kuala Lumpur are involved in region-wide projects where GI at larger scales is improved and connected for better protection of biodiversity.

In cities such as Milan, traffic pollution has a dramatic impact on air quality. Ideas that may in the past have been dismissed outright are now being reconsidered and even implemented, such as the famous 27-storey vertical forest, 'Bosco Verticale', comprising of some 900 trees (excluding shrubs). Bosco Verticale is a novel concept by the architect Stefano Boeri in which trees and plants are planted in the building itself. This project is a world first. The expected benefits are reduction of pollution, capture of particulate matter, reduction of the ambient and surface temperature of the building, increased diversity of plants, protection from radiation and acoustic pollution, energy savings and increased quality of living. The project is expected to cost 65 million Euro and would become part of the city's green belt.

Additionally, while they have not been discussed in this report, there are many upcoming GI initiatives and opportunities for the application of GI in the developing world. For example, according to NRDC (2012b), China has committed to reducing CO_2 emissions by 40-45% from 2005 levels by 2020. This is expected to be achieved by transferring to non-fossil fuels to minimise sources of CO_2 and by increasing forest cover by 40 million hectares and forest volume by 1.3 billion m^3 to maximise carbon sinks. India has also made commitments to reduce CO_2 emissions to 20-25% below 2005 levels by 2020 (NRDC, 2012b). Some of the expected strategies include improving fuel efficiency, increasing renewable energy production and increasing forest cover to sequester 10% of annual emissions.

3.12 CONCLUSIONS

From the case studies examined in this section, it is clear that there is a growing awareness of the benefits of applying GI practices in urban areas. Cities around the world are implementing GI practices to solve the issues that they are currently facing (e.g. damage to infrastructure or health), as well as those they can expect to face in the future, taking into account both growing urban populations and climate change.

Most developed countries have drawn up strategies to implement climate change adaptation plans and some have taken a long-term view, looking to 2030 and beyond. The cities reviewed in the case studies are aware of how climate change will affect them and of the risks they face in the future. Some forward-thinking cities such as Copenhagen are pioneers in their implementation of GI strategies and are already reaping the benefits; others, such as Brisbane, are in the early stages of planning and testing GI with loose guidelines for future applications.

While many of the same issues are faced by each of the cities studied, they manifest differently in each case. These issues include water stress in cities with limited land area such as Singapore; flooding for cities such as Brisbane and London that have been built on or near floodplains; the need to provide transport for increasing populations as in Curitiba. The different climatic conditions of the cities and their respective geographies also influence the scale and nature of the impacts that each urban centre faces. Consequently, rather than relying on any one type of GI, each city implements a variety of approaches to support ecosystem services and to reduce the adverse effects of the built environment. There is no one strategy but rather multiple practical interventions and a range of efforts to draw on that together provide various types of new green space, restore what has been degraded and improve connectivity between disparate green spaces. The strategies range from stormwater management, reduction of heat island effect and the mitigation of climate change through to the provision of effective and efficient transport and energy, with each city providing their experience and vision of integrating successful GI practices. Rather than planning GI for cities, it may be beneficial to plan GI for entire regions, as Europe appears to be doing. This would enable localised improvement whilst enhancing connectivity, which is especially useful when considering biodiversity (species need large space for habitat and migration).

There are research gaps in the quantification and comparison of GI with grey infrastructure throughout the world, as was apparent in the case studies we reviewed. The lack of data can be blamed on the slow implementation of GI strategies, which can often have high start-up costs. Cost-benefit analysis also proves difficult as GI provides multiple benefits whilst grey infrastructure tends to serve a specific function and affords narrower benefits. Yet if we cannot account for the multiple benefits, developers and planners may be forced to use conventional infrastructure in future.

Overall, the case studies demonstrate how cities have implemented GI for multi-functionality, often providing solutions to global issues (such as the emission of greenhouse gases) whilst focusing on local issues (such as pollution mitigation or prevention). According to CABE (2009), there has been a shift in investment, albeit a small one, with increasing investment in GI. Additionally, the idea of connectivity is prevalent in the case studies; the need for connected infrastructure via green transport is likely to enhance the overall benefits and experience of city residents.

There have been many GI developments internationally, so there are many potential developments from which practitioners in New Zealand can draw from to gain an understanding of what works and why. However, their successful adoption is dependent upon factors such as whether the GI fits within the local context in terms of climate, social and cultural behaviours, cost of use, available land, among other considerations. The next chapter investigates existing GI in New Zealand and discusses the potential use of GI specifically for Auckland.

4. GI FOR AUCKLAND

Prior to November 2010, the Auckland region (Figure 19) comprised four cities: Auckland, Manukau, North Shore and Waitakere; and three districts: Franklin, Rodney and Papakura. In November 2010, the Auckland Council was created and the cities and districts were amalgamated to form one regional 'super city'. Auckland has a land area of 4,894 km², with 3,702km of coastline (Auckland Council, 2011a). The region had an estimated population of 1.5 million people as at 30 June 2011 (Statistics New Zealand, 2011a) and the population is projected to increase to approximately 2 million by 2031 (Statistics New Zealand, 2012). Despite the overall slowing of population growth in New Zealand (0.9% in 2011 as opposed to 1.2% in 2010), Auckland's population has grown by 1.6% per year (Statistics New Zealand, 2011b) due to a range of factors such as in-migration. Whilst New Zealand's average population density is relatively low, at 16 people/km² (30 June 2009), Auckland region's population density is much higher, with 240 people/km² (Statistics New Zealand, 2009).

Figure 19 Auckland

Source: Auckland Council (2013a), http://www.new-zealand-travel-showcase.com/PDF-Maps.html)

The Auckland region encompasses the Auckland Volcanic Field, including 53 volcanoes classified as extinct. Auckland is surrounded by water: the Waitematā Harbour, Tāmaki River, Mangere Inlet and Manukau Harbour. Auckland's climate can be characterised as 'oceanic', a mix of subtropical and temperate with warm, humid summers and mild, wet winters (MetService, 2012). Auckland experiences average high temperatures of 23.8°C in summer and 14.7°C in winter and average low temperature of 16.4°C in summer and 8°C in winter. From 1969 to 1998, Auckland experienced variations with maximum temperature reaching 34.4°C and minimum temperature of -6°C (MetService, 2012). The city of Auckland receives an average rainfall of around 1,100 mm to 1,300 mm annually with frequent and intense rainfall during winter. Auckland receives approximately 2,100 hours of sunshine per annum. The UV Index increases during summer. This is because of a lack of ozone and unpolluted air which means that UV is not blocked.

4.1 LIVEABILITY AND THE AUCKLAND PLAN

Like other cities around the world, Auckland faces issues pertaining to urban sprawl, stormwater runoff, pollution and climate change – all of which pose risks to its growing population. This chapter outlines some of these issues facing Auckland, describes existing GI within the city and identifies possible areas of improvement for the benefit of Aucklanders and the region's many and diverse ecosystems.

4.1.1 LIVEABILITY

In 2011, two international surveys ranked Auckland tenth and third respectively for liveability or quality of life. The Global Liveability Survey, produced by the Economist Intelligence Unit (EIU), ranked 140 cities worldwide according to over 30 qualitative and quantitative criteria based on political stability, healthcare, culture and environment, education and infrastructure (New Zealand Herald, 2011). According to EIU, the top 10 cities and their scores out of 100 are as follows:

1. Melbourne, Australia 97.5
2. Vienna, Austria 97.4
3. Vancouver, Canada 97.3
4. Toronto, Canada 97.2
5. Calgary, Canada 96.6
6. Sydney, Australia 96.1
7. Helsinki, Finland 96.0
8. Perth, Australia 95.9
9. Adelaide, Australia 95.9
10. Auckland, New Zealand 95.7

Auckland's scores included healthcare at 95.8, education at 100 and infrastructure at 92.9.

The Mercer survey, Quality of Living worldwide city rankings, ranked Auckland as the third most liveable city out of 221 cities, with Vienna and Zurich ranked first and second respectively (Mercer, 2012). The survey evaluated cities according to the 39 criteria reproduced in Table 38.

Table 38 Criteria for Mercer's 2011 Quality of Living survey

Political and Social Environment
- Relationship with other Countries
- Internal Stability
- Crime
- Law Enforcement
- Ease of Entry and Exit

Economic Environment
- Currency Exchange Regulations
- Banking Services

Socio-Cultural Environment
- Limitation on Personal Freedom
- Media and Censorship

Medical and Health Considerations
- Hospital Services
- Medical Supplies
- Infectious Diseases
- Water Potability
- Sewage
- Waste removal
- Air Pollution
- Troublesome and Destructive Animals and Insects

Schools and Education
- Schools

Natural Environment
- Climate
- Record of Natural Disasters

Public Services and Transport
- Electricity
- Water Availability
- Telephone
- Mail
- Public Transport
- Traffic Congestion
- Airport

Recreation
- Variety of Restaurants
- Theatrical and Musical
- Performances
- Cinemas
- Sport and Leisure Activities

Consumer Goods
- Meat and Fish
- Fruits and Vegetables
- Daily Consumption Items
- Alcoholic Beverages
- Automobiles

Housing
- Housing
- Household Appliances and Furniture
- Household Maintenance and Repair

Reproduced from: Mercer (2012)

In addition to the international surveys, Auckland Council (2011b) developed its own scorecard to assess and track progress of the city against 19 indicators. The scores for 2010 and 2011 are given in Table 39, together with the differences between 2010 and 2011, where % denotes an increase and -% denotes a decline.

Table 39 Annual Auckland Scorecard

Indicator	2010	2011	%Change
Educational achievement (%)	71.7	72.2	0.7
Crime (offences/100,000 people)	9,526	9,346	-1.9
Graffiti eradication (number of items removed)	350,937	342,164	-2.5
Public transport use (total trips/year)	60,622,293	65,763,655	8.5
Cycling and walking (trips to CBD/day)	5,312	5,584	5.1
Congestion (change in time loss/km travelled (s))	33	30	9.1
Household transport spending** (%)	14.1	12.6	-10.8
Employment (people employed in Auckland)	644,700	679,300	5.37
Income (median personal income $)	800	840	5
Visitor nights (total guest night in Auckland RTO)	5,602,194	6,140,210	9.6
Marine water quality** (%)	77	80	3.9
Air pollution (average particulate concentration under 10microns) (micrograms/m3)	15.06	14.08	-6.51
Youth unemployment (%)	33.1	34.1	3

Housing affordability (%, relative to rest of NZ)	121.1	122.1	0.8
Spending on local roads ($)	195,665,359	184,794,020	-5.6
GDP per capita ($)	47,903	46,484	-2.96
Exports* ($, growth in exporting)	28,087,304,888	28,012,420,365	-0.27
Housing availability (av. no. of people per household)	2.9	3	0.83
Carbon footprint (tonnes released/person/year	6.27	6	0.48

* Measures 2009 and 2010 and ** measures 2007 and 2010, due to data availability

Source: Auckland Council (2011b)

4.1.2 THE AUCKLAND PLAN

As we have seen, Auckland already scores highly for quality of living. However, Auckland Council has set a goal of making Auckland the most liveable city in the world by 2040. This is one of the goals of the Auckland Plan (Auckland Council, 2011a) and requires five 'transformational shifts' to be achieved:

1. Dramatically accelerate the prospects of Auckland's children and young people;
2. Strongly commit to environmental action and green growth;
3. Move to outstanding public transport within one network;
4. Radically improve the quality of urban living; and
5. Substantially raise living standards for all Aucklanders and focus on those most in need.

The transformational shifts are further clarified by the following ideals:

- Making a quality, compact Auckland work – urban intensification and balance between rural and urban land;
- Development areas – intensification of town centres and corridors;
- A network of interconnected towns and villages with one international city centre;
- Opportunities for employment growth and location – areas of future business growth and infrastructure to support growth;
- A 'Less is More' approach with commitment to action and delivery;
- Critical infrastructure – transport, water, energy, telecommunications, health, education, corrections as priorities;
- Land use and transportation integration – improvements for bus, rail, ferry, cycle and walkways.

According to Auckland Council (2011a), the city's planned capital expenditure was NZ$939 million in 2011/2012, with NZ$410 million to be funded from external sources. In order to realise the city's visions and ideals, Table 40 outlines the expected costs according to areas of action. Development of the Auckland region is to be carried out through two major initiatives. The first is the development of the City Centre, which includes development of seven metropolitan centres (Manukau, Takapuna, New Lynn, Sylvia Park, Papakura, Albany and Westgate) chosen for their current growth, their capacity to grow in the future, as well as current connectivity in terms of the availability of transport networks. The Auckland City Centre Masterplan and Waterfront Plan have been devised to enable growth within urban Auckland. The second is the Southern Initiative, which will focus on improving Mangere-Otahuhu, Otara-Papatoetoe, Manurewa and Papakura, chosen due to their potential for growth and according to the urgency of current issues such as failing education, high unemployment, health inequalities and growing population (Auckland Council, 2011a). The nature of the Mercer Quality of Living survey does not measure these factors (see Table 39).

Table 40 Auckland Plan and expected capital expenditure for 2011/2012

Action	NZ Cost in 2011/2012
Community – strong communities via funding of libraries, community services, emergency management and cemeteries.	$252.7 million
Lifestyle – supporting arts services and galleries, events, museums, parks, recreation and zoo.	$555.2 million
Economic development – internationally competitive region in which to live, work, visit, invest and do business.	$68.3 million
Planning and regulation – protect and enhance Auckland's natural and built environment, protect public health and safety.	$445.3 million
Environmental management – protecting and enhancing Auckland's harbours, coasts, beaches and islands (minimise effects of pollution on the region's air, land and water resources).	$59.5 million
Solid waste – waste and recycling activities.	$96.7 million
Water and wastewater.	Undisclosed
Stormwater management.	$170.9 million
Transport – numerous projects to improve transport links via land, rail and water.	$653.8 million
Commercial and investment – in order to optimise financial returns.	$24.9 million
Governance.	$63.2 million

GI in Auckland will assist with the City's vision to be the most liveable city in the world by 2040. In association with the above actions (Table 40), practical implementation of GI might mean wider footpaths, wider pavements, median strips, more public transport, cycle lanes, traffic restrictions, removal of off-ramps, transformation of car parks, new railway stations, light rail tram (e.g. on Queen Street), tree-lined streets connecting Albert Park with the Domain and other open spaces, transformation of motorway bridges, waterfront development, among other possibilities. Thus far, the draft Auckland Plan consists of eight actions aimed at overall improvement in connectivity and function of infrastructure in the city, although these initiatives are not labelled as 'green infrastructure' per se.

One of the major projects signalled in the Auckland Plan is the development of Auckland's waterfront for which Auckland Waterfront Development Agency (better known as Waterfront Auckland) is responsible (Figure 20). Auckland's waterfront has always been an important element in the city's development. It is currently a hub for commerce, tourism and culture. Future redevelopment efforts on Auckland's waterfront are expected to contribute $4.29 billion to Auckland's economy by 2040

(Waterfront Auckland, 2012). The Waterfront Plan, published in 2012, proposes numerous projects for urban development and renewal covering 450,000 m² of waterfront property. The objectives for the Waterfront Plan (Waterfront Auckland, 2012) and Auckland's Sustainable Development Framework (Waterfront Auckland, 2013), are as follows:

- 'Reduce greenhouse gas (GHG) emissions and develop a low carbon precinct;
- Increase resiliency of the built and natural environment and of the community;
- Design and develop the waterfront public land according to sustainable design principles;
- Identify opportunities to restore and enhance environmental quality;
- Develop a diverse business and residential community;
- Manage travel demand and prioritise and promote sustainable transport; and
- Create an authentic waterfront experience respecting cultural and heritage values.'

Numerous green initiatives are incorporated in this proposed development, some of which are GI initiatives. Significant additional GI/GSI is under construction in the Auckland Waterfront precinct as of the end of 2013. Examples of some green initiatives are outlined in Table 41 with reference to their location within the waterfront.

Table 41 Waterfront green infrastructure initiatives

Location	Green Infrastructure Initiatives
North Wharf	• Seismic strengthening of the old sea wall and refurbishment of the old red shed; • Rainwater retention – 16,000 litres of non-potable water plumbed in to all external taps and for toilet flushing and external cleaning; • Skylights for internal natural day lighting, time clock control of communal lighting, 'North Wharf' signage lights solar powered; • Solar boosted gas hot water heating; • Wynyard Crossing (a pedestrian and cycling bridge) completed in August 2012 connecting the Gateway Plaza to the Viaduct – great connectivity to city centre; and • Living roof made from native tussocks and grasses installed on the information kiosk in Karanga Plaza. This was designed to reduce stormwater volume by up to 75%, saves energy via insulation and enhances biodiversity in Wynyard Quarter (birds and insects).
Jellicoe Street	• Bioretention rain gardens constructed to treat stormwater and provide passive irrigation (target 95% of all stormwater treated in project area). The rain gardens catch water, which is then filtered through an engineered medium to remove pollutants. The rain gardens serve important sustainability functions such as minimising stormwater export and coupling as street vegetation; however, poor media design has led to additional irrigation needs; • Shared space, wider footpaths and cycle ways and heritage tram.
ASB Building (Jellicoe Street)	The building has been designed 'from the inside out', incorporating a number of sustainability features: • A light reflector on the top of the funnel allows natural light into the heart of the building, reducing the need for interior lighting; • Windows open manually, giving occupants access to the sea air; and • The northern (seaward) side of the building has metallic sunscreens in the shape of leaves, with vertical fins on the other side. They shade the façade, reducing glare and heat build-up in internal spaces.

Viaduct Events Centre

The building has been designed to achieve 5 Stars in the Green Star New Zealand Office Design environmental rating system. The energy cost for the VEC is predicted to be 40-50% lower than for a conventional office building. In addition (based on design criteria):

- Water consumption will be 50-60% lower than conventional office building;
- Efficient daylight building – high-performance façades;
- Use of seawater as a heating and cooling source via reversible heat pumps;
- Large roof overhangs provide solar shielding in summer but let in the sun's rays in winter; and
- Rainwater will be collected from the roof and re-used for toilet flushing.

Silo Park

- Open space for relaxation and play;
- Retention of the 35 m Golden Bay cement silo and 'six-pack' in recognition of the area's industrial heritage; and
- Silo Park polishing ponds – the final stage of water treatment, to ensure water is of a quality suitable to discharge into the sea.

Queens Wharf

- Retention and refurbishment of Shed 10;
- Strengthening and maintenance of the wharf and upgrade of utilities infrastructure (for future proofing); and
- New landscaped open areas and multipurpose temporary facility, known as The Cloud.

Daldy and Halsey Streets

Once construction has been complted, Daldy Street will form a 38 m-wide linear park, walkway and cycleway and a slow-speed (30 km/hr) street linking Victoria Park to the waterfront including:

- A 38 m wide green park, walkway, cycleway, slow speed (30 km/hr limit) kerb-less street (accommodating trams, buses and private cars);
- Rain gardens along the 4 m wide footpaths for stormwater management;
- Native trees and plants and is also expect to include a community edible garden;
- Promotion of local culture via art works (e.g. tank sculptures that act as water recycling systems);
- Energy efficient LED street lights and control systems.

Halsely Street is expected to have similar features (generous footpaths, bioretention/rain gardens for stormwater management, native trees, etc.) as well as indented car parking.

1 – North Wharf 2 - Jellicoe Street 3 - ASB Building 4 - Viaduct Events Centre 5 – Silo Park

Figure 20 Auckland waterfront showing green infrastructure initiatives (draft only)

4.1 ISSUES FACING AUCKLAND

As part of the Auckland Plan, Auckland Council (2013b) published numerous technical documents pertaining to the infrastructure in the Auckland region, covering a variety of issues such as water, energy, telecommunications, waste and climate change (Auckland Council, 2011d, 2011e, 2011f). These reports provided insight into the current and future issues that provide challenges for Auckland's growth. Information based on these issues and the completed Auckland Plan highlight areas where GI may be implemented.

4.1.1 AIR ISSUES

Whilst Auckland's air quality is within WHO guidelines, the social cost of air pollution in the city has been estimated to be approximately NZ$1.07 billion per annum. Air pollution causes 300 premature deaths each year (Auckland Council, 2012a). Asthma is the fourth-highest cause of hospitalisation in the Auckland region: some 12-23% of adults and 25% of children are asthmatic (Auckland Regional Public Health Service, 2009). The cost of asthma is estimated at NZ$825 million per annum. The principal causes of Auckland's air pollution are household heating (specific to particulate matter), transport (with approximately 744,000 registered vehicles) and industry. According to Auckland Council (2011c), the level of particulate matter and nitrogen oxides regularly exceeds standards and guidelines. The city centre failed to meet standards approximately 16-17 times per annum during the period 2005 to 2010. Additionally, there is a visible brown haze of smog (average of 30 days per year) and chemical pollutants such as arsenic, benzene and benzo(a)pyrene exceed guidelines from time to time. Auckland Council monitors particulate matter (PM10 and PM2.5), nitrogen dioxide (NO2), carbon monoxide (CO), ozone (O3) and sulphur dioxide (SO2) (Auckland Regional Council, 2010a).

4.1.2 WATER ISSUES

The Auckland region's primary water sources are the Waitakere Ranges (25%), Hunua Ranges (60%), Waikato River (10%), with the remaining 5% coming from bores and springs (Watercare Services Limited, 2011). Auckland's water infrastructure comprises 11 dams, 149 reservoirs, 9,000 kilometres of water pipes, 19 wastewater treatment plants (Figure 21 and Table 41) and 7,000 kilometres of sewers (Watercare Services Limited, 2011). This network caters to the supply of over 450,000 households, supplying water to more than 1.5 million people. The metered user-pays basis adopted for water consumption and waste management has helped the city manage demand, as consumers have an economic incentive to conserve water. Watercare Services Limited (2011) states that current water demand is 140 L per person less than it was in the 1980s. This has enabled Auckland to reduce capital costs by deferring investments. Current water consumption is approximately 275 L/person/day. Nevertheless, as the population of Auckland grows, it will put additional strain on existing water infrastructure. Watercare and Auckland Council have plans to further reduce per capita water consumption, with a target of a 15% reduction by 2025 (Watercare Services Limited, 2011).

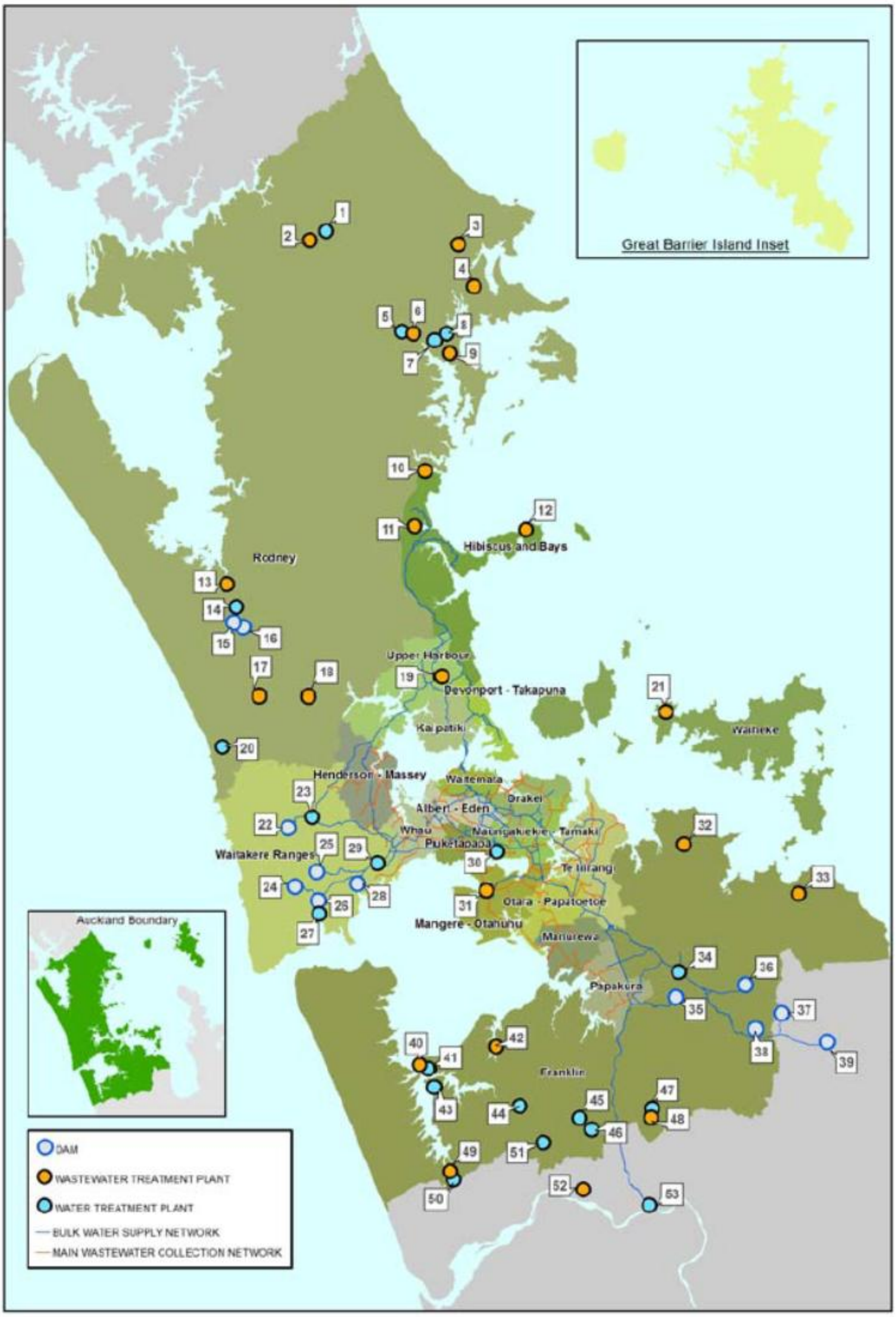


Figure 20 Dams, wastewater and water treatment plants in Auckland

Source: Watercare Services Limited (2011)

Table 42 Dams, wastewater and water treatment plants in Auckland

1	Wellsford Water Treatment Plant	27	Huia Village Water Treatment Plant
2	Wellsford Wastewater Treatment Plant	28	Lower Nihotupu Dam
3	Matakana Wastewater Treatment Plant	29	Huia Water Treatment Plant
4	Omaha Wastewater Treatment Plant	30	Onehunga Water Treatment Plant
5	Warkworth Water Treatment Plant	31	Mangere Wastewater Treatment Plant
6	Warkworth Wastewater Treatment Plant	32	Beachlands Wastewater Treatment Plant
7	Hamilton Road Water Treatment Plant	33	Kawakawa Bay Wastewater Treatment Plant
8	James Road Water Treatment Plant	34	Ardmore Water Treatment Plant
9	Snells Beach Wastewater Treatment Plant	35	Hays Creek Dam
10	Waiwera Wastewater Treatment Plant	36	Cosseys Dam
11	Orewa Wastewater Treatment Plant	37	Upper Mangatawhiri Dam
12	Army Bay Wastewater Treatment Plant	38	Wairoa Dam
13	Helensville Wastewater Treatment Plant	39	Mangatangi Dam
14	Helensville Water Treatment Plant	40	Clarks Beach Wastewater Treatment Plant
15	Lower Mangakura Dam	41	Waiau Water Treatment Plant
16	Upper Mangakura Dam	42	Kingseat Wastewater Treatment Plant
17	Denehurst Drive Wastewater Treatment Plant	43	Glenbrook Beach Water Treatment Plant
18	Huapai Wastewater Treatment Plant	44	Patumahoe Water Treatment Plant
19	Rosedale Wastewater Treatment Plant	45	Pukekohe Water Treatment Plant
20	Muriwai Water Treatment Plant	46	Buckland Water Treatment Plant
21	Owhanake Wastewater Treatment Plant	47	Bombay Water Treatment Plant
22	Waitakere Dam	48	Bombay Wastewater Treatment Plant
23	Waitakere Water Treatment Plant	49	Waiuku Wastewater Treatment Plant
24	Upper Huia Dam	50	Waiuku Water Treatment Plant
25	Upper Nihotupu Dam	51	Douglas Road Water Treatment Plant
26	Lower Huia Dam	52	Pukekohe (Tuakau) Wastewater Treatment Plant
		53	Waikato Water Treatment Plant

Source: Watercare Services Limited (2011)

Whilst Auckland has sufficient rainfall, there have been occasional droughts in the past when water restrictions have been applied. For the future, Watercare's demand management practices will refer to the 'Six Es of water efficiency and demand management': Engage, educate, encourage, engineer, enact and economic (Watercare Services Limited, 2011: 17). They include using more water-efficient products (e.g. toilets, washing machines, dish washers), fixing leaking pipes, reusing grey water and stormwater. The 'Three Waters Strategy' (Watercare Services Limited, 2008) investigated the potential use of grey water, treated wastewater and stormwater (referred to as 'beneficial use options') to supplement potable water in Auckland (up to 10%). According to Watercare Services Limited (2011: 29), beneficial use options 'do not become economically viable on a regional scale until other water source options have been exhausted'. The report states that the next best sources of water for the region until 2100 is the Waikato River, after which other developments can be utilised, including treated wastewater, aquifers and drawing from other rivers such as the Hoteo, Araparera and Wairoa Rivers (Figure 21).

Domestic rain water tanks are considered to have high marginal costs, including the initial installation cost, potential health costs and resilience to drought, when they would fail to meet Watercare's drought standards (Watercare Services Limited, 2011). With respect to drought, Lawton et al. (2008) noted that Australian droughts have led to a rapid increase in the availability of rainwater tanks in Australia. It is not clear whether the availability of rainwater tanks is correlated with their ability to relieve demand during droughts. Nevertheless, Lawton et al. (2008) note that rainwater harvesting and grey water reuse are urban on-site solutions, especially when there is high outdoor water consumption (EPA, 2012).

Some notable benefits of rain water tanks include 40% reduction in mains water consumption, better stormwater management, decentralisation and consequently greater resilience to water supply problems and lower peak loads (Lawton et al., 2008). Whilst Watercare Services Limited (2008) acknowledged the potential to install rainwater tanks in new developments, they did not assess the benefit of retrofitting tanks in existing properties, as the cost was likely to be high at $15,000 – $20,000 per property. Further research and assessment of costs and benefits for retrofitting the 450,000 existing households would be beneficial, especially considering the potential benefits of decentralised water supply to residents. Watercare Services Limited (2011) identified the following (assumption-based) potential benefits of the Three Waters Strategy:

- Rain tanks on all new domestic properties: projected saving of up to 80,000 m^3/d by 2100;
- Beneficial wastewater use for industrial purposes will start at 5,000 m^3/d from 2015 and increase to 20,000 m^3/d by 2025;
- Universal wastewater charging will be in place by 2015: savings of approximately 6,000 m^3/d in water use;
- Pressure and leakage management: savings of around 15,000 m^3/d by 2045;
- Additional groundwater recharge and/or use will increase from current levels by 1,000 m^3/d in 2015, rising to 15,000 m^3/d by 2025;
- Water audits of schools, industry and domestic use: savings of 20,000 m^3/d from 2015; and
- The use of water-efficient devices will reduce water demand by 500 m^3/d by 2015 and by 23,000 m^3/d by 2100.

The marginal cost of the various options are shown in Figure 22.

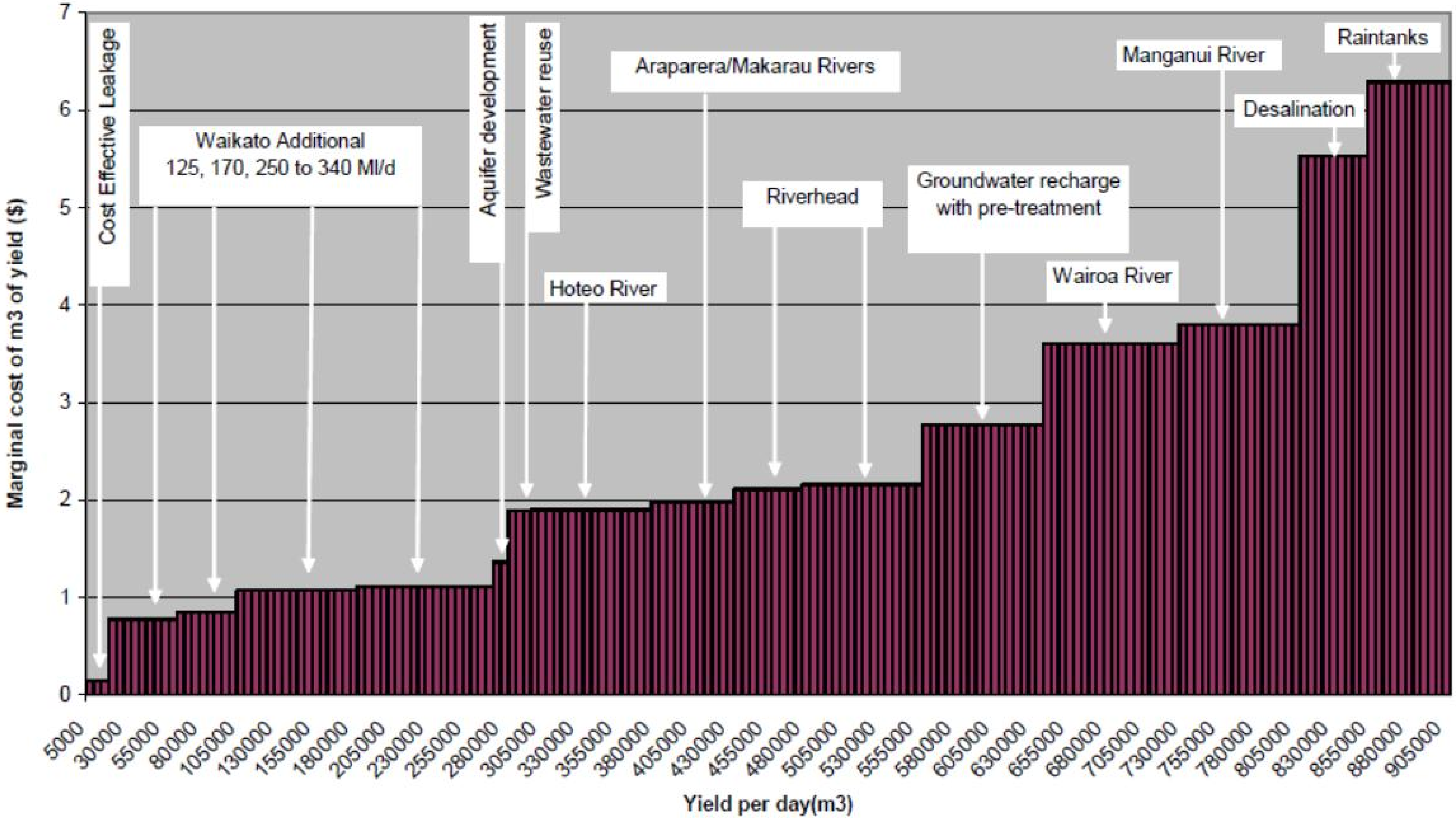


Figure 21 Cost curve, showing marginal cost increasing with each of the Three Waters options

Source: Watercare Services Limited (2011)

In addition to increasing demand, water sources suffer from a number of human-induced impacts. For example, Auckland's streams have high concentrations of nutrients and suspended sediments, carry pollutants such as heavy metals, suffer from bank erosion, have high levels of faecal coliform bacteria and high temperatures (Auckland Council, 2012c). These impacts are associated with intensive land use in the region, impervious surfaces and greater stormwater runoff. More intensive land use in future is bound to exacerbate matters. Stormwater runoff from agriculture (particularly dairy farming) and urban land use has had an adverse impact on marine environments in the Auckland region. For example, the *Hauraki Gulf State of the Environment Report* (Auckland Council, 2011l) outlines the impact of human activities on marine environments and the depleted life-supporting capacity of related ecosystems. The report also highlighted the progress already made in reducing contaminants in wastewater, largely as a result of centralised wastewater treatment, although there are on-going problems during high rainfall events with combined wastewater and stormwater overflow. Another significant area of progress has been the protection of islands in the Hauraki Gulf and ecological restoration of some islands. These efforts have provided sanctuaries for threatened native flora, fauna and fish species, allowing them to regenerate (Auckland Council, 2011l). In order to reduce impacts from stormwater runoff, Auckland Council endorsed a variety of GI procedures, such as rain gardens, living roofs, permeable pavements and grassed swales, in an effort to reduce contaminant discharges and alteration of natural hydrologic regimes.

