Global green infrastructure

How is green infrastructure research translated into practice outside the UK?

Centre for Sustainable Planning and Environments, University of the West of England, Bristol

Report commissioned by Innovation Programmes and Partnerships, Natural Environment Research Council.

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Executive summary

The Centre for Sustainable Planning and Environments at the University of the West of England, Bristol have been commissioned by the Natural Environment Research Council (NERC) to conduct a review of how the evidence base for Green Infrastructure (GI) is being translated into practice across the international community. This builds on previous work that focussed on the grey literature targeted to a UK audience (Sinnett et al., 2016). This review will inform the future investment in GI from Innovation Programme and Partnerships within NERC.

We reviewed 26 pieces of grey literature aimed at an international audience. These include those from government departments (e.g. US Department of Agriculture) and global institutions (e.g. World Bank). Differences in the definition of GI internationally meant that some documents focussed almost exclusively on water management. Others included comprehensive reviews of the health and well-being outcomes associated with the use and presence of GI as well as broader evidence summaries.

The review examined the extent to which academic evidence is cited in the grey literature and which ecosystem services are prioritised in these documents. The findings can be summarised as follows:

- There is a strong focus on regulating services across all documents, with the exception of those solely looking at the health and well-being outcomes. These cite evidence that the following features of GI can impact on a range of services:
    - Trees, green roofs, parks and greenspaces can impact on air quality in cities;
    - Trees, green roofs and walls, Sustainable Drainage Systems (SuDS), parks, greenspaces, and greenery can cool the built environment, reducing the impact of the urban heat island and providing shading for people and buildings;
    - GI can significantly aid water management, with specific features including trees, green roofs, parks and gardens, but the greatest benefits occur when a 'green infrastructure approach' or SuDS are included instead of focusing on individual features;
    - GI features more commonly associated with rural and coastal areas including flood plains, wetlands, mangroves and coral reefs were also highlighted for the water management services they provide to urban environments;
    - Trees, and, to a lesser extent, SuDS, green roofs, peatlands, and wetlands can provide carbon storage;
    - Trees and riparian buffers can provide soil regulation, primarily through controlling soil erosion.
- There is also a robust evidence base on the cultural services, primarily provided through a few health focussed literature reviews but supported by summaries of evidence in the other documents. These report that trees, parks, greenspaces and neighbourhood greenery contribute to:

    - Sense of place, social cohesion and social interaction;
    - Physical and mental health through restorative benefits and providing opportunity for physical activity;
    - Health outcomes in deprived areas and for particular demographic groups including children and teenagers and older people;
    - Some negative health outcomes including from allergens and zoonoses;
    - Crime rates, perception of crime, recreation and tourism.
- Several documents cite evidence that trees, green roofs, parks and greenspaces, green corridors and floodplains can contribute to urban biodiversity and nature conservation;
- Some also include the risks to and from GI from invasive species and natural disasters and the impact of these on biodiversity;
- Very few sources include evidence on the potential for GI to provide supporting services;
- A few documents cite evidence on the provisioning services from GI, but this is almost exclusively focussed on community food production;
- Some evidence is reported that the presence of greenery can foster pro-environmental attitudes in young people.
- Many of the services provided by GI are also translated into economic benefits. These primarily relate to improvements in air quality, local climate regulation due to improvements in the thermal performance of buildings, flood risk management, and property prices.
- Some grey literature also refers to evidence related to the planning and long-term management of GI and how this relates to spatial planning and the delivery of high quality places, the importance of multidisciplinary and cross-sector collaboration, and of ensuring long-term maintenance and management is considered at the design stage and secured from the outset.

We have also compiled a suite of 43 case studies displaying a range of GI initiatives with a further nine summarised in more depth. These demonstrate that GI initiatives are being delivered globally to provide services including climate change adaptation and high quality places for people.

As with the planning and management evidence from the review, the lessons learned from some of the case studies highlight the importance of interdisciplinary collaboration, ensuring those involved in the planning, design and delivery of GI have the right skills and expertise, working with the community, and ensuring that long-term management is prioritised.

In general, the findings are similar as for the UK-focussed review in terms of the ecosystem services delivered by GI. However, there is greater prominence to issues including coastal defences, gender equality, the relationship between GI and health outcomes, and the economic case of GI reflecting the different priorities of an international audience and the emphasis of the grey literature we reviewed. There is an opportunity for the evidence base to be enhanced with high quality evaluation of projects and a greater consideration of the delivery of GI as well as the benefits it brings.

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Introduction

The Centre for Sustainable Planning and Environments at the University of the West of England, Bristol have been commissioned by the Natural Environment Research Council (NERC) to conduct a review of how the evidence base for Green Infrastructure (GI) is being translated into practice across the international community. This builds on previous work that focussed on the grey literature targeted to a UK audience (Sinnett et al., 2016). This review will inform the future investment in GI from Innovation Programme and Partnerships within NERC.

Definitions of green infrastructure

There are many definitions of green infrastructure. The definitions provided in the international grey literature are relatively varied and can be grouped as:

- Green infrastructure as a means to manage water in the built environment. These definitions focus on the role of green infrastructure in providing more natural water management than a typical built environment. The approaches to green infrastructure in this definition include Sustainable Drainage Systems (SuDS), Low Impact Development (LID), Water Sensitive Urban Design (WSUD) with features such as green roofs, rain gardens, swales, retention ponds, permeable paving, filter beds and rainwater harvesting dominating. These definitions primarily occur in the grey literature targeted at a US audience, reflecting the origins of the term (e.g. CNT, 2010; American Rivers et al., 2012; The Nature Conservancy, 2014); others are far more international in their scope (e.g. UNEP, 2014, World Bank, 2016).
- Some definitions allude to other benefits and so recognise that green infrastructure has a wider role than solely for water management but without specific mention of what this may include (The Nature Conservancy, 2014; UNEP, 2014)
- The remainder use definitions much more analogous to those used in the UK which refer to connected multifunctional networks of green and blue features that provide a number of benefits (or ecosystem services) (e.g. USDA, 2010; EPA, 2016). Although one is focussed on urban forests as 'the backbone of green infrastructure' (FAO, 2016) the emphasis is on its connectivity and multifunctionality.
- Some documents do not provide definitions of green infrastructure but instead focus on green spaces or 'managed landscapes' and the land uses these may include with no mention of their spatial relationship or functionality. These include parks, gardens, institutional land, playgrounds and amenity land, in urban or suburban areas, both private and publically-owned land. These are a mix of documents targeting different audiences but with a focus on health (e.g. Toronto Public Health, 2015; NCCEH, 2015; World Resources Institute, 2013).
- We also noted that in many countries the term green infrastructure primarily refers to features that would be associated with green buildings in the UK such as rain water harvesting, solar panels.