Various projects have been carried out in the Auckland region to improve water quality through community engagement. One such programme was 'Project Twin Streams' in Waitakere, which addressed flood control and riparian restoration. This programme has been beneficial in many ways, with greater awareness and changed behaviour, aesthetic improvement and economic benefits (Hall and Helsel, 2009). There have been numerous other local projects. For example, 'Project Pipi' involved treating wastewater by natural processes, using worms and plants. Such systems cost NZ$8,000–10,000 and are suitable for use in rural Auckland (Auckland Council, 2011g).

4.1.3 WASTE MANAGEMENT ISSUES

There is potential to use GI in waste management, for instance by 'closing the loop' on organic waste. If organic waste is separated from other waste and composted, the composted material can be used to feed plants and trees in GI assets such as urban forests, rain gardens and parks. The composted biosolids from wastewater treatment can also be used in the same way. Furthermore, there is some potential for renewable energy by capturing gases from the composting facility.

Auckland City has three large landfills (Redvale Landfill on the North Shore, Whitford Landfill in Manukau and Hampton Downs Landfill in Waikato) and one small landfill, all serviced by 17 transfer stations (Auckland City, 2011g). Redvale Landfill is Auckland's largest landfill. It occupies 80 hectares and has a capacity of 16 million tonnes. Redvale is expected to reach capacity in 2023. Currently, 1.39 million tonnes of waste is landfilled in the four landfills. Additionally, there are four organic waste facilities catering to 120,000 tonnes of waste per year, as well as glass, paper and cardboard and ferrous metal recyclers. According to WasteNot Consulting (2011), the annual waste volume is projected to rise to approximately 1.7 million by 2021, assuming the waste trends from 1984 to 2010 continue.

As Auckland's population increases, the amount of landfill waste may increase considerably. As well as the need for more landfill space, there are issues pertaining to the logistics of waste collection, energy use, carbon emissions and traffic congestion issues associated with collection, leaching from landfills and greenhouse gas emissions from landfilled materials. Auckland Council's Waste Management and Minimisation Plan has set a target to reduce the amount of waste going to landfills (aiming for a 30% reduction in domestic waste by 2018), in addition to organic waste collection and product stewardship schemes. The draft guide to the Plan (Auckland Council, 2011h) includes multiple options for waste reduction and closing the loop on waste, including the following proposed initiatives:

- Development of a Resource Recovery Network of centres, where hazardous waste, construction/demolition materials and reusable goods and materials can be safely dropped off;
- Urging government to change the legislation so that the waste industry has the same responsibilities for reducing waste as Council;
- Advocating mandatory product stewardship schemes for packaging (such as refundable container deposits on drink containers) and for electronic goods, tyres and batteries;
- Supporting waste reduction by businesses, particularly in the construction and demolition industries;
- Creating a community grants scheme to encourage local enterprise and creating waste minimisation programmes that could be run by local groups;
- Providing pre-paid refuse bags for boaties, holiday makers and residents of the Hauraki Gulf Islands;
- Providing domestic-type kerbside collection services for businesses;
- Developing waste and recycling services for apartment buildings and other multi-unit dwellings;
- Providing schools with kerbside recycling services;
- Developing and improving waste exchange and brokering services;
- Providing public recycling bins;
- Encouraging Council-organised events to be run as zero waste events;
- Reducing litter and illegal dumping;
- 'Walking the talk' within the Council itself, with in-house waste reduction, procurement policy, Council contracts; and
- Having a bylaw to support and help enforce the Waste Plan.

Currently there are pilot programmes such as generating renewable energy from landfill waste, following on from those at Greenmount (six generation units with 5.5 MW capacity), Rosedale and Redvale Landfill. All three were initiated in the early 1990s. The Redvale programme, initiated in 1993, has been capturing methane and generating electricity since 2000 (Titchall, 2008). While Redvale reduces greenhouse gas emissions by capturing methane and is also a source of electrical energy, it is not considered to be cost-effective due to the insecure local network, leading to overheating and malfunctioning equipment (requiring infrastructure upgrade).

4.1.4 ENERGY ISSUES

Auckland's energy needs are currently met by electricity from the National Grid, natural gas from Taranaki and fuel from the Marsden Point refinery (Auckland Council, 2012d). Currently over 70% of Auckland's electricity is imported. Vector and Counties Power are responsible for the distribution of electricity and have 520,000 and 36,000 customers respectively (Vector, 2011 and Counties Power, 2011). Within Auckland, electricity is generated by a 380 MW combined-cycle plant (owned by Contact Energy), a 175 MW gas-fired co-generation facility (owned by Mighty River Power), as well as smaller co-generation plants (landfills, hospitals) and a hydro plant at Mangatangi dam (Auckland Council, 2011e). According to Auckland Council (2011e), the city's electricity demand is expected to grow by 2.4% per annum for the next decade (from 1,467 MW in 2011 to 1,864 MW by 2021) as its population increases. Another issue is the centralised nature of the electricity grid. A lack of alternative routes affects the resilience of electricity supply (Transpower, 2010). Other issues for electricity generation and distribution include unsightliness of grid components, lowering of property values in the vicinity of power transmission components and the health stigma associated with transmissions lines.

Both residents (16%) and businesses (11%) use natural gas via Vector's distribution system (Auckland Council, 2011e). However, due to the finite and declining gas resource from the Maui field, the future of natural gas is uncertain. Alternative sources of gas may potentially exist in the form of shale gas, although there are major concerns about potential water and air pollution as well as the cost of gas extraction (Hughes (2011) as cited by Auckland Council (2011e)). Energy for transport is primarily provided by hydrocarbon-based fuel where pipelines transport fuel from Marsden Point to Wiri Oil Terminal where it is distributed via tankers and pipelines. Fossil fuel supply may be uncertain in the future due to peak oil.

Potential solutions for Auckland's energy (electricity) security include the improvement of existing infrastructure (e.g. upgrades estimated at 1.7 billion over the next 10 years), distributed generation to minimise reliance on the National Grid and to feed electricity into the National Grid and renewable generation (Auckland Council, 2011e; Transpower, 2011). Furthermore, energy conservation for lighting, heating and cooling through positive changes in user behaviour as well as changes to urban environments may be beneficial. GI also contributes to energy savings for buildings with, for example, the provision of insulation (green walls and living roofs). On a larger scale, urban greenery/trees can act as wind breaks as well as create comfortable microclimates within the city (e.g. urban parks play an important role in reducing heat island effect as shown in a number of case studies reviewed in the previous chapter).

4.1.5 TRANSPORT ISSUES

While Auckland has developed infrastructure for numerous modes of transport, road transport continues to be the primary travel mode for many Aucklanders. Auckland's transport infrastructure comprises 99 bridges, 51 boardwalks, 165 jetties or wharves, 326 boat ramps (Auckland Council, 2011i) as well as roads, streets and motorways. As observed in the Draft Auckland Plan (Auckland Council, 2011i), Auckland's transport infrastructure is overburdened. In order to improve efficiency and minimise adverse impacts and thus increase connectivity and accessibility, the Council has created five targets as follows:

1. Increase non-car trips in the peak period from 23% (200,000) to 37% (420,000) of all trips by 2040;
2. Increase public transport mode share for mechanised trips (public transport and cars) into the City Centre for the morning peak from 47% in 2011 to 69% by 2040;
3. Reduce road deaths from 61 (2007) to no more than 40 and serious injury from crashes from 483 (2007) to no more than 288 in 2040;
4. Reduce freight congestion in peak periods by 20% by 2040;
5. Increase the number of growth centres with QTN (quality transit network) or RTN (rapid transit network) services from 44% to 80% by 2040.

As population increases and demand for accessibility grows, it is inevitable that new transport infrastructure be built. There is potential for net benefits provided there is increased efficiency (e.g. mass transport as opposed to personal vehicle transport). However, new transport infrastructure can cause a number of adverse impacts such as fragmentation of natural habitat and consequent loss of biodiversity, as well as an increased incentive to use a private vehicle (especially if more roads are built where public transport is costly or unavailable). It can also lead to increases in impermeable surfaces, which affects stormwater management. The loss of greenery that comes with paving would also lead to enhanced heat island effect unless deliberate measures are taken to green streets.

As mentioned under the air quality issues section above, transport is a major contributor to air pollution. Increasing levels of congestion and the number of vehicles on the road exacerbate the issue of pollution. The *State of the Auckland Region Report 2010* (Auckland Regional Council, 2010a) states that 83% of vehicles in Auckland have good emissions, while 10% of vehicle fleet create 50% of the overall air pollution problem. While well-maintained older vehicles produce less pollution, newer vehicles emit less pollution in general (Auckland Regional Council, 2010a). Petrol vehicles contribute nitrous oxides and carbon monoxide emissions while diesel vehicles are responsible for higher particulate matter in terms of smoke. The findings also show that older Japanese vehicles (e.g. imported second-hand vehicles) emit less pollution than New Zealand-new vehicles in general. In terms of exposure to traffic pollution, a research report on transport systems in Auckland and Christchurch by Kingham et al. (2011: 9) concludes that:

- ‘Car drivers are consistently exposed to the highest average levels of carbon monoxide: 60% higher than cyclists, 40–100% higher than bus passengers and over 100% higher than train passengers;
- On-road cyclists are exposed to higher levels of carbon monoxide (10%), [particulate matter with aerodynamic diameter 0.02–0.1 micrometres] (PM1) (25%) and [ultrafine particles] (UFPs) (over 100%) than off-road cyclists. This could have significant policy implications for the location of cycle routes;
- Car drivers and bus passengers are exposed to higher average levels of UFP than cyclists. However, for very short, acute exposures (i.e. a few seconds), on-road cyclists can be exposed to higher peaks;
- At some parts of their journeys, travellers are exposed to very high levels of pollution, often for short periods of time. This has potential health implications;
- Locating cycle paths just a short distance from roads can reduce pollution exposure significantly: for example, locating a cyclist 5–7m away can reduce exposure by 20–40%;
- One hour of commuting (i.e. 4% of the day) could contribute up to 20% of the total daily dose of carbon monoxide and UFP; and
- Particulate matter up to 10 micrometres in size (PM10) and particulate matter up to 2.5 micrometres in size (PM2.5) are inappropriate indicators of exposure to vehicle emissions.’

A significant issue facing Auckland’s transport networks is the extent of congestion at peak flow. The economic cost of Auckland’s congestion (owing to lost income, time and pollution) is estimated to be more than NZ$1 billion per year (Sankaran et al., 2005). Some of the potential solutions to Auckland’s transport issues are:

- Investment in public transport – efficient and convenient walking and cycling networks;
- Traffic management – metering and application of road tolls; and
- Mode shift from private vehicles to public transport, walking and cycling.

According to the Auckland Regional Council (2010b) transport strategy, Auckland’s congestion problems will worsen with the expected growth in population and thus measures to reduce the number of vehicles, which ultimately means less pollution, less greenhouse gas emissions and less resource use (fossil fuel) are absolutely necessary. The application of green technology, specifically GI, could help enhance and protect existing transport infrastructure from future stressors. For example, research shows that street trees and urban forests are able to reduce air pollution, absorbing ozone, carbon monoxide, carbon dioxide, sulphur dioxide, nitrogen oxides and particulate matter (Nowak et al., 2006). GI incorporated on motorways in the form of street trees and urban forests adjacent to motorways could help reduce health costs as pollutants are regulated. Once designed appropriately GI can also help stormwater management, carbon sequestration by acting as carbon sinks and also help to create comfortable microclimates of cooler temperatures. Currently many motorways have greenery adjacent to the roads, however these have tended to be planted without priority given to ecosystem integrity and preservation. Auckland has high potential for integrated public transport via road, water and rail for improved accessibility and connection. For example, according to Auckland Transport (2011), public transport had 65,763,655 patrons from the period June 2010 to June 2011, showing an increase in use by 8.5%. Nevertheless, currently most alternatives to the private car are inconvenient and some are considered to be quite dangerous (e.g. cycling in the inner city). Parkin (2007) found that, for cycling, perception of safety is more important for behavioural response than actual risk to safety. While laws such as New Zealand's bicycle helmet law have been enacted to enhance safety, concerns over their effectiveness and potential as a detterant of cycling has been raised (Clarke, 2012a).

4.1.5 BIODIVERSITY

Due to urban sprawl, Auckland's biodiversity has suffered fragmentation, causing decline in biodiversity (Auckland Regional Council, 2010c). Land use changes that follow human settlement, invasive and predatory species (e.g. domestic pets) are responsible for the decline in habitat and species. Around 24% to 27% of Auckland's indigenous land cover remains in some sort of intact state (Lindsay et al., 2009; Auckland Regional Council, 2010c). Figure 23 shows the state of vegetation at 2004 compared to pre-European settlement. A similar decline in environmental quality is reflected in fresh water quality, with increasing levels of contamination and sedimentation build-up in sheltered marine areas adversely affecting aquatic biodiversity. Despite urban expansion pressures, the Waitakere and Hunua Ranges, as well as Auckland's offshore islands, have not yet been fragmented by urban sprawl – although this may change in the future as Auckland's population increases. Additionally, Auckland is home to several threatened species (e.g. the pateke, Auckland green gecko and chevron skink). Protection of the remaining biodiversity, as well as restoration of ecosystems, remains a critical priority. To this end, Auckland Council has established a Biodiversity Steering Group to develop a Biodiversity Strategy and monitor the delivery of outcomes. The objectives of the Draft Biodiversity Strategy (Auckland Council, 2011j: 60-61) are as follows:

1. 'Conserve the greatest number and most diverse range of Auckland's indigenous ecosystems and sequences;
2. Achieve long-term recovery of the greatest number of threatened species whose range includes the Auckland Region;
3. Maintain and enhance the goods and services provided by our natural environment in a way that supports indigenous biodiversity;
4. Sustain the mauri of natural and physical resources in ways which enable provision for the social, economic and cultural wellbeing of Māori;
5. Achieve greater understanding, valuing and guardianship of biodiversity with our community;
6. Improve knowledge and understanding of biodiversity in the region in order to protect and manage it effectively;
7. Achieve increased interagency, cross-Council, cross-boundary and cross-discipline integration in biodiversity management; and
8. Improve implementation of Council statutory responsibilities to support our biodiversity mandate.'

Coastal, wetland and terrestrial systems with volcanic cones, unique landscapes, corridors and greenbelts are in need of urgent protection. These areas also need to be supplied with adequate and convenient access for enhanced and responsible recreation so as to allow for increased awareness of biodiversity within Auckland. While access for recreational use is significant, highly sensitive areas should be allowed special protection to prevent further degradation. For example, special protection is afforded to the Waitakere Ranges under the Waitakere Ranges Heritage Area Act 2008 (New Zealand Government, 2008) where terrestrial and coastal areas are protected due to their large area and high biodiversity value (Auckland Council, 2011k). Similarly, there is potential for further protection where priority sites have been identified (Figure 23).

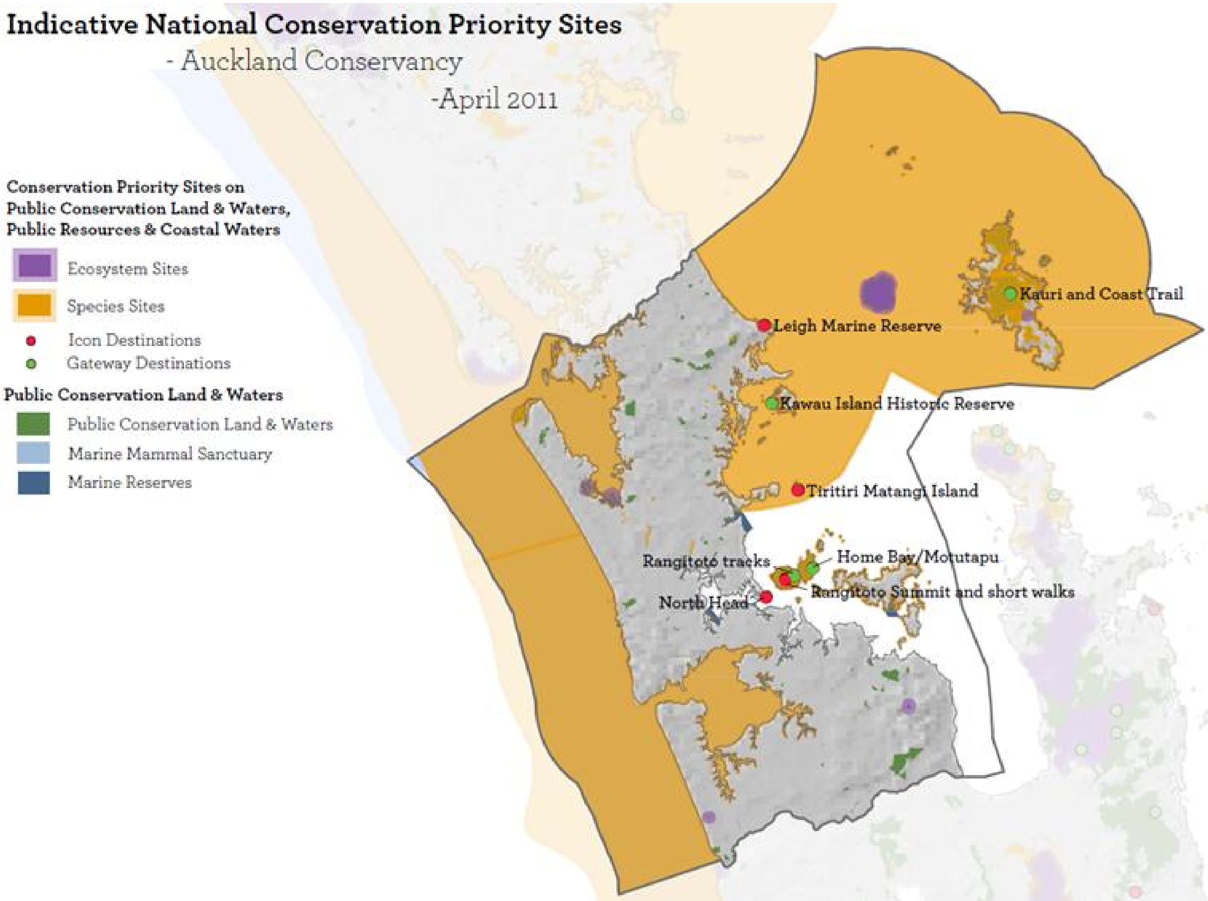


Figure 22 Indicative national conservation priority sites – Auckland Conservancy

Source: DOC (2011)

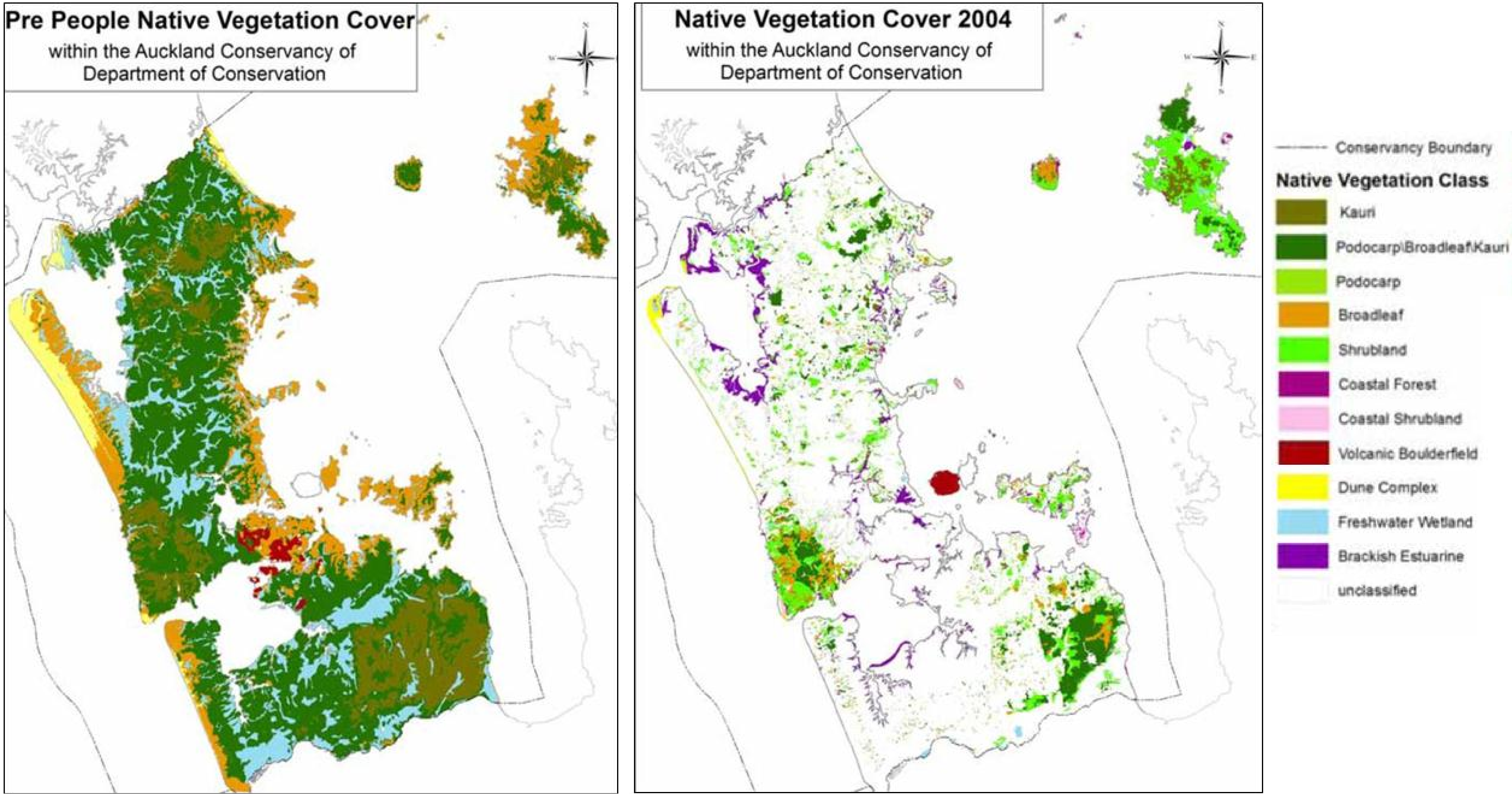


Figure 23 Vegetation cover before human settlement and in 2004, Auckland Conservancy

Source: Lindsay et al. (2009)

4.1.6 CLIMATE CHANGE

Auckland's total greenhouse gas emissions for 2009 amounted to 10.2 million tonnes of CO_2 equivalent, or 14.5% of New Zealand's total greenhouse gas emissions. The moderate-scenario projections of New Zealand's Climate Change Office indicate that the Auckland region may experience the following changes:

- Higher average temperatures (between 0.2°C and 2.5°C by 2040 and 0.6°C and 5.8°C by 2090);
- An additional 40-60 days per annum when maximum temperatures exceed 25°C by the end of the century;
- Lower annual rainfall (1-3% reductions by 2040 and 3-5% reduction by 2090);
- Increased evaporation and more frequent heavy rainfall;
- Higher frequency of westerly and north easterly winds;
- Sea-level rise of approximately 0.8 m by 2100, with storm surges more likely; and
- Increased frequency of droughts by 2080; severe droughts that now occur once in 20 years occurring as often as once every five years.

The consequences of these projections range from droughts and lower hydro flows, altered growing conditions for agriculture and fisheries, intensification of storm events and surface flooding, loss of habitat due to invasive species, costly maintenance of infrastructure, more photochemical smog, among others. The combined effect would be to exacerbate existing problems related to air, water, waste, energy, transport and biodiversity.

4.2 GREEN INFRASTRUCTURE FOR AUCKLAND

On the macro scale, GI in Auckland includes the system of parks and reserves, the ranges, wetlands and waterways. Grey infrastructure dominates in Auckland's transport, building, energy and water management systems. On the micro-scale (i.e. site level), LID practices such as green walls, living roofs, green streets, distributed energy generation and so on can be applied locally. Auckland's potential for GI depends on a number of factors including the existing infrastructure; the capacity to retrofit existing infrastructure; the cost of establishing new GI as well as ongoing costs of maintenance and upgrades; and the benefits in the Auckland context. Provided that GI assets and techniques fit well within the environment (inclusive of the social and economic environment), GI could allow for the provision of vital ecosystem services for current and future generations of Aucklanders. It is possible that projects that are planned for the improvement of Auckland's liveability (according to the Auckland Plan) would have longer-term benefits if GI approaches were integrated into the proposals. The following section identifies Auckland's potential use of GI and the benefits that they may provide. This section considers findings from the literature review and the case studies to discuss Auckland's potential for GI assets such as parks, reserves and corridors (protected areas), GI for green transport (low energy modes and green transport infrastructure) and LID methods such as permeable paving, living roofs, green walls and bioretention.

4.2.1 PROTECTED AREAS

According to the Ministry for Environment (2010), 14% of land within the Auckland region is protected; e.g. there are more than 800 reserves and parks. Some of the notable parks within Auckland City include Auckland Domain, Albert Park, Dove-Myer Robinson Park, Western Park and Western Springs Park. The Auckland Domain is Auckland's oldest park, with a land area of 75 hectares located close to the CBD (Auckland Council, 2012e). Other prominent outdoor recreational areas in the region are the Michael Joseph Savage Memorial, Mt Eden, Cornwall Park and One Tree Hill Domain and Bastion Point. The larger parks in central Auckland are easily accessible by public transport and walkways connect many of them.

These reserves and parks incorporate much of the remaining native forests, regenerating scrub as well as wetlands. It is estimated that 90% of New Zealand's original wetland areas have been lost since human settlement (Ministry for the Environment, 2007). What little remains is threatened by pollution, nutrients, sedimentation, drainage, grazing and invasive species (Auckland Regional Council, 2010a). Yet wetlands are also critical habitats for many threatened species. In addition to biodiversity, the ecosystem services offered by wetlands (e.g. flood management, treatment of pollution, carbon sequestration) are lost when wetlands are drained. Currently only 38% of the remaining wetlands in the Auckland region are under protection (Auckland Regional Council, 2010a).

Many reserves, parks, wetlands and rivers in the Auckland region are under pressure due to urban sprawl as greenfield development encroaches on the urban-rural fringe, diminishing the capacity of those natural habitats to maintain ecosystem services. As can be seen from previous chapters, it is possible to retain and protect nature within urban areas (consider Copenhagen, Singapore and Stockholm, where development is constrained by natural boundaries). Conservation corridors and greenbelts can contribute by maintaining and protecting land in its native state (forests, wetlands). These provide numerous benefits, such as preventing further habitat fragmentation, which are crucially important for biodiversity. Reserves, parks and wetlands, together with their connecting corridors and greenbelts, can also assist with the provision of ecosystem services, as described in Chapter 2 (e.g. managing stormwater runoff, treatment of contaminated air, water and land, provision of food, among other functions). Whilst there are over 800 parks and reserves in the Auckland region, they are mostly not connected by conservation corridors, as can be seen in maps of the region (Figures 25 and 26).

Figure 25 illustrates a typical suburb in the Auckland region. Whilst there are green and blue spaces in the form of parks and waterways, there is limited green connectivity among the various green spaces (and none that act as corridors for biodiversity). This situation also applies to the parks within the city of Auckland (near the CBD) as shown in Figure 26.

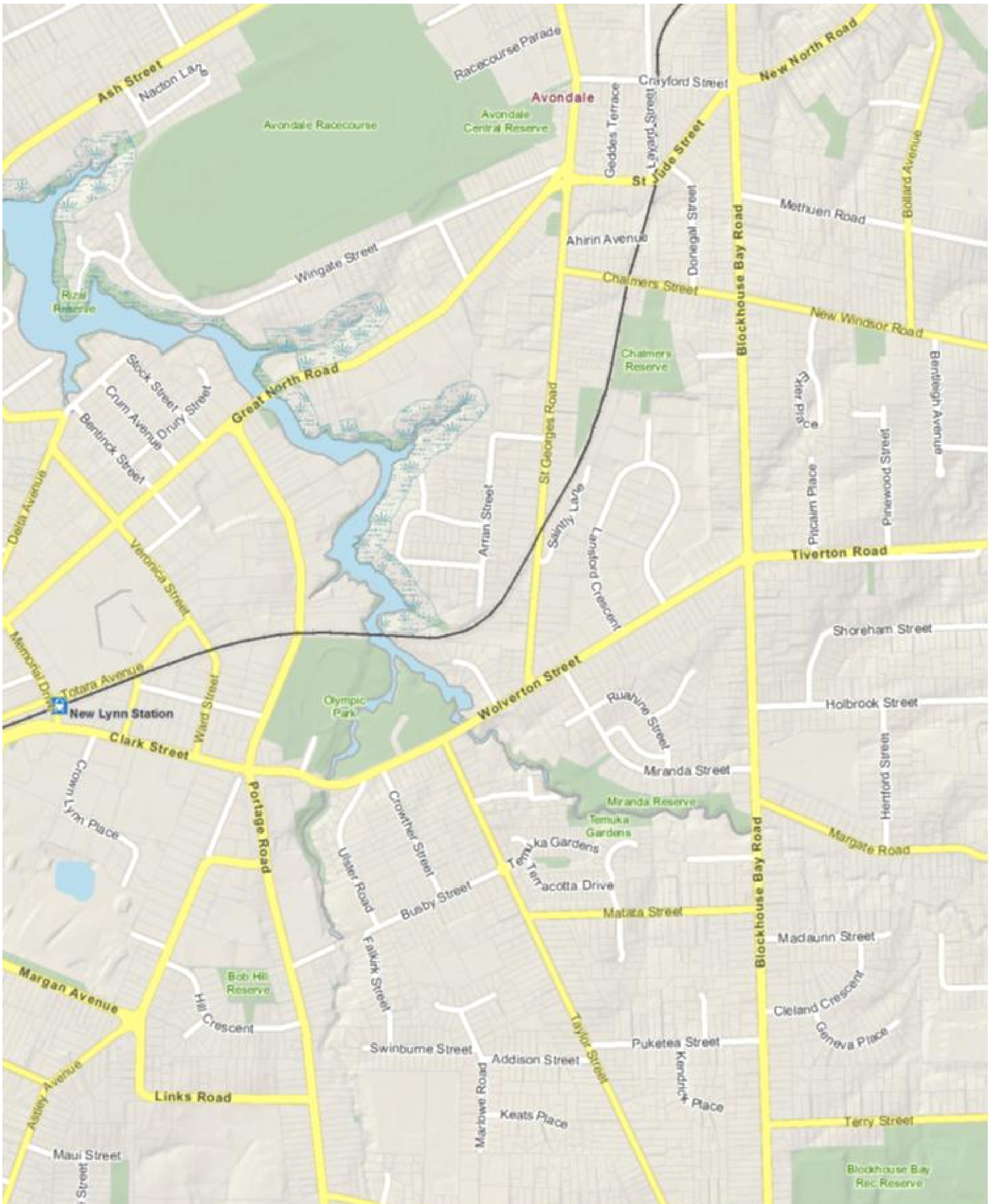


Figure 25 Map of Avondale suburb showing sparse connectivity of reserves and green space

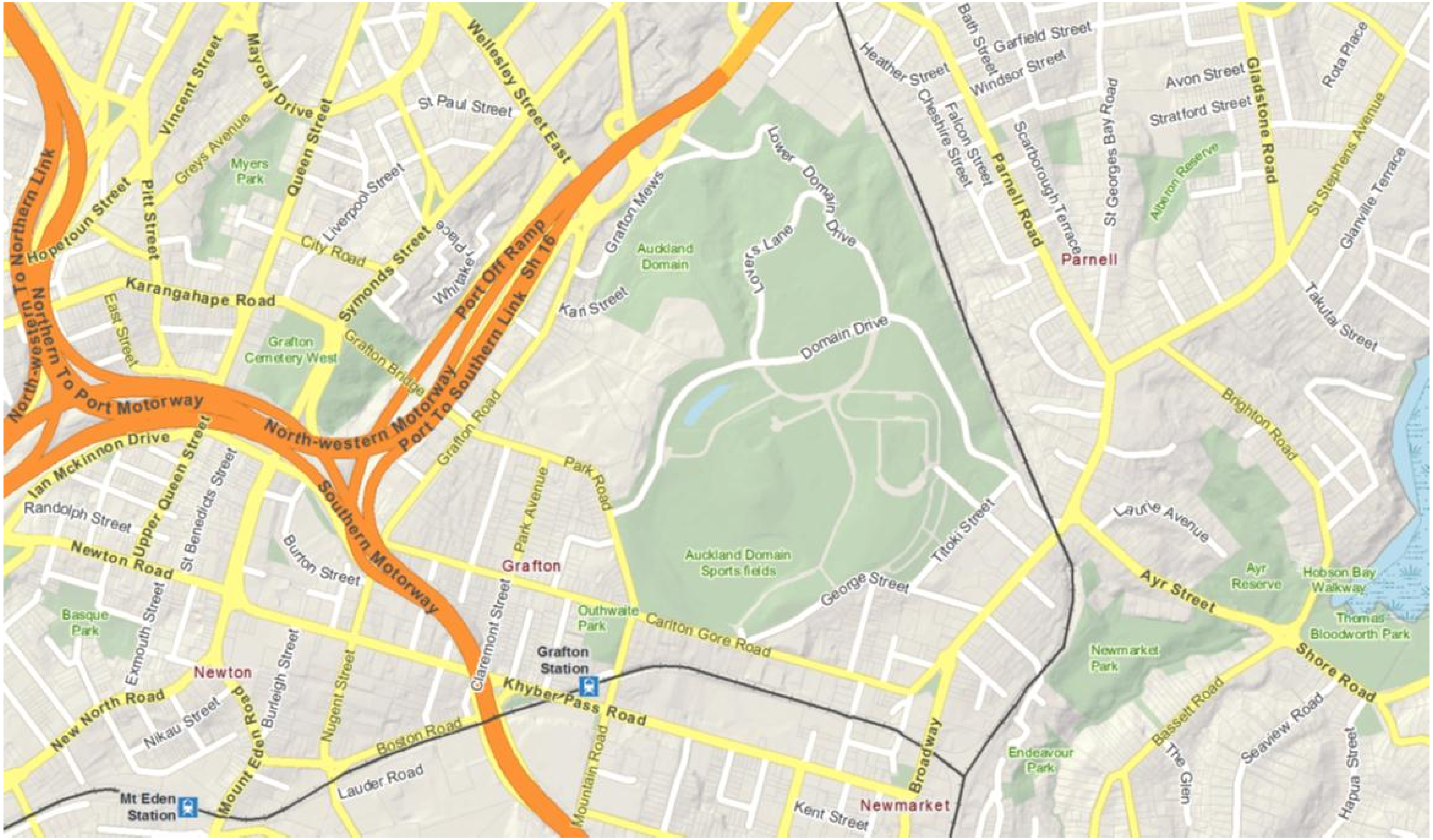


Figure 26 Map of Auckland showing The Domain and parks in the vicinity

There are many ways to solve the connectivity problem, including developing conservation corridors. Yet land within the city is limited and there is unlikely to be enough to provide sufficient land area for large conservation corridors. The research we have reviewed shows that larger corridors are more effective for maintaining biodiversity, so this is a limitation. Yet it may be sufficient to modify existing pathways (such as roads and streets) and it is certainly less harmful than the application of grey infrastructure. For example, tree planting in association with LID techniques such as rain gardens, bio-swales and permeable paving, along with narrower roads and streets, would provide many of the benefits outlined in Chapter 2 (e.g. shading, green transport, incentives for walking and related improvements in population health). However, issues with space and cost, as well as competing infrastructure (roads and motorways), may limit the provision of connecting corridors in Auckland.

4.2.2 Green transport and its infrastructure

GI can contribute to green transport by improving connectivity and providing greener modes of transport for the city, as well as streets, roads and pathways that help ameliorate air, water, land use and waste issues. By definition, green transport includes low emitting modes of transport (such as walking and cycling) as well as public transport. The Auckland Plan contains strategies that will enhance Auckland's transport networks. Rather than relying on grey infrastructure, GI may be integrated with the planned networks so as to obtain connectivity and ecosystem services. This may enable Auckland to emulate practices illustrated by the case studies of Curitiba and Brisbane. GI can contribute the following to Auckland's transport projects:

- Practical and safe transport that is less polluting and less energy intensive (e.g. safer cycling routes); and
- Green streets – street trees, permeable paving, bioretention cells and bio-swales for multiple goals such as stormwater and pollutant management, biodiversity and carbon sequestration.

Evaluating the Auckland Plan, it is apparent that efforts will be made to improve the connections between Auckland's main hubs (towns and cities) via numerous modes of transport (Figure 27). These improvements would require new infrastructure and thus represents an important opportunity for installing GI techniques and enabling shifts in transport mode. The most green transport modes are walking and cycling, but both depend on appropriate infrastructure that guarantee safety (e.g. safe from pollution and traffic incidents). The literature shows many benefits of cycling, both for human health and for the environment. For example, research conducted in New Zealand by Lindsay et al. (2011) estimated the effects on health, air pollution and greenhouse gas emissions in shifting from driving to cycling in the urban environment. They concluded that the shift would reduce air pollution and greenhouse emissions and improve public health. The specific quantified costs and benefits, according to Lindsay et al. (2011), are:

- Reduction in vehicle travel by 223 million km/year;
- Reduction in the use of 22 million litres of fuel;

- Reduction by 0.4% of transport-related greenhouse gas emissions;
- Avoidance of 116 deaths from increased exercise;
- Avoidance of 6 deaths from air pollution related to vehicle emissions;
- Avoidance of 5 cyclist fatalities in road accidents; and
- Overall economic savings of approximately NZ$200 million per year.

Research by Tin Tin et al. (2010a) investigated New Zealand's exposure rates and profiles of injuries to cyclists during traffic incidents, while Tin Tin et al. (2010b) considered the role of environmental and policy measures in encouraging cyclists to cycle more often. The former study concluded that fatalities and injuries requiring hospitalisation have been on the rise, despite road safety and injury prevention programmes (Tin Tin et al., 2010a). Whilst this is of great concern, other research by Tin Tin (2011) concluded that there is a 'risk in scarcity' effect where the risk to cyclists increases if there are fewer people cycling and more people driving cars.

The later study by Tin Tin et al. (2010b) focused on determining the incentives for cycling. This study sampled 2,469 cyclists who had enrolled in the 2006 Wattyl Lake Taupo Cycle Challenge and found that 88% were encouraged by the provision of cycle lanes; 76% were encouraged by cycle paths; 64% were encouraged by anti-theft security; 55% were encouraged by reduced vehicle speed; and 38% were encouraged by bike-friendly public transport. The study also analysed the factors that increased cycling by those who already cycle to work. It found that out of the 2,469 cyclists, 2,223 were already cycling to work at least one day a week. The factors that would encourage them to cycle more included the availability of showers at work (61%); easy intersections (43%); rising fuel costs (41%); availability (27%) and cost (25%) of car parking; and bicycles suitable for commuting (26%). Safer cycling routes (i.e. separate paths and lanes), cycling amenities and a reduction in vehicles may encourage more cycling within the urban environment. This would require changes to the design of new streets and roads as well as modification of existing ones.

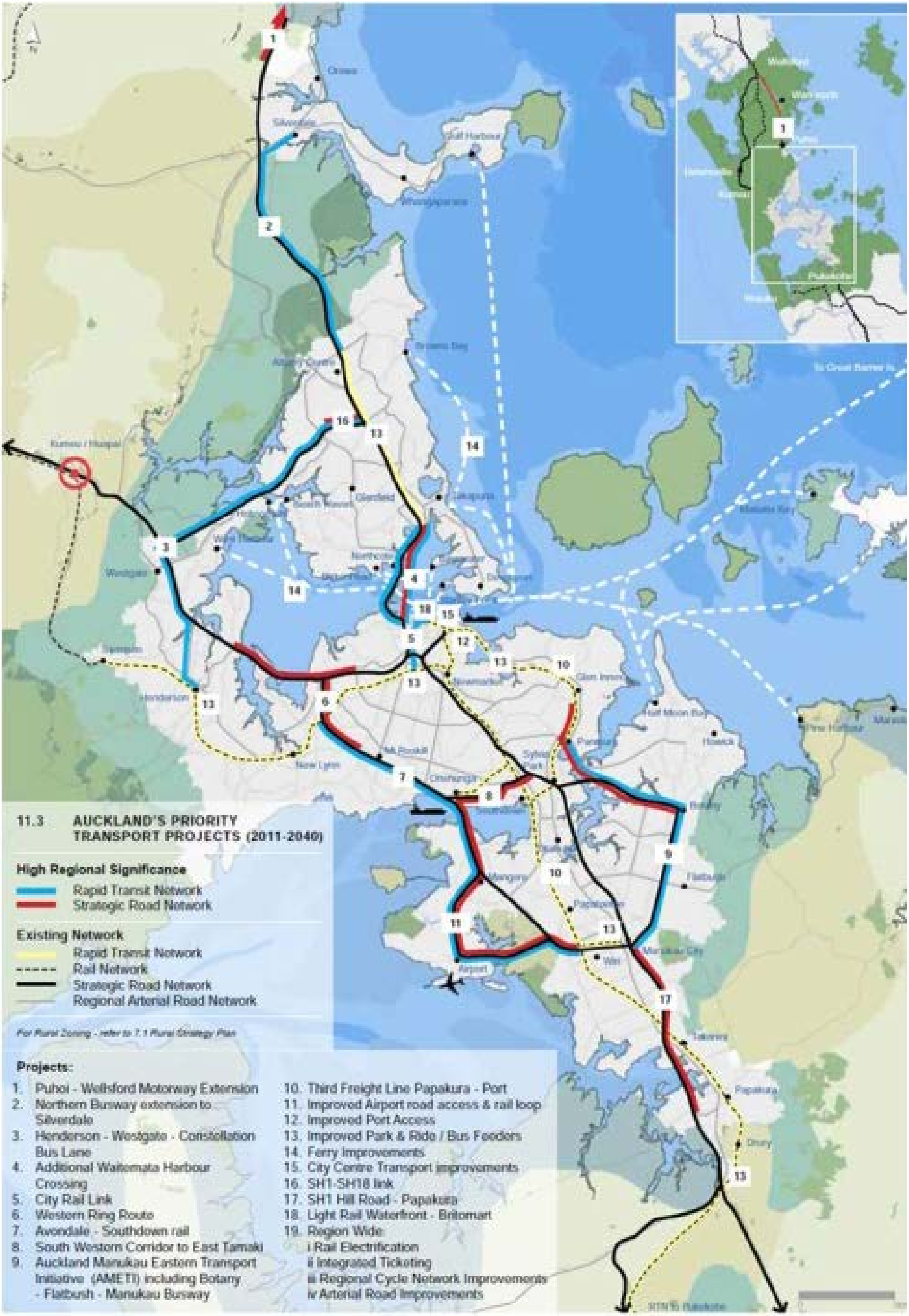


Figure 24 Transport projects to enhance Auckland's transport networks

Source: Auckland Council (2012b)

4.2.3 Permeable paving

An Auckland Regional Council (2003: 2-2) report claimed that 'urbanisation creates impervious surfaces which reduces vegetative interception, depression storage, infiltration and surface roughness (flow retardation).' This has led to changes in Auckland's hydrological cycle, specifically due to the increase in total runoff and decreases in infiltration and evapotranspiration (Auckland Regional Council, 2003). Permeable pavement has many benefits over conventional impermeable paving, typically an ability to detain and retain some stormwater and discharge fewer contaminants compared to conventional pavements. Limited studies have been conducted on the use of permeable paving in Auckland. A study of permeable modular pavers, also known as permeable interlocking concrete pavers, on a highly sloped (6.0-7.4°) 200 m^2 area over the impermeable subgrade soils of Birkdale Road on the North Shore in Auckland was undertaken by Fassman and Blackbourn (2010, 2011). Results from the test site study found that the underdrawn discharge from permeable pavement:

- Delayed the onset of runoff (average lag time of 3.2 hrs);
- Mimicked or was less than predevelopment peak flows for most events (81 storms monitored);
- Reduced runoff volumes, especially for small storms, even though it was installed over clay subsoils;
- Contained significantly less pollutant concentrations and mass than a reference asphalt road surface (mass differences TSS – 65%; Total Cu – 68%; and Total Zn – 88%).

The application of such paving on roadways and car parks in Auckland may provide accumulated benefits for stormwater management. Whilst the above results are promising and the test site specific to Auckland, a growing body of international evidence also affirms that well designed and maintained permeable pavement that is appropriately sited and installed may provide significant stormwater control advantages over the long term. There appears to be few meaningful differences in performance between different permeable pavement types (Collins et al., 2008), but there have been relatively few comparative tests of different types in the international literature to date. Permeable pavement could also be applied to car parks and driveways in residential and industrial areas, with similar results expected (e.g. delayed runoff, reduced peak flow and reduced pollutants). A significant benefit of permeable pavement is that it may be considered as a 'self-mitigating surface' given that it filters into the substrate layers, whereas runoff from conventional asphalt pavements (which currently flows into stormwater drains and ends up in waterways untreated) should be captured at source and treated appropriately in downstream stormwater management facilities.

Auckland Council provides guidelines for the maximum allowable impermeable and minimum required permeable surface areas for residential sites (Auckland Council, 2012h). These guidelines are based on the area of the site and residential zone and classified according to population density. For example, for the most common zone

(6A), a maximum area of 25% of the site may be covered by impermeable surfaces while there should be a minimum permeable surface (landscaped) of 40%. In areas with lower population density, the maximum impermeable surface is 25% while the minimum permeable surface is 45%. Large trees and permeable landscaped areas are encouraged for such sites (Northshore City Council, 2009). Permeable paving can be applied to many surfaces with design adjustments and restrictions in order to maximise its effectiveness. For example, Northshore City Council's (2009) guidelines required permeable pavements for car parks, driveways and roads to be designed for 20 years of use, while being restricted to gentle slopes (3°). Auckland Council's new guideline for permeable pavement design for stormwater management is currently in progress.

4.2.4 LIVING ROOFS AND WALLS

As discussed, living roofs and green walls are a means of incorporating GI into dense urban environments and are particularly important where there is limited land area for tree planting and ground-level gardens. Living roofs occupy an otherwise impervious surface that is often underutilised. Whilst Auckland is not as constrained for land as Singapore, Auckland can learn from and emulate Singapore's successes with increased greenery particularly in the CBD by installing more living roofs and green walls. It should be noted that the benefits from living roofs and green walls in Auckland are likely to be quite different to the benefits that densely populated cities like Singapore and Chicago are likely to gain, due in part to climatic differences. For example, living roofs and green walls help to regulate extreme temperatures, allowing for a greater cooling effect in cities such as Singapore. In this factor alone, Singapore would gain greater benefit due to its high average temperature (according to the literature, the greater the temperature, the greater the benefit in terms of cooling).

Whilst the heat island effect may not necessarily be as significant an issue for Auckland as it is for New York City and Singapore, living roofs in Auckland could be used effectively for localised temperature regulation within the CBD. Furthermore, since climate change will lead to an overall warming of the region, the application of living roofs and green walls may alleviate this trend and contribute to future cooling needs. In addition to climate change considerations, living roofs also play an important role in stormwater management, thermal and noise insulation, protection of building roofs from UV rays, as well as the uptake or removal of air-borne pollutants.

Auckland has an extensive documentation of the quantified benefits of living roofs for stormwater management (see Simcock et al., 2005; Simcock et al., 2006; Fassman et al., 2010a; Fassman et al., 2010b; Voyde et al., 2010a; Voyde et al., 2010b; Fassman-Beck et al., 2013) and the specific design and construction guides for living roof design for stormwater management (Fassman-Beck and Simcock, 2013). Research and development has documented locally-relevent substrate design (Fassman and Simcock, 2012), plant suitability (Davies et al., 2010; Fassman et al., 2010b) and stormwater mitigation performance (i.e. hydrology and water quality) (Fassman et al., 2010b; Voyde et al., 2010a; Fassman-Beck et al., 2013).

Field monitoring has been carried out on a number of roof systems of varying depths from 50 to 150 mm (e.g. the 50 mm non-irrigated roof on the University of Auckland's Faculty of Engineering building; the 100 mm deep living roof on the Waitakere Civic Centre; 100-150 mm mini living roofs at Tamaki), using different design combinations. Monitoring results show that the annual runoff volume from the University of Auckland's living roof was substantially reduced. Up to approximately 67% of rainfall was captured and evapotranspired from the average 60 mm depth living roof (Voyde et al., 2010b; Fassman-Beck et al., 2013). Monitoring results for multiple living roofs, show that up to 60-66% reduced runoff was generated compared to a conventional roof surface at the same site, recorded over a period of 8 to 28 months. Substantial retention, even by living roofs as shallow as 50 mm in depth, was attributed to the frequency of relatively small storms (< 30 mm) in Auckland coupled with substrates designed to maximize water holding capacity. For the majority of individual storm events, there was complete retention (i.e. zero runoff). When runoff did occur, across all sites, the magnitude of the peak flows from living roofs was significantly less than each living roof's corresponding control roof. From the results, it is evident that living roofs applied in Auckland would lead to retention of runoff and peak flow, which could alleviate the stress on Auckland's stormwater management systems (grey infrastructure) and thus reduce the degradation of land and receiving water bodies.

Two living roof systems were monitored for water quality. The Tamaki and Waitakere living roof studies indicated that mass loads of Cu and Zn may be reduced when a metal roof surface is covered with a living roof. Total suspended solids was not problematic. Living roof runoff in nutrient-sensitive receiving environments may need additional ground-level treatment, but the living roofs do not require fertilisers once the plants are established (Fassman et al., 2010b).

Greenroofs Ltd. (2009) estimated the potential cost of building living roofs, noting that costs are likely to differ on a project basis. Estimates for a sedum plants roof of 200 m^2 would be approximately NZ\$150/m^2. A roof with New Zealand native plants would cost approximately NZ\$230/m^2 (pricing based on 2009 figures, excluding craneage, delivery, or GST).

In contrast to the availability of research on living roofs in Auckland, research on the application and performance of green walls in the context of Auckland is limited, although a number of green walls exist. For example, New Zealand's largest living wall is located at the Atrium on Takutai at one of the entrances to the Britomart Transport Centre in downtown Auckland. This wall has 60 custom-designed panels and features native and exotic plant species selected to suit conditions such as low lighting and maintenance requirements. The Square Bar, Hotel Novotel at Auckland International Airport also features a green wall (a two-storey green wall that was designed, built and installed by Natural Habitat). However, studies to establish performance measures are required.

4.2.5 BIORETENTION

As discussed in the literature reviewed in section 2.2.9, bioretention systems such as rain gardens have multiple applications related to stormwater management. They delay runoff, reduce peak flow, reduce the volume of runoff, treat water pollution via filtration, settling and sorption and may help recharge groundwater. A number of pilot programmes testing rain gardens have been running in Auckland, including the Paul Matthews bioretention system in North Shore and the rain gardens in Talbot Park, Glen Innes. These two studies are reviewed further to evaluate the potential impacts of their use in Auckland.

Research conducted in Auckland by Trowsdale and Simcock (2011) outlined the soil physics, hydrological performance and hydrochemical efficiency of the Paul Matthews bioretention system, a 200 m^3 rain garden located on a busy road (nearly 5 million vehicles annually) that receives water from a light industrial area. *Apodasmia similis*, a native species with a weed-suppressing canopy and ability to withstand ponding as well as dry conditions, was planted in the rain garden. The study showed that the rain garden was successful in reducing peak flow and volume for the rain events monitored. The rain garden was also successful in reducing the concentrations of sediment. Instantaneous concentrations of individual samples (i.e. not event mean concentrations) of total suspended solids (TSS) from the inflow were 30 mg/L (median) and 375 mg/L (maximum), whilst TSS at outflow was 3 mg/L (median) and 42 mg/L (maximum)), zinc (the area had high instantaneous concentrations of Zn and the system was able to reduce it to a median of 29 µg/L) and lead (median inflow of 11 µg/L reduced to 1 µg/L in outflow. However, it was unsuccessful in treating copper, where the outflow (15 µg/L) was greater than the inflow (10 µg/L). The source of the Cu was thought to be fungicides in the potting mix (Trowsdale and Simcock, 2011).

The Talbot Park rain garden study (Bracey et al., 2008) reviewed the developer's experiences pertaining to the planning, construction and maintenance of the rain garden. The garden was constructed as part of the Talbot Park Community Renewal Project (expected to cost NZ$48 million, according to Bracey (2007)), which is located in a low-income area of Glen Innes where more than 50% of properties are owned by Housing New Zealand (Bracey et al., 2008). This is an area where a significant proportion of residents experience unemployment, poor health, low personal safety and inadequate social services. The development programme applied multiple procedures that fall within the scope of GI, such as rain gardens, solar water heating systems and rainwater tanks. According to Bracey (2007), general improvements in the area have been observed, such as reduced incidents of graffiti and property damage. The tenants have reported greater happiness and an improved sense of safety, linked to increased desirability to live in the area.

Some of the issues encountered were due to improper design and the contractor's lack of previous knowledge of and experience with implementing rain gardens. For example, narrow slots at the base of the kerb restricted water flows; high grates prevented water in-flows; and gardens were overfilled. Out of the six rain gardens constructed, a mean infiltration rate of 1000 mm/hr was achieved with minimum infiltration of 12 mm/hr. A significant lesson from this relatively early project was the need to prevent clogging due to migration of sediments from nearby construction sites. It was recommended that rain gardens be constructed after other developments have been completed. Bracey et al (2008) highlight the following key lessons from the project:

- Ensure that key stakeholders (e.g. local authority) accept and are committed to the LIUDD approach and objectives at the start of the project;
- Ensure contractors understand the critical design features of rain gardens;
- Plants, when mature, should allow visibility of children on footpaths;
- Use organic mulch that does not float during establishment of the garden;
- Either protect rain gardens from sediment accumulation (from nearby construction sites) and thus clogging, or construct rain gardens after construction has been completed;
- Employ an on-site gardener who is aware of the specific objectives and approaches of rain gardens; and
- Ensure frequent maintenance such as weeding and removing litter and sediment that blocks inlets and outlets.

4.2.6 Strategic tree planting

Trees play a vital role in ecosystems. With respect to their functional role, the review of GI procedures and assets clearly illustrates that trees are capable of pollutant removal (i.e. air pollutants such as carbon monoxide (CO), nitrogen oxides, (NO_x), ozone (O_3), volatile organic compounds (VOCs), sulphur dioxides (SO_2), particulate matter (PM) and polycyclic aromatic hydrocarbons (PAHs)). They can also absorb many waterborne pollutants, including heavy metals. A further benefit of trees is their ability to create microclimates within urban environments, providing cooler shaded areas for leisure and recreation. Through their root structure, trees also provide soil stability and thereby can reduce erosion loads into rivers and streams. Moreover, they provide habitats for birds, reptiles and insects. With respect to climate change, trees are a sink for carbon sequestration and with this comes the potential for financial benefits arising from carbon credits and trading.

In order to determine the level of carbon capture, the number of trees in the region needs to be known. Research on the type and number of trees in Auckland is currently in progress, with initial estimates of 70,000 street trees and 50,000 park trees in Auckland city (Auckland Council, 2008). The Ministry for Primary Industries (formed from the merger of the Ministry for Agriculture and Forestry, Ministry of Fisheries and the New Zealand Food Safety Authority) has compiled a number of studies that quantified the carbon storage and carbon sequestration rates of trees in New Zealand (MPI, 2011) (Tables 42 and 43).

Table 43 Above ground carbon storage in forests, shrubland and pasture in New Zealand

Description land cover/species	Carbon storage	Reference
Forest – general average of above ground carbon for all New Zealand forests from the National Vegetation Survey data.	525 tCO_2/ha	Hall (2001)
Pasture – pasture without grazing, including above and below ground live biomass only.	11 tCO_2/ha	Ford-Robertson et al. (1999)
Unimproved Pasture – overall average carbon stock for unimproved pasture in New Zealand. Live biomass only is included.	7 tCO_2/ha	Tate et al. (1997)
Radiata Pine – Pinus radiata afforestation on a high productivity site, 800 stems per hectare planted, pruning to 6.3 m and thinning to waste to 400stems per hectare. Clear-fell harvest at 28 years. Long-term carbon stock averaged over three rotations. Includes live biomass only.	814 tCO_2/ha	Ford-Robertson et al. (1999)
Radiata Pine – Pinus radiata afforestation on low productivity site, 1200 stems per hectare planted, pruning to 6 m, thinning to waste to 250 stems per hectare. Clear-fell harvest at 28 years. Long-term carbon stock averaged over three rotations. Includes live biomass only.	550 tCO_2/ha	Ford-Robertson et al. (1999)
Radiata Pine – 28 year old Pinus radiata plantation, planted at 1,200 stems/ hectare, pruned to 6 m, waste thinned to 250 stems/hectare, located on the Central North Island Volcanic Plateau. Includes live biomass both above and below ground and the litter layer.	918 tCO_2/ha	Robertson et al. (2004)
Pine – This is a general figure for New Zealand pine forests, assuming a 25-30 year rotation in perpetuity. This includes above ground biomass only.	411 tCO_2/ha	Maclaren (1996)
Woody Scrub – This is estimated from standing biomass and does not include soil carbon.	128 tCO_2/ha	Tate et al. (1997)
South Island Indigenous Shrubland – Natural Indigenous Shrubland (South Island). All carbon pools are included, i.e. living biomass above and below ground, CWD, fine litter and mineral soil.	598 tCO_2/ha	Coomes et al. (2002)
Manuka/Kanuka Shrubland – 25 year old, manuka dominated stand.	238 tCO_2/ha	Scott et al. (2000)
Manuka/Kanuka Shrubland – 35 and 55 year old stands of mixed Kanuka and Manuka.	554 tCO_2/ha	Scott et al. (2000)
Lowland podocarp-broadleaf forest – This is estimated from standing biomass and does not include soil carbon.	1238 tCO_2/ha	Tate et al. (1997)
Mature beech-podocarp forest – This is estimated from standing biomass and does not include soil carbon.	1290 tCO_2/ha	Tate et al. (1997)
Hard beech forest -–This is estimated from standing biomass and does not include soil carbon.	1172 tCO_2/ha	Tate et al. (1997)
Mountain beech forest – This is estimated from standing biomass and does not include soil carbon.	938 tCO_2/ha	Tate et al. (1997)
South Island Indigenous Forest – Natural Indigenous Forest in the South Island. All carbon pools are included, i.e. living biomass above and below ground, CWD, fine litter and mineral soil.	1065 tCO_2/ha	Coomes et al. (2002)

Source: MPI (2011)

Table 44 Carbon sequestration rates for trees and forests in New Zealand

Description land cover/species	Rate of carbon sequestration	Reference
Planted Forests – This is an overall average carbon sequestration rate for planted forest in New Zealand during a rapid growth phase.	18 tCO_2/ha/yr	Tate et al. (1997)
Kauri Plantation – 69 year old stand in Taranaki Region, between 24 and 46 cm diameter at breast height. Includes live biomass, both above and belowground.	15.9 tCO_2/ha/yr	Steward (2011)
Manuka/Kanuka Shrubland – General New Zealand mean net increment for Manuka/Kanuka scrubland during an active growth phase averaged over 40 years and taking into account changes in all carbon pools.	7.0-9.2 tCO_2/ha/yr	Trotter et al. (2005)
Kanuka–red beech and coastal broadleaved forest, natural regeneration, lowland forest, South Island, sequestration rate (aboveground biomass) over the first 50 years of succession.	8.4 tCO_2/ha/yr	Carswell et al. (2012)
Urban afforestation – planted forest (27 years old), mainly native tree species, Newmarket Park, Auckland. Includes live biomass, both above and belowground.	6.2 tCO_2/ha/yr	Schwendenmann and Mitchell (2014)

The carbon storage and sequestration rates given in Table 43 and Table 44 are indicative: actual carbon storage potential and sequestration rates vary due to factors such as the species of tree, forest age, climate, soils, and management. These factors affect the tree growth rates and hence the rates of carbon uptake. According to CoalNZ (2009), species grown for the forestry industry such as *Pinus radiata* can sequester 45% more CO_2 than a Douglas fir (over a period of 30 years), whereas a *Pinus radiata* can sequester 70% more CO_2 in its second 10 years of life. Furthermore, the location of the trees has a significant impact on sequestration. For example, it is claimed that *Pinus radiata* is able to sequester 50% more CO_2 in Gisborne than in Canterbury (over 30 years) (CoalNZ, 2009). The amount of CO_2 sequestered is thus dependent on numerous variables such as geographical location, type of species, age of trees, health of trees and soil type, among other factors. It should be noted that due to the variability of these factors, the scientific basis on which the amount of CO_2 captured by trees can be calculated is limited (CarbonZero NZ, 2012).

Considering that different tree and plant species have different needs and thus may influence their surroundings according to variables such as climate, soil, water and nutrients, an understanding of those species and their environmental characteristics is essential if they are to be effective agents in GI. Tiwary et al. (2009) proposed a mix of tree species as a cost-effective means of providing services such as pollution removal. Freer-Smith et al. (2005) noted that some species are more effective in removing different types of pollutants than others, recognising the need to understand their natural variability. These are important considerations with respect to the choice of species used to plant any given area. Furthermore, since tree planting has numerous benefits, multiple functionality and multiple benefits should be sought. For example, a tree planted in an urban street may assist in stormwater management as well as provide local benefits such as shading and aesthetic appeal and at the same time it should be recognised for its role in helping mitigate climate change via sequestration and storage of carbon.

Depending on local conditions, some species may aggravate adverse impacts. An example is the increased emission of Volatile Organic Compounds (VOCs) from trees that may be harmful to human health (e.g. black spruce emits VOCs at greater rates when temperatures increase, according to Fulton et al. (1998)). In the case of VOCs, flow-on effects such as ozone formation may result (AEA Technology, 2002). Similar issues exist with respect to flowers and pollen, where the incidence of allergic reactions may increase due to close proximity to certain species of trees.

Overall, despite some of the issues noted above, trees are a pivotal element of GI and are instrumental to the greening of Auckland. They provide multiple functions and multiple benefits for the local and regional environment and are crucial to the health and wellbeing of urban citizens and non-human species. However, care needs to be taken in choosing the types of species that would thrive in an area and also that which also leads to the greatest value from a systems perspective such that adverse flow-on effects are minimised while benefits are capitalised upon. In addition to introducing more trees into the urban environment, it is important to protect existing trees. Recently, the New Zealand government has proposed to amend the provisions of the RMA with respect to trees. The impact of those changes, specifically the revoking of tree protection rules, is as yet unclear but could be detrimental to increasing urban trees in Auckland. In order to increase native biodiversity, Ignatieva et al. (2008) advocated planting podocarps, elaeocarps, lemonwood, ribbonwood, lacebark, cedar, kauri, pohutukawa, rewarewa, puriri, taraire, tawa, titoki, maire tawake, kowhai, kanuka and cabbage trees.

4.3 EXISTING GI IN AUCKLAND

Auckland is already hosts a number of GI assets and procedures and there has some research carried out to establish performance criteria and improve design guidance in Auckland. Some of the existing examples of GI include parks such as Albert Park and Auckland Domain in the inner city and One Tree Hill Domain and Western Springs in the suburbs. Many 'park-n-ride' facilities along the Northern Busway include rain gardens and swales. Rain gardens have gained in popularity; they have been established throughout the Wynyard Quarter, in Talbot Park (Bracey et al., 2008), at Lucas Creek in Albany, Judge's Bay in Parnell and throughout the Waitakere Civic Centre in Henderson. New projects are underway, such as rain gardens in Gardner Reserve (New Lynn) and a suite of rain gardens, permeable pavement and bioswales along Northside Drive (near Hobsonville, West Auckland). The Auckland Council-owned Albany Lakes Civic Park incorporates rain gardens, tree pits and permeable pavement, among other technologies. Living roofs that have been constructed at the University of Auckland's Engineering School, Waitakere City and Auckland Regional Council Botanic Gardens (Manurewa); permeable pavement trials have occurred on the North Shore (e.g. Birkdale Road and Clemows Road). Masterplanned communities including Stonefields, Hobsonville Point and Long Bay cover 110-167 hectares, incorporating a variety of GI features throughout these new developments.

GI techniques such as tree planting are continual in many cities and Auckland too has programmes that aim to increase the city's canopy cover. For example, Auckland Council has launched the 'Trees for Babies' scheme, where families are given the opportunity to plant a native tree to celebrate the birth of their baby, thereby incentivising the community to get directly involved in tree-planting. Auckland city has greater potential than is currently being realised in terms of green forms of transport that cater for non-motorised modes of transport such as cycling. However, projects involving the mapping of future green links for pedestrians and cyclists through parks, reserves and roads, called 'Greenway Plans', are currently underway. Plans currently in progress include the Puketapapa Greenways Plan, the Kaipatiki Connections Network Plan, Maungakiekie Tamaki Greenways, Whau Greenways, Waitemata Greenways and Albert Eden Greenways (Clarke, 2012b).

Auckland Council comprises a number of working groups, such as the stormwater group, planning group, biodiversity group and transport group. Since each of these sectors utilise GI assets and contribute towards different aspects of GI, co-operation and consultation among these different groups might best be facilitated by their representation on overarching group. Such co-operation would be useful for exploring the multiple functions of GI, allowing projects to better deliver on multiple benefits. A systems perspective may prove vital for providing net benefits when planning for complex projects involving infrastructure for cities.

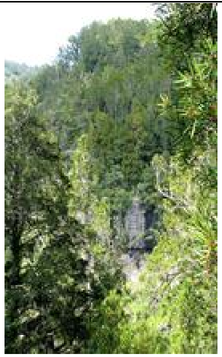
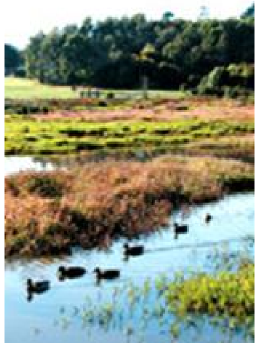
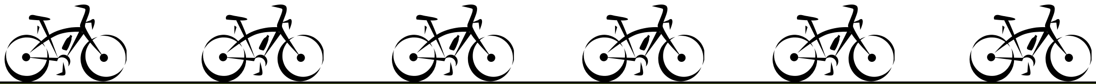
5. SUMMARY: PRIORITISING GI FOR AUCKLAND

The first part of the report established an overall understanding of GI and the range of procedures involved in its implementation. It also outlined where GI fits with related concepts such as low impact design (LID) and green buildings. A key finding is that GI procedures and assets overlap with a range of similar concepts used and employed internationally and in fact those concepts can be broadly categorised as part of GI, ranging from the micro to macro scale. Table 45 indicates types of GI evident at different scales.

The second part of the report identified the functions and benefits of a range of GI assets and processes and issues associated with their implementation and ongoing functioning. A key finding is that all GI assets and procedures provide multiple benefits – not just ecological, but also economic, social and cultural benefits. Careful planning is necessary to reap net benefits whilst minimising issues associated with each procedure/asset. The functions, benefits and issues associated with a range of examples of GI are summarised in Table 46.

The third part of the report reviewed GI best practice from international case studies. The review focused on cities that have implemented GI strategies to overcome current challenges, such as stormwater management, as well as cities that have developed plans for mitigating or adapting to future changes associated with growing populations and climate change. Since each city has its own set of context-dependent issues to address (e.g. Brisbane and London are susceptible to flooding given that they are located on floodplains), a prudent approach is to draw from a raft of available GI assets and strategies. This diversity may help to protect ecosystem services and reduce the severity and cumulative impact of densely populated built environments. Some of the most notable projects are summarised in Table 47, with data provided on costs and quantified benefits.