- Drawing all these points together NERC may wish to consider always providing a definition of GI in future funding calls to ensure that applicants fully understand the remit of the call, especially if this is likely to include international collaborations.

Our approach to the review

This review consists of two strands of work. Using the definitions above, we first reviewed a selection of grey literature produced across the international community. Second, we have drawn together a number of case studies that outline some of the initiatives that are taking place in practice.

The primary aim of the review is to examine the extent to which academic research is translated into practice across the international community and reflect on any differences with the UK. Therefore, the focus is grey literature aimed at a non-academic audience and specifically which draws evidence from the academic literature. The scope was grey literature focused on presenting the evidence related to GI or some aspect of it (e.g. trees, greenspaces). There is a substantial amount of grey literature available so the following was used to prioritise the documents considered:

- Grey literature aimed at an international audience, either a specific country or the international community as a whole;
- Grey literature written by a range of organisations for different disciplinary or geographical audiences;
- Citations of primary research whether in a literature review, summary of evidence or guidance;
- The grey literature was in English and available to download from the internet at no cost with a cut-off date of 31st December 2016;
- Some key global organisations were targeted within the search for relevant documents, including the World Bank and WHO. These would provide documents with global scope;
- Two documents are duplicated from the UK review: Science for Environment Policy (2012), which was judged to include a UK audience, and Bowen & Parry (2015) which provides a very recent and thorough analysis of the health and well-being evidence not available in explicitly UK-focussed grey literature at the time.

In total twenty-six pieces of grey literature were reviewed (Table 1). Grey literature that presented primary research only was not included as the aim of this review was to examine the use of academic evidence.

The evidence cited in the grey literature was organised by type of green infrastructure (e.g. green roofs, parks), then by the ecosystem services delivered by these. Ecosystem services are used to describe the goods and services, or benefits, provided by nature to human health and well-being. It is a useful framework to consider the evidence for green infrastructure and so is used to structure this report and the summary table. However, it presupposes the existence of 'nature', so the benefits that green infrastructure might provide to nature conservation and biodiversity do not fit into it so are summarised

separately, before the ecosystem services. Similarly, often the next step in the assessment of ecosystem services is some form of economic valuation of these services so this evidence is summarised. In contrast to the UK-focussed review some grey literature included evidence related to the planning and long-term management of green infrastructure. This evidence is also included.

A list of the academic literature is provided at the end of the report. An overview is provided in Table 2.

Table 1 Grey literature included in this report

Title	Year	Organisation (Authorship)	Literature review	Evidence summary	Guidance	Case studies
The benefits of parks	2006	The Trust for Public Land		✓		✓
Nature and health	2008	Health Council of the Netherlands	✓			
The value of parks	2008	Parks Forum		✓		✓
The value of green infrastructure	2010	Center for Neighbourhood Technology (CNT) and American Rivers		✓	✓	✓
Green and open space planning for urban consolidation	2010	Griffith University	✓		✓	✓
Sustaining America's urban trees and forests	2010	United States Department of Agriculture (USDA)	✓		✓	✓
Healthy open spaces	2010	Regional Public Health		✓		✓
Banking on green: A look at how green infrastructure can save municipalities money and provide economic benefits community-wide	2012	American Rivers, Water Environment Federation, American Society of Landscape Architects, ECONorthwest	✓			✓
The multifunctionality of green infrastructure	2012	Science for Environmental Policy, European Commission	✓			✓
Cool communities: Urban trees, climate and health	2013	Curtin University and World Health Organisation (WHO)		✓	✓	✓
Green infrastructure: An essential foundation sustainable urban futures in Africa	2013	CLUVA		✓	✓	✓
Creating value through ecosystem service management in urban and suburban landscapes	2013	World Resources Institute		✓	✓	
The natural environments initiative	2014	Center for Health and the Global Environment	✓			
A flood of benefits	2014	The Nature Conservancy		✓	✓	✓
Green infrastructure: Guide for water management	2014	United Nations Environment Programme (UNEP)		✓	✓	✓
The evidence base for linkages between green infrastructure, public health and economic benefit	2015	Bowen and Parry	✓			
Exploring nature-based solutions	2015	European Environment Agency (EEA)	✓			
Green space and mental health: Pathways, impacts and gaps	2015	National Collaborating Centre for Environmental Health (NCCEH)	✓			
Green city: Why nature matters to health. An evidence review	2015	Toronto Public Health	✓			
Urban street trees	2014	WALGA		✓	✓	
The impact of green space on heat and air pollution in urban communities	2015	Green Belt and David Suzuki Foundation	✓		✓	
Integrating ecosystem approaches, green infrastructure and spatial planning	2016	Environment Protection Agency (Ireland)			✓	✓
Guidelines on urban and peri-urban forestry	2016	Food and Agriculture Organisation of the United Nations (FAO)			✓	✓
Urban green spaces and health	2016	WHO	✓		✓	
The role of green infrastructure solutions in urban flood risk management	2016a	World Bank		✓	✓	✓
Managing coasts with natural solutions	2016b	World Bank			✓	✓

Findings

Biodiversity and nature conservation

Green infrastructure has the potential to increase biodiversity in the urban environment. Several pieces of grey literature highlight the negative consequences of the loss of biodiversity and ecosystem function (CNT, 2010; Africa et al., 2014). Following on from this they point to the ability of GI or its constituent features to enhance habitats and biodiversity (EPA, 2016); these include **trees** (USDA, 2010; FAO, 2016), **green roofs** (UNEP, 2014), **green spaces** and **parks** (Griffith University, 2010; WHO, 2016), **corridors** (EPA, 2016) and **floodplains** (EEA, 2015). Some refer to the role of these features in acting as 'reservoirs' for vulnerable species (USDA, 2010; EPA, 2016). One refers more specifically to the benefits to birds, mammals, fish and reptile species (FAO, 2016).