Table 45 Green Infrastructure indicative of different scales

 Waitakere Council living roof (Waitakere City Council, 2011)	 Tree lined Symonds Street, Auckland City	 Albert Park, Auckland City	 Cascade Kauri Park (RFBPSNZ, n.d.)	 Waiatarua Reserve (Auckland Council, 2012g)	 Whatipu (Auckland Council, 2010)
Living roofs Rain gardens	Green streets	Urban forests ranging from street trees to urban parks	Conservation corridors	Nature reserves	Wetlands (constructed and natural), rivers, lakes
Permeable paving, street trees					
Green transport: Cycle lanes 					

Local **Regional**

Micro → **Macro**

Table 46 GI assets and practices: functions, benefits and issues

	GI function	Benefits	Issues
Regional	Nature reserves (Sylwester, 2009 and Forest Research, 2010).	• Protection of biodiversity; • Carbon sequestration – forests acting as carbon sinks; • Opportunity for recreation, education, scientific research; • Opportunities for tourism; • Ecosystem services; • Mitigation of climate change impacts; • Provision of flood protection; • Replenishment of water catchments; • Stops avalanches in polar regions; • Preservation of a country's heritage.	• Potential for human-wildlife conflict; • Poaching; • Invasive species.
	Wetlands, rivers	• Protection of biodiversity; • Opportunity for recreation, education, scientific research; • Opportunities for tourism; • Ecosystem services – provision of water, food; • Flood control mechanisms; • Climate regulation; • Water regulation; • Erosion regulation; • Soil formation and nutrient cycling; • Replenishment of water catchments; • Transport; • Aesthetic, cultural and spiritual value.	• Potential for human-wildlife conflict; • Water pollution; • Pest species; • Flooding, if not managed.
	Conservation corridor	• Protect threatened species and biodiversity; • Assisting the movement of species (migratory) between habitats according to lifecycles and dispersal of species; • Acts as greenbelts and buffers; • Allows colonisation of new sites and spread of biodiversity; • Allows wildlife to leave unsuitable sites; • Enhances water resource management and quality protection; • Reduces risk of flooding and allows groundwater recharge; • Allows recreation, wildlife watching, hiking; • Engages community and cultural cohesion; • Acts as windbreaks and thus reduces soil erosion and resists desertification; • Economic benefits via environmental services, increased crop yields, increased crop quality, increased livestock production, improved livestock health, reduced energy consumption, increased property values and recreation revenues.	• Possible spread of pests; • Improper design can lead to fragmentation and loss of species; • High maintenance costs; • Poor vegetation quality; • Spread of pests but also infiltration of pests into corridors themselves, degrading flora and fauna quality.

Table 46 GI assets and practices: functions, benefits and issues (cont.)

	GI function	Benefits	Issues
Local	Urban parks, urban forests	• Favourable micro-climates; • Reduction of the 'urban heat island' effect; • Space for socialising - Natural beauty and respite from traffic and noise; • Cleaner air – trees and vegetation filtering out pollutants; • Cleaner water, as roots trap silt and contaminants before they flow into local water bodies; • Reduced health costs through opportunities for physical fitness; • Improved learning opportunities from 'outdoor classrooms'; • Increased urban tourism with resulting increased commerce and sales tax revenue; • Increased business vitality based on attraction of good parks; • Biodiversity.	• Possibility of crime in areas of poor visibility • Dangers from getting lost (specially for children) • Diseases (e.g. Lyme's disease) and allergies • Combats heat island effect, though only on micro scale – i.e. effects are not localised to whole city • Pests such as insects, mammals (rats, mice, etc.), birds • Pest plant such as poison ivy • Increasing dust and debris such as leaves which increase costs for cleaning
	Green streets	• Reducing stormwater runoff volume, flow rate and contaminant loads; • Manage stormwater on-site; • Reducing pollution of waterways via detaining and filtering pollutants; • Assist plant growth and biodiversity; • Reduction of heat island effect (large parking complexes).	• May lead to flooding if water table rises during intense storms; • Cost (more expensive); • Issues with clogging with time (can be alleviated with cleaning); • Structural damage due to incorrect sub-base material use; • Applicability; • Maintenance; • Potential issues with ground water contamination is inappropriate designs are used.
	Living roofs	• Reduce or slow down stormwater runoff from urban areas; • Reduce risk of flooding, river/stream bank erosion; • Improve thermal insulation of building and reduce energy costs related to heating and cooling; • Reduce urban heat island effect; • Vegetation can filter air and reduce pollution; • Create habitat for birds, butterflies and insects; • Increase aesthetic appeal on hard built structures; • Noise insulation (Dunnett and Kingsbury, 2004); • Increase property values; • Provides garden space, agriculture; • Increase roof durability from lack of sun exposure; • Fire resistance (Köhler 2003); • Although not very common, enables the use of recycled materials on roof (EFB, 2012).	• Initial cost of development is high; • Potentially reduced aesthetic appeal in dry seasons depending on level of irrigation and type of plants; • Need for irrigation on some installations; • Uncertainty of benefits associated with the lack of complete urban area coverage (i.e. what are the impacts if 100% of roofs are not green?).

Table 46 GI assets and practices: functions, benefits and issues (cont.)

	GI function	Benefits	Issues
Local	Green walls	• Filters out dust and pollution; • Assists insulation; • Provides shading; • Protects wall surfaces from damage from the sun, wind, rain; • Assists in cooling (in hot climates) via evapotranspiration; • Energy savings for cooling; • Potential visual enhancement; • Resting areas for birds, insects and invertebrates; • Dampening of noise; • Allows increased biodiversity and urban agriculture.	• Initial cost of development is high; • Potential issues if decay sets in; • Most effective at cooling in tropical climates; • It may take years for some systems to be established; • Requires maintenance; • Requires irrigation in some climates; • Interfering with light penetration for residents.
Local	Rain gardens and vegetated swales	• Reduce volume of stormwater runoff by water evapotranspiration and infiltration; • Although not designed for flood control, they control hydrologic impacts from the most frequently occurring rainfall events; • Reduce pollution of waterways via detaining and filtering pollutants and reducing total runoff volume discharged to waterways; • May satisfy landscaping requirements in parking lot applications; • Can providegroundwater recharge; • Can improve biodiversity; • Can be aesthetically pleasing; • Cost effective.	• Difficult climatic conditions inhibit plant growth; • Overflow is necessary for larger storm events; • Proper siting requires minimum separation from building foundations and seasonally high groundwater elevation.
Local	Native flora	• Assist in stormwater management; • May not require as much water; • Adapted to survive in local environments; • Contribute to urban biodiversity.	• Maintenance needs apply to all forms of plants.
Local	Wet ponds	• Reduce peak rate of stormwater runoff by water detention; • Pollution control; • Can be aesthetically pleasing; • Can lead to increased property values.	• Limited capacity in highly urbanised areas; • Can be impractical in arid areas; • Can cause stream/river warming due to increased water temperatures; • Can pose as safety hazards if not properly fenced; • Mosquito breeding; • Increase water temperatures; • Sediment saturation leading to leaching of contaminants as system ages.

Table 46 GI assets and practices: functions, benefits and issues (cont.)

	GI function	Benefits	Issues
Local to national	Constructed wetlands	• Provide fish and wildlife habitat; • Opportunity for recreation (e.g. bird watching), education, scientific research; • Flood control mechanisms; • Stormwater treatment; • Wastewater treatment; • Pollution attenuation; • Erosion regulation; • Aesthetic value; • Low-cost, low energy process requiring minimal operational attention.	• Pest species; • Flooding if not designed and maintained appropriately.
	Green transport	• Reduce or slow down stormwater runoff from urban areas into streams, rivers, etc.; • Divert stormwater from sewer system to reduce backups and overwhelming of sewers; • Reduce impervious surfaces to encourage infiltration for groundwater recharge; • Reduction in soil erosion; • Reduce polluted water entering rivers and other waterways; • Reduce demand for pipe systems and costs thereof; • Reduce air pollution from vehicle traffic; • Reduce air temperature; • Improve safety for pedestrians and cyclers; • Aesthetic enhancement of streets and motorways; • Enhanced pedestrian experience; • Encouragement of green transport (cycling) and walking; • Safety for biodiversity; • Increase in urban green space and wildlife habitat; • Enhance neighbourhood liveability; • Increase community and property values; • If narrowing of streets is considered, safety benefits due to reduced speeds and reduced vehicle accidents; • Reduced commuter stress; • Increased environmental awareness.	• Initial cost of development is high; • Potential for biodiversity loss due to increased access to roads; • Safety concerns when sharing roads with automobile traffic (cycling).

Table 47 Summary of benefits and costs for internationally based GI case studies

	Project Description	Benefits (US$)	Costs (US$)
Chicago	Fed Ex Cargo Sort Building (ASLA, 2012d) – living roof	• 12 jobs created; • 90% of stormwater detained for 3 hours; • No irrigation needed for plants; • Air quality control.	$1-5million; $420,000 for components; $220,000 for drainage aggregate; $800,000 for labour; $1 million for sedum mat
Chicago	City of Chicago's City Hall Rooftop Garden – 1,858 m^2 (20,000 ft^2) garden.	• Reducing urban heat island effect – on average, 7^0 cooler than surrounding roofs. In summer almost 30^0 cooler (City of Chicago, 2012); • Stormwater management –75% of a 2.5 cm rainfall before there is stormwater runoff into the sewers (greenroofs.com, 2010); • Biodiversity consisting of 20,000 plants of more than 150 species; • Saves $5,000 a year on utility bills (including energy costs of US$3,600 /year, amounting to a savings of 9272 kWh/year) – roof exhibits superior insulation properties, requiring as much as 30% less from City Hall's heating and air conditioning systems over the last four years (Clean Energy Awards, 2012).	$2.5 million.
Chicago	Chicago's urban forest (Nowak et al., 2010)	3.59 million trees store approximately 716,000 tons of carbon/year (value of $14.8 million/year) removing approximately 25,200 tonnes of carbon/year (sequestration) (value of $521,000/year) and 888 tonnes of air pollution/year (value of $6.4 million). Additionally, annual residential energy cost reductions of $360,000/year are gained from trees in Chicago.	Chicago spends $8-$10 million annually to plant 4,000 to 6,000 trees (NRDC, 2006).
Philadelphia	Heron Park (ASLA, 2012g) consisting of bioretention, rain garden, bioswale, porous pavement and asphalt, native trees.	• Retention of stormwater; • Increased permeability due to reduction of impermeable surface; • Creation of green space; • Increased biodiversity.	$100,000 - $500,000.
Philadelphia	Waterview Recreation center (ASLA, 2012h) consisting of porous concrete sidewalk, planters, etc.	Collection of runoff from street with associated benefits including bioretention and water quality management 0.31 acre-inches (31.8 m^3).	$100,000 - $500,000

Table 47 Summary: Benefits and costs for internationally based GI case studies (cont.)

	Project Description	Benefits (US$)	Costs (US$)
Philadelphia	'Green Cities Clean Waters' Plan (Philadelphia Water Department, 2011) expected to transform over 4,000 acres (34%) of impervious areas within the City's Combined Sewer System to green space over the next 20 years through the use of GI.	• Reducing overflows in their CSO system; • Heat Stress Mortality Reduction (35%); • Recreation (22%); • Property Value Added (18%); • Water Quality and Habitat (14.5%); • Air Quality (4.6%); • Avoided Social Costs from Green Jobs (3.7%); • Energy Savings (1.0%); • Carbon Footprint Reduction (0.6%); • Reduction in Construction-Related Disruptions (0.2%); The above would lead to value of $2.2 billion dollars as opposed to $16 billion via conventional grey infrastructure.	Potentially $1.6 - 2.4 billion dollar: $1.67 billion allocated to green stormwater infrastructure; $345 million allocated to stream corridor restoration and preservation; and $420 million allocated to address wet weather treatment plant upgrades.
	Living roofs total (Planned and Constructed) (Alarcón, 2007).	The annual benefits in energy savings and pollution reduction would be $860,000 if 25% of the properties in a one square-mile area installed living roofs. A net benefit of $640,000 may be accrued.	If 25% of the properties in a one mile^2 area installed living roofs, the cost would be $220,000.
New York	New York City's 2010 Green Infrastructure Plan.	Reduce the city's sewer management costs by $2.4 billion over 20 years (Foster et al., 2011). The plan estimates that every fully vegetated acre of green infrastructure would provide total annual benefits of: • $8,522 in reduced energy demand; • $166 in reduced CO_2 emissions; $1,044 in improved air quality; and • $4,725 in increased property value. It estimates that the city can reduce CSO volumes by 2 billion gallons by 2030, using green practices at a total cost of $1.5 billion less than traditional methods (Foster et al., 2011). Using natural systems in place of traditional sewers has saved taxpayers $80 million in infrastructure costs, raised property values and restored damaged habitats.	GI to reduce stormwater from entering the system from over 10% of available impervious surfaces in combined sewer drainage areas by 2030 is expected to cost a total of $2.4 billion public and private investment over the next 20 years including $1.6 billion in traditional grey infrastructure projects (Cohen, 2011; NYDEC, 2011).

Table 47 Summary: Benefits and costs for internationally based GI case studies (cont.)

	Project Description	Benefits	Costs (US$)
Copenhagen	Cycling lanes (City of Copenhagen, 2012).	• Healthier citizens reduce health care costs at an estimated rate of US$1 per km cycled; • Cycling provides a low-cost form of transport and by reducing journey times and congestion, increases economic productivity; • Reduced noise, air pollution and CO_2 emissions (90,000 tonne reduction annually).	It costs approximately US$1.3 million (DKK 8 million) to create 1km of cycle track and a further $82,125 (DKK 500,000) to mark 1km of cycle lanes. As a comparison, it costs $0.16 billion (DKK 1 billion) to create 1km of metro and $11.5-16 million (DKK 70-100 million) for 1km of wide motorway (City of Copenhagen, 2012). (City of Copenhagen, 2012).
Stockholm	Hammarby Sjöstad	Energy savings – Sweden's average annual energy used per hour is 200kwhr/m^2; Hammarby aims for a rate of 100 kwhr/m^2; According to Suzuki et al. (2010) preliminary evaluations for ELP (Brick, 2008) show: • 30 % reduction in non-renewable energy use (NRE); • 41%reduction in water use; • 29% reduction in global warming potential (GWP); • 41% reduction in photochemical ozone creation production (POCP); • 36% reduction in acidification potential (AP); • 68% reduction in eutrophication potential (EP); and • 33% reduction in radioactive waste (RW). CO_2 emissions per apartment from personal transport by car are more than 50% lower in Hammarby Sjöstad than in the reference district. These savings alone would yield a reduction of approximately 2,373 tonnes of CO_2/year (Brick, 2008).	According to Suzuki et al. (2010), the programme lasted from 1998 to 2002 and allocated US$0.89 billion (SKr 6.2 billion = €671 million) to 211 local investment programmes involving 1,814 projects in 161 municipalities. This national investment leveraged $3.9 billion (SKr 27.3 billion = almost €3 billion) from municipalities, businesses and other organizations. Of this amount, $3 billion (SKr 21 billion = about €2.3 billion) were investments directly related to sustainability and the environment. It has been estimated that 20,000 full-time short-term or permanent jobs were created (Swedish EPA and IEH, 2004).
London	The East London Green Grid (ELGG) identified around 300 projects with a total implementation value of US$341million (£220million).	• Connection and provision of open space for formal and informal recreational uses; • Promote healthy living via provision of areas for exercise; • Cultural and aesthetic value of surroundings increased; • Climate change adaptation; • Reduce flood risk; • Enhance surface water management; • Habitat for biodiversity.	Design for London and the LDA have provided US$ 3.8 million (£2.4 million revenue funding for project development and worked with partners have been successful in securing $170 million (£110 million) to deliver physical projects across East London.

Table 47 Summary: Benefits and costs for internationally based GI case studies (cont.)

	Project Description	Benefits	Costs (US$)
London	Olympic parklands	Enhanced community involvement; Retain and restore natural environment of the Gateway's landscapes as well as the promotion of heritage; 'Improve 400 ha of green space and 5.2 ha of public spaces, 35.4 km of foot and cycle routes including 14.9 km of routes to the Thames waterfront. 10.9 km of watercourses will be improved and restored, enhancing habitats and reducing flood risk for 1,070 properties. The programme will enhance the quality of life of the 118,700 residents who live within 300 m of the projects and a further 298,000 living within 1km' (Design for London, n.d).	$54 million (£35 million) including $15.5 million (£10 million) capital funding toward five projects.
	Eastern Curve, Dalston, London (Landscape Institute, 2011) – restoration of 0.25 hectares former railway land used as unofficial landfill site.	Trees planting leading to shade, cooling and improvements to air quality, offsetting pollution associated with traffic; Vegetable and herb growing areas for food production as well as promotion of horticultural skill development; Reconnecting local people with their natural environment.	US$310,188 (£200,000)
	Greening for Growth in Victoria, London (Landscape Institute, 2011; Land Use Consultants and Green Roof Consultancy, 2010) – embed natural environment into business area.	Potential for 1.25 ha of new terrestrial green infrastructure, 1.7 hectares of enhancements to existing green infrastructure and suitable space for 25 ha of living roofs; Solve surface water flooding issues of the area – the 25 hectares of living roofs is expected to assist with 80,000 m^3 of rain water each year: Extensive living roof will attenuate between 45-55% of annual rainfall; A semi-intensive living roof will attenuate between 60-65% of annual rainfall; An intensive living roof will attenuate between 90-100% of annual rainfall.	Delivery of living roofs is expected to cost approximately US$78-233/$m^2$ (£50 - £150/m^2), plus cost of structural surveys, design advice and construction
	Tree Lined Streets (Greater London Authority, 2008) – consists of plans to plant over 1,139 new trees with the aim of forming a network of green streets (with existing tree lined streets and parks) so as to provide green space for pedestrians and cyclists.	• Upgrade to safety of children • Aesthetic improvement and community engagement; • Enhancement of existing green space and connection to water; • Increased connectivity to parks; • Carbon sink via trees; • Water management and runoff control; • Pollution control; • Enhanced aesthetic appeal for pedestrians and cyclists – improved health as a result.	US$3.9 million (£2,500,000); Maintenance of $271,000 (£175,000) per year for the first year, followed by a lifelong increased maintenance of $109,000 (£70,000).

Table 47 Summary: Benefits and costs for internationally based GI case studies (cont.)

	Project Description	Benefits	Costs (US$)
Singapore	Braddell Road Campus – Zero Energy Building (4,500 m^2 in area) (Yudelson Associates, 2011).	• Photovoltaic panels for the purpose of energy generation and sun shading; • Passive solutions for cooling; • Minimising heat transmittance; • Daylighting; • Natural ventilation.	Cost: US$8.6 million; $178/sq.ft. (S$11 million, S$227/$ft^2$).
Curitiba	Transport – Rehabilitation of the Green Line (highway linking eastern and western Curitiba; Development of metro.	• 4 new exclusive bus lanes and three lanes for private vehicles in each direction helping to cut down on commuting times and encourage use of public transport; • Half the busses on the line are driven by soybean based biofuel; • Expected to allow 500,000 commuters to travel between 22 metro stations.	Metro: US$1.2 billion
	Sanitation Program - From River to River – 2018.	Improving sanitation and drainage and the quality of the state's water basins.	US$585 million
Vancouver	Crown Street redevelopment (NRDC, 2009) consisting of reduction of street width and development of swales for infiltration	Retention of 90% of annual rainfall volume using swales with the remaining 10% treated via vegetated swales prior to discharge.	$707,000 (expensive than conventional means of managing stormwater due to additional design consultation necessary as this was a brand new venture – future developments may not incur as high a cost.
	The Country Lane Program (NRDC, 2009) consisting of the replacement of impervious alleys and lanes with a permeable alternative as well as infiltration bulges	• Onsite infiltration of stormwater (structural grass and pavement made of permeable material; • Improved pedestrian paths; • Improved water quality and increased infiltration; • Improved wildlife habitat; • Reduction in the urban heat-island effect; • Reduction in peak flows in streams and rivers; • Increase of base flows in streams and rivers; • Improved traffic calming measures; • Aesthetic 'liveable' improvements.	$233/m (more expensive than conventional paving).

Table 47 Summary: Benefits and costs for internationally based GI case studies (cont.)

	Project Description	Benefits	Costs (US$)
Vancouver	Vancouver's living roofs – consisting of over 30 projects, one of which is the Vancouver Public Library (ASLA, 2012m) living roof with 14 inches (35.6 cm) of growing media spanning 934 m^3 (33,000 ft^3).	Controls runoff via retention: • 48% reduction in stormwater volume of the roof as compared to conventional roof (analysis over 8 months); • Peak stormwater flows reduced between 5% and 30% during wet winter months; peak flows were reduced by 80% in summer; • Based on data from Environment Canada, a grass roof with 2,000 m^2 of unmown grass could cleanse 4,000 kg of dirt from the air per year (2 kg/m^2 of roof).	$100,000 - $500,000
Vancouver	Vancouver gas collection and utilisation project (CSCD, 2004).	Capture of greenhouse gas emissions.	$10 million, invested by Maxim Power Corp.
Brisbane	Mount Gravatt rooftop farm – organic rooftop hydroponics and aquaculture (Nowak, 2004).	• After 17 months, the farm is expected to provide returns on invested capital of approximately 20% per year; • Provide jobs; • Other benefits not mentioned by Nowak (2004) could include those that are provided by conventional living roofs such as stormwater management, reduction in ambient temperature, etc.	US$217,000 (A$212,455)
Brisbane	Brisbane City Hall rain garden, bioswale and downspout removal (ASLA, 2012n).	• Aesthetic landscape; • Runoff management via infiltration/bioinfiltration; • Pollution removal.	$100,000 - $500,000

Whilst a vast amount of research has been undertaken on GI, research gaps remain in the quantification and comparison of GI with grey infrastructure. This gap may be attributed to the slow implementation of GI strategies, which often have high start-up costs. Furthermore, cost-benefit analysis of GI has proven difficult, as GI provides multiple benefits that may not be easily defined or quantified, whereas grey infrastructure tends to provide a specific, defined function and thus well-defined benefits. The literature illustrates that GI strategies are effective when compared with conventional infrastructure and techniques. Naturally there is variability in effectiveness, due to differences in site and design, the scale and size of the strategy implemented, site variation in terms of geography and climate and maintenance efforts. Overall, the case studies demonstrate how cities have implemented GI for multi-functionality, often providing solutions to global issues (such as reducing greenhouse gas emissions) while addressing local issues (such as pollution mitigation or prevention). There is increasing investment in GI worldwide. The importance of connectivity is prevalent throughout the case studies and connecting infrastructure by green transport mechanisms is likely to be of significant overall benefit for urban residents.

The final section of the report identified examples of and opportunities for implementing GI in Auckland. Auckland faces numerous challenges with respect to the quality and future supply of water resources, preserving biodiversity and enhancing nature in the urban environment, improving air quality, providing for transport and energy needs. While traditional grey infrastructure can be implemented to address some of these challenges, it can also have the effect of shifting the problem or creating new problems that then require more infrastructural investment to solve. Auckland Council's recognition of the need for enhancement in order to fulfil the vision of becoming the most liveable city in the world may pave the way to transforming Auckland into an eco-city. One of the ways in which this may be achieved is through the implementation of GI. Examples of the potential benefits of the use of GI for Auckland are summarised in Table 48.

Table 48 Potential GI benefits for Auckland

	GI	Potential GI solutions to Auckland's issues
Regional	Nature reserves Wetlands, rivers Conservation corridor	According to the reviewed literature and various case studies, GI assets such as nature reserves, wetland, rivers and conservation corridors are able to provide the following services to Auckland: • Temperature regulation (cooling in summer); • Stormwater management; • Catchment renewal; and • Pollution detention and treatment. Considering the macro scale of nature reserves, wetlands, rivers and conservation corridors, these GI assets would need to be considered in an integrated form. Additionally, considering the high levels of threats to biodiversity in the region, the protection and enhancement of these assets can be considered a priority. Without these, Auckland will be deprived of significant ecosystem serves include recharging of catchments, flood protection, regulation of temperatures and pollution control for air, water and land. Further decline in quality of GI assets are likely to pose greater risks to the resilience of the Auckland region, especially when taking into account changes due to climate change. Thus protection and restoration of these assets is crucial to the future of Auckland's liveability.
	Constructed wetlands	The literature review leads to the conclusion that constructed wetlands can provide numerous benefits (when designed appropriately). The benefits include the potential to offset the loss of natural wetlands, provision of cost effective treatment for wastewater and stormwater, provision of habitat for fauna and fauna hence encouraging wildlife, potential for recreation.
Local	Urban parks, urban forests	Urban parks can be considered as extensions of the regional GI where natural habitat are preserved but with the goal of providing green space for urban communities. Enhancement of human wellbeing via provision of space for recreational activity and exercise are evident throughout the literature where close proximity to parks that are well maintained and attractive may encourage more activity. In addition to the potential gains in human well-being, there is the potential for biodiversity and provision of ecosystem services, provided they are designed for.

Table 48 Potential GI benefits for Auckland (cont.)

GI	Potential GI solutions to Auckland's issues
Green transport: green streets, green alleys, permeable pavement and green modes of transport	Considering the extent of current impermeable surfaces such as roads, streets car parks and pavements, permeable pavement offers some solutions to reduce peak volume, retain some stormwater during precipitation events, delay stormwater runoff and treat water pollutants. Permeable paving may also be of use for catchment renewal as water is retained rather than being piped to outlets (rivers) where they cause issues due to increased temperature, pollution, sediment, etc. Permeable surfaces have shown to be effective for stormwater management in case study cities although issues such as declining permeability and design considerations exist. Additionally, careful siting is necessary in order to prevent ground water contamination. Greening of streets should also include enhancement of road and rail verges with multiple functions (biodiversity, stormwater management) in order to reap multiple benefits. Shifting modes of transport to more benign modes such as walking and cycling has numerous benefits as outlined in the review and case studies.
Living roofs	Living roofs may be utilised for cooling as well as for insulation. For example, cities such as Singapore use living roofs (roof gardens) both as living space as well as mechanisms to regulate temperature and reduce air and water pollution. Examples of benefits include: Extending the life of the roof via protection from UV and elements; Delay and reduce stormwater runoff; Improve thermal performance of the roof; Provide habitat for birds and insects; Absorb carbon dioxide and reduce greenhouse gases; Filter dust and pollutants via plants on the roof; Improve acoustic performance by reducing noise; Aesthetics – depends on the type of plants and their water requirements; Save/reduce energy costs; Filtering dust and pollutants from air passing through the plants; Extensive living roofs are recommended for Auckland over intensive types due to reduced cost of additional structural support.
Green walls	Research from Singapore found that when completely covered by vegetation, a 74% reduction in energy for cooling was achieved. With windows, they found a 10% reduction in energy for cooling. Therefore, living walls could serve to reduce heat island effect and provide insulation when designed appropriately. When installed outside, they can provide space for food production and attract wildlife. Research for New Zealand, especially considering aspects such as heating requirements in winter, are necessary in order to determine applicability for Auckland.
Rain gardens and vegetated swales – bioswales, grassed swales	This approach would be beneficial for enhancing streetscapes and managing stormwater runoff due to impermeable surfaces. Quantified benefits include the reduction of total suspended solids (TSS) and other pollutants (with the exception of Cu), retention of stormwater and thus reduced peak flows and catchment renewal. Bioswales, much like rain gardens, are able to reduce peak flow, reduce runoff and filter certain types of pollution. Swales were found to be more effective for frequently occurring rainfall events where peak flow reduction was inversely proportional to the size of the rainfall event.

Table 48 Potential GI benefits for Auckland (cont.)

	GI	Potential GI solutions to Auckland's issues
Local to national	Dry and wet ponds	Considering the potential for warming, these ponds may lead to spread of pests such as mosquitoes and thus encourage vector borne diseases in the region. Ponds should almost always be the last choice due to their limited protection function.
	Renewable energy	Decentralised energy, local co-generation, micro-generation and distributed energy systems allowing residents to harness renewable energy through wind and solar technologies is possible though current technology is current not very efficient and life cycle costs of the technology may outweigh the benefits.
	Green transport	See above for 'Green transport: green streets and green modes of transport'.

GI practices may be prioritised in a number of ways:

- According to costs and the benefits illustrated by case study cities;
- Ease of implementation – retrofitting existing infrastructure with minimum cost or new developments; or
- Practicality for Auckland's requirements, so as to enable optimised use for the city's unique conditions (potentially a reflection of the research conducted for Auckland so far).

From the GI assets and procedures given in the table above, the following have been thoroughly investigated in research undertaken in New Zealand:

- Permeable paving;
- Living roofs; and
- Rain gardens and grassed swales.

While the GI practices outlined above provide multiple purposes, their primary purpose is stormwater management. The case study cities reviewed in Chapter 3 illustrate a wider scope of GI practices for varying goals ranging from stormwater management, reducing urban heat island effect, mitigating climate change and ameliorating pollution. For example, North American cities such as Philadelphia use GI primarily for stormwater management given their existing infrastructural challenges pertaining to combined sewer overflow (CSO) whereas European cities place emphasis on climate change and pollution amelioration. Therefore, the scope of potential GI for Auckland needs to be based on implementing technologies and practices that have a high potential for providing net benefits. GI assets such as parks, reserves and corridors are significant for Auckland although current research does not fully account for all the benefits these assets provide. For example, benefits to society, such as the aesthetic value of nature, are typically difficult to quantify. Despite the level of research available, measurability of benefits could be improved via more practical research. An example is Nowak's (2007a; 2007b; 2010) research on urban forests in American cities, which uses the UFORE model to illustrate the net benefits of urban forests for carbon storage, carbon sequestration and pollution control.

The international case studies and the research projects conducted in Auckland show that a number of GI assets and strategies are often implemented in tandem. A local example of this is the Talbot Park project, where different stormwater management methods are being used together. Future projects should consider multiple goals so as to provide holistic solutions to the issues. In addition to planning GI within cities, it may be beneficial to include the bigger picture and plan GI for entire regions, as Europe appears to be doing. This would enable localised improvement whilst enhancing connectivity, which is especially useful when considering biodiversity (animal and plant species need large spaces for habitat and migration). Overall, Auckland can utilise the substantial body of literature and knowledge gained from the work done in other cities; however, caution must be used, as the quantified benefits from other cities may not necessarily be transferable to the New Zealand context.

6. References

ABS (2011) *Population Growth: Past, present and future.* Australian Bureau of Statistics. [Online]. Available: http://www.ausstats.abs.gov.au/ausstats/subscriber.nsf/LookupAttach/4102.0Publication30.06.102/$File/41020_PopulationGrowth.pdf.

AEA Technology (2002) *Modelling of Atmospheric Ozone Formation.* Report produced for the Department for Environment, Food and Rural Affairs. Defra, London.

Agudelo, R., Penuela, G., Aguirre, N., Moratod, J., Jaramill, M.L. (2010) Simultaneous removal of chlorpyrifos and dissolved organic carbon using horizontal sub-surface flow pilot wetlands. *Ecological Engineering*, 36: 1401-1408.

Ahern, J. (1995) Greenways as a planning strategy. *Landscape and Urban Planning*, 33 (1-3): 131-155. [Online]. Available: http://www.carmelacanzonieri.com/3740/readings/Greenways/greenways%20as%20planning%20strategy.pdf.

AIA (2011) *Response to the 2010/2011 Queensland flooding*, Commission of Inquiry order No. 1. Australian Institute Of Architects.

Åkerlund, U. (2011) Stockholm's Green Wedges – Concepts, learning and collaboration on urban and peri-urban forestry. Experience paper for *EUFAP Workshop on Urban and Peri-Urban Forestry*. 28 January 2011, Brussels, Belgium. [Online]. Available: http://ec.europa.eu/agriculture/fore/events/28-01-2011/akerlund_en.pdf.

Aldous, D.E. (2010) Greening South East Asian Capital Cities. *22nd International Federation of Parks and Recreation Administration (IFPRA) World Congress*. 15-18 November 2010, Hong Kong.

Alexandri, E. (2005) *Investigations into Mitigating the Heat Island Effect through Green Roofs and Green Walls.* PhD dissertation, Welsh School of Architecture, Cardiff University, Wales.

Alexandri, E. and Jones, P. (2008) Temperature decreases in an urban canyon due to green walls and green roofs in diverse climates. *Building and Environment*, 43(4): 480-493.

American Planning Association (2006) *Planning and Urban Design Standards.* Hoboken, NJ: John Wily and Sons.

Andam, K.S., Ferraro, P.J., Sims, K.R.E., Healy, A., Holland, M.B. (2010) Protected areas reduced poverty in Costa Rica and Thailand. *Proceedings of the National Academy of Sciences of the United States of America*, 107(22): 9996-10001.

Anderson, A. (2011) *Hydrologic Evaluation of Established Rain Gardens in Lincoln, Nebraska, Using a Storm Runoff Simulator.* Environmental Engineering Theses and Graduate Student Research Paper 5. [Online]. Available: http://digitalcommons.unl.edu/envengdiss/5.

Anderson, G.S. and Danielson, B.J. (1997) The effects of landscape composition and physiognomy on metapopulation size: The role of corridors. *Landscape Ecology*, 12: 261-271.

Ando, A., Camm, J., Polasky, S., Solow, A. (1998) Species distributions, land values and efficient conservation. *Science*, 279(5359): 2126-2128.

Andrews, J. (1993) The reality and management of wildlife corridors. *British Wildlife*, 5: 1-7.

Aquitaine Region (2011) *Reverse: European Project to Preserve Biodiversity.* Lead partner of the *Reverse* project: Conseil Régional Aquitaine, Bordeaux, France. [Online]. Available: http://reverse.aquitaine.eu/-4-project-description-.

Arkell, B.P. and Darch, G.J.C. (2006) Impact of climate change on London's transport network. *Proceedings of the Institution of Civil Engineers: Municipal Engineer*, 159(4): 231-237.

ASLA (2011) *Stormwater Case Studies*. American Society of Landscape Architects. [Online]. Available: http://www.asla.org/ContentDetail.aspx?id=31301.

ASLA (2012a) *Stormwater Case Studies by State.* American Society of Landscape Architects. [Online]. Available: http://www.asla.org/stormwatercasestudies.aspx#illinois.