The opportunity for GI to reverse the impact of habitat fragmentation by providing green or ecological **corridors** is reported (Griffith University, 2010; Science for Environment Policy, 2012; EPA, 2016). However, the loss of GI is also highlighted as one threat to further habitat fragmentation (USDA, 2010). Similarly, some documents cite concerns that some features of GI are associated with increased risks of invasive species and vector-borne diseases; this includes artificial **wetlands** (UNEP, 2014). WHO (2016) highlights that the regulating services provided by GI (see below), including air and noise pollution and extreme weather events also benefit other species than humans.

One document highlights the role of GI in providing access to wildlife for urban populations to enjoy or acting as an indicator of wider environmental quality (USDA, 2010). Another suggests that green spaces may provide benefits to wildlife by reducing noise pollution (WHO, 2016).

Finally, one source also highlights a number of risks to green infrastructure, specifically, trees, from the presence of non-native and/or invasive species, increased urbanisation, wildfires and natural disasters (USDA, 2010).

The international grey literature places greater emphasis on the impacts of GI on nature conservation and biodiversity than the UK-focussed literature. The latter tended to focus on the benefits of contact with nature from having high quality habitats accessible to urban populations.

Supporting services

Supporting services are those that underpin the other services. They include soil formation, photosynthesis, primary production, and nutrient and water cycling. There is very little attention given to the role of GI in supporting services across the grey literature. Much of the research activity examining supporting services has focussed on productive systems

such as agriculture and forestry with these services in urban environments given far less attention. There is evidence related to urban soil quality, but this is often from the perspective of the risk assessment of contaminated land or the interventions on urban soils that may enable vegetation establishment (for example, soil amendments or cultivation) as opposed to the benefits that urban vegetation may bring to urban soil function.

However, there are a few instances where supporting services do feature in the grey literature:

- The role of **forests and forested wetlands** in **soil and peat formation** (Science for Environment Policy, 2012);
- The role of **trees** in **photosynthetic** oxygen production (The Trust for Public Land, 2008);
- The dependency of fisheries and fish stocks on the **organic matter** supplied by **mangroves** (UNEP, 2014).

Water cycling is generally discussed in the context of flood risk management and/or climate change adaptation and so the role of GI in this supporting service is included under *Regulating services* (see below).

The lack of consideration of the ability of GI to provide supporting services mirrors the findings from the UK-focussed review of grey literature. The only exception to this absence is the importance of the supporting role of mangroves.

Provisioning services

Provisioning services are those where a resource is provided by the ecosystem in question. This could include food, timber, fibre, fuel, or fresh water. As with the supporting services there is very little consideration of the role of GI in provisioning services, again presumably because the focus of these services is primarily in rural settings.

However, there are some exceptions. The benefits **community gardens** and other forms of **urban agriculture** can provide in improving nutrition in the diets of urban populations is highlighted by Griffith University (2010), Toronto Public Health (2015) and CLUVA (2013). In some cases the economic benefits for particular social groups is also specifically referred to where, for example, the food has benefited food banks, schools, community organisations or the urban poor in developing countries (FAO, 2016; World Bank, 2016). The only land use associated with food and timber production specifically were **floodplains** (EEA, 2015)

The beneficial role of a **buffer zone** between an urban and rural fringe in **Spain** in promoting organic **food** was highlighted (Science for Environment Policy, 2012).

There is very little mention of the provision of fuel, timber or other materials. However, the production of **charcoal** in the **Democratic Republic of the Congo** (FAO, 2016) is

referred to, as is the role of mangroves in providing materials for fuel, construction, medicines and industrial processes (UNEP, 2014).

As with water cycling the provision of **fresh water** is primarily discussed in the context of water regulation and so is included in the section on *Regulating services* (see below).

These findings are also similar to the UK-focussed review in that the emphasis is on the social or health benefits of involvement in food growing initiatives. However, those documents that are perhaps more global in their reach do include additional benefits, for example to the urban poor.

Regulating services

The regulating services provided by different features of GI are an active area of research and are often a key feature of the grey literature. As noted above some grey literature focusses almost exclusively on the water regulation services of GI. However, services such as air quality, climate and water regulation are far more visible in the grey literature than others including pollination, carbon storage and soil regulation.

Air quality

The ability of vegetation to mitigate poor air quality has received considerable attention in much of the grey literature. Some documents refer more generally to '**vegetation**' or '**greeness**' (World Resources Institute, 2013; Green Belt and David Suzuki Foundation, 2015; WHO, 2016). Many report evidence that **trees** can remove pollutants from the air (The Trust for Public Land, 2006; USDA, 2010; American Rivers et al., 2012; Science for Environment Policy, 2012; Curtin University and WHO, 2013; Walga, 2014; Green Belt and David Suzuki Foundation, 2015; FAO, 2016; WHO, 2016). This includes the interception of particulate matter (The Trust for Public Land, 2006; Parks Forum, 2008; CNT, 2010; World Resources Institute, 2013; Green Belt and David Suzuki Foundation, 2015; Walga, 2014) and uptake of ozone, sulphur dioxide, nitrogen dioxide and carbon monoxide (The Trust for Public Land, 2006; CNT, 2010; Green Belt and David Suzuki Foundation, 2015). In addition, the association between poor air quality and low tree cover in deprived neighbourhoods has also been highlighted (Green Belt and David Suzuki Foundation, 2015).

A number of sources cite evidence that **green roofs** are also capable of removing air pollutants including particulate matter, nitrous oxide, sulphur dioxide, carbon monoxide and ozone (American Rivers et al., 2012; Science for Environment Policy, 2012; UNEP, 2014; Green Belt and David Suzuki Foundation, 2015). One document reports that green roofs are not as effective as trees but may provide an opportunity in locations where the availability of space for tree planting is limited (Green Belt and David Suzuki Foundation, 2015).

One piece of grey literature cites evidence that **rain gardens** and **bioswales** may also reduce air pollution (UNEP, 2014).

Several pieces of grey literature cite evidence that **urban parks** and **green spaces** can improve air quality by removing particulate matter, ozone, carbon monoxide, carbon dioxide, sulphur dioxide, nitrogen dioxide (UNEP, 2014; WHO, 2016), with the highest removal rates being for PM10 and ozone. Green Belt and David Suzuki Foundation (2015) highlight that there is a research gap in this area and only moderate evidence.

The documents refer to studies on the impacts of **trees** in New York City, Los Angeles, the conterminous United States, and the Greater London Area; **green roofs** in Chicago, US; and **green spaces** in Portugal and France.

However, several sources also report that the impact of GI on air quality is complex. For example, tree canopies may reduce ventilation in street canyons, trapping pollution at a height where human exposure will be greatest (Green Belt and David Suzuki Foundation, 2015; WHO, 2016) and vegetation produces volatile organic compounds (VOCs; Green Belt and David Suzuki Foundation, 2015). But stress that it is possible to avoid this through careful planting design and species selection (WHO, 2016; Green Belt and David Suzuki Foundation, 2015). Similarly, a minimal effect or nuance in the impact of trees on air pollution is reported, for example depending on the ambient concentration (Green Belt and David Suzuki Foundation, 2015), or highlighting the temporary nature of particulate interceptions as they are resuspended or washed off into the soil system (Walga, 2014). The impact on air quality is also reported to be dependent on species, leaf morphology and vegetation size (Green Belt and David Suzuki Foundation, 2015).

While most of the studies cited report on the impact on air quality some relate these to the health outcomes. These include studies that report numbers of avoided deaths, acute respiratory symptoms and hospital admissions from green infrastructure (Green Belt and David Suzuki Foundation, 2015). One source suggests that physical activity in parks adjacent to sources of air pollution may result in an increased exposure to these pollutions (WHO, 2016); although they highlight another study that reported that air pollution did not affect the benefits of physical activity on mortality.

In addition to the impacts of green infrastraucture on human health, one source also included evidence of the detrimental effects of air pollution on vegetation health, including from the deposition of ozone, nitrogen, sulphur and hydrogen, metals and 'other toxic particulates' (USDA, 2010).

Local climate regulation

Many pieces of grey literature referred to evidence that **trees** can cool the urban environment. Mechanisms include through the provision of shade to buildings and people in the outdoor environment (USDA, 2010; American Rivers, 2012; Curtin University and WHO, 2013; Walga, 2014; Green Belt and David Suzuki Foundation, 2015; WHO, 2016), and through evapotranspiration (USDA, 2010; Curtin University and WHO, 2013; Walga, 2014). The benefits cited include reduced energy consumption in buildings (The Trust for Public

Land, 2006;CNT, 2010; USDA, 2010; American Rivers et al., 2011; Curtin University and WHO, 2013; World Resources Institute, 2013; Walga, 2014; FAO, 2016; WHO, 2016), reduction in heat stress (USDA, 2010; Curtin University and WHO, 2013; WHO, 2016), and increasing the life of road and pavement surfacing (Walga, 2014). As well as reduced costs from shading buildings, trees may also increase heating costs through shading in colder months (Walga, 2014; Green Belt and David Suzuki Foundation, 2015). However, they may protect buildings from winds, also increasing their energy performance (Walga, 2014).

Green roofs and walls are also reported by many of the documents to reduce temperatures in the urban environment. As with trees the mechanisms are primarily through shading and evapotranspiration (American Rivers et al., 2012; Science for Environment Policy, 2012). Reported impacts include reductions in roof or wall surface and/or air temperatures (American Rivers et al., 2012; Science for Environment Policy, 2013; UNEP, 2014; Green Belt and David Suzuki Foundation, 2015; WHO, 2016), and improving the energy performance of buildings, including through insulation (American Rivers et al., 2012; Science for Environment Policy, 2013; UNEP, 2014).

The reduced heat storage of pervious paving, often included in **SuDS**, was also reported, with higher day time and lower night time temperatures compared with traditional concrete (CNT, 2010). Similarly, the co-benefits of urban cooling through the use of GI to manage water has also been highlighted (CNT, 2010).

The role of vegetation in **parks** and **green spaces** in reducing urban air and surface temperatures has also been highlighted in much of the grey literature (Science for Environment Policy, 2012; EEA, 2015; Green Belt and David Suzuki Foundation, 2015; WHO, 2016). This cooling effect was reported to continue up to one kilometre outside the boundary of the park (Green Belt and David Suzuki Foundation, 2015; WHO, 2016). However, one study was cited of a park having no cooling effect, and another found no effect on the surrounding area (Green Belt and David Suzuki Foundation, 2015).

Other documents refer to the beneficial effect of **riparian buffers** (UNEP, 2014) and **greenery** in general on local climate (Curtin University and WHO, 2013; Walga, 2014; Green Belt and David Suzuki Foundation, 2015; WHO, 2016). These include studies that find increased urban cooling in areas with greater **greenery**, **green space** or **tree density** (Green Belt and David Suzuki Foundation, 2015; WHO, 2016).

Some report that the effectiveness of GI in climate regulation varies with species (CNT, 2010; CULVA, 2013; Walga, 2014; Green Belt and David Suzuki Foundation, 2015), planting design (CNT, 2010; Africa et al., 2014; Walga, 2014; Green Belt and David Suzuki Foundation, 2015), and density of vegetation (Green Belt and David Suzuki Foundation, 2015), inclusion of water bodies (WHO, 2016). Other factors include local temperature and wind conditions (Green Belt and David Suzuki Foundation, 2015) and the depth of the growing medium in green roofs (CNT, 2010).

The evidence cited includes studies on the impact of **trees** in Washington and the American Mid-West, and Lisbon, Italy; **green roofs** in Chicago and Toronto, US; Basel, Switzerland; **parks** in Athens, Greece; Addis Ababa, Ethiopia; Ljubljana, Slovenia; Manchester and London, England; and Pheonix, US.

As with the impacts on air quality, the grey literature cites associations between surface temperature and levels of greenspace and greenery and how these are also related to levels of neighbourhood deprivation and different population groups such as older people and ethnic minorities (Green Belt and David Suzuki Foundation, 2015; WHO, 2016). One document also cites evidence from a cross-sectional study that reported self-reported health benefits from urban cooling in parks (Green Belt and David Suzuki Foundation, 2015).

Two pieces of grey literature also highlight that changes in the urban climate may also affect the health and function of urban vegetation (USDA, 2010; Africa et al., 2014), whilst another highlights xeriscaping using drought-tolerant species to reduce the need for water (USDA, 2010).

Water regulation/purification

The ability of GI to manage urban water through stormwater management, flood prevention, improvements to water quality and water conservation is well documented. Many of the pieces of grey literature reviewed had a focus on urban water management. The term **green infrastructure** is used interchangeably with **SuDS**, **Low Impact Development** and **Water Sensitive Urban Design**.

Several sources highlight the beneficial impact of GI on water management. This includes improved groundwater recharge (American Rivers et al., 2012), stormwater management (CNT, 2010; American Rivers et al., 2012; Science for Environment Policy, 2012; World Resources Institute, 2013; Walga, 2014; EPA, 2016; FAO, 2016), erosion control (American Rivers et al., 2012) and water quality (Science for Environment Policy, 2012; Walga, 2014; EPA, 2016; FAO, 2016).