ASLA (2012b) *Green infrastructure and stormwater management case study: Ball Horticulture Corporate Campus.* American Society of Landscape Architects. [Online]. Available: http://www.asla.org/uploadedFiles/CMS/Advocacy/Federal_Government_Affairs/Stormwater_Case_Studies/Stormwater%20Case%20239%20Ball%20Horticulture%20Corporate%20Campus,%20West%20Chicago,%20IL.pdf.

ASLA (2012c) *Green infrastructure and stormwater management case study: Cermak Road Sustainable Streetscape.* American Society of Landscape Architects. [Online]. Available: http://www.asla.org/uploadedFiles/CMS/Advocacy/Federal_Government_Affairs/Stormwater_Case_Studies/Stormwater%20Case%20155%20Cermak%20Road%20Sustainable%20Streetscape,%20Chicago,%20IL.pdf.

ASLA (2012d) *Green infrastructure and stormwater management case study: Fed Ex Cargo Sort Building.* American Society of Landscape Architects. [Online]. Available: http://www.asla.org/uploadedFiles/CMS/Advocacy/Federal_Government_Affairs/Stormwater_Case_Studies/Stormwater%20Case%20432%20Fed%20Ex%20Cargo%20Sort%20Building,%20Chicago,%20IL.pdf.

ASLA (2012e) *Green infrastructure and stormwater management case study: Cliveden Park.* American Society of Landscape Architects. [Online]. Available: http://www.asla.org/uploadedFiles/CMS/Advocacy/Federal_Government_Affairs

/Stormwater_Case_Studies/Stormwater%20Case%20005%20Cliveden%20Park,%20Philadelphia,%20PA.pdf.

ASLA (2012f) *Green infrastructure and stormwater management case study: Columbus Square Park.* American Society of Landscape Architects. [Online]. Available: http://www.asla.org/uploadedFiles/CMS/Advocacy/Federal_Government_Affairs/Stormwater_Case_Studies/Stormwater%20Case%20466%20Columbus%20Square,%20Philadelphia,%20PA.pdf.

ASLA (2012g) *Green infrastructure and stormwater management case study: Heron park.* American Society of Landscape Architects. [Online]. Available: http://www.asla.org/uploadedFiles/CMS/Advocacy/Federal_Government_Affairs/Stormwater_Case_Studies/Stormwater%20Case%20448%20Heron%20Park,%20Philadelphia,%20PA.pdf.

ASLA (2012h) *Green infrastructure and stormwater management case study: Waterview Recreation center.* American Society of Landscape Architects. [Online]. Available: http://www.asla.org/uploadedFiles/CMS/Advocacy/Federal_Government_Affairs/Stormwater_Case_Studies/Stormwater%20Case%20473%20Waterview%20Recreation%20Center%20Philadelphia%20PA.pdf.

ASLA (2012i) *Green infrastructure and stormwater management case study: 5 Boro Green Roof.* American Society of Landscape Architects. [Online]. Available: http://asla.org/uploadedFiles/CMS/Advocacy/Federal_Government_Affairs/Stormwater_Case_Studies/Stormwater%20Case%20129%205-Boro%20Green%20Roof,%20New%20York%20City,%20NY.pdf.

ASLA (2012j) *Green infrastructure and stormwater management case study: Bronx River Floodplain.* [Online]. Available: http://asla.org/uploadedFiles/CMS/Advocacy/Federal_Government_Affairs/Stormwater_Case_Studies/Stormwater%20Case%20082%20Bronx%20River%20Floodplain,%20New%20York%20City,%20NY.pdf.

ASLA (2012k) *Green infrastructure and stormwater management case study: Queens Botanical Garden Visitor and Administration Center.* [Online]. Available: http://asla.org/uploadedFiles/CMS/Advocacy/Federal_Government_Affairs/Stormwater_Case_Studies/Stormwater%20Case%20185%20Queens%20Botanical%20Garden%20Visitor%20and%20Administration%20Center,%20New%20York%20City,%20NY.pdf.

ASLA (2012l) *Green infrastructure and stormwater management case study: Gowanus Canal Pilot Streetend Sponge Park.* [Online]. Available: http://asla.org/uploadedFiles/CMS/Advocacy/Federal_Government_Affairs/Stormwater_Case_Studies/Stormwater%20Case%20320%20Gowanus%20Canal%20Pilot%20Streetend%20Sponge%20Park%20TM,%20New%20York,%20NY%281%29.pdf.

ASLA (2012m) *Green infrastructure and stormwater management case study: Vancouver Public library.* American Society of Landscape Architects. [Online]. Available: http://www.asla.org/uploadedFiles/CMS/Advocacy/Federal_Government_Affairs

/Stormwater_Case_Studies/Stormwater%20Case%20004%20Vancouver%20Public%20Library,%20Vancouver,%20Canada.pdf.

ASLA (2012n) *Green infrastructure and stormwater management case study: Brisbane City Hall.* American Society of Landscape Architects. [Online]. Available: http://www.asla.org/uploadedFiles/CMS/Government_Affairs/Stormwater%20Case%20084%20Brisbane%20City%20Hall%20Rain%20Garden,%20Brisbane,%20CA.pdf.

Auckland Council (2003) *Stormwater management devices: Design guidelines manual 2003: Technical Publication 10 – Design guideline manual stormwater treatment devices Chapter 2 – 2003.* [Online]. Available: http://www.aucklandcouncil.govt.nz/EN/planspoliciesprojects/reports/technicalpublications/Pages/technicalpublications1-50.aspx

Auckland City Council (2008) *Our Collective Taonga: Places for People, Places for Nature: A Framework for the Future of Auckland's Open Spaces.* Auckland City Council.

Auckland Council (2010) *Whatipu Scientific Reserve.* [Online]. Available: http://regionalparks.aucklandcouncil.govt.nz/whatipu.

Auckland Council (2011a) *Creating the world's most liveable city.* [Online]. Available: http://www.aucklandcouncil.govt.nz/EN/planspoliciesprojects/plansstrategies/theaucklandplan/Documents/draftaucklandplansummary.pdf.

Auckland Council (2011b) *Scorecard shows Auckland liveability improving.* [Online]. Available: http://www.aucklandcouncil.govt.nz/EN/newseventsculture/OurAuckland/mediareleases/Pages/scorecardaucklandliveability.aspx.

Auckland Council (2011c) *Environment and Sustainability Forum*. [Online]. Available: http://www.aucklandcouncil.govt.nz/SiteCollectionDocuments/aboutcouncil/committees/environmentsustainabilityforum/meetings/environmentsustainabilityfmag20110719.pdf.

Auckland Council (2011d) Infrastructure: Water. *Draft Auckland Plan*. Auckland Council, New Zealand.

Auckland Council (2011e) Infrastructure: Energy. *Draft Auckland Plan*. Auckland Council.

Auckland Council (2011f) Infrastructure: Waste. *Draft Auckland Plan*. Auckland Council.

Auckland Council (2011g) *Project Pipi – A new way to treat wastewater.* [Online]. Available: http://www.waitakere.govt.nz/cnlser/wtr/wstewater.asp#project-pipi.

Auckland Council (2011h) *A quick guide to the draft Auckland Waste Management and Minimisation Plan.* [Online]. Available: http://wasteplan.aucklandcouncil.govt.nz/downloads-cat/.

Auckland Council (2011i) Auckland's transport. Chapter 11, *Draft Auckland Plan*. Auckland Council, New Zealand.

Auckland Council (2011j) *Draft Auckland Council Biodiversity Strategy.* Parks Recreation and Heritage Forum. [Online]. Available: http://www.aucklandcouncil.govt.nz/SiteCollectionDocuments/aboutcouncil/committees/parksrecreationheritageforum/meetings/parksreceratonheritagefmagitem41-7520111018.pdf.

Auckland Council (2011k) *The Auckland Plan Discussion Document: People and Environment.* [Online]. Available: http://www.aucklandcouncil.govt.nz/EN/AboutCouncil/PlansPoliciesPublications/theaucklandplan/Documents/theaucklandplandiscussiondocument.pdf.

Auckland Council (2011l) *State of our Gulf: Tīkapa Moana – Hauraki Gulf: State of the Environment Report.* [Online]. Available: http://www.arc.govt.nz/albany/fms/main/Documents/Environment/Coastal%20and%20marine/hgfstateoftheenvreport2011.pdf.

Auckland Council (2012a) *State of Auckland air quality report card.* [Online]. Available: http://stateofauckland.aucklandcouncil.govt.nz/wp-content/files_mf/state_of_auckland_air.pdf

Auckland Council (2012b) Auckland's transport. Chapter 13, *The Auckland Plan*. [Online]. Available: http://theplan.theaucklandplan.govt.nz/aucklands-transport/.

Auckland Council (2012c) Auckland's environment. Chapter 7, *The Auckland Plan*. [Online]. Available: http://theplan.theaucklandplan.govt.nz/aucklands-environment/#priority-1-value-our-natural-heritage.

Auckland Council (2012d) *Powering Auckland low carbon transformation towards delivering an Auckland energy and climate change mitigation strategy.* Discussion document. [Online]. Available: http://www.aucklandcouncil.govt.nz/EN/planspoliciesprojects/plansstrategies/theaucklandplan/Documents/aucklandslowcarbontransformation.pdf.

Auckland Council (2012e) *Parks in Auckland: Auckland Domain*. [Online]. Available: http://www.aucklandcouncil.govt.nz/EN/parksfacilities/premierparks/Pages/aucklanddomain.aspx.

Auckland Council (2012f) *Our Auckland – March.* [Online]. Available: http://www.aucklandcouncil.govt.nz/SiteCollectionDocuments/ourauckland/magazine/ouraucklandalbany201203.pdf.

Auckland Council (2012g) *Waiatarua Reserve*. [Online]. Available: http://www.aucklandcity.govt.nz/whatson/places/parksonline/detail.asp?pParkId=2235.

Auckland Council (2012h) *Residential activity – Rules: Development controls.* [Online]. Available: http://www.aucklandcity.govt.nz/council/documents/district/part07c.pdf.

Auckland Council (2013a) Map A1: Auckland local board areas. *The Auckland Plan*. Auckland Council. [Online]. Available: http://theplan.theaucklandplan.govt.nz/a-plan-for-all-aucklanders/.

Auckland Council (2013b) *The Auckland Plan*. Auckland Council, Auckland, New Zealand. [Online]. Available: http://theplan.theaucklandplan.govt.nz/.

Auckland Regional Council (2010a) *State of the Auckland Region report 2010: State of the environment and biodiversity and air*. Auckland Regional Council. [Online]. Available: http://www.arc.govt.nz/albany/fms/main/Documents/Plans/Reports/Full%20report%202009/Chapter%204_0%20-%20State%20of%20the%20environment%20and%20bioversity%20overview%20-%20%20and%204_1%20-%20Air.pdf.

Auckland Regional Council (2010b) *Auckland Regional Land Transport Strategy 2010-2040*. Auckland Regional Council. [Online]. Available: http://www.arc.govt.nz/albany/fms/main/Documents/Transport/RLTS/RLTS%202009/Regional%20Land%20Transport%20Strategy%20(RLTS)%202010-2040.pdf.

Auckland Regional Council (2010c) *State of the environment and biodiversity – Terrestrial biodiversity*. Auckland Regional Council. [Online]. Available: http://www.arc.govt.nz/albany/fms/main/Documents/Plans/Reports/Full%20report%202009/Chapter%204_5%20-%20Terrestrial%20biodiversity.pdf.

Auckland Regional Public Health Service (2009) *The Review of National Environmental Standards for Air Quality: Request for Submission.* [Online]. Available: http://www.arphs.govt.nz/Portals/0/About%20us/Submissions/2009%20Submissions/August%202009/20090821_AirQualityRegulationReview.pdf.

Auckland Transport (2011) *June 2011 Statistics Report.* [Online]. Available: http://www.aucklandtransport.govt.nz/about-us/publications/Reports/Documents/AT%20PT%20Statistics%20Report%20June%202011.pdf.

Bachand, P.A.M. and Horne, A.J. (1999) Denitrification in constructed free-water surface wetlands: II. Effects of vegetation and temperature. *Ecological Engineering*, 14(1-2): 17-32.

Banting, D., Doshi, H., Li, J., Missios, P., Au, A., Currie, B.A, Verrati, M. (2005) *Report on the Environmental Benefits and Costs of Green Roof Technology for the City of Toronto.* Prepared for the Toronto City Planning Division and Ontario Centres of Excellence – Earth and Environmental Technologies (OCE-ETech), 31 October 2005. [Online]. Available: http://www.toronto.ca/greenroofs/pdf/executivesummary.pdf.

Baron, J.S., Poff, N.L., Angermeier, P.L., Dahm, C.N., Gleick, P.H., Hairston, N.G., Jackson, R.B., Johnston, C.A., Richter, B.G., Steinman, A.D. (2002) Meeting ecological and societal needs for freshwater. *Ecological Applications,* 12: 1247-1260.

Barrett, M., Limouzin, M., Lawler, D. (2011). Performance Comparison of Biofiltration Designs. *World Environmental and Water Resources Congress 2011*: 395-404.

Barrett, M.E., Walsh, P.M., Malina, J.F. Jr., Charbeneau, R.J. (1998) Performance of vegetative controls for treating highway runoff. *Journal of Environmental Engineering*, 124(11): 1121-1128.

Barrett, M.E. (2005) BMP Performance Comparisons: Examples from the International Stormwater BMP Database, in *World Water Congress 2005*, 15 May 2005, Anchorage, Alaska, USA.

Bartens, J., Day, S.D., Harris, J.R., Dove, J.E., Wynn, T.M. (2008) Can urban tree roots improve infiltration through compacted subsoils for stormwater management? *Journal of Environmental Quality*, 37(6): 2048-2057.

Baumann, I.R. (1986) The Constructural Importance of Climbing Plants. *Anthos*, 1: 22-28.

Bean, E.Z, Hunt, W.F., Bidelspach, D.A, Smith, J. (2004) *Study on the surface infiltration rate of permeable pavements.* [Online]. Available: http://www.bae.ncsu.edu/info/permeable-pavement/icpi.pdf.

Bean, E.Z., Hunt, W.F., Bidelspach, D.A. (2007a) Evaluation of four permeable pavement sites in eastern North Carolina for runoff reduction and water quality impacts.' *Journal of Irrigation and Drainage Engineering,* 133(3): 583-592.

Bean, E.Z., Hunt, W.F., Bidelspach, D.A. (2007b). Field survey of permeable pavement surface infiltration rates. *Journal of Irrigation and Drainage Engineering,* 133(3): 247-255.

Beatley, T. (2009) *Green urbanism down under: Learning from sustainable communities in Australia.* Washington DC: Island Press.

Beck, B. and Crowe, B. (2008) *Climate Change Adaptation.* A report to the Vancouver City Council. [Online]. Available: http://vancouver.ca/sustainability/documents/7193ClimateAdaptationReport27May2008.pdf.

Beier, P. and Noss, R.F. (1998) Do Habitat Corridors Provide Connectivity? *Conservation Biology*, 12: 1241-1252.

Benedict, M.A. and MacMahon, E.T. (2002) Green infrastructure: Smart conservation for the 21st century. *Renewable Resources Journal*, 20(3): 12-17.

Benedict, M.A. and McMahon, E.T. (2006) *Green infrastructure: Linking landscapes and communities.* The Conservation Fund. Washington DC: Island Press.

Bennett, A. (2003) *Linkages in the landscape: The role of corridors and connectivity in wildlife conservation.* IUCN's Forest Conservation Programme. [Online]. Available: http://app.iucn.org/dbtw-wpd/edocs/FR-021.pdf.

Bernatzky, A. (1982) The contribution of trees and green spaces to a town climate. *Energy and Buildings*, 5: 1-10.

Birk, M. and Geller, R. (2005) *Bridging the Gaps: How the Quality and Quantity of a Connected Bikeway Network Correlates with Increasing Bicycle Use.* Paper presented at the Transportation Research Board 2006 Annual Meeting. [Online].

Available: www.onegreencity.com/images/crucial/builditandtheywillcome.pdf. [4 June 2009].

Blackman, D. and Thackray, R. (2007) *The Green Infrastructure of Sustainable Communities.* England's Community Forests. [Online]. Available: www.roomfordesign.co.uk.

Blanc, P. (2002) *Etre Plante à l'Ombre des Forêts Tropicales.* Paris, France: Nathan.

Blunden, M. (2010) Council spends another £130,000 on living wall after the first one died. *London Evening Standard*, 23 April 2010. [Online]. Available: http://www.standard.co.uk/news/council-spends-another-130000-on-living-wall-after-the-first-one-died-6462162.html.

Bolund, P. and Hunhammar, S. (1999) Ecosystem services in urban areas. *Ecological Economics*, 29: 293-301.

Bornkamm, R. (1961) Vegetation und Vegetationsentwicklung auf Kiesdächern. *Vegetatio*, 10: 1-10.

Boving, T.B., Stolt, M.H., Augenstern, J., Brosnan, B. (2008) Potential for localized groundwater contamination in a porous pavement parking lot setting in Rhode Island. *Environmental Geology*, 55(3): 571-582.

Bowler, D., Buyung-Ali, L., Knight, T., Pullin, A. (2010) Urban greening to cool towns and cities: A systematic review of the empirical evidence. *Landscape and Urban Planning*, 97(3): 147-155.

Bracey, S. (2007) *Making Talbot Park a better place to live.* [Online]. Available: http://www.branz.co.nz/cms_show_download.php?id=6d4cefcec4e56872ec3aeefbb568188589e52fb5.

Bracey, S., Scott, K., Simcock, R. (2008) Important lessons applying low-impact urban design: Talbot Park, in *Proceedings of New Zealand Water and Waste Association (NZWWA) Conference*, held in Rotorua, New Zealand, 15-16 May 2008. [Online]. Available: http://www.landcareresearch.co.nz/publications/researchpubs/Bracey_etal_NZWWA_2008.pdf.

Braden, J.B. and Johnston, D.M. (2004) Downstream Economic Benefits from Storm-Water Management. *Journal of Water Resources Planning and Management,* 130(6): 498-505.

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

Brattebo, B.O. and Booth, D.B. (2003) Long-term stormwater quantity and quality performance of permeable pavement systems. *Water Research*, 37(18): 4369-4376.

Brick, K. (2008) *Barriers for Implementation of the Environmental Load Profile and Other LCA-Based Tools.* Licentiate thesis, Royal Institute of Technology, Stockholm, Sweden.

Briffet, C., Sodhi, N., Yuen, B., Kong, L. (2004) Green Corridors and the Quality of Urban Life in Singapore. *Proceedings of the 4th International Urban Wildlife Symposium.* Singapore: 56-63. [Online]. Available: http://ag.arizona.edu/pubs/adjunct/snr0704/snr07041g.pdf.

Brisbane City Council (2010a) *Brisbane's Plan for Action on Climate Change and Energy 2007.* [Online]. Available: http://www.brisbane.qld.gov.au/2010%20Library/2009%20PDF%20and%20Docs/1.About%20Council/1.6%20Council%20vision%20and%20strategies/councilvision_and_strategies_planforactiononclimatechange.pdf.

Brisbane City Council (2010b) *WaterSmart Strategy*. [Online]. Available: http://www.brisbane.qld.gov.au/environment-waste/water/watersmart-strategy/index.htm.

Brisbane City Council (2012) *Brisbane bushland acquisition: Bushland acquired by Brisbane City Council*. [Online]. Availabl: http://www.brisbane.qld.gov.au/environment-waste/natural-environment/bushland-parklands-wetlands/bushland-preservation-levy.

Brix, H. (1994) Use of constructed wetlands in water-pollution control – Historical development, present status and future perspectives. *Water Science and Technology*, 30(8): 209-223.

Brogren, M. and Green, A. (2003) Hammarby Sjöstad – An interdisciplinary case study of the integration of photovoltaics in a new ecologically sustainable residential area in Stockholm. *Solar Energy Materials and Solar Cells*, 75 (3-4): 761-765.

Buehler, R. (2008) *Transport policies, travel behavior and sustainability: A comparison of Germany and the U.S.* PhD dissertation. Rutgers The State University of New Jersey, New Brunswick, United States of America.

Buehler, R. and Pucher, J. (2012) Cycling to work in 90 large American cities: New evidence on the role of bike paths and lanes. *Transportation*, 39(2): 409-432.

Bureau of Public Affairs (2012) *Nature Reserves and Protected Areas.* U.S. Department of State Diplomacy in Action. [Online]. Available: http://www.state.gov/e/oes/env/tenyearframework/141876.htm.

Byrd, H. and Leardini, P. (2011) Green buildings: Issues for New Zealand. *Procedia Engineering*, 21: 481-488.

CABE (2009) *Grey to Green: How we shift funding and skills to green our cities.* Commission for Architecture and the Built Environment (CABE), London. [Online]. Available: http://www.designcouncil.org.uk/Documents/Documents/Publications/CABE/grey-to-green.pdf.

CABE (2011) *Four National Taps.* Commission for Architecture and the Built Environment (CABE), London. [Online]. Available: http://webarchive.nationalarchives.gov.uk/20110118095356/http:/www.cabe.org.uk/sustainable-places/water/examples.

CABE Space (2011a) *Sustainable Places.* Commission for Architecture and the Built Environment (CABE), London. [Online]. Available: http://webarchive.nationalarchives.gov.uk/20110118095356/http://www.cabe.org.uk/sustainable-places.

CABE Space (2011b) *Sustainable Places: Curitiba*. Commission for Architecture and the Built Environment(CABE), London. [Online]. Available: http://webarchive.nationalarchives.gov.uk/20110118095356/http:/www.cabe.org.uk/sustainable-places/examples/curitiba.

CABE Space (2012) *Hammarby Sjöstad, Stockholm, Sweden: Evaluation.* Commission for Architecture and the Built Environment, UK. [Online]. Available: http://webarchive.nationalarchives.gov.uk/20110118095356/http://www.cabe.org.uk/case-studies/hammarby-sjostad/evaluation.

California Stormwater Quality Association (2003) California Stormwater BMP Handbook: New Development and Redevelopment. [Online]. Available: http://www.cabmphandbooks.com/documents/Development/DevelopmentHandbook.pdf.

CarbonZero NZ (2012) FAQ: How much carbon dioxide is sequestered by one tree? [Online]. Available: http://www.carbonzero.co.nz/faq.asp.

Cardiff University (n.d.) *Case Study: Stockholm's Green Infrastructure.* [Online]. Available: http://www.cardiff.ac.uk/archi/programmes/cost8/case/greenblue/stockholmgreen.html.

Carson, T.B., Marasco, D.E., Culligan, P.J., McGillis, W.R. (2013) Hydrological performance of extensive green roofs in New York City: Observations and multi-year modeling of three, full-scale systems. *Environmental Research Letters*, 8(2): 024036 (13pp). [Online]. Available: http://iopscience.iop.org/1748-9326/8/2/024036/pdf/1748-9326_8_2_024036.pdf.

Carswell, F.E. Burrows, L.E., Hall, G.M.J., Mason, N.W.H., Allen R.B. (2012) Carbon and plant diversity gain during 200 years of woody succession in lowland. *New Zealand Journal of Ecology,* 36(2): 191-202.

Carter, T.L. and Rasmussen, T.C. (2006) Hydrologic behavior of vegetated roofs. *Journal of the American Water Resources Association*, 42: 1261-1274.

Caspersen, O., Konijnendijk, C., Olafsson, A. (2006) Green space planning and land use: An assessment of urban regional and green structure planning in Greater Copenhagen. *Danish Journal of Geography*, 106(2): 7-20. [Online]. Available: http://rdgs.dk/djg/pdfs/106/2/02.pdf.

Castleton, H., Stovin, V., Beck, S., Davison, J. (2010) Green roofs: Building energy savings and the potential for retrofit. *Energy and Buildings*, 42: 1582-1591. [Online]. Available: ftp://iristor.vub.ac.be/patio/ARCH/pub/fdescamp/paper/GreenRoofs.pdf.

Cavill, N. and Davis, A. (2007) *Cycling and Health: What's the Evidence?* London, UK: Cycling England: 27 pp. [Online]. Available: http://www.ecf.com/wp-content/uploads/2011/10/Cycling-and-health-Whats-the-evidence.pdf.

CBD (2012a) Case studies on the implementation of the CBD and the 2010 biodiversity target. *Convention on Biological Diversity*. [Online]. Available: http://www.cbd.int/authorities/casestudies.shtml.

CBD (2012b) City of Curitiba, Brazil. *Convention on Biological Diversity*. [Online]. Available: http://www.cbd.int/authorities/casestudy/curitiba.shtml.

CCICED (2010) *Ecosystem services and management strategy in China: Study report for AGM 2010.* Beijing: China Council for International Cooperation on Environment and Development.

Chan, L. and Djoghlaf, A. (2009) Invitation to help compile an index of biodiversity in cities. *Nature*, 460: 33.

Chen, Y. and Whalley, A. (2012) Green Infrastructure: The Effects of Urban Rail Transit on Air Quality. *American Economic Journal: Economic Policy*, 4(1): 58-97.

Chen, Y. and Wong, N.H. (2006) Thermal benefits of city parks, *Energy and Buildings*, 38: 105-120.

Cherkauer, K. and Sinha, T. (2010) Hydrologic Impacts of Projected Future Climate Change in the Lake Michigan Region. *Journal of Great Lakes Research*, 36(2): 33-50.

Chicago Department of Environment (2009) *Chicago's Urban Forest Agenda*. Chicago: City of Chicago. [Online]. Available: http://www.cityofchicago.org/content/dam/city/depts/doe/general/NaturalResourcesAndWaterConservation_PDFs/UrbanForestAgenda/ChicagosUrbanForestAgenda2009.pdf.

Chicago Department of Transportation (2010) *The Chicago Green Alley Handbook: An action guide to create a greener, environmentally sustainable Chicago.* Chicago: City of Chicago. [Online]. Available: http://www.cityofchicago.org/dam/city/depts/cdot/Green_Alley_Handbook_2010.pdf.

Chicago Wilderness (2004) *Chicago Wilderness Green Infrastructure Vision: Final Report.* [Online]. Available: http://www.chicagowilderness.org/files/8513/3020/2252/Green_Infrastructure_Vision_Final_Report.pdf.

Chicago Wilderness (2011) *Chicago Wilderness Climate Action Plan for Nature*. [Online]. Available: http://www.chicagowilderness.org/pdf/Climate_Action_Plan_for_Nature.pdf.

Chicago Wilderness (2012) Chicago Wilderness: Who we are, Chicago Wilderness Magazine Archive, available at: http://www.chicagowilderness.org/who-we-are/

City and County of San Francisco (2009) *City and County of San Francisco 2030 Sewer System Master Plan.* Technical Memorandum No. 802. Green Treatment Plant

Technologies. City and County of San Francisco. USA. [Online]. Available: http://www.sfwater.org/modules/showdocument.aspx?documentid=570.

City of Chicago, (2012) *Chicago's City Hall Rooftop Garden.* [Online]. Available: http://www.cityofchicago.org/city/en/depts/doe/supp_info/chicago_s_city_hallrooftopgarden.html.

City of Copenhagen (2011) *Copenhagen: Solutions for Sustainable Cities.* [Online]. Available: http://www.kk.dk/sitecore/content/Subsites/CityOfCopenhagen/~/media/9933EE8E38A547C7B3A3C52BC4CAD89D.ashx.

City of Copenhagen (2012) *Cycle Statistics*. [Online]. Available: http://www.kk.dk/sitecore/content/Subsites/CityOfCopenhagen/SubsiteFrontpage/LivingInCopenhagen/CityAndTraffic/CityOfCyclists/CycleStatistics.aspx.

City of New York (2006) *New York City Population Projections by Age/Sex and Borough 2000–2030*. [Online]. Available: http://www.nyc.gov/html/dcp/pdf/census/projections_report.pdf.

City of Philadelphia (2007) *Local action plan for climate change*. Prepared by City of Philadelphia, Sustainability Working group. [Online]. Available: http://dvgbc.org/sites/dvgbc.org/files/resources/PhiladelphiaClimateChangeLocalActionPlan2007.pdf.

City of Portland (2012) *Portland Green Streets Policy*. [Online]. Available: http://www.portlandonline.com/BES/index.cfm?c=44407.

City of Stockholm (2007) Adapting to Climate Change in Stockholm, Stockholm's action programme on climate change, Environment and Health Administration. [Online]. Available: http://miljobarometern.stockholm.se/content/docs/gc/1/Adapting%20to%20ClimateChange_Sthlm_english.pdf.

City of Stockholm (2012) *Population*. [Online]. Available: http://international.stockholm.se/Press-and-media/Stockholm-facts/General-facts-and-numbers/Population/.

City of Vancouver (2009) *Standard city improvement*. [Online]. Available: http://vancouver.ca/engsvcs/streets/localimprovements/improvementTypes/curbs/standard.htm.

City of Vancouver (2012a) *Greenest City 2020 Action Plan*. [Online]. Available: http://vancouver.ca/greenestcity/PDF/GC2020ActionPlan.pdf.

City of Vancouver (2012b) *Rain barrel program*. [Online]. Available: http://vancouver.ca/engsvcs/watersewers/water/conservation/programs/rainbarrel.htm.

City-data (2009) *Philadelphia: Geography and Climate*. [Online]. Available: http://www.city-data.com/us-cities/The-Northeast/Philadelphia-Geography-and-Climate.html.

Clark, C., Adriaens, P., Talbot, F.B. (2008) Green roof valuation: A probabilistic economic analysis of environmental benefits. *Environmental Science and Technology*, 42(6): 2155-2161.

Clarke, C.F. (2012a) Evaluation of New Zealand's bicycle helmet law. *The New Zealand Medical Journal*, 125(1349): 1-10.

Clarke, L. (2012b) Assistant Landscape Architect, Parks, Sport and Recreation, *personal communication* (6 July 2012).

Clean Energy Awards (2012) *Green Roofs: Mitigating the Urban Heat Island Effect*. [Online]. Available: http://www.cleanenergyawards.com/top-navigation/nominees-projects/nominee-detail/project/27/.

Clean Water America Alliance (2011) *Barriers and Gateways to Green Infrastructure.* [Online]. Available: http://www.cleanwateramericaalliance.org/pdfs/gireport.pdf.

Clifford, N.J. (2007) River restoration: Paradigms, paradoxes and the urban dimension. *Water Science and Technology: Water Supply*, 7(2): 57-68.

Coffee, J.E., Parzen, J., Wagstaff, M., Lewis, R.S. (2010) Preparing for a changing climate: The Chicago climate action plan's adaptation strategy. *Journal of Great Lakes Research*, 36(SUPPL. 2): 115-117.

Coffman, L.S. (2002) Low Impact Development: Smart Technology for Clean Water - Definitions, Issues, Roadblocks, and Next Steps, in *Urban Drainage 2002: Global Solutions for Urban Drainage*, edited by E.W. Strecker and W.C. Huber. 9th International Conference on Urban Drainage. American Society of Civil Engineers.

Cohen, S. (2011) *New York's Exciting Experiment in Green Infrastructure.* [Online]. Available: http://www.huffingtonpost.com/steven-cohen/new-yorks-exciting-experi_b_1092181.html.

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

Coomes, D.A., Allen, R.B., Scott, N.A., Goulding, C., Beets, P. (2002) Designing Systems to Monitor Carbon Stocks in Forests and Shrublands. *Forest Ecology and Management*, (164): 89-108.

Copenhagen (2011) *Copenhagen Climate Adaptation Plan: Copenhagen carbon neutral by 2025*. [Online]. Available: http://kk.sites.itera.dk/apps/kk_publikationer/pdf/794_kZEjcvbgJt.pdf.

Copenhagen City (2006) *Copenhagen City Statistical ten-year review 2005.* Statistical Office. [Online]. Available: http://www.kk.dk/FaktaOmKommunen/KoebenhavnITalOgOrd/StatistikOmKoebenhavnOgKoebenhavnere/UdgaedePublikationer/BlandedePublikationer/~/media/332C4F5D993F4B64A5054D413EB3C9E7.ashx.

Corrie, C., Talbot, B., Bulkley, J., Adriaens, P. (2005) Optimization of green roofs for air pollution mitigation, in *Proceedings of the Third Annual Greening Rooftops for Sustainable Communities Conference, Awards and Trade Show*. Washington, DC, 4-6 May 2005.

Costanza, R., D'Arge, R., De Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R.V., Paruelo, J., Raskin, R.G., Sutton, P., van den Belt, M. (1997) The value of the world's ecosystem services and natural capital. *Nature*, 387(6630): 253-260.

Crompton, J.L. (2001) The impact of Parks on Property Values: A Review of the Empirical Evidence. *Journal of Leisure Research*, 33(1): 1-31.

CSCD (2004) *Demonstrating the economic benefits of integrated, green infrastructure, Centre for Sustainability Community Development*. [Online]. Available: http://www.fcm.ca/Documents/tools/GMF/Demonstrating_the_Economic_Benefits_of_Integrated_Green_Infrastructure_Final_Report_EN.pdf.

CSI (2008) *Creating a Setting for Investment (CSI).* Project Report. [Online]. Available: http://www.environmentinvestment.com/images/downloads/final_report.pdf.

Currie, B.A. and Bass, B. (2008) Estimates of air pollution mitigation with green plants and green roofs using the UFORE model. *Urban Ecosystems*, 11: 409-422.

Currie, B. and Bass, B. (2010) *Using Green Roofs to Enhance Biodiversity in the City of Toronto.* A Discussion Paper Prepared for Toronto City Planning. [Online]. Available: http://www.toronto.ca/greenroofs/pdf/greenroofs_biodiversity.pdf.

CWGIV (2004) *Chicago Wilderness Green Infrastructure Vision*. Final report. [Online]. Available: http://www.chicagowilderness.org/pdf/Green_Infrastructure_Vision_Final_Report.pdf.

Dadvand, P., de Nazelle, A., Figueras, F., Basagaña, X., Su, J., Amoly, E., Jerrett, M., Vrijheid, M., Sunyer, J., Nieuwenhuijsen, M.J. (2012) Green space, health inequality and pregnancy. *Environment International*, 40(1): 110-115.

Daily, G. (1997) Introduction: What are ecosystem services? in *Nature's Services: Societal dependence on natural ecosystems*, by G.C. Daily. Washington DC: Island Press: 1-10.

Daily, G., ed. (1999) *Nature's Services*. Washington, DC: Island Press.

Davies, C., McGloin, C., MacFarlane, R., Roe, M. (2006) *Green infrastructure planning guide project: Final report.* North East Community Forests (NECF), Annfield Plain, UK. [Online]. Available: http://www.greeninfrastructure.eu/images/GREEN_INFRASTRUCTURE_PLANNING_GUIDE.pdf.

Davies, R., Simcock, R. and Toft, R. (2010) Islands in the sky, urban biodiversity enhancement in New Zealand on indigenous living roof landscapes. *44th Annual Conference of the Architectural Science Association*. ANZAScA 2010, Unitec Institute of Technology, Auckland.