Some grey literature highlights the relative effectiveness of different forms of GI in water management, for example porous pavement is more cost-effective than a green street, followed by green roofs (American Rivers et al., 2012). The efficacy of GI as an approach compared with street trees alone (Science for Environment Policy, 2012), and its increased effectiveness compared with conventional stormwater management (CNT, 2010; American Rivers et al., 2012; EPA, 2016) and agricultural systems is also reported (World Resources Institute, 2013). CNT (2010) highlight findings from one study that SuDS can improve as the plants mature whereas conventional systems degrade over time.

The grey literature also highlights the ability of **trees** specifically to contribute to water management. Again, this includes through the recycling of water (The Trust for Public Land, 2006; FAO, 2016), reducing surface water run off (The Trust for Public Land, 2006; USDA,

2010; American Rivers et al., 2012; Curtin University and WHO, 2013; World Resources Institute, 2013; UNEP, 2014; Walga, 2014; FAO, 2016; World Bank, 2016) and filtering water pollution (The Trust for Public Land, 2006; USDA, 2010; Walga, 2014). Although one document suggests that, due to the time taken to mature, trees are not as effective as green roofs (Science for Environment Policy, 2012).

Similarly, the benefits of **green roofs** for stormwater management are also cited by a number of grey literature documents (CNT, 2010; American Rivers et al., 2012, Science for Environment Policy, 2012; CLUVA, 2013; UNEP, 2014).

Some documents relate the improved water management to indirect benefits including reducing energy costs from not having to import water (American Rivers et al., 2012), and reduced costs from water treatment (USDA, 2010).

Parks and **green spaces** are also recognised in the grey literature for their flood risk management (World Resources Institute, 2013; WHO, 2016) and ability to improve water quality (World Resources Institute, 2013).

The grey literature also recognises several features of GI for their ability to regulate water that are often missing from general discussions on the benefits of GI: **agricultural** and **forest systems**; **wetlands**, **floodplains** and **riparian systems**; and **coastal wetlands**, **mangrove forests** and **coral reefs** (see below). These are often located outside of urban areas, yet have an important role to play in protecting cities from flooding and storm surges.

However, two documents highlight that vegetation can block stormwater drains, and that watercourses with excessive amounts of dead plant material can become toxic to aquatic species (Walga, 2014; UNEP, 2014).

Well-managed **agricultural** and **forest systems** are reported to be effective at preventing water pollutants from entering watercourses and drinking water supplies (World Resources Institute, 2013; UNEP, 2014).

Similarly, **wetlands**, **floodplains** and **riparian buffers** have also been found to provide protection from stormwater (Parks Forum, 2008; American Rivers et al., 2012; Science for Environment Policy, 2012; The Nature Conservancy, 2014; UNEP, 2014; EEA, 2015) and allow groundwater recharge (The Nature Conservancy, 2014; UNEP, 2014). In addition, they can protect watercourses from sediment and nutrient pollution (Parks Forum, 2008; The Nature Conservancy, 2014; EEA, 2015; UNEP, 2014; FAO, 2016), with **riparian buffers** being particularly effective, providing erosion control and providing shade which further improves water quality (UNEP, 2014). One document also reports on the effectiveness of **constructed wetlands** (UNEP, 2014).

Studies cited include the use of **SuDS** to manage water in Los Angeles, Chicago, New Hampshire, Illinois, Portland, Seattle, and Texas, US; Vancouver, Canada; **trees** in Modesto

and Santa Monica, California, New York City, Mid-West, Dayton, and Ohio, US; **green roofs** in Chicago, Minneapolis, and Washington, US; Manchester, England; and **green spaces** in Beijing, China. In more rural settings studies are included of **agricultural** and **forest systems** upstream of New York City, US; **floodplains** in Africa, along the Danube, and Boston, US; **wetlands** in New Zealand, and **riparian buffers** in Denmark.

Mangroves, coastal wetlands and **forests** are recognised in the grey literature for their ability to protect coastal communities and infrastructure from storm surges, floods and tsunami (Science for Environment Policy, 2012; UNEP, 2014; EEA, 2015; World Bank, 2016b). The mechanisms include mangrove forests reducing wave height, speed and distance travelled, and, along with wetlands, wind speed (World Bank, 2016b). World Bank (2016b) presents particularly detailed evidence, case studies and guidance. This includes the effects of different species, vegetation structure density and volume, maturity and width (distance inland) of mangrove forest, surface roughness of vegetation, topography and the presence of channels, pools, open water, and foreshore habitats such as coral reefs (see below). They also report that mangroves influence sedimentation and erosion processes therefore affecting local topography.

The grey literature refers to examples from the **mangroves** of Vietnam, Australia, Japan, Thailand, India, Bangladesh, China, Indonesia, Malaysia, Sri Lanka and US; a **coastal forest** in Indonesia, and **coastal wetlands** in the UK and US.

In some cases evidence is provided for the direct beneficial impact on reducing property and crop damage, and loss of life (Science for Environment Policy, 2012; World Bank, 2016b), including reduced maintenance costs for hard infrastructure (UNEP, 2014).

Finally, **coral reefs** also play an important role in protecting coastal communities from storm surges and flooding. Although not 'green' or vegetated, they are included here as they often feature along with mangroves, wetlands and forests in terms of coastal green infrastructure. They provide breakwaters and bottom friction that reduce wave energy and height (UNEP, 2014; World Bank, 2016b), also increasing the transport of sediments, nutrients and larvae (World Bank, 2016b).

Several characteristics of coral reefs impact on their ability to provide protection from storms including the morphology of the reef, its slope and surface roughness and the depth of the water (World Bank, 2016b).

World Bank (2016b) cite evidence on the ability of **coral reefs** to provide coastal protection in the Caribbean, Maldives, Australia, China, Japan, Guam, Indonesia, Marshall Islands, New Zealand, Mexico, Mayotte and Hawaii, US.

Carbon storage/reduction

Several pieces of grey literature report evidence that GI can sequester and store carbon from the atmosphere. Most of the evidence relates the effectiveness of **trees** for this service (CNT, 2010; World Resources Institute, 2013; EEA, 2015; WHO, 2016), including the impact of different tree sizes and planting positions (CNT, 2010). Documents cite studies from the conterminous and Mid-West US, Washington, US and Johannesburg, South Africa.