Davies, Z.G. and Pullin, A.S. (2007) Are hedgerows effective corridors between fragments of woodland habitat? An evidence-based approach. *Landscape Ecology,* 22: 333-351.

Davis A.P. (2007) Field performance of bioretention: Water quality. *Environmental Engineering Science*, 24(8): 1048-1064.

Davis, A.P., Hunt, W.F., Traver, R.G. (2009) Bioretention technology: Overview of current practice and future needs. *Journal of Environmental Engineering,* 135(3): 109-117.

Dawson, A., ed. (2009) *Water in Road Structures – Movement, Drainage and Effects*. Nottingham, UK: Springer.

de Vries, S., Verheij, R.A., Groenewegen, P.P., Spreeuwenberg, P. (2003) Natural environments – healthy environments? *Environment and Planning*, 35: 1717-1731.

Dematte, J.E., O'Mara, K., Buescher, J., Whitney, C.G., Forsythe, S., McNamee, T., Adiga, R.B., Ndukwu, M. (1998) Near-fatal heat stroke during the 1995 heat wave in Chicago. *Annals of Internal Medicine,* 129(3): 173-181.

DeNardo, J.C., Jarrett, A.R., Manbeck, H.B., Beattie, D.J., Berghage, R.D. (2005) Stormwater mitigation and surface temperature reduction by green roofs. *Transactions of the American Society of Agricultural Engineers (ASAE)*, 48(4): 1491-1496.

Deng, T. and Nelson, J.D. (2011) Recent developments in bus rapid transit: A review of the literature. *Transport Reviews*, 31(1): 69-96.

DEP (2008) *Assessment and action plan: A report based on the ongoing work of the DEP climate change task force.* The New York City Department of Environmental Protection. [Online]. Available: http://www.nyc.gov/html/dep/pdf/climate/climate_chapter1.pdf.

Department of Statistics, Ministry of Trade and Industry (2010) *Yearbook of Statistics.* Singapore: Government of Singapore.

Deutsch, B., Whitlow, H., Sullivan, M., Savineau, A., Busiek, B. (2007) *The Green Build-out Model: Quantifying the Stormwater Management Benefits of Trees and Green Roofs in Washington, DC.* [Online]. Available: http://www.capitolgreenroofs.com/pdfs/Green_Infrastructure_Report.pdf.

Di, H.F. and Wang, D.N. (1999) Cooling effect of ivy on a wall. *Experimental Heat Transfer*, 12: 235-245.

Dietz, M.E. (2007) Lot impact development practices: A review of current research and recommendations for future directions. *Water Air and Soil Pollution,* 186: 351-363.

Dietz, M.E. and Clausen, J.C. (2005) A field evaluation of rain garden flow and pollutant treatment. *Water, Air and Soil Pollution*, 167: 123-138.

Dietz, M.E. and Clausen, J.C. (2008) Stormwater runoff and export changes with development in a traditional and low impact subdivision. *Journal of Environmental Management*, 87(4): 560-566.

Dill, J. and Gliebe, J. (2008) *Understanding and measuring bicycling behaviour: A focus on travel time and route choice.* Oregon Transportation Research and Education Consortium (OTREC). [Online]. Available: http://www.lulu.com/items/volume_64/5687000/5687029/1/print/OTREC-RR-08-03_Dill_BicyclingBehavior_FinalReport.pdf.

Dill, J. and Voros, K. (2007) Factors Affecting Bicycling Demand: Initial Survey Findings from the Portland, Oregon Region. *Transportation Research Record*, 2031: 9-17.

Dinsdale, S., Pearen, B., Wilson, C. (2006) *Feasibility study for green roof application on Queen's University campus.* Queen's Physical Plant Services, Queen's University, Ontario, Canada: 58pp. [Online]. Available: http://www.queensu.ca/pps/reports/greenroof.pdf.

Dixon, K. and Wolf, K. (2007) Benefits and Risks of Urban Roadside Landscape: Finding a Livable, Balanced Response. Paper presented at the *3rd Urban Street Symposium*. 24-27 June 2007, Seattle, Washington, USA.

Dobbs, C., Escobedo, F., Zipperer, W. (2011) A framework for developing urban forest ecosystem services and goods indicators. *Landscape and Urban Planning*, 99(3-4): 196-206.

Dobson, A.P., Bradshaw, A.D., Baker, A.J.M. (1997a) Hopes for the future: Restoration ecology and conservation biology. *Science*, 277(5325): 515-522.

Dobson, A.P., Rodriguez, J.P., Roberts, W.M., Wilcove, D.S. (1997b) Geographic distribution of endangered species in the United States. *Science,* 275: 550-553.

DOC (2011) *Indicative national conservation priority sites – Auckland Conservancy.* The Department of Conservation, New Zealand. [Online]. Available: http://www.doc.govt.nz/upload/documents/about-doc/role/policies-and-plans/cms/cms-map-auckland.pdf.

Doernach, R. (1979) Uber den Nutzungen von Biotektonischen Grunsystemen. (On the Use of Biotectural Systems). *Garten und Landschaft*, 89(6): 452-457.

Drake, J., Bradford, A., Van Seters, T. (2010) Performance of permeable pavements in cold climate environments. *Low Impact Development 2010: Redefining Water in the City.* Proceedings of the 2010 International Low Impact Development Conference held in San Francisco, California, 11-14 April 2010: 1369-1378.

Dreelin, E.A., Fowler, L., Carroll, C.R. (2006). A test of porous pavement effectiveness on clay soils during natural storm events. *Water Research*, 40(4): 799-805.

Dumbaugh, E. (2006) Design of Safe Urban Roadsides: An Empirical Analysis. *Transportation Research Record*, 1961: 62-74.

Dunnett, N. and Kingsbury, N. (2004) *Planting Green Roofs and Living Walls.* Portland Oregon: Timber Press.

Durhman, A., Rowe, D.B., Rugh, C.L. (2007) Effect of substrate depth on initial growth, coverage and survival of 25 succulent green roof plant taxa. *HortScience*, 42(3): 588-595.

Dvorak, B. and Volder, A. (2010) Green roof vegetation for North American eco-regions: A literature review. *Landscape and Urban Planning*, 96(4): 197-213.

Dzurik, A. and Theriaque, D. (2003) *Water Resources Planning.* Third Edition. Maryland, U.S.: Rowman and Littlefield Publishers Inc.

ECONorthwest (2011) *Green infrastructure economic benefits and financing literature review.* [Online]. Available: http://www.nrdc.org/water/pollution/rooftopsII/files/RooftopstoRivers_appendix.pdf.

EEA (2011) *Green infrastructure and territorial cohesion: The concept of green infrastructure and its integration into policies using monitoring systems*. European Environment Agency. [Online]. Available: http://www.eea.europa.eu/publications/green-infrastructure-and-territorial-cohesion?andutm_campaign=newsletter.2011-12-19.4606149473andutm_medium=emailandutm_source=EEASubscriptions.

EFB (2012) *Environmental advantages.* European Federation of Green Roof Association. [Online]. Available: http://www.efb-greenroof.eu/verband/fachbei/fa01_englisch.html.

EMDA (2008) *Green Infrastructure Programme: Evaluation and Recommendations for Future Developments.* Final report, East Midlands Development Agency, UK. [Online]. Available: http://www.emda.org.uk/uploaddocuments/FINALREPORTGreenInfrastructure.pdf.

Engberg, L.A. and Svane, Ö. (2007) Compromise, failure or necessity – Analysing the brownfield development of hammarby sjöstad, Stockholm, as negotiated sustainability processes in governance networks*.* Paper presented at the International Conference of Sustainable Urban Areas W15–Housing and Urban Sustainability held in Rotterdam, The Netherlands, 25-28 June 2007.

EPA (1995) *Handbook of Constructed Wetlands.* United States Environmental Protection Agency. [Online]. Available: http://www.epa.gov/owow/wetlands/pdf/hand.pdf.

EPA (1999) *Storm Water Technology Fact Sheet Vegetated Swales*. United States Environmental Protection Agency. [Online]. Available: http://water.epa.gov/scitech/wastetech/upload/2002_06_28_mtb_vegswale.pdf.

EPA (2000) *Low Impact Development (LID): A Literature Review.* United States Environmental Protection Agency. [Online]. Available: http://www.lowimpactdevelopment.org/pubs/LID_litreview.pdf.

EPA (2001) *The 'Living Machine' Wastewater Treatment Technology: An Evaluation of Performance and System Cost.* United States Environmental Protection Agency. [Online]. Available:

http://yosemite.epa.gov/water/owrccatalog.nsf/9da204a4b4406ef885256ae0007a79c7/5d2a6584de0e37df85256b06007254a3/$FILE/The%20Living%20Machine%20Wastewater%20Treatment%20Technology.pdf.

EPA (2004) *Best Management Practices (BMP) EPA Guidelines.* Washington, DC: United States Environmental Protection Agency.

EPA (2006) *Green Parking*. United States Environmental Protection Agency. [Online]. Available: http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=factsheet_resultsandview=specificandbmp=89.

EPA (2006) *Performance of Stormwater Retention Ponds and Constructed Wetlands in Reducing Microbial Concentrations*. United States Environmental Protection Agency. [Online]. Available: http://nepis.epa.gov/Adobe/PDF/P10089WM.pdf.

EPA (2008) R*educing Urban Heat Islands: Compendium of Strategies*. United States Environmental Protection Agency. [Online]. Available: http://epa.gov/heatisland/resources/pdf/GreenRoofsCompendium.pdf.

EPA (2009) *Green Roofs for Stormwater Runoff Control*. Office of Research and Development National Risk Management Research Laboratory – Water Supply and Water Resources Division, United States Environmental Protection Agency. [Online]. Available: http://www.epa.gov/nrmrl/pubs/600r09026/600r09026.pdf.

EPA (2010) *Green Infrastructure Case Studies: Municipal Policies for Managing Stormwater with Green Infrastructure*. United States Environmental Protection Agency. [Online]. Available: http://www.epa.gov/owow/NPS/lid/gi_case_studies_2010.pdf.

EPA (2010b) *Why build green?* United States Environmental Protection Agency. [Online]. Available: http://www.epa.gov/greenbuilding/pubs/whybuild.htm.

EPA (2011a) *Green Infrastructure*. United States Environmental Protection Agency. [Online]. Available: http://cfpub.epa.gov/npdes/home.cfm?program_id=298.

EPA (2011b) *Green Building*. United States Environmental Protection Agency. [Online]. Available: http://www.epa.gov/greenbuilding/pubs/about.htm.

EPA (2011c) *Low Impact Development*. United States Environmental Protection Agency. [Online]. Available: http://www.epa.gov/owow/NPS/lid/.

EPA (2011d) *Managing Wet Weather with Green Infrastructure.* United States Environmental Protection Agency. [Online]. Available: http://cfpub.epa.gov/npdes/home.cfm?program_id=298.

EPA (2012) *Dry Detention Ponds*. United States Environmental Protection Agency. [Online]. Available: http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=browseandRbutton=detailandbmp=67.

EPA (2012b) *Bioretention (Rain Gardens)*. United States Environmental Protection Agency. [Online]. Available:

http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=factsheet_resultsandview=specificandbmp=72.

EPA (2012c) *Wet Ponds.* United States Environmental Protection Agency. [Online]. Available: http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=factsheet_resultsandview=specificandbmp=68.

EPA (2012d) *How Can I Overcome the Barriers to Green Infrastructure?* United States Environmental Protection Agency. [Online]. Available: http://water.epa.gov/infrastructure/greeninfrastructure/gi_barrier.cfm.

EPA (2012e) *Grassed Swales, National Pollutant Discharge Elimination System (NPDES).* United States Environmental Protection Agency. [Online]. Available: http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=factsheet_results&view=specific&bmp=75.

EPA (2012f) *Rain Gardens, National Pollutant Discharge Elimination System (NPDES).* United States Environmental Protection Agency. [Online]. Available: http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=factsheet_results&view=specific&bmp=72&minmeasure=5.

Ergas, S.J., Sengupta, S., Siegel, R., Pandit, A., Yifu, Y., Yuan, X. (2010) Performance of Nitrogen-Removing Bioretention Systems for Control of Agricultural Runoff. *Journal of Environmental Engineering*, 136(10): 1105-1112.

Erickson, D. (2006) *Metro Green: Connecting open space in North American cities.* Washington, DC: Island Press.

Espie, J., Findley, M., Walden, E. (2005) *Pennsylvania Suburbs Population Projection and Forecast.* Plan 605, Spring 2005, D.L. Phillips. [Online]. Available: http://www.arch.virginia.edu/~dlp/PAB/work/PLAN605/pop_proj/PennSuburb_espie_findley_walden.pdf.

Eumorfopoulou, E.A. and Kontoleon, K.J. (2009) Experimental approach to the contribution of plant-covered walls to the thermal behaviour of building envelopes. *Building and Environment,* 44: 1024-1038.

Fach, S. and Geiger, W. (2005) Effective pollutant retention capacity of permeable pavements for infiltrated road runoffs determined by laboratory tests. *Water Science and Technology*, 51(2): 37-45.

Fahrig, L. (2003) Effects of habitat fragmentation on biodiversity. *Annual Review of Ecology, Evolution and Systematics,* 34: 487-515.

Fassman, E.A. and Blackbourn, S. (2010) Urban Runoff Mitigation by a Permeable Pavement System over Impermeable Soils. *Journal of Hydrologic Engineering,* 15(6): 475-485.

Fassman, E.A. and Blackbourn, S.D. (2011) Road Runoff Water-Quality Mitigation by Permeable Modular Concrete Pavers. *Journal of Irrigation and Drainage Engineering,* 137(11): 720-729.

Fassman, E.A. and Liao, M. (2009) Monitoring of a Series of Swales within a Stormwater Treatment Train [online], in *Proceedings of H2O 09: 32nd Hydrology and Water Resources Symposium, Newcastle: Adapting to Change*. Barton, A.C.T.: Engineers Australia, 2009: 368-378. [Online]. Available: <http://search.informit.com.au/documentSummary;dn=751077419595143;res=IELENG> ISBN: 97808258259461.

Fassman, E.A., Simcock, R., Voyde, E. (2010a) *Extensive Green (Living) Roofs for Stormwater Mitigation: Part 1 Design and Construction.* Prepared by Auckland UniServices for Auckland Regional Council. Auckland Regional Council Technical Report 2010/017.

Fassman, E.A., Simcock, R., Voyde, E., Hong, Y.S. (2010b draft) *Extensive Green Roofs for Stormwater Management. Part 2: Performance Monitoring.* Auckland UniServices Technical Report to Auckland Regional Council. Auckland Regional Council TR 2010/018.

Fassman, E.A. and Simcock, R. (2012) Moisture Measurements as Performance Criteria for Extensive Living Roof Substrates. *Journal of Environmental Engineering,* 138(8): 841-851.

Fassman, E.A., Simcock, R., Wang, S. (2013) *Bioretention Media Specification.* Auckland UniServices Technical Report to Auckland Council. Auckland Council TR2013/011. [Online]. Available: http://www.aucklandcouncil.govt.nz/EN/planspoliciesprojects/reports/technicalpublications/Pages/technicalreports2013.aspx.

Fassman-Beck, E.A. and Simcock, R. (2013) *Living Roof Review and Design Recommendations for Stormwater Management.* Auckland UniServices Technical Report to Auckland Council. Auckland Council TR2013/045. [Online]. Available: http://www.aucklandcouncil.govt.nz/EN/planspoliciesprojects/reports/technicalpublications/Pages/technicalreports2013.aspx.

Fassman-Beck, E.A., Simcock, R., Voyde, E., Hong, Y.S. (2013) 4 Living Roofs in 3 Locations: Does Configuration Affect Runoff Quality or Quantity? *Journal of Hydrology,* 490(2013): 11-20.

Faulwetter, J.L., Gagnon, V., Sundberg, C., Chazarenc, F., Burr, M.D., Brisson, J., Camper, A.K., Stein, O.R. (2009) Microbial processes influencing performance of treatment wetlands: A review. *Ecological Engineering*, 35(6): 987-1004.

Feller, M. (2011) Quantifying evapotranspiration in green infrastructure: A green roof case study. Master of Science in Civil Engineering, The Graduate School Department of Civil and Environmental Engineering, Villanova University, Pennsylvania, USA. [Online]. Available: http://www3.villanova.edu/VUSP/Outreach/Pdf/Thesis/Feller-Thesis11.pdf.

Fischer, E. (2010) Issues in Green Building and the Federal Response: An Introduction. *Congressional Research Service*, 7-5700. [Online]. Available: http://www.fas.org/sgp/crs/misc/R40147.pdf.

Flyvbjerg, B., Holm, M.K.S., Buhl, S.L. (2006) Inaccuracy in traffic forecasts. *Transport Reviews*, 26(1): 1-24.

Fontoulakis, M., Terzakis, S., Kalogerakis, N., Manios, T. (2009) Removal of polycyclic aromatic hydrocarbons and linear alkylbenzene sulfonates from domestic wastewater in pilot constructed wetlands and a gravel filter. *Ecological Engineering*, 35: 1702-1709.

Ford-Robertson, J., Robertson, K., Maclaren, P. (1999) Modelling the effect of land-use practices on greenhouse gas emissions and sinks in New Zealand. *Environmental Science and Policy*, 2: 135-144.

Forest Research (2010) *Benefits of green infrastructure.* Report to Defra and CLG. Forest Research, Farnham. [Online]. Available: http://randd.defra.gov.uk/Document.aspx?Document=WC0807_9605_FRP.pdf.

Forman, R. (1991) Landscape corridors: From theoretical foundations to public policy, in *Nature Conservation 2: The role of corridors*, edited by D. Saunders and R. Hobbs. Chipping Norton, Australia: Surrey Beaty and Sons: 71-84.

Forman, R., Sperling, D., Bissonette, J., Clevenger, A., Cutshall, C., Dale, V., Fahrig, L., France, R., Goldman, C., Heanue, K., Jones, J., Swanson, F., Turrentine, T., Winter, T. (2003) *Road Ecology: Science and Solutions*. Washington DC: Island Press.

Foster, J., Lowe, A., Winkelman, S. (2011) *The Value of Green Infrastructure for Urban Climate Adaptation.* Center for Clean Air Policy. [Online]. Available: http://ccap.org/assets/The-Value-of-Green-Infrastructure-for-Urban-Climate-Adaptation_CCAP-Feb-2011.pdf.

Frank, L.D., Saelens, B.E., Powell, K.E., Chapman, J.E. (2007) Stepping towards causation: Do built environments or neighborhood and travel preferences explain physical activity, driving and obesity? *Social Science and Medicine*, 65: 1898-1914.

Fränne, L. (2007) *Hammarby Sjöstad – A unique environmental project in Stockholm.* Glashusëtt, Stockholm. [Online]. Available: http://www.hammarbysjostad.se/inenglish/pdf/HS_miljo_bok_eng_ny.pdf.

Freer-Smith, P.H., Beckett, K.P., Taylor, G. (2005) Deposition velocities to Sorbus aria, Acer campestre, Populus deltoids x trichocarpa 'Beaupre', Pinus nigra and x Cupressocyparis leylandii for coarse, fine and ultra-fine particles in the urban environment. *Environmental Pollution*, 133: 157-167.

Friberg, L. (2000) Innovative Solutions for Public Transport: Curitiba, Brazil. *Sustainable Development International*, 4: 153-156. [Online]. Available: http://www.p2pays.org/ref/40/39732.pdf.

Frith, M. (1998) *Wild Linesides, Wildlife on London's railways London Wildlife Trust.* London: Railtrack.

Fryxell, S. (2008) Planning Hammarby Sjöstad, Stockholm. Presentation at the *Europe Trends Conference: Rethinking Tomorrow; Real Estate in a Fast Changing World*, held in Stockholm, Sweden, 29 May 2008: Urban Land Institute.

Fulton, P., Gillespie, T., Fuentes, J., Wang, D. (1998) Volatile organic compound emissions from young black spruce trees. *Agricultural and Forest Meteorology,* 90: 247-255.

Gaffney, A., Huang, V., Maravilla, K., Soubotin, N. (2007) Hammarby Sjostad Case Study. CP 249. Urban Design in Planning. [Online]. Available: http://www.solaripedia.com/files/718.pdf.

Getter, K.L. and Rowe, D.B. (2006) The role of extensive green roofs in sustainable development. *HortScience*, 41(5): 1276-1285.

Getter, K.L., Rowe, D.B., Andresen, J.A. (2007) Quantifying the effect of slope on extensive green roof stormwater retention. *Ecological Engineering,* 31(4): 225-231.

Getter, K., Rowe, D., Robertson, G., Cregg, B., Andresen, J. (2009) Carbon Sequestration Potential of Extensive Green Roofs. *Environmental Science and Technology,* 43: 7564-7570.

Ghesquière, H.C. (2007) *Singapore's Success: Engineering Economic Growth.* Singapore: Thomson Learning.

Gill, S., Handley, J., Ennos, A., Pauleit, S. (2007) Adapting cities for climate change: The role of green infrastructure. *Climate Change and Cities*, 33(1): 115-133.

GlashusEtt. (2006) Hammarby sjöstad: En unik miljösatsning i stockholm. Stockholm: GlashusEtt.

Gorham, R. (2002) *Air pollution from ground transportation: An assessment of causes, strategies and tactics and proposed actions for the international community*. The Global Initiative on Transport Emissions: A Partnership of the United Nations and the World Bank. [Online]. Available: http://www.un.org/esa/gite/csd/gorham.pdf.

GRaBS (2010) *GRaBS Briefing delivering green infrastructure benefits to communities and places through planning, Briefing paper 2*. Town and Country Planning Association, London. [Online]. Available: http://www.grabs-eu.org/downloads/GRaBS_Briefing_Paper_2%20-%20GI%20Benefits_1.pdf.

Greater London Authority (2003) *Working paper 3: Valuing greenness. Is there a segmented preference for housing attributes in London?* June 2003. Greater London Authority (GLA), London. [Online]. Available: www.london.gov.uk/mayor/economic_unit/docs/valuing_greenness_paper.pdf.

Greater London Authority (2008) *Living Roofs and Walls Technical Report: Supporting London Plan Policy*. [Online]. Available: http://static.london.gov.uk/mayor/strategies/sds/docs/living-roofs.pdf.

Green Roof Guidelines (2012) *Green roofs*. [Online]. Available: http://www.greenroofguide.co.uk/pdfs/.

Green Roofs for Healthy Cities (2008) *Introduction to Green Walls Technology, Benefits and Design.* [Online]. Available: http://www.greenroofs.net/components/com_lms/flash/Green%20Walls%20Intro%20908b.pdf.

Green Stockholm (2010) *Green Stockholm: From 19th century innovation to 21st century Stockholm Royal Seaport.* [Online]. Available: http://www.investstockholm.com/Global/Investment%20promotion/Dokument/green%20cap%20LR.pdf.

Green, A. (2006) Hållbar energianvändning i svensk stadsplanering—från visioner till uppföljning av hammarby sjöstad och västra hamnen. Published Doctorial Thesis. Linköping: Linköping University, Linköping Studies in Arts and Science.

Greenroofs Ltd. (2009) *GreenRoofs FAQs*. [Online]. Available: http://www.greenroofs.co.nz/faq2.html#18.

Greenroofs.com (2010) *Chicago City Hall*. [Online]. Available: http://www.greenroofs.com/projects/pview.php?id=21.

GRO (2011) *The GRO Green Roof Code: Green Roof Code of Best Practice for the UK 2011.* [Online]. Available: http://livingroofs.org/images/stories/pdfs/GRO_CODE_2011.pdf.

Gunerhan, H., Hepbasli, A., Giresunlu, U. (2009) Environmental impacts from the solar energy systems. *Energy Sources, Part A: Recovery, Utilization and Environmental Effects*, 31(2): 131-138.

Haarstad, K., Bavor, H.J., Mæhlum, T. (2012) Organic and metallic pollutants in water treatment and natural wetlands: A review. *Water Science and Technology,* 65(1): 76-99.

Haddad, N.M. and Tewksbury, J.J. (2006) Impacts of corridors on populations and communities, in *Connectivity Conservation*, edited by Crooks, K. and Sanjayan, M. Cambridge, UK: Cambridge University Press: 390-415.

Hall, G.M.J. (2001) Mitigating an Organization's future net carbon emissions by native forest restoration. *Ecological Applications,* 11: 1622-1633.

Hall, K.L. and Helsel, C.M. (2009) *The Waitakere guidelines for riparian restoration: Lessons from Project Twin Streams.* Proceedings from Stormwater 2009: 6th South Pacific Stormwater Conference held in Auckland, New Zealand, 29 April-1 May 2009. [Online]. Available: http://www.projecttwinstreams.com/documents/research-paper.pdf.

Hallegatte, S., Ranger, N., Mestre, O., Dumas, P., Corfee Morlot, J., Herweijer, C., Muir Wood, R. (2011) Assessing climate change impacts, sea-level rise and storm surge risk in port cities: A case study on Copenhagen. *Climate Change*, 104(1): 113-137.

Hammarby Sjöstad (1998) Miljöprogram. Stadsbyggnadskontoret, Miljöförvaltningen och Gatu-och fastighetskontoret: Stockholm.

Hammer, D.A. and Bastian, R.K. (1989) Wetland ecosystem: Natural water purifiers? in *Constructed wetlands for wastewater treatment: Municipal, industrial, agricultural*, edited by Hammer, D.A. Michigan, U.S.A.: Lewis Publishers: 5-20.

Han, Y., Lau, S.-L., Kayhanian, M., Stenstrom, M.K. (2006) Characteristics of highway storm-water runoff. *Water Environment Research*, 78: 2377-2388.

Harnik, P., Ryan, R.L., Houck, M.C., Lusk, A.C., Solecki, W.D., Rosenzweig, C. (2006) *Part Two: From City Parks to Regional Green Infrastructure. The Humane Metropolis: People and Nature in the 21st-Century City.* Paper 3. [Online]. Available: http://scholarworks.umass.edu/cgi/viewcontent.cgi?article=1003andcontext=umpress_thm.

Haselbach, L., Boyer, M., Kevern, J.T., Schaefer, V.R. (2011) Cyclic heat island impacts on traditional versus pervious concrete pavement systems. *Transportation Research Record: Journal of the Transportation Research Board*, 2240(1): 107-115.

Hatt, B.E., Fletcher, T.D., Deletić, A. (2008). Hydraulic and pollutant removal performance of fine media stormwater filtration systems. *Environmental Science and Technology*, 42(7): 2535-2541.

Hawke, C.J. and José, P.V. (1996) *Reedbed Management for Commercial and Wildlife Interests*. Sandy, UK: Royal Society for the Protection of Birds.

Hawkins, K. (2009) *Chicago Green Roofs: Seven Million Square Feet and Growing*. [Online]. Available: hpigreen.com/2009/11/13/chicago-green-roofs-seven-million-square-feet-and-growing/. [13 November 2009].

Hayhoe, K., Sheridan, S., Kalkstein, L., Greene, S. (2010) Climate change, heat waves and mortality projections for Chicago. *Journal of Great Lakes Research*, 36(SUPPL. 2): 65-73.

Helfand, G.E., Sik Park, J., Nassauer, J.I., Kosek, S. (2006) The economics of native plants in residential landscape designs. *Landscape and Urban Planning*, 78(3): 229-240.

Hellström, D. (2005) Slutrapport från modellstaden hammarby sjöstad. Research report: 2005:4. Göteborg: Chalmers Tekniska Högskola.

Henderson, V. and Tighe, S. (2012) Evaluation of pervious concrete pavement performance in cold weather climates. *International Journal of Pavement Engineering,* 13(3): 197-208.

Heritage Conservancy (2008) *Growing with Green Infrastructure*. [Online]. Available: http://www.dcnr.state.pa.us/brc/publications/Pubs/green_infra.pdf.

Herman, R. (2003) Green roofs in Germany: Yesterday, today and tomorrow, in *Proceedings of the First North American Green Roof Conference: Greening Rooftops for Sustainable Communities*, held in Chicago, 29-30 May 2003. The Cardinal Group, Toronto: 41-45.

Herrera Environmental Consultants (2006) *Summary of Biofilter Effectiveness from Local and National Data Sets*. Prepared for Seattle Public Utilities. [Online].

Available: http://www.psparchives.com/publications/our_work/stormwater/lid/bio_docs/Biofilter%20Performance%20Review-Herrera.pdf.

Hess, G.R. and Fischer, R.A. (2001) Communicating clearly about conservation corridors. *Landscape and Urban Planning,* 55: 195-208.

Hirokawa, K.H. (2011) Sustainability and the Urban Forest: An Ecosystem Services Perspective. *Natural Resources Journal*, 51(2): 233-259.

Horner, R.R., Skupien, J.J., Livingston, E.H., Shaver, H.E. (1994) *Fundamentals of Urban Runoff Management: Technical and Institutional Issues.* Washington, D.C., USA: Terrene Institute.

Hunt, J.D. and Abraham, E. (2007) Influences on Bicycle Use. *Transportation*, 34: 453-570.

Hunt, W. and Collins, K. (2008) Permeable Pavement: Research Update and Design Implications. *North Carolina Cooperative Extension Service Bulletin. Urban Waterways Series.* AG-588-14. North Carolina State University. Raleigh, NC. [Online]. Available: http://www.bae.ncsu.edu/stormwater/PublicationFiles/PermPave2008.pdf.

Hunt, W.F., Apperson, C.S., Kennedy, S.G., Harrison, B.A., Lord, W.G. (2006a) Occurrence and relative abundance of mosquitoes in stormwater retention facilities in North Carolina, USA. *Water Science and Technology*, 52(6-7): 315-321.

Hunt, W.F., Jarrett, A.R., Smith, J.T., Sharkey, L.J. (2006b) Evaluating bioretention hydrology and nutrient removal at three field sites in North Carolina. *Journal of Irrigation and Drainage Engineering*, 132(6), 600-608.

Hutchinson, D., Abrams, P., Retzlaff, R., Liptan, T. (2003) Stormwater monitoring two ecoroofs in Portland, Oregon, USA, in: *Proceedings of the the First North American Green Roof Conference: Greening Rooftops for Sustainable Communities,* held in Chicago, 29-30 May 2003: 372-389.

IEEP (2007) *Guidance on the maintenance of landscape connectivity features of major importance for wild flora and fauna: Guidance on the implementation of Article 3 of the Birds Directive (79/409/EEC) and Article 10 of the Habitats Directive (92/43/EEC), Institute for European Environmental Policy.* [Online]. Available: http://ec.europa.eu/environment/nature/ecosystems/docs/adaptation_fragmentation_guidelines.pdf.

Ignatieva, M., Meurk, C., van Roon, M., Simcock, R., Stewart, G. (2008) *How to Put Nature into our Neighbourhoods: Application of Low Impact Urban Design and Development (LIUDD) Principles, with a Biodiversity Focus, for New Zealand Developers and Homeowners.* Landcare Research Science Series No.35, Manaaki Whenua Press. [Online]. Available: http://www.mwpress.co.nz/store/downloads/LRSS35_nature_neighbourhoods.pdf.

IGRA (2012) *Regulations and Guidelines for Green Roofs.* International Green Roof Association (IGRA). [Online]. Available: http://www.igra-world.com/guidelines_and_standards/index.php.

International Stormwater BMP Database (2012). [Online]. Available: http://www.bmpdatabase.org.

Ip, K., Lam, M., Miller, A. (2010) Shading performance of a vertical deciduous climbing plant canopy. *Building and Environment*, 45: 81-88.

ITDP (2011) *Case study Hammarby Sjöstad, Stockholm, Sweden*. Institute for Transportation and Development Policy (ITDP), New York. [Online]. Available: http://www.itdp.org/documents/092211_ITDP_NED_Hammarby.pdf.

IUCN (1980) *World Conservation Strategy: Living Resource Conservation for Sustainable Development.* Prepared by the International Union for Conservation of Nature and Natural Resources (IUCN) with the advice, cooperation and financial assistance of the United Nations Environment Programme (UNEP) and the World Wildlife Fund (WWF).

IUCN (2012) *IUCN Protected Area Management Categories.* International Union for the Conservation of Nature. [Online]. Available: http://www.iucn.org/about/work/programmes/pa/pa_products/wcpa_categories/.

Jenkins, C. and Joppa, L. (2009) Expansion of the global terrestrial protected area system. *Biological Conservation*, 142: 2166-2174.

Jenssen, P.D., Maehlum, T., Krogstad, T. (1993) Potential use of constructed wetlands for wastewater treatment in northern environments. *Water Science and Technology*, 28(10): 149-157.

Johnston, J. and Newton, J. (2003) *Building Green: A Guide to Using Plants on Roofs, Walls and Pavements.* London: London Ecology Unit.

Jones, M.P. and W.F. Hunt. (2010) Effect of Stormwater Wetlands and Wet Ponds on Runoff Temperature in Trout Sensitive Waters. *Journal of Irrigation and Drainage Engineering*, 136(9): 656-661.

Joppa, L.N. and Pfaff, A. (2011) Global protected area impacts. *Proceedings of the Royal Society B: Biological Sciences*, 278(1712): 1633-1638.

Kaczynski, A. and Henderson, K. (2007) Environmental correlates of physical activity: A review of evidence about parks and recreation. *Leisure Sciences,* 29(4): 315-354.

Kaplan, R. and Kaplan, S. (1989) *The Experience of Nature. A Psychological Perspective*. New York: Cambridge University Press.

Karasawa, A., Toriiminami, K., Ezumi, N., Kamaya, K. (2006). Evaluation of performance of water-retentive concrete block pavements, in *Sustainable Paving for Our Future: Proceedings of the 8th International Conference on Concrete Block Paving*. San Francisco, California: Interlocking Concrete Pavement Institute (ICPI).

Kazmierczak, A. and Carter, J. (2010) *Adaptation to climate change using green and blue infrastructure. A database of case studies.* The University of Manchester, UK.

Kettunen, M., Terry, A., Tucker, G., Jones, A. (2007) *Guidance on the maintenance of landscape features of major importance for wild flora and fauna – Guidance on the implementation of Article 3 of the Birds Directive (79/409/EEC) and Article 10 of the Habitats Directive (92/43/EEC).* Institute for European Environmental Policy (IEEP), Brussels, 114pp. and Annexes.

Kevern, J., Schaefer, V., Wang, K., Suleiman, M. (2008) Pervious concrete mixture proportions for improved freeze-thaw durability. *Journal of ASTM International*, 5(2): 12pp. American Society for Testing and Materials (ASRM), West Conshohocken, PA.