In addition, some of the grey literature cites limited evidence that **green roofs** (CNT, 2010; UNEP, 2014), **rain gardens** and **swales** (UNEP, 2014), greenspaces (Griffith University, 2016) and **urban vegetation** in general, including lawns, (World Resources Institute, 2013) can store carbon.

Two sources also refer to the effectiveness of more rural systems in carbon storage, including new **forests** (Science for Environment Policy, 2012), **peatlands** and **wetlands** (UNEP, 2014).

Soil regulation

Several documents provide evidence that GI can reduce soil erosion and stabilise the land. Again **trees** are particularly effective (The Trust for Public Land, 2006; UNEP, 2014; EEA, 2015; FAO, 2016), as well as **riparian buffers** (UNEP, 2014) and '**vegetative cover**' (World Resources Institute, 2013).

Two pieces of grey literature also refer to the relationship between GI and soil contamination. One highlights the potential for **trees** and other **vegetation** to remediate contaminated soils (USDA, 2010) and the other cautions that **urban agriculture** on such soils could increase the risk of exposure to contaminants (Africa et al., 2014).

As with the review of UK grey literature, there is a focus on the services green infrastructure provides to water management, climate regulation and mitigating poor air quality. Again, more evidence is presented for the role of trees, parks and greenspaces, and, particularly in the US, green roofs. However, there are different features of green infrastructure that are given far more prominence in the international grey literature; most notably mangroves, wetlands and coral reefs reflecting the differing habitats but also the greater risks from coastal flooding. Similarly, the role of green infrastructure in soil stabilisation and protection from erosion is given more attention.

Cultural services

Aesthetic experience, sense of place

There are a few references of the contribution GI makes to aesthetic experience or sense of place in the documents examined. These include the positive affect of experiencing nature in the built environment (USDA, 2010; Center for Health and Global Environment, 2014),

and the connection with cultural heritage (Parks Forum, 2008), sense of place and place identity provided by **parks** and **green spaces** (Curtin University and WHO, 2013; WHO, 2016). Some of the grey literature refers to the contribution to the aesthetic experience from **trees** and **forests** (USDA, 2010; UNEP 2014; WALGA, 2014). Several documents also cite evidence related to the mitigation of traffic noise, which is a specific sensory benefit of GI (USDA 2010; Curtin University and WHO, 2013; WHO, 2016).

The evidence cited includes studies on the impact on traffic noise from **trees** and **parks** in Mexico; **vegetated courtyards**, in Sweden; **fountain** and **bird song noise** in Belgium, and **vegetation** in India.

Social cohesion and social interaction

Green infrastructure is described as improving social cohesion. This is often in terms of improved sense of community or neighbourhood social ties, increased quality of life or reduced loneliness and isolation (The Trust for Public Land, 2006; Health Council of the Netherlands, 2008; CNT, 2010; Griffith University, 2010; Regional Public Health, 2010; Center for Health and Global Environment, 2014; Bowen & Parry, 2015; NCCEH, 2015; WHO 2016). Most of the citations are in relation to **trees**, **community gardens**, **parks**, **green spaces** or **greenery** in general. Social cohesion comes in part from increased social interaction, which can result from organised activities (Regional Public Health, 2010; NCCEH, 2015). Some social benefits are cited specifically in relation to the elderly (NCCEH, 2015, WHO, 2016), or children and the young (WHO, 2016), or in deprived neighbourhoods (Regional Public Health, 2010). Social interaction is also highlighted as being particularly beneficial for people with disorders including anxiety, depression and schizophrenia (Parks Forum, 2008, Griffith University, 2010; Regional Public Health, 2010, Center for Health and the Global Environment, 2014; NCCEH, 2015; WHO, 2016). Some documents also suggest that increased social capital as a result of GI interventions can help communities to be more resilient to change or disaster (The Trust for Public Land, 2006; WHO, 2016).

The evidence cited includes studies on the impact of **trees**, in Baltimore and Oregon, US; **greenspace**, in Maryland, US and Zurich, Switzerland; **gardens** in Finland; **community gardens** in New York, US; **urban forestry** in New York, US, and **greenery**, in the Netherlands.

Psychological and mental health outcomes

Many of the documents reviewed cited evidence of the numerous psychological benefits of GI. Some of these are reported in terms of self-esteem, well-being, life satisfaction, mood, reduced negativity, restoration and relaxation, and mental health (The Trust for Public Land, 2006; Health Council of the Netherlands, 2008; CNT, 2010; Curtin University and WHO, 2013; Center for Health and the Global Environment, 2014; NCCEH, 2015; Toronto Public Health, 2015; WHO, 2016; World Bank, 2016a). The above benefits are usually described in

relation to **trees**, **gardens**, **green spaces**, **water features**, or **greenery** in general. A limited number of studies also report on GI having no, or negative, psychological effects (Center for Health and the Global Environment, 2014).

Some of the evidence presented concerns effects on specific psychological disorders, conditions and negative states (Parks Forum, 2008; Regional Public Health, 2010; Science for Environment Policy, 2012; World Resources Institute, 2013; Center for Health and the Global Environment, 2014; WALGA, 2014; Bowen & Parry, 2015; NCCEH, 2015; Toronto Public Health, 2015; WHO, 2016). These include anxiety, ADHD in children, autism, aggression, fatigue, sadness, Alzheimer's, dementia and schizophrenia. A few of the studies cited report that GI had no effect on anxiety (Center for Health and the Global Environment, 2014).

Numerous pieces of grey literature specifically refer to the impact of GI on depression and stress. In relation to depression, evidence explores beneficial potential of microbes, the importance of proximity to, and amount of, GI, gardening as an activity and GI as a site for the treatment of depression (Parks Forum, 2008; World Resources Institute, 2013; Center for Health and the Global Environment, 2014; NCCEH, 2015; FAO, 2016; WHO, 2016). A few studies are also referred to which report GI as having no effect on depression (Bowen and Parry, 2015; NCCEH, 2015). Similarly, the impact on stress is examined based on proximity to, and amount of, GI as well as the role of gardening as an activity. But evidence is also presented on the effect on different demographic groups and natural sensory input (Health Council of the Netherlands, 2008; Regional Public health, 2010; Science for Environment Policy, 2012; Center for Health and the Global Environment, 2014; WALGA, 2014; Bowen and Parry, 2015; NCCEH, 2015; WHO, 2016). Most of the citations around benefits for depression and stress relate to **trees**, **forests**, **parks**, **natural environments** in general and, particularly, **green spaces**.

Evidence is cited relating to the impact of GI on cognitive performance, including improvement in memory and restoration of performance after stress, and in children who exhibited improved educational performance (The Trust for Public Land, 2006; Health Council of the Netherlands, 2008; Center for Health and the Global Environment, 2014; Bowen & Parry, 2015; NCCEH, 2015; WHO, 2016). Similarly, the benefits of wild and natural environments in providing opportunities for children and young people to develop their risk management skills through undertaking risky and adventurous behaviour (WHO, 2016).

The studies include evidence on the health outcomes from **trees**, in the US, Michigan, Chicago, and London, England; **parks** and **green spaces** in Adelaide, Australia, Lithuania, Scotland and Helsinki, Finland, the UK, Sweden, US, Netherlands, Denmark and Michigan and Chicago, Miami, US; **private gardens** in the UK, **blue space** in Germany, UK and Denmark; **street greenery** in Adelaide, Australia and Lithuania; **forests** in Helsinki, Finland, Zurich, Switzerland, Scotland, China, Korea, and Japan; **natural environments** in

Baltimore, US, Pakistan and Scotland; and **neighbourhood greenery** in the US, New Zealand and Australia.

A few documents cite evidence that the quality of the green infrastructure is important in delivering mental health outcomes (Center for Health and Global Environment, 2014; NCCEH, 2015; WHO, 2016). This includes maintenance standards, accessibility and various sensory qualities. Other evidence examines psychological effects based on gender or age, or has noted that the psychological outcomes are specifically beneficial for those in deprived areas (WHO, 2016). A couple of citations refer to the psychological benefits of exercise in green surroundings (Health Council of the Netherlands, 2008; Parks Forum, 2008) and others note that green infrastructure can be useful as a site for various psychological treatments (NCCEH, 2015). Linked to experience of green infrastructure is connection with nature, which is, in turn, associated with improved mental health outcomes (Center for Health and the Global Environment, 2014). Evidence also suggests green infrastructure can aid sleep (Center for Health and the Global Environment, 2014; WHO, 2016).

Physical activity and physical health

Many of the grey literature sources cite evidence related to green infrastructure and physical health. These include reduced risk of a number of non-communicable diseases including cancer, stroke, respiratory, cardiovascular and circulatory conditions, allergies and diabetes (Centre for Health and the Global Environment, 2014; Toronto Public Health, 2015; WHO, 2016). These citations relate to **street trees**, **parks**, **green spaces**, **forests**, and **residential greenness**.

The grey literature also includes evidence of the relationship between green infrastructure and physical activity or obesity including in children (Health Council of the Netherlands, 2008; Curtin University and WHO, 2013; Center for Health and the Global Environment, 2014; NCCEH, 2015; Toronto Public Health, 2015; FAO, 2016; WHO, 2016; Word Bank, 2016a). This includes evidence for the differential effect on physical activity levels across demographic groups (FAO, 2016; WHO, 2016), including older people (WHO, 2016). Some sources also cite evidence suggesting that green infrastructure does not relate to lowered obesity (Toronto Public Health, 2015) or increased physical activity (Health Council of the Netherlands, 2008, NCCEH, 2015). Walking is the form of exercise most often cited in relation to green infrastructure (Center for Health and the Global Environment, 2014; WHO, 2016). The outcomes are generally related to **trees**, **forests**, **parks**, **green spaces**, **gardens** and general levels of **greenery**.

As mentioned in the discussion of provisioning services some sources cite evidence of a positive relationship between green infrastructure, specifically, **community gardens**, and diet and nutrition (Griffith University, 2010; CLUVA, 2013; Centre for Health and the Global Environment, 2014; Bowen & Parry, 2015; Toronto Public Health, 2015; EPA, 2016).

The grey literature also refer, to a lesser extent, to a number of other physical health outcomes, including:

- Improvements in the immune systems (Center for Health and the Global Environment, 2014; WHO, 2016);
- Better self-reported health in older people (WHO, 2016);
- Quicker recovery from illness, (Nowak et al, 2010; Center for Health and the Global Environment, 2014; Bowen and Parry 2015; FAO, 2016);
- Reduced mortality by various causes (Health Council for the Netherlands, 2008; Center for Health and the Global Environment, 2014; Toronto Public Health, 2015; WHO, 2016), although other studies find no effect on mortality (Center for Health and the Global Environment, 2014, Toronto Public Health, 2015);
- Benefits for pregnancy, mainly increased birth weight (Center for Health and the Global Environment, 2014; NCCEH, 2015; Toronto Public Health, 2015; WHO, 2016);
- Increased levels of vitamin D (WHO, 2016).

The evidence cited includes studies on the impact of **trees** in London, England, US, New York, Philadelphia, US and Barcelona, Spain; **parks** and **green spaces** in Denmark, Israel, Germany, US, Netherlands, Canada, Australia, New Zealand, England, and the UK, Lithuania, Mexico, Shanghai, China, and California, Florida, Boston, and Philadelphia, US; **community gardens** in the US; **blue space** in Denmark and Canada; **forests** in Japan, Spain and Pennsylvania, US, and **neighbourhood greenness** in Spain, Germany, England, Netherlands and Australia.

Some of the documents also cite a small number of studies that examine health outcomes in different demographic groups (Health Council of the Netherlands, 2008; Center for Health and the Global Environment, 2014; WHO 2016) and, related to this, the impact on health inequalities (Regional Public Health, 2010; Toronto Public Health, 2015; WHO, 2016).

A small body of evidence is also include that highlights some risks from GI, including:

- Allergens and diseases spread through mosquitoes or ticks (UNEP, 2011; Center for Health and the Global Environment, 2014; WHO, 2016);
- Carcinogenic effects of some weed-killers (WHO, 2016);
- Increased risk of skin cancer because of increased outdoor living; although the shading provided by green infrastructure is also highlighted (Toronto Public Health, 2015; WHO, 2016);
- Increased risk of accidents including trees obscuring visibility of traffic signs, vegetation being dangerous for vehicles veering off roads, and falls and drowning associated with activities in green spaces (WALGA, 2014; WHO, 2016).