Kingham, S., Pattinson, W., Shrestha, K., Longley, I., Salmond, J. (2011) *Determination of personal exposure to traffic pollution while travelling by different modes.* New Zealand Transport Agency research report 457. [Online]. Available: http://www.nzta.govt.nz/resources/research/reports/457/docs/457.pdf.

Knapton, J. (2003) *Paving*. [Online]. Available: http://www.john-knapton.com/paving.htm.

Knight, R.L., Walton, W.E., O'Meara, G.F., Reisen, W.K., Wass, R. (2003) Strategies for effective mosquito control in constructed treatment wetlands. *Ecological Engineering,* 21: 211-232.

Köhler, M. (1989) Okologische Untersuchungen an Extensiven Dachbergrunung (Ecological Analysis of Extensive Green Roofs). *Poster zu Verhandlung der Gesellschaft fur Okologie (Essen 1988)*. band XVIII: 249-255.

Köhler, M. (2003) *Plant survival research and biodiversity: Lessons from Europe.* Paper presented at the First Annual Greening Rooftops for Sustainable Communities Conference, Awards and Trade Show, 20-30 May 2003, Chicago.

Köhler, M. (2007) Rain water management with green roofs and living walls, in: *Proceedings of the International Water Conference*, held in Berlin, 11-15 September 2007.

Köhler, M. (2008) Green Facades – A view back and some visions. *Urban Ecosystems,* 11(4): 423-436.

Köhler, M., Schmidt, M., Grimme, F., Laar, M., Gusmao, F. (2001) Urban Water Retention by Greened Roofs in Temperate and Tropical Climate, in: *Proceedings of the 38th International Federation of Landscape Architects World Congress*. Singapore: 12pp.

Köhler, M., Schmidt, M., Laar, M., Wachsmann, U., Krauter, S. (2002) *Photovoltaic panels on green roofs: Positive interaction between two elements of sustainable architecture.* RIO 02 - World Climate and Energy Event, 6-11 January 2002. [Online]. Available: http://rio02.com/proceedings/pdf/151_Koehler.pdf.

Kolokotroni, M. and Giridharan, R. (2008) Urban heat island intensity in London: An investigation of the impact of physical characteristics on changes in outdoor air temperature during summer. *Solar Energy,* 82(11): 986-998.

Kolokotroni, M., Ren, X., Davies, M., Mavrogianni, A. (2012) London's urban heat island: Impact on current and future energy consumption in office buildings. *Energy and Buildings*, 47: 302-311.

Konrad, C.P., Booth, D.B., Burges, S.J., Montgomery D.R. (2002) Partial entrainment of gravel bars during floods. *Water Resources Research,* 38(7): 9-1 – 9-16.

Kontoleon, K.J. and Eumorfopoulou, E.A. (2010) The effect of the orientation and proportion of a plant-covered wall layer on the thermal performance of a building zone. *Building and Environment,* 45: 1287-1303.

Koppe, C., Kovats, S., Jendritzky, G., Menne, B. (2004) *Health and global environmental change: Heat waves: Risk and responses.* Series No.2. Energy, Environment and Sustainable Development, World Health Organization, Copenhagen.

Kwiatkowski, M., Welker, A.L., Traver, R.G., Vanacore, M., Ladd, T. (2007) Evaluation of an infiltration best management practice (BMP) utilising pervious concrete. *Journal of the American Water Resources Association,* 43(5): 1208-1222.

Land Use Consultants (2006) *The environment, economic growth and competitiveness. The environment as an economic driver.* [Online]. Available: http://www.landuse.co.uk/files/EnvandeconomyJan06.pdf.pdf.

Land Use Consultants and Green Roof Consultancy (2010) *A Green Infrastructure Audit of the Victoria Business Improvement District*. Report prepared for Victoria BID Partnership. [Online]. Available: http://www.insw1.com/Branches/Victoria%20BID/inSW1/Files/Documents/Press/Releases/VBID_GI_Report_2010.pdf.

Landcare Research (2012) *Green roofs*. [Online]. Available: http://www.landcareresearch.co.nz/research/built/liudd/greenroofs.asp.

Landscape Institute (2009) *Green Infrastructure: Connected and multifunctional landscapes – position document*. [Online]. Available: http://www.landscapeinstitute.org/PDF/Contribute/GreenInfrastructurepositionstatement13May09.pdf.

Landscape Institute (2011) *Local Green Infrastructure: Helping communities make the most of their landscape*. [Online]. Available: http://www.landscapeinstitute.org/PDF/Contribute/LocalGreenInfrastructurewebversion_000.pdf.

Landscape Urbanism (2012) *Marina Bay*. [Online]. Available: http://landscapeurbanism.com/strategy/marina-bay/.

Lawton, M., Birchfield, D., Wilson, D. (2008) *Slowing the Flow: A comprehensive demand management framework for reticulated water supply.* A report for Beacon Pathway Ltd., New Zealand. [Online]. Available:

http://www.beaconpathway.co.nz/images/uploads/Slowing_the_Flow_demand_management_framework.pdf.

LCCP (2012) *A Summary of Climate Change Risks for London*. London Climate Change Partnership. [Online]. Available: http://www.london.gov.uk/lccp/docs/London_summary.pdf.

LDA (2010) *East London Green Grid Initiative*. London Development Agency. [Online]. Available: http://www.lda.gov.uk/projects/east-london-green-grid/index.aspx.

Lee, C. and Vernez Moudon, A. (2008) Neighborhood design and physical activity. *Building Research and Information*, 36(5): 395-411.

Lee, P.O. (2010) The four taps: Water self-sufficiency in Singapore, in *Management of success: Singapore revisited*, edited by T. Chong. Singapore: Institute of Southeast Asian Studies: 417-439.

Lehner, P.H., Aponte Clark, G.P., Cameron, D.M., Frank, A.G. (2001) *Stormwater Strategies: Community Responses to Runoff Pollution.* Natural Resources Defense Council. [Online]. Available: http://www.nrdc.org/water/pollution/storm/stoinx.asp. [26 October 2007].

Leng, O. and Sia, A., eds. (2002) *Handbook on Skyrise Greening in Singapore.* National Parks Board and Center for Total Building Performance, School of Design and Environment, National University of Singapore.

Lewis, M., Simcock, R., Davidson, G., Bull, L. (2010). *Landscape and Ecology Values within Stormwater Management.* Prepared by Boffa Miskell for Auckland Regional Council. Auckland Regional Council Technical Report TR2009/083, [Online]. Available: http://www.aucklandcity.govt.nz/council/documents/technicalpublications/TR2009083.pdf.

Li, H. and Davis, A.P. (2009) Water quality improvement through reductions of pollutant loads using bioretention. *Journal of Environmental Engineering*, 135(8): 567-576.

Liebsch, M.K. (2011) *Hydrologic effectiveness and plant survivability in the Holmes Lake rain garden program: Year three.* Masters of Science Thesis. University of Nebraska-Lincoln: Department of Agronomy and Horticulture.

Lindsay, G., Macmillan, A., Woodward, A. (2011) Moving urban trips from cars to bicycles: Impact on health and emissions. *Australian and New Zealand Journal of Public Health*, 35(1): 54-60.

Lindsay, H., Wild, C., Byers, S. (2009) *Auckland Protection Strategy.* A report to the Nature Heritage Fund Committee, Nature Heritage Fund, Wellington. [Online]. Available: http://www.doc.govt.nz/upload/documents/getting-involved/landowners/nature-heritage-fund/nhf-akld-protection-strat.pdf.

Litman, T. (2008). *Barrier Effect. Evaluating Nonmotorized Transport.* Victoria, B.C., Canada: Victoria Transport Policy Institute.

Litman, T. (2011) *Pavement Busters Guide: Why and How to Reduce the Amount of Land Paved for Roads and Parking Facilities.* Victoria, B.C., Canada: Victoria Transport Policy Institute. [Online]. Available: http://www.vtpi.org/pavbust.pdf.

Little, C. (1990) *Greenways for America.* Baltimore, USA: The John Hopkins University Press.

Liu, K. and Baskaran, B. (2003) *Thermal Performance of Green Roofs Through Field Evaluation.* National Research Council of Canada. Report No. NRCC-46412.

Lizama, A.K., Fletcher, T.D., Sun, G. (2011) Removal processes for arsenic in constructed wetlands. *Chemosphere*, 84(8): 1032-1043.

Lloyd, S., Wong, T.H.F., Chesterfield, C.J. (2001) Opportunities and impediments to water sensitive urban design in Australia, in *Proceedings of The Second South Pacific Stormwater Conference: Rain the forgotten resource*. Auckland, New Zealand: 302-309.

Lloyd-Jones, T. (1996) Curitiba: Sustainability by design. *Urban Design*, 57: 26-32.

Lohan, E. and Kirksey, W. (n.d.) *Ecosystems as infrastructure*. [Online]. Available: http://www.livingmachines.com/Services/White-Papers/Lohan-and-Kirksey-Ecosystems-as-Infrastructure.aspx.

Lohan, E., Muñoz, P., Salthouse, G., Fisher, C., Black, K. (2011) *Performance of Decentralised Wastewater Systems for Green Building Projects in North America and Australia.* [Online]. Available: http://www.livingmachines.com/Services/White-Papers/Lohan-et-al-2011.aspx.

Long, J. (2001) Desecuritizing the water issue in Singapore–Malaysia relations. *Contemporary Southeast Asia*, 23(3): 504-532.

Luan, I.O.B. (2010) Singapore Water Management Policies and Practices. *International Journal of Water Resources Development*, 26(1): 65-80.

Lucas, W.C. and Greenway, M. (2011). Phosphorus Retention by Bioretention Mesocosms Using Media Formulated for Phosphorus Sorption: Response to Accelerated Loads. *Journal of Irrigation and Drainage Engineering*, 137(March): 144. doi:10.1061/(ASCE)IR.1943-4774.

Lyderson, K. (2011) Pressures to Improve Water Quality in Chicago River. *The New York Times*, 19 May 2011. [Online]. Available: http://www.nytimes.com/2011/05/20/science/earth/20cncriver.html?_r=1.

MacArthur, R.H. and Wilson, E.O. (1967) *The theory of island biogeography*. Princetown, New Jersey, USA: Princetown University Press.

Macdonald, E., Sanders, R., Anderson, A. (2010) *Performance Measures for Complete, Green Streets: A Proposal for Urban Arterials in California.* University of California, Berkeley.

MacDonald, M. (2003) The role of corridors in biodiversity conservation in production forest landscapes: A literature review. *Tasforests,* 14: 41-52.

MacFarlane, R., Davies, C., Roe, M. (2005) *Green Infrastructure and the City Regions*. Discussion Paper. Dunston, UK: North East Community Forest.

Maclaren, J.P. (1996) Plantation forestry: Its role as a carbon sink, in *Greenhouse: Coping with climate change*, edited by W.J. Bouma, G.I. Pearman, M.R. Manning. Collingwood, Victoria, Australia: CSIRO Publishing.

Macmillan, A., Connor, J., Witten, K., Kearns, R., Woodward, A. (2014) The societal costs and benefits of commuter bicycling: Simulating the effects of specific policies using system dynamics modelling. *Environmental Health Perspectives*, 122(4): 335-344.

MacMullan, E. and Reich, S. (2007) The Economics of Low-Impact Development: A Literature Review. *ECONorthwest*. [Online]. Available: http://www.econw.com/reports/ECONorthwest_Low-Impact-Development-Economics-Literature-Review.pdf/.

Madden, S. (2010) *Choosing Green Over Gray: Philadelphia's Innovative Stormwater Infrastructure Plan.* Master in City Planning, Department of Urban Studies and Planning, Massachusetts Institute of Technology. [Online]. Available: http://stuff.mit.edu/afs/athena/dept/cron/project/urban-sustainability/Stormwater_Sarah%20Madden/sarahmadden_thesis_MIT.pdf.

Masi, F., Conte, G., Lepri, L., Martellini, T., Del Bubba, M. (2005) *Endocrine disrupting chemicals (EDCs) and pathogens removal in an hybrid CW system for a tourist facility in wastewater treatment and reuse.* [Online]. Available: http://www.iridra.it/.

Margules C.R. and Pressey R.L. (2000) Systematic conservation planning. *Nature*, 405(6783): 243-253.

Martin, B. (2008) *The Dynamic Stormwater Response of a Green Roof.* A thesis for the degree of Master of Landscape Architecture, University of Guelph, Ontario, Canada. [Online]. Available: http://atrium.lib.uoguelph.ca/xmlui/bitstream/handle/10214/1905/Final%20Thesis_Bruce%20Martin.pdf?sequence=1.

Matteo, M., Randhir, T., Bloniarz, D. (2006) Watershed scale impacts of forest buffers on water quality and runoff in urbanizing environment. *Journal of Water Resources Planning and Management*, 132(3): 144-152.

May, A.D. (2004) Singapore: The development of a world class transport system. *Transport Reviews*, 24(1): 79-101.

McIntosh, A. (2010) *Green roofs in Seattle: A survey of vegetated roofs and rooftop gardens*. Report prepared for the City of Seattle and the University of Washington Green Futures Lab. [Online]. Available: http://www.seattle.gov/dpd/greenbuilding/docs/dpdp020213.pdf.

McPherson, E.G., Nowak, D., Heisler, G., Grimmond, S., Souch, C., Grant, R., Rowntree, R. (1997) Quantifying urban forest structure, function, and value: the Chicago Urban Forest Climate Project. *Urban Ecosystems*, 1: 49-61.

McPherson, G., Simpson, J., Peper, P., Maco, S., Gardner, S., Cozad, S., Xiao, Q. (2006) *Midwest Community Tree Guide: Benefits, Costs and Strategic Planting.* United States Department of Agriculture, Forest Service, Pacific Southwest Research Station, Davis, California, USA.

Mell, I.C. (2009) Can green infrastructure promote urban sustainability? *Engineering Sustainability*, 162(1): 23-34.

Mell, I.C. (2010) *Green Infrastructure: Concepts, perceptions and its use in spatial planning.* Thesis submitted for the Degree of Doctor of Philosophy School of Architecture, Planning and Landscape, Newcastle University.

Mell, I.C. (2011) Green infrastructure planning: A contemporary approach for innovative interventions in urban landscape management. *Journal of Biourbanism*, 1: 29-39. [Online]. Available: http://journalofbiourbanism.files.wordpress.com/2013/01/jbu1_2011_mell.pdf.

Melo, L., Sautter, K., Janissek, P. (2009) Studies for the management of urban solid waste in Curitiba. *Eng. Sanit. Ambient*, 14(4): 551-558. [Online]. Available: http://dx.doi.org.ezproxy.auckland.ac.nz/10.1590/S1413-41522009000400015.

Menckhoff, G. (2005) Latin American experience with bus rapid transit, presented at the *World Bank Annual Meeting – Institute of Transportation Engineers*, held in Melbourne, Australia. [Online]. Available: http://www.gobrt.org/Latin_American_Experience_with_Bus_Rapid_Transit.pdf.

MEP (1994) *Regulations of the People's Republic of China on Nature Reserves.* Ministry of Environmental Protection of the People's Republic of China (MEP). [Online]. Available: http://english.mep.gov.cn/Policies_Regulations/regulations/Natural_Conservation_Biosafety/200711/t20071123_113364.htm.

Mercer (2011) *Mercer 2011 Quality of Living Survey highlights – Defining 'Quality of Living'*. [Online]. Available: http://www.mercer.com/articles/quality-of-living-definition-1436405.

Mercer (2012) *Quality of Living worldwide city rankings – Mercer survey*. [Online]. Available: http://www.mercer.com/qualityoflivingpr#city-rankings.

Metro Vancouver (2007) *Metro Vancouver Greenspace Map*. [Online]. Available: http://www.metrovancouver.org/about/maps/Maps/MetroVancouverGreenspace-map.pdf.

Metro Vancouver (2009) *Metro Vancouver 2040 – Backgrounder*. Metro 2040 Residential Growth Projections. [Online]. Available: http://www.metrovancouver.org/planning/development//strategy/RGSBackgroundersNew/RGSMetro2040ResidentialGrowth.pdf.

MetService (2012) *Climate summary.* [Online]. Available: http://www.metservice.com/learning/climate-summary

Michaelis, L. (1997) *CO_2 Emissions from Road Vehicles.* Annex I, Expert Group Meeting on the United Nations Framework Convention on Climate Change, Organisation for Economic Cooperation and Development. Working Paper No. 1, OECD/GD(97)69, Paris.

Millennium Ecosystem Assessment (2005a) *Ecosystems and Human Wellbeing: Synthesis*. Washington, DC: Island Press. [Online]. Available: http://www.millenniumassessment.org/documents/document.356.aspx.pdf.

Millennium Ecosystem Assessment (2005b) *Ecosystems and Human Well-being: Wetlands and Water, Synthesis.* Washington, DC: World Resources Institute. [Online]. Available: http://www.unep.org/maweb/documents/document.358.aspx.pdf.

Millennium Ecosystem Assessment (2005c) *Ecosystems and Human Well-being: Biodiversity Synthesis.* Washington, DC: World Resources Institute. [Online]. Available: http://www.unep.org/maweb/documents/document.354.aspx.pdf.

Ministry for the Environment (2007) *Environment New Zealand 2007*. Ministry for the Environment, Wellington. [Online]. Available: http://www.mfe.govt.nz/publications/ser/enz07-dec07/index.html.

Ministry for the Environment (2010) *Legally protected conservation land in New Zealand, Environmental Report Card.* April 2010; INFO 492. [Online]. Available: http://www.mfe.govt.nz/environmental-reporting/report-cards/biodiversity/2010/.

Monterusso, M.A., Rowe, D.B., Rugh, C.L., Russell, D.K. (2004) Runoff water quantity and quality from green roof systems. *ISHS Acta Horticulturae*, 639: 369-376. [Online]. Available: http://www.actahort.org/books/639/639_49.htm.

Moran, A., Hunt, B., Smith, J. (2005) *Hydrologic and water quality performance from greenroofs in Goldsboro and Raleigh, North Carolina*. Paper presented at the Third Annual Greening Rooftops for Sustainable Communities Conference, Awards and Trade Show. 4-6 May 2005, Washington, DC.

MPI (2011) *Carbon Sequestration Rates, Permanent Forest Sink Initiative.* Ministry for Primary Industries, New Zealand. [Online]. Available: www.mpi.govt.nz/forestry/funding-programmes/permanent-forest-sink-initiative/carbon-sequestration-rates.

Mungasavalli, D.P. and Viraraghavan, T. (2006) Constructed wetlands for stormwater management: A review. *Fresenius Environmental Bulletin*, 15(11): 1363-1372.

Naderi, J., Kweon, B., Maghelal, P. (2008) The Street Tree Effect and Driver Safety. *ITE Journal on the Web*, February: 69-73.

NARC (2012) *Green Infrastructure Principles: Planning, Design and Implementation*. National Association of Regional Councils. [Online]. Available: http://narc.org/activities/environment/green-infrastructure-and-landcare/green-infrastructure-principles.html.

National Parks Board (2012) *Heritage Roads: Unique Tree-scapes along Singapore Roads*. [Online]. Available:

http://www.nparks.gov.sg/cms/index.php?option=com_content&view=article&id=75&Itemid=65.

National Population and Talent Division (2013) *A sustainable population for a dynamic Singapore: Population white paper, Singapore.* [Online]. Available: http://www.nptd.gov.sg/content/NPTD/news/_jcr_content/par_content/download_98/file.res/population-white-paper.pdf.

National Stads Park (n.d.) *The Royal National Park*. [Online]. Available: mhttp://www.nationalstadsparken.se/Sve/Filer/NSP_informationsfoldern_EN_L.pdf.

Natural England (2009a) *Green Infrastructure Guidance*. [Online]. Available: http://www.urbanspaces.eu/files/Green_Infrastructure_Guidance.pdf.

Natural England (2009b) *Green Growth for Green Communities: A selection of regional case studies*. ParkCity Conference 2009. [Online]. Available: http://www.doc88.com/p-403540844051.html.

Natural England (2010) *Natural England – Green Infrastructure.* [Online]. Available: http://www.naturalengland.org.uk/ourwork/planningtransportlocalgov/greeninfrastructure/default.aspx.

Natural England (2012) *Green Infrastructure.* [Online]. Available: http://www.naturalengland.org.uk/regions/london/ourwork/futurelondon/gi.aspx.

Natural England (n.d.) *Green Infrastructure London*. [Online]. Available: http://www.naturalengland.org.uk/regions/london/ourwork/futurelondon/gi.aspx.

Naumann, S., McKenna, D., Kaphengst, T., Pieterse, M., Rayment, M. (2011) *Design, implementation and cost elements of Green Infrastructure projects.* Final report to the European Commission, DG Environment. Contract no.070307/2010/577182/ETU/F.1. Ecologic Institute and GHK Consulting.

Neal, P. (2012) *Learning legacy: Lessons learned from the London 2012 Games construction project.* [Online]. Available: http://learninglegacy.london2012.com/documents/pdfs/design-and-engineering-innovation/164-green-structure-dei.pdf.

Nelson, E.J. and Booth, D.B. (2002) Sediment budget of a mixed-land use, urbanizing watershed. *Journal of Hydrology*, 264: 51-68.

Neuvonen, M., Sievanen, T., Tonnes, S., Koskela, T. (2007) Access to green areas and the frequency of visits – A case study in Helsinki. *Urban Forestry and Urban Greening*, 6: 235-247.

New Zealand Government (2008) *Waitakere Ranges Heritage Area Act.* [Online]. Available: http://www.legislation.govt.nz/act/local/2008/0001/latest/DLM1076035.html.

Nielsen, T.S. and Hansen, T.B. (2007) Do green areas affect health? Results from a Danish survey on the use of green areas and health indicators. *Health and Place*, 13(4): 839-850.

Nixon, H. and Saphores, J. (2003) *Impacts of Motor Vehicle Operation on Water Quality: A Preliminary Assessment.* UC Irvine (www.uctc.net). [Online]. Available: www.uctc.net/papers/671.pdf.

Noakes, D.J. (2011) *Impacts of Salmon Farms on Fraser River Sockeye Salmon: Results of the Noakes investigation.* Cohen Commission Technical Report 5C. 113p. Vancouver, B.C., Canada. [Online]. Available: www.cohencommission.ca.

Normile, D. (2010) Restoration or devastation? *Science*, 327(5973): 1568-1570.

Northshore City Council (2009) *Stormwater Management Practice Note NSC 11: Pervious Paving.* [Online]. Available: http://www.northshorecity.govt.nz/IDSM/downloads/PDFs/Permeable_Pavement_Design_Guidelines_Draft_092004.pdf.

Noss, R.F. and Daly, K.M. (2006) Incorporating connectivity into broad-scale conservation planning, in *Connectivity Conservation*, edited by M. Sanjayan. Cambridge: Cambridge University Press: 587-619.

Novotny, V. and Olem, H. (1994) *Water Quality: Prevention, identification and management of diffuse pollution.* New York: Van Nostrand Reinhold.

Nowak, D. and Crane, D. (2000) The Urban Forest Effects (UFORE) Model: Quantifying urban forest structure and functions, in *Proceedings: Integrated tools for natural resources inventories in the 21st century,* edited by M. Hansen and T. Burke. International Union of Forest Research Organization (IUFRO) Conference, 16-20 August 1998, Boise, ID. General Technical Report NC-212, U.S. Department of Agriculture, Forest Service, North Central Research Station, St. Paul, MN: 714-720.

Nowak, D., Crane, D., Stevens, J. (2006) Air Pollution Removal by Urban Trees and Shrubs in the United States. *Urban Forestry and Urban Greening*, 4(3-4): 115-123.

Nowak, D., Hoehn, R., Crane, D., Stevens, J., Walton, J. (2007) *Assessing Urban Forest Effects and Values: Philadelphia's Urban Forest.* USDA Forest Service. [Online]. Available: http://www.nrs.fs.fed.us/pubs/rb/rb_nrs007.pdf.

Nowak, D., Hoehn, R., Crane, D., Stevens, J., Fisher, C. (2010) *Assessing Urban Forest Effects and Values: Chicago's Urban Forest.* USDA Forest Service. [Online]. Available: http://www.itreetools.org/resources/reports/Chicago%27s%20Urban%20Forest.pdf.

Nowak, M. (2004) *Urban Agriculture on the Rooftop.* Senior Honors Thesis, Cornell University. Available online: http://lib.fo.am/_media/roofgarden_thesis.pdf.

NRDC (2006) *Rooftops to Rivers: Green Strategies for Controlling Stormwater and Combined Sewer Overflows.* Natural Resources Defense Council. [Online]. Available: http://www.nrdc.org/water/pollution/rooftops/rooftops.pdf.

NRDC (2009) *Rooftops to Rivers: Aurora, New York.* Natural Resources Defense Council. [Online]. Available: http://www.lowimpactdevelopment.org/lid%20articles/rooftops.pdf.

NRDC (2011a) *Chicago: Illinois – A Case Study of How Green Infrastructure is Helping Manage Urban Stormwater Challenges.* Natural Resources Defense Council. [Online]. Available: http://www.nrdc.org/water/stormwater/files/RooftopstoRivers_Chicago.pdf.

NRDC (2011b) *Rooftops to Rivers II: Green strategies for controlling stormwater and combined sewer overflows.* Natural Resources Defense Council. [Online]. Available: http://www.nrdc.org/water/pollution/rooftopsii/files/rooftopstoriversII.pdf.

NRDC (2012a) *Case Study: The Solaire, New York.* Natural Resources Defense Council. [Online]. Available: http://www.nrdc.org/buildinggreen/casestudies/solaire.pdf.

NRDC (2012b) *From Copenhagen Accord to Climate Action: Tracking national commitments to curb global warming*. [Online]. Available: http://www.nrdc.org/international/copenhagenaccords/.

NYC (2010) *New York City Green Infrastructure Plan: A sustainable strategy for clean waterways.* [Online]. Available: http://www.nyc.gov/html/dep/pdf/green_infrastructure/NYCGreenInfrastructurePlan_LowRes.pdf.

NYDEC (2011) *Reach Innovative Draft Agreement to Improve New York Harbor Water Quality.* New York State Department of Environmental Conservation, Press release. [Online]. Available: http://www.dec.ny.gov/press/77894.html.

New Zealand Herald (2011) *Auckland named world's 10th most liveable city.* [Online]. Available: http://www.nzherald.co.nz/nz/news/article.cfm?c_id=1&objectid=10748419.

Oberndorfer, E., Lundholm, J., Bass, B., Coffman, R. (2007) Green Roofs as Urban Ecosystems: Ecological Structures, Functions and Services. *Bio Science,* 57(10): 823-833. [Online]. Available: http://www.aibs.org/bioscience-press-releases/resources/11-07.pdf

Odefey, J., Detwiler, S., Rousseau, K., Trice, A., Blackwell, R., O'Hara, K., Buckley, M., Souhlas, T., Brown, S., Raviprakash, P. (2012) *Banking on Green: A Look at How Green Infrastructure Can Save Municipalities Money and Provide Economic Benefits Community-wide.* A Joint Report by American Rivers, the Water Environment Federation, the American Society of Landscape Architects and ECONorthwest. [Online]. Available: http://www.americanrivers.org/assets/pdfs/reports-and-publications/banking-on-green-report.pdf.

Office for National Statistics (2011) *Regional Profiles – Population and Migration – London – October 2011.* [Online]. Available: http://www.ons.gov.uk/ons/rel/regional-trends/region-and-country-profiles/population-and-migration/population-and-migration---london.html.

Olsenius, C. (2010) Institutional barriers to wetlands protection at the local level. *National Wetlands Newsletter*, 32(3): 16-19.

Onemap (2012) *Singapore GIS tool*. [Online]. Available: http://www.onemap.sg/index.html.

O'Neill, S.W. and Davis, A.P. (2012a). Water Treatment Residual as a Bioretention Amendment for Phosphorus. I: Evaluation Studies. *Journal of Environmental Engineering*, 138(3): 318-327.

O'Neill, S W. and Davis, A.P. (2012b) Water Treatment Residual as a Bioretention Amendment for Phosphorus. II: Long-Term Column Studies. *Journal of Environmental Engineering*, 138(3): 328-336.

Open Green Map (2012a) *Map of Copenhagen*. [Online]. Available: http://www.opengreenmap.org/greenmap/baerbyen-copenhagen.

Open Green Map (2012b) *Curitiba*. [Online]. Available: http://www.opengreenmap.org/greenmap/mapa-verde-curitiba.

Osmundson, T. (1999) *Roof Gardens: History, design and construction.* New York: W.W. Norton and Company.

Ottelé, M., Perini, K., Fraaij, A., Haas, E., Raiteri, R. (2011) Comparative life cycle analysis for green façades and living wall systems. *Energy and Buildings*, 43(12): 3419-3429.

Palmer, M., Allan, J.D., Meyer, J., Bernhardt, E.S. (2007) River restoration in the twenty-first century: Data and experiential knowledge to inform future efforts. *Restoration Ecology*, 15(3): 472-481.

Palmer, M.A. and Bernhardt, E.S. (2006) Hydroecology and river restoration: Ripe for research and synthesis. *Water Resources Research*, 42(3): W03S07.

Pandis Iverot, S. and Brandt, N. (2011) The development of a sustainable urban district in Hammarby Sjöstad, Stockholm, Sweden? *Environment, Development and Sustainability,* 13(6): 1043-1064.

Parkin, J., Wardman, M., Page, M. (2007) Models of perceived cycling risk and route acceptability. *Accident Analysis and Prevention*, 39(2): 364-371.

PCSD (1999) *Towards a Sustainable America.* The President's Council on Sustainable Development. [Online]. Available: http://clinton2.nara.gov/PCSD/Publications/.

Pearsall, III S.H. (1984) In absentia benefits of nature preserves: A review. *Environmental Conservation*, 11(1): 3-10.

Peck, S. and Kuhn, M. (2003) *Design Guidelines for Green Roofs.* Canada Mortgage and Housing Corporation and the Ontario Association of Architects. [Online]. Available: http://www.cmhc-schl.gc.ca/en/inpr/bude/himu/coedar/upload/Design-Guidelines-for-Green-Roofs.pdf.

Pérez, G., Rincón, L., Vila, A., González, J.M., Cabeza, L.F. (2011) Green vertical systems for buildings as passive systems for energy savings. *Applied Energy*, 88(12): 4854-4859.

Perini, K., Ottelé, M., Fraaij, A.L.A., Haas, E.M., Raiteri, R. (2011) Vertical greening systems and the effect on air flow and temperature on the building envelope. *Building and Environment*, 46(11): 2287-2294.

Peryman, T. (2009) Green Roofing and Living Walls – A stormwater solution in today's sustainably focused world? *The New Zealand Water and Wastes Association (NZWWA) Journal.* [Online]. Available: http://www.verticalplantscapes.co.nz/NZWWAJournalMarch09.pdf.

Peterson, T.C., Zhang, X., Brunet-India, M., Vazquez-Aguirre, J.L. (2008) Changes in North American extremes derived from daily weather data. *Journal of Geophysical Research: Atmospheres,* 113(D7): 2156-2202.

Philadelphia Water Department (PWD) (2011) *Amended Green City Clean Waters.* [Online]. Available: http://www.phillywatersheds.org/doc/GCCW_AmendedJune2011_LOWRES-web.pdf.

Pickett, S. and Cadenasso, M. (2008) Linking ecological and built components of urban mosaics: An open cycle of ecological design. *Journal of Ecology*, 96(1): 8-12.

Pitt, R., Clark, S., Field, R. (1999) Groundwater contamination potential from stormwater infiltration practices. *Urban Water*, 1(3): 217-236.

Pittock, J. and Ming, X. (2011) World Resources Report Case Study. Controlling Yangtze River Floods: A New Approach. *World Resources Report.* Washington DC: 1-13. [Online]. Available: http://www.worldresourcesreport.org.

Platt, R.H., Rowntree, R.A., Muick, P.C., eds. (1994) *The Ecological City: Preserving and restoring urban biodiversity.* Amherst: University of Massachusetts Press.

Plumb, M. and Seggos, B. (2007) *Sustainable Raindrops: Cleaning New York Harbor by Greening the Urban Landscape.* Riverkeeper. [Online]. Available: http://riverkeeper.org/special/Sustainable_Raindrops_FINAL_2007-03-15.pdf.

Poldermans, C. (2006) *Sustainable Urban Development: The Case of Hammarby Sjöstad.* Paper for Kulturgeografiska Institutionen, Advanced Course in Human Geography, Fall Semester 2005. [Online]. Available: http://www.solaripedia.com/files/720.pdf.

Postel, S. and Richter, B. (2003) *Rivers for Life: Managing water for people and nature.* Island Press: Washington, D.C.

Potts, I.B., Harwood, D.W., Richard, K.R. (2007) Relationship of Lane Width to Safety on Urban and Suburban Arterials. *Transportation Research Record*, 2023: 63-82.

Pressey, R.L., Humphries, C.J., Margules, C.R., Vane-Wright, R.I., Williams, P.H. (1993) Beyond opportunism: Key principles for systematic reserve selection. *Trends in Ecology and Evolution*, 8(4): 124-128.

Price, J. (2010) *Green Facade Energetics.* Thesis submitted to the Faculty of the Graduate School of the University of Maryland, College Park, in partial fulfillment of the requirements for the degree of Master of Science, University of Maryland, USA.

Pucher, J. and Buehler, R. (2006) Why Canadians cycle more than Americans: A comparative analysis of bicycling trends and policies. *Transport Policy*, 13(3): 265-279.

Pugh, T.A.M., MacKenzie, A.R., Whyatt, J.D., Hewitt, C.N. (2012) Effectiveness of green infrastructure for improvement of air quality in urban street canyons. *Environmental Science and Technology*, 46(14): 7692-7699.

Purcel, D. (2010) *Population up, Philadelphia still No. 6, Census says*. Philly.com. [Online]. Available: http://articles.philly.com/2010-06-22/news/24966540_1_census-counts-census-data-fastest-growing-cities.

Rabinovitch, J. (1992) Curitiba: Towards sustainable urban development. *Environment and Urbanization*, 4(2): 62-73.

Ramsar Convention Secretariat (2006) *The Ramsar Convention Manual: A guide to the Convention on Wetlands.* Ramsar, Iran (1971), 4th ed. Ramsar Convention Secretariat: Gland, Switzerland.

Rayner, J.P., Raynor, K.J., Williams, N.S.G. (2010) Façade greening: A case study from Melbourne, Australia. *ACTA Horticulturae*, 881: 709-713.

Regeneris (2009) *The economic contribution of the Mersey Forest's objective one – funded investments.* Regeneris Consulting. [Online]. Available: http://www.merseyforest.org.uk/pages/displayDocuments.asp?iDocumentID=246.

Revitt, R., Shutes, B., Scholes, L. (1999) The use of constructed wetlands for reducing the impacts of urban surface runoff on receiving water quality, in *Impacts of urban growth on surface water and groundwater quality: Proceedings of an International Union of Geodesy and Geophysics Symposium*, edited by J.B. Ellis. Birmingham, UK. International Association of Hydrological Sciences, Wallingford: 349-356.

RFBPSNZ (n.d.) *Ark in the Park.* Royal Forest and Bird Protection Society of New Zealand and Auckland Council. [Online]. Available: http://www.arkinthepark.org.nz/.

Richards, L. (2009). Managing stormwater runoff: A green infrastructure approach. *Planning Commissioner's Journal*, 73 (Winter). [Online]. Available: http://northassoc.org/2009/01/27/managing-stormwater-runoff-green-infrastructure-approach.aspx.

Richter, E.D., Berman, T., Friedman, L., Ben-David, G. (2006) Speed, Road Injury and Public Health. *Annual Review of Public Health*, 27: 125-152.

Robertson, K., Loza-Balbuena, I., Ford-Robertson, J. (2004) Monitoring and economic factors affecting the economic viability of afforestation for carbon sequestration projects. *Environmental Science and Policy*, (7): 465-475.

Roseen, R., Ballestero, T., Houle, J., Briggs, J., Houle, K. (2012) Water Quality and Hydrologic Performance of a Porous Asphalt Pavement as a Storm-Water Treatment Strategy in a Cold Climate. *Journal of Environmental Engineering,* 138(1): 81-89.

Roseen, R., Houle, J., Puls, T., Ballestero, T. (2013) *Final Report on a Cold Climate Permeable Interlocking Concrete Pavement Test Facility at the University of New Hampshire Stormwater Center.* [Online]. Available: http://www.unh.edu/unhsc/. [1 October 2013].

Rosenzweig, C. and Solecki, W.D., eds. (2001) *Climate Change and a Global City: The Potential Consequences of Climate Variability and Change – Metro East Coast (MEC).* Report for the United States Global Change Research Program, National Assessment of the Potential Consequences of Climate Variability and Change for the United States. Columbia Earth Institute, New York.

Rosenzweig, C., Solecki, W., Slosberg, R. (2006) *Mitigating New York City's Heat Island with urban forestry, living roofs and light surfaces.* A report to the New York State Energy Research and Development Authority. New York, United States of America.

Rowe, D.B. (2011) Green roofs as a means of pollution abatement. *Environmental Pollution*, 159(8-9): 2100-2110.

Rowe, A.A., Borst, M., O'Connor, T.P., Stander, E.K. (2010) Permeable pavement monitoring at the Edison Environmental Center demonstration site, in: *Proceedings of the World Environmental and Water Resources Congress 2010:* Challenges of Change, held in Providence, Rhode Island, USA, 16-20 May 2010. 2908-2916.

Rowntree, R. (1986) Ecology of the urban forest – Introduction to Part II. *Urban Ecology*, 9: 229-243.

Roy-Poirier, A., Champagne, P., Filion, Y. (2010) Review of bioretention system research and design: Past, present and future. *Journal of Environmental Engineering*, 136: 878-889.

Rusciano, G.M. and Obropta, C.C. (2007) Bioretention column study: Fecal coliform and total suspended solids reductions. *Transactions of the American Society of Agricultural and Biological Engineers (ASABE)*, 50(4): 1261-1269.

Sailor, D.J. (2008) A green roof model for building energy simulation programs. *Energy and Buildings*, 40(8): 1466-1478.

Saiz, S., Kennedy, C., Bass, B., Pressnail, K. (2006) Comparative life cycle assessment of standard and green roofs. *Environmental Science and Technology,* 40: 4312-4316.

Sankaran, J., Gore, A., Coldwell, B. (2005) The impact of road traffic congestion on supply chains: Insights from Auckland, New Zealand. *International Journal of Logistics: Research and Applications*, 8(2): 159-180.

Santos, G., Behrendt, H., Teytelboym, A. (2010) Part II: Policy instruments for sustainable road transport. *Research in Transportation Economics*, 28(1): 46-91.

Saunders, S.M., Dade, E., Van Niel, K. (2011) An Urban Forest Effects (UFORE) model study of the integrated effects of vegetation on local air pollution in the western suburbs of Perth, WA, in *Proceedings of the 19th International Congress on Modelling and Simulation: Sustaining Our Future – Understanding and Living with Uncertainty,* held in Perth, Australia, 12-16 December 2011: 1824-1830.

Schmidt, M. (2006) The evapotranspiration of greened roofs and facades, in *Proceedings of the 4th Greening Rooftops for Sustainable Communities.* Boston, MA, United States of America.

Scholes, L., Shutes, R.B.E., Revitt, D.M., Forshaw, M., Purchase, D. (1998) The treatment of metals in urban runoff by constructed wetlands. *The Science of the Total Environment*, 214: 211-219.

Scholz, M. and Lee, B.-H. (2005) Constructed wetlands: A review. *International Journal of Environmental Studies*, 62(4): 421-447.

Schueler, T. (1997) Comparative Pollutant Removal Capability of Urban BMPs: A reanalysis. *Watershed Protection Techniques,* 2(2): 379-383.

Schumann, L. (2007) *Ecologically Inspired Design of Green Roof Retrofit.* Masters of Science Thesis, Biological Resources Engineering, University of Maryland, College Park. 269pp. [Online]. Available: http://hdl.handle.net/1903/7399.

Schwela, D. and Zali, O. (1999) Motor vehicles and air pollution, in *Urban Traffic Pollution*, edited by D. Schwela and O. Zali. London, UK: E & FN Spon.

Schwendenmann, L. and Mitchell, N. (2014) Carbon accumulation by native trees and soils in an urban park, Auckland. *New Zealand Journal of Ecology,* 38(2): 213-220.

Scott, N.A., White, J.D., Townsend, J.A., Whitehead, D., Leathwick, J.R., Hall, G.M.J., Marden, M., Rogers, G.N.D., Watson, A.J., Whaley, P.T. (2000) Carbon and nitrogen distribution and accumulation in a New Zealand Shrubland Ecosystem. *Canadian Journal of Forest Research*, 30(8): 1246-1255.

Semenza, J.C., McCullough, J., Flanders, D., McGeehin, M., Lumpkin, J. (1999) Excess hospital admissions during the 1995 heat wave in Chicago. *American Journal of Preventative Medicine,* 16: 269-277.

Shadie, P. and Moore, P. (2010) *Connectivity Conservation: International Experience in Planning, Establishment and Management of Biodiversity Corridors.* International Union for the Conservation of Nature. [Online]. Available: http://cmsdata.iucn.org/downloads/070723_bci_international_report_final.pdf.

Shaver, E. (2000) *Low Impact Design Manual for the Auckland Region.* Technical Publication 124, Auckland Regional Council. [Online]. Available:

http://www.arc.govt.nz/auckland/low-impact-design/low-impact-design_home.cfm.

Sherer, P. (2006) *The Benefits of Parks: Why America Needs More City Parks and Open Space.* The Trust for Public Land, San Francisco. [Online]. Available: http://www.childrenandnature.org/downloads/parks_for_people_Jul2005.pdf.

Sheweka, S. and Magdy, N. (2011) The living walls as an approach for a healthy urban environment. *Energy Procedia*, 6: 592-599.

Shin, J-H. and Chung, J-Y. (2011) The four major rivers restoration project in South Korea. *Proceedings of the Institute of Civil Engineers (ICE) – Civil Engineering*, 164(1): 19-26.

Simberloff, D., Farr, J., Cox, J., Mehlman, D. (1992) Movement Corridors: Conservation Bargains or Poor Investments? *Conservation Biology*, 6(4): 493-504.

Simcock, R., Dando, J., Ross, C., Smale, M. (2005) Waitakere Indigenous Green Roof: Substrate Selection and Plant Species. LC0405/148, Landcare Research.

Simcock, R., Smale, M., Ross, C., Whitelaw, L., Dando, J., Lamert, R., Trowsdale, S. (2006) Developing an Indigenous Green Roof for Waitakere City Council, presented at the *New Zealand Water and Wastes Association Stormwater Conference*, held in Rotorua, New Zealand, 4-5 May 2006: 7.

Simmons, M.T., Gardiner, B., Windhager, S., Tinsley, J. (2008) Green roofs are not created equal: The hydrologic and thermal performance of six different extensive green roofs and reflective and non-reflective roofs in a sub-tropical climate. *Urban Ecosystems*, 11(4): 339-348.

Smith, H. and Raemaekers, J. (1998) Land use pattern and transport in Curitiba. *Land Use Policy*, 15(3): 233-251.

SNCCS (2008) *Singapore's National Climate Change Strategy.* [Online]. Available: http://app.mewr.gov.sg/data/ImgUpd/NCCS_Full_Version.pdf.

Sousa, L. and Rosales, J. (2010) Contextually complete streets, Green Streets and Highways 2010: An Interactive Conference on the State of the Art and How to Achieve Sustainable Outcomes. *Proceedings of the Green Streets and Highways 2010 Conference*, 389: 94-106.

Sovocool, K.A., Morgan, M., Bennett, D. (2006) An in-depth investigation of Xeriscape as a water conservation measure. *Journal – American Water Works Association*, 98(2): 82-93.

Spirn, A.W. (1984) *The granite garden: Urban nature and human design.* New York: Basic Books.

St. Hilaire, R., Arnold, M.A., Wilkerson, D.C., Devitt, D.A., Hurd, B.H., Lesikar, B.J., Lohr, V.I., Martin, C.A, McDonald, G.V., Morris, R.L., Pittenger, D.R., Shaw, D.A., Zoldoske D.F. (2008) Efficient water use in residential urban landscapes. *HortScience*, 43(7): 2081-2092.

Starke, P., Göbel, P., Coldewey, W.G. (2010) Urban evaporation rates for water-permeable pavements. *Water Science and Technology*, 62(5): 1161-1169.

Starke, P., Göbel, P., Coldewey, W.G. (2011) Effects on evaporation rates from different water-permeable pavement designs. *Water Science and Technology,* 63(11): 2619-2627.

State of Queensland (2008) *Climate Change in Queensland: What the science is telling us?* Office of Climate Change Environmental Protection Agency, Brisbane, Australia. [Online]. Available: http://www.climatechange.qld.gov.au/pdf/climatesciencereport.pdf.

Statistics Canada (2011a) *Census of Canada 2011*. [Online]. Available: http://www.metrovancouver.org/about/publications/Publications/Census2011PopulationGrowthTrends.pdf.

Statistics Canada (2011b) *City of Vancouver Planning Department Information Sheet, City Facts Census Data Series, Population, 1891-2011.* [Online]. Available: http://vancouver.ca/commsvcs/planning/census/2011/pop1891-2011.pdf.

Statistics Denmark (2011) *Population 1st January, by urban areas*. [Online]. Available: http://statistikbanken.dk/statbank5a/default.asp?w=768.

Statistics Denmark (2012) *Summary components of change according to population projections for municipalities*. [Online]. Available: http://statistikbanken.dk/statbank5a/default.asp?w=768.

Statistics New Zealand (2009) *Subnational Population Estimates: At 30 June 2009*. [Online]. Available: http://www.stats.govt.nz/browse_for_stats/population/estimates_and_projections/SubnationalPopulationEstimates_HOTP30Jun09/Commentary.aspx.

Statistics New Zealand (2011a) *Subnational Population Estimates: At 30 June 2011.* [Online]. Available: http://www.stats.govt.nz/browse_for_stats/population/estimates_and_projections/SubnationalPopulationEstimates_HOTPJun11.aspx.

Statistics New Zealand (2011b) *Subnational Population Estimates: At 30 June 2011.* [Online]. Available: http://www.stats.govt.nz/~/media/Statistics/Browse%20for%20stats/SubnationalPopulationEstimates/HOTPJun11/SubnationalPopulationEstimatesJun11HOTP.pdf.

Statistics New Zealand (2012) *Subnational Population Projections: 2006 (base) – 2031 update.* [Online]. Available: http://www.stats.govt.nz/browse_for_stats/population/estimates_and_projections/subnational-population-projections-info-releases.aspx.

Stemberg, T., Viles, H., Carthersides, A., Edwards, M. (2010) Dust particulate absorption by Ivy (Hedera Helix L.) on historic walls in urban environments. *Science of the Total Environment*, 409: 162-168.

Steward, G.A. (2011) *Growth and Yield of New Zealand Kauri (Agathis australis (D. Don) Lindl.).* Master Thesis. University of Canterbury, Christchurch, New Zealand. [Online]. Available: http://hdl.handle.net/10092/6262.

Stockwell, A. (2009) *Analysis of Barriers to Low Impact Development in the North Coast, Redwood Region, California.* Masters Thesis, Humboldt State University, California, United States of America.

Sumner, J. and Barchfield, V., eds. (2010) *Latin American Green City Index: Assessing the environmental performance of Latin America's major cities.* A research project conducted by J. Friederich and H. Langer, Economist Intelligence Unit, Frankurt. Sponsored by Siemens AG, Munchen, Germany. 51pp. [Online]. Available: http://www.siemens.com/entry/cc/features/greencityindex_international/all/en/pdf/report_latam_en.pdf.

Suzuki, H., Dastur, A., Moffatt, S., Yabuki, N., Maruyama, H. (2010) *Eco2 Cities: Ecological Cities as Economic Cities.* Washington, DC: The World Bank. [Online]. Available: http://siteresources.worldbank.org/INTURBANDEVELOPMENT/Resources/336387-1270074782769/Eco2_Cities_Book.pdf.

Svane, Ö. (2005) *Situations of Opportunity – Hammarby Sjöstad and Stockholm City's Process of Environmental Management.* [Online]. Available: http://borg.hi.is/enhr2005iceland/ppr/Svane.pdf. [5 January 2006].

Sylwester, A. (2009) *Green Infrastructure – Supporting connectivity, maintaining sustainability.* European Commission, DG Environment.

Takano, T., Nakamura, K., Watanabe, M. (2002) Urban residential environments and senior citizens' longevity in mega-city areas: The importance of walk-able green space. *Journal of Epidemiology and Community Health*, 56(12): 913-916.

Tan, K.W. (2006) A greenway network for Singapore. *Landscape and Urban Planning*, 76(1-4): 45-66.

Tan, P.Y., Yeo, B., Yip, W.X., Lua, H.S. (2009) *Carbon Storage and Sequestration by Urban Trees in Singapore.* Centre for Urban Greenery and Ecology, National Parks Board, Singapore.

Tanner, C.C. (1996) Plants for constructed wetland treatment systems – A comparison of the growth and nutrient uptake of eight emergent species. *Ecological Engineering*, 7(1): 59-83.

Tanuwidjaja, G. (2010) *Park connector network planning in Singapore: Integrating the green in the garden city.* Paper presented at the 5th International Conference of the International Forum on Urbanism (IFoU) 2011. [Online]. Available: http://greenimpactindo.wordpress.com/2010/11/23/park-connector-network-planning-in-singapore-integrating-the-green-in-the-garden-city/.

Tarkalson, D.D. and Ippolito, J.A. (2010) Clinoptilolite Zeolite Influence on Inorganic Nitrogen in Silt Loam and Sandy Agricultural Soils. *Soil Science*, 175(7): 357-362.

Tate, K.R., Giltrap, D.J., Claydon, J.J., Newsome, P.F., Atkinson, A.E., Taylor, M.D., Lee, R. (1997) Organic Carbon Stocks in New Zealand's Terrestrial Ecosystems. *Journal of the Royal Society of New Zealand*, 27: 315-335.

Taylor, D.A. (2007) Growing green roofs, city by city. *Environmental Health Perspectives,* 115(6): 306-311.

TCPA (2008) *The essential role of green infrastructure: Eco-towns green infrastructure worksheet.* Town and Country Planning Association, UK. [Online]. Available: http://www.tcpa.org.uk/data/files/etws_green_infrastructure.pdf.

Teemusk, A. and Mander, U. (2006) The use of greenroofs for the mitigation of environmental problems in urban areas. *WIT Transactions on Ecology and the Environment*, 93: 3-17.

Tennis, P.D., Leming, M.L., Akers, D.J. (2004) *Pervious concrete pavements.* Technical Report EB302.02. Portland Cement Association, Skokie, IL and National Ready Mixed Concrete Association, Silver Spring, Maryland, USA.

The Conservation Fund (2011) *What is Green Infrastructure? Green Infrastructure.* [Online]. Available: http://www.greeninfrastructure.net/content/definition-green-infrastructure.

The Conservation Fund (2012) *Benefits of Green Infrastructure.* [Online]. Available: http://www.greeninfrastructure.net/benefits-green-infrastructure.

Theakston, F., ed. (1992) *Acute Effects on Health of Smog Episodes: Report on a WHO meeting, Hertogenbosch, Netherlands, 30 October-2 November 1990.* World Health Organization Regional Publication, Europe 39. Copenhagen, Denmark: WHO Regional Office for Europe.

Tian, S. (2011) *Managing Stormwater Runoff with Green Infrastructure: Exploring preactical strategies to overcome arriers in citywide implementation.* Masters Thesis in the Community and Regional Planning Program at the University of Nebraska-Lincoln, USA. [Online]. Available: http://digitalcommons.unl.edu/arch_crp_theses/7.

Tilahun, N.Y., Levinson, D.M., Krizek, K.J. (2007) Trails, lanes, or traffic: Valuing bicycle facilities with an adaptive stated preference survey. *Transportation Research Part A,* 41: 287-301.

Tin Tin, S., Woodward, A., Ameratunga, S. (2010a) Injuries to pedal cyclists on New Zealand roads, 1988-2007. *BMC Public Health*. 10(655): 1-10.

Tin Tin, S., Woodward, A., Thornley, S., Langley, J., Rodgers, A., Ameratunga, S. (2010b) Cyclists' attitudes toward policies encouraging bicycle travel: Findings from the Taupo Bicycle Study in New Zealand. *Health Promotion International,* 25(1): 54-62.

Tin Tin, S., Woodward, A., Thornley, S., Ameratunga, S. (2011) Regional variations in pedal cyclist injuries in New Zealand: Safety in numbers or risk in scarcity? *Australian and New Zealand Journal of Public Health*, 35(4): 357-363.

Titchall, A. (2008) Renewable energy from rubbish. *Energy NZ*, (5). [Online]. Available: http://www.contrafedpublishing.co.nz/Energy+NZ/Issue+5+Winter+2008/Renewable+energy+from+rubbish.html.

Tiwary, A., Sinnett, D., Peachey, C.J., Chalabi, Z., Vardoulakis, S., Fletcher, T., Leonardi, G., Grundy, C., Azapagic, A., Hutchings, T.R. (2009) An integrated tool to assess the role of new planting in PM10 capture and the human health benefits: A case study in London. *Environmental Pollution,* 157: 2645-2653.

Tortajada, C. (2006) Water Management in Singapore. *Water Resources Development*, 22(2): 227-240.

Tortajada, C. and Pobre, K. (2011) The Singapore-Malaysia water relationship: An analysis of the media perspectives. *Hydrological Sciences Journal*, 56(4): 597-614.

Töre, G., Meriç, S., Lofrano, G., De Feo, G. (2012) Removal of Trace Pollutants from Wastewater in Constructed Wetlands, in *Emerging Compounds Removal from Wastewater*, edited by G. Lofrano. SpringerBriefs in Green Chemistry for Sustainability: 39-58. [Online]. Available: http://link.springer.com/content/pdf/10.1007%2F978-94-007-3916-1_3.

Trotter, C., Tate, K., Scott, N., Townsend, J., Wilde, H., Lambie, S., Marden, M., Pinkney, T. (2005) Afforestation/reforestation of New Zealand marginal pasture lands by indigenous shrublands: The potential for Kyoto forest sinks. *Annal of Forestry Science*, (62): 865-871.

Trowsdale, S.A. and Simcock, R. (2011) Urban stormwater treatment using bioretention. *Journal of Hydrology*, 397(3-4): 167-174.

TSO (2008) *Planning Policy Statement 12: Creating strong safe and prosperous communities through Local Spatial Planning.* The Stationary Office, London. [Online]. Available: http://www.communities.gov.uk/documents/planningandbuilding/pdf/pps12lsp.pdf.

Tsoutsos, T., Frantzeskaki, N., Gekas, V. (2005) Environmental impacts from the solar energy technologies. *Energy Policy*, 33(3): 289-296.

Tyner, J., Wright, W., Dobbs, P. (2009) Increasing exfiltration from pervious concrete and temperature monitoring. *Journal of Environmental Management*, 90: 2636-2641.

Tzoulas, K., Korpela, K., Venn, S., Ylipelkonen, V., Kazmierczak, A., Niemela, J., James, P. (2007) *Conceptual framework integrating Green Infrastructure, ecosystem and human health*. [Online]. Available: http://usir.salford.ac.uk/9497/1/Tzoulas_et_al_2007.pdf.

UK National Ecosystem Assessment (2011) *The UK National Ecosystem Assessment: Technical Report.* UNEP-WCMC, Cambridge. [Online]. Available: http://uknea.unep-wcmc.org/LinkClick.aspx?fileticket=m%2BvhAV3c9uk%3D&tabid=82.

Ulrich, R.S. and Addoms, D.L. (1981) Psychological and Recreational Benefits of a Residential Park. *Journal of Leisure Research*, 13(1): 43-65.

UNEP (2011) *Transport: Investing in energy and resource efficiency*. United Nations Environmental Program. [Online]. Available: http://www.unep.org/transport/lowcarbon/newsletter/pdf/GER_10_Transport.pdf.

UNEP-WCMC (2008) *National and Regional Networks of Marine Protected Areas: A Review of Progress.* UNEP-WCMC, Cambridge. [Online]. Available: http://www.unep.org/regionalseas/publications/otherpubs/pdfs/MPA_Network_report.pdf.

United States Census Bureau (2010) *Philadelphia city, Pennsylvania QuickLinks*. [Online]. Available: http://quickfacts.census.gov/qfd/states/42/4260000lk.html.

United States Census Bureau (2012a) *Chicago population census 2010*. [Online]. Available: http://quickfacts.census.gov/qfd/states/17/1714000.html.

United States Census Bureau (2012b) *Philadelphia population census 2010*. [Online]. Available: http://quickfacts.census.gov/qfd/states/42/4260000.html.

United States Census Bureau (2012c) *New York population census 2010*. [Online]. Available: http://quickfacts.census.gov/qfd/states/36/3651000.html.

University of Washington (n.d.) *Botanical Gardens, Open Space Seattle 2100*. [Online]. Available: http://depts.washington.edu/open2100/pdf/2_OpenSpaceTypes/Open_Space_Types/botanical_gardens.pdf.

Urban Green Spaces Task Force (2002) *Green spaces. Better places.* London, UK: Department for Transport, Local Government and the Regions.

USDA (2004) *Conservation Corridor Planning at the Landscape Level – Managing for Wildlife Habitat, National Biology Handbook: Subpart B – Conservation Planning.* United States Department of Agriculture. [Online]. Available: ftp://ftp-fc.sc.egov.usda.gov/WHMI/NBHpdf/nbh613.pdf.

Van der Horst, R. and de Ridder, S. (2007) *The Influence of Roadside Infrastructure on Driving Behavior: A Driving Simulator Stud.* Journal of the Transportation Research Board. 2018(1): 36-44.

van Diemen, N. (2009) *Permeable Paving Systems.* International Specialised Skills Institute Incorporated. [Online]. Available: http://issinstitute.org.au/wp-content/media/2011/04/ISS-FEL-REPORT-van-Diemen-Low-Res.pdf.

van Roon, M. and van Roon, H. (2005) *Low Impact Urban Design and Development Principles for Assessment of Planning, Policy and Development Outcomes.* Centre for Urban Ecosystem Sustainability, University of Auckland. [Online]. Available: http://www.landcareresearch.co.nz/research/built/liudd/documents/LIUDD_WkP051_2005_Text.pdf.

Vavrus, S. and van Dorn, J. (2010) Projected future temperature and precipitation extremes in Chicago. *Journal of Great Lakes Research*, 36(SUPPL. 2): 22-32.

Vavrus, S., Walsh, J.E., Chapman, W.L., Portis, D. (2006) The behavior of extreme cold-air outbreaks under greenhouse warming. *International Journal of Climatology*, 26: 1133-1147.

Vestbro, D.U. (2004) *Conflicting Perspectives in the Development of Hammarby Sjöstad, Stockholm.* Stockholm, Sweden: Royal Institute of Technology (KTH).

Virginia Department of Forestry (2012) *Rain Gardens.* Virginia Department of Forestry. [Online]. Available: http://www.dof.virginia.gov/rfb/rain-gardens.shtml.

Voyde, E. (2011) *Quantifying the Complete Hydrologic Budget for an Extensive Living Roof.* PhD dissertation in Civil Engineering. University of Auckland, New Zealand.

Voyde, E., Fassman, E., Simcock, R. (2010a) Hydrology of an extensive living roof under sub-tropical climate conditions in Auckland, New Zealand. *Journal of Hydrology*, 394(3-4): 384-395.

Voyde, E., Fassman, E., Simcock, R., Wells, J. (2010b) Quantifying Evapotranspiration Rates for New Zealand Green Roofs. *Journal of Hydrologic Engineering*, 15(6): 395-403.

Vymazal, J. (2002) The use of subsurface constructed wetlands for wastewater treatment in the Czech Republic: 10 years experience. *Ecological Engineering*, 18(5): 633-646.

Vymazal, J. (2011) Plants used in constructed wetlands with horizontal subsurface flow: A review. *Hydrobiologia*, 674(1): 133-156.

Wadzuk, B., Rea, M., Woodruff, G., Flynn, K., Traver, R. (2010) Water Quality Performance of a Constructed Stormwater Wetland for All Flow Conditions. *Journal of the American Water Resources Association*, 46(2): 385-394.

Waitakere City Council (2011) *Waitakere Council green roof.* [Online]. Available: http://www.waitakere.govt.nz/abtcit/ec/ecoinit/greenroof.asp.

Walker, B.H., Holling, C.S., Carpenter, S.C., Kinzig, A.P. (2004) Resilience, adaptability and transformability. *Ecology and Society*, 9(2): 5.

Walker, C. (2004) The Public Value of Urban Parks. *Beyond Recreation: A Broader View of Urban Parks.* 1-8. Washinton, DC: The Urban Institute; New York: The Wallace Foundation. [Online]. Available: http://www.urban.org/uploadedPDF/311011_urban_parks.pdf.

Wang, K., Schaefer, V.R., Kevern, J.T., Suleiman, M.T. (2006) *Development of mix proportion for functional and durable pervious concrete*. Nashville, TN: National Ready Mixed Concrete Association Technology Forum: Focus on Pervious Concrete. [Online]. Available: https://fp.auburn.edu/heinmic/PerviousConcrete/PerviousMixDevelopment.pdf.

Wark, C.G. and Wark, W.W. (2003) Green Roof Specifications and Standards: Establishing an emerging technology. *The Construction Specifier,* 56(8): 1-12. [Online]. Available: http://www.fussypainting.com/pdf/GreenRoof.pdf.

WasteNot Consulting (2011) *Auckland Council Waste Assessment – Data Update*. Prepared for Auckland Council Solid Waste Business Unit. [Online]. Available: http://www.aucklandcouncil.govt.nz/EN/environmentwaste/rubbishrecycling/wastemanagementandminimisationplan/Documents/aucklandwasteassessmentappf.pdf.

Watercare Services Limited (2011) *Auckland Regional Water Demand Management Plan.* [Online]. Available: http://www.watercare.co.nz/SiteCollectionDocuments/AllPDFs/Publications/Demand_Management_Report_2011.pdf.

Waterfront Auckland (2012) *The Waterfront Plan 2012*. [Online]. Available: http://staging.waterfrontauckland.co.nz/getmedia/68b631ad-87ef-4501-b8cc-3083698b70da/39347-WAKL-Waterfront-Plan_Y.pdf.aspx/.

Waterfront Auckland (2013) *Sustainable Development Framework 2013.* [Online]. Available: http://www.waterfrontauckland.co.nz/getmedia/e644ab8a-e22c-47a2-a30b-d718d21919ef/41282_WAKL_Sustainable_Waterfront__WEB.pdf.aspx/.

Weldon, S. and Bailey, C. in collaboration with O'Brien, L. (2007) *New pathways to health and well-being: Summary of research to understand and overcome barriers to accessing woodland.* Scotland: Forestry Commission.

WERF (2009) *Chicago, Illinois: Becoming the 'Greenest City in America'*. Water Environment Research Foundation. [Online]. Available: http://www.werf.org/liveablecommunities/studies_chic_il.htm.

White, C. (2010) *Flood-proof road destroyed in deluge*. ABC News. [Online]. Available: http://www.abc.net.au/news/stories/2010/10/12/3036241.htm?site=Brisbane.

Whittinghill, L.J. and Rowe, D.B. (2011) Salt tolerance of common green roof and green wall plants. *Urban Ecosystems*, 14(4): 783-794.

WHO (1948) *Preamble to the Constitution of the World Health Organization as adopted by the International Health Conference.* New York, 19-22 June 1946; signed on 22 July 1946 by the representatives of 61 States (Official Records of the World Health Organization, (2): 100) and entered into force on 7 April 1948.

Wilcove, D.S., McLellan, C.H., Dobson, A.P. (1986) Habitat fragmentation in the temperate zone, in *Conservation Biology: The science of scarcity and diversity*, edited by M.E. Soulé. Sunderland, Massachusetts: Sinauer Associates: 237-256.

Wilcox, B.A. and Murphy, D.D. (1985) Conservation strategy: The effects of fragmentation on extinction. *American Naturalist*, 125: 879-887.

Williams, N., Rayner, J., Raynor, K. (2010) Green roofs for a wide brown land: Opportunities and barriers for rooftop greening in Australia. *Urban Forestry and Urban Greening*, 9(3): 245-251.

Williamson, K. (2003) *Growing with Green Infrastructure.* Doylestown, PA: Heritage Conservancy.

Wilson, G. (2010) *Brisbane's Future Greenery Could Capture More Than 100,000 tonnes of Carbon Dioxide a Year.* World Green Infrastructure Network. [Online].

Available: http://solar-e.com/articles/brisbane%E2%80%99s-future-greenery-could-capture-more-than-100000-tonnes-of-carbon-dioxide-a-year/.

Wong, N.H. and Yu, C. (2005) Study of green areas and urban heat island in a tropical city. *Habitat International*, 29(3): 547-558.

Wong, N.H., Chen, Y., Ong, C.L., Sia, A. (2003a) Investigation of thermal benefits of rooftop garden in the tropical environment. *Building and Environment*, 38(2): 261-270.

Wong, N.H., Tay, S.F., Wong, R., Ong, C.L., Sia, A. (2003b) Life cycle cost analysis of rooftop gardens in Singapore. *Building and Environment*, 38(3): 499-509.

Wong, T.H.F., Somes, N.L.G., Evangelisti, M.R. (1996) *Design of Constructed Wetlands and Wet Detention Basins for Stormwater Quality Management, Interim Guidelines for South West Western Australia.* Paper for Public Discussion, Waters and Rivers Commission, Australia.

World Economic Forum (2009) *Green Investing Towards a Clean Energy Infrastructure.* [Online]. Available: http://www3.weforum.org/docs/WEF_IV_GreenInvesting_Report_2009.pdf.

Worman, A. and Kronnas, V. (2005) Effect of pond shape and vegetation heterogeneity on flow and treatment performance of constructed wetlands. *Journal of Hydrology*, 301(1-4): 123-138.

Worrell Water Technologies (2007) *Tidal wetland Living Machine® system description and scientific basis.* [Online] Available: http://www.scribd.com/doc/90133941/Tidal-Wetland-Living-Machine-Technology-Description.

WWF (2011) *Green Infrastructure Sustainable Investments for the Benefit of Both People and Nature*. [Online]. Available: http://wwf.panda.org/who_we_are/wwf_offices/bulgaria/news/?200156/Green-Infrastructure-Sustainable-Investments-for-the-Benefit-of-Both-People-and-Nature.

WWF (2012) *Giant Panda Projects.* [Online]. Available: http://www.worldwildlife.org/species/finder/giantpanda/projects.html.

Xiao, Q.F. and McPherson, E.G. (2011) Performance of engineered soil and trees in a parking lot bioswale. *Urban Water Journal*, 8(4): 241-253.

Xing, Y., Handy, S., Buehler, T. (2008) Factors Associated with Bicycle Ownership and Use: A Study of 6 Small U.S. Cities. Paper presented at *87th Annual Meeting of the Transportation Research Board,* Washington, DC. [Online] Available: http://industrializedcyclist.com/factorsassocwbikeownrship.pdf.

Yadav, P., Foster, W.A., Mitsch, W.J., Grewal, P.S. (2012) Factors affecting mosquito populations in created wetlands in urban landscapes. *Urban Ecosystems*, 15(2): 499-511.

Yang, J., Yu, Q., Gong, P. (2008) Quantifying air pollution removal by green roofs in Chicago. *Atmospheric Environment*, 42(31): 7266-7273.

Younger, M., Morrow-Almeida, H., Vindigni, S., Dannenberg, A. (2008) The built environment, climate change and health opportunities for co-benefits. *American Journal of Preventive Medicine*, 35(5): 517-526.

Yu, S.L., Kuo, J., Fassman, E.A., Pan, H. (2001) Field Test of Grassed-Swale Performance in Removing Runoff Pollution. *Journal of Water Resources Planning and Management (ASCE*). 127(3): 168-171.

Yu, X., Jiang, L., Wang, J., Wang, L., Lei, G., Pittock, J. (2009) Freshwater management and climate change adaptation: Experiences from the central Yangtze in China. *Climate and Development*, 1: 241-248.

Yudelson Associates (2011) *Building and Construction Authority Zero Energy Building: Braddell Road Campus, Singapore.* [Online]. Available: http://www.solaripedia.com/files/1009.pdf.

Zhang, H-G. and Hong, J-M. (2006) Functions of plants of constructed wetlands. *Wetland Science*, 4(2): 146-154.

Zhang, Z., Liu, L., Li, X. (2009) Ecotourism and nature-reserve sustainability in environmentally fragile poor areas: The case of the Ordos Relict Gull Reserve in China. *Sustainability: Science, Practice and Policy*, 4(2): 12-22.

Zhang, S. (2010) Green Street: Landscape design approach to street stormwater management. *Advanced Materials Research*, 113-114: 1601-1605.

Zhang, X., Shen, L., Tam, V., Lee, W. (2012) Barriers to implement extensive green roof systems: A Hong Kong study. *Renewable and Sustainable Energy Reviews*, 16(1): 314-319.

Zwick, P. (1992) Stream habitat fragmentation – A threat to biodiversity. *Biodiversity and Conservation*, 1(2): 80-97.