Crime and perception of crime

Several publications report on an association between GI and crime or fear of crime. The majority of the evidence presented suggests that GI, particularly **trees**, are related to reduced crime or fear of crime (The Trust for Public Land, 2006; Regional Public Health, 2010; Center for Health and the Global Environment, 2014; CNT, 2010; FAO 2016; WALGA, 2014; WHO, 2016). A smaller number of studies are cited that suggest that GI increased crime (WHO, 2016). Some of the documents highlight that certain demographic groups, including women and ethnic minorities may be more vulnerable to crime and fear of crime in **green spaces** (WHO 2016). Related to this one reference suggests that understanding gender may be crucial in relation to GI and climate change programs (World Bank, 2016a).

The evidence cited includes studies on the impact of **trees**, in Baltimore and Oregon, US; **parks** in Sydney, Australia and Philadelphia, US, and **greenery** in Chicago, US.

Recreation and tourism

Several pieces of grey literature cite evidence of the recreational benefits of GI including **parks**, **green spaces** and **floodplains** (Health Council of the Netherlands, 2008; CNT, 2010; Science for Environment Policy, 2012; UNEP, 2014). Other sources highlight the role of **forests**, **parks**, **green spaces** and **coral reefs** as tourist attractions (The Trust for Public Land, 2006; Parks Forum, 2008, Science for Environment Policy, 2012; UNEP, 2014).

The evidence cited includes studies on the impact of **parks** in Australia and **green infrastructure** in Minnesota, US.

Pro-environmental attitudes

Some of the documents reviewed included evidence on the link between **experience of nature**, particularly in children and teenagers, and pro-environmental attitudes (Health Council of the Netherlands, 2008; Center for Health and the Global Environment, 2014; WHO, 2016). In general, exposure to GI is associated with increased responsibility towards environmental and sustainability issues, care for nature, and support for locally sourced food and can reduce 'future discounting' so that those experiencing nature value the environment more highly than those who do not.

Measures of green infrastructure

The evidence cited in the grey literature uses a multiple of measures or characteristics of GI to examine the relationship with health outcomes and use. These include:

- Comparisons between green versus non-green locations for physical activity (Health Council for the Netherlands, 2008; Center for Health and the Global Environment, 2014; Bowen and Parry, 2015; NCCEH, 2015; WHO, 2016);

- Proportion of, and residential proximity to, green space in the neighbourhood (Center for Health and the Global Environment, 2014; FAO, 2016; WHO, 2016). This includes findings that green space access is often lower in deprived neighbourhoods exacerbating health inequalities (WHO, 2016);
- The quality of GI (NCCEH, 2015; Toronto Public Health, 2015; WHO, 2016,), including for older adults (WHO, 2016);
- The presence of water features (Center for Health and the Global Environment, 2014).

The evidence related to cultural services was generally very similar in scope as that presented in the UK-focussed grey literature. There was more of an emphasis on full literature reviews of the health and well-being outcomes and these documents tended to also present the potential negative outcomes from green infrastructure interventions or those studies where no effect was observed. The global remit of many of the documents was also reflected in some of the health outcomes, for example, the risk from mosquitos and skin cancer, and the importance of gender equality in green infrastructure provision. There was a greater focus on the health outcomes for specific demographic groups in the international literature, although that may be a reflection of the inclusion of several detailed reviews of health outcomes. There was also more focus on the role of specific features of GI with respect to different cultural beliefs and practices.

Economic impacts

Ecosystem services

Many studies have further examined how the impacts on ecosystem services outlined above have an economic impact of some form. The grey literature cites many of these to demonstrate the benefits or disbenefits of GI. In some cases total amounts are provided for the overall value of the GI in delivering a range of services (Griffith University, 2010; USDA, 2010; UNEP, 2014; EPA, 2016; FAO, 2016; WHO, 2016). Where the value is related to specific benefits or services these are summarised below.

As already stated there is a relative paucity of evidence presented on the ability of GI to deliver **supporting** and **provisioning services**. However, a number of documents do refer to assessments of the economic benefits of such services:

- Oxygen production from trees and forests (The Trust for Public Land, 2006; Science for Environment Policy; 2012);
- Food produced from urban agriculture and used by the urban poor (World Bank, 2016) or donated to deprived groups in Seattle, US (FAO, 2016);
- Fisheries and other industries supported by functioning coral reefs (UNEP, 2014);
- Charcoal production in Kinshasa, Democratic Republic of the Congo which provided greater economic benefit than timber exports (FAO, 2016).

In terms of **regulating services**, a substantial body of evidence is referred to outlining the economic benefits from GI, including:

- Respiratory benefits through improvements in air quality by **trees** (The Trust for Public Land, 2006; USDA, 2010; American Rivers et al., 2012; Science for Environment Policy, 2012; World Resources Institute, 2013; Green Belt and David Suzuki Foundation, 2015), for example, in the conterminous US; Washington, Los Angeles, US; Lisbon, Italy, and **green roofs** (American Rivers et al., 2012; UNEP, 2014) in Chicago, US.
- Reduced energy costs from **trees** providing shade and/or protection to buildings and the outdoor environment (USDA, 2010; American Rivers et al., 2012; World Resources Institute, 2013; Walga, 2014; FAO, 2016), for example, in the conterminous US; Washington, US; Lisbon, Italy, and **green roofs** (American Rivers et al., 2012; UNEP, 2014), for example, in Chicago, US.
- Reduced maintenance costs to pavements and road surfacing from **tree** shading (Walga, 2014). **Green roofs** are also reported to protect and, therefore, increase the life span of roofs (UNEP, 2014).
- Reduced stormwater runoff from **trees** (The Trust for Public Land, 2006; American Rivers et al., 2012; Walga, 2014, FAO, 2016), for example, in New York City, Washington, Texas, California, US; Lisbon, Italy and **SuDS** including permeable paving (CNT, 2010; American Rivers et al., 2012), for example, in Texas, Chicago, US. Some studies compared these economic benefits with the cost-effectiveness of traditional stormwater management and found that a **GI approach** was more cost-effective (CNT, 2010; UNEP, 2014; EPA, 2016; FAO, 2016; World Bank, 2016), for example near Chicago, and in Seattle, Philadelphia, and Illinois, US. Similarly, **mangrove forests** have been demonstrated to be more cost-effective than maintaining engineered coastal defences (UNEP, 2014), for example in Vietnam.
- Reduced flood protection from **floodplains** and **wetlands** (Science for Environment Policy, 2012; EEA, 2015) for example, in the UK, US and along the river Danube. The cost of restoration and long-term management of wetlands versus their slow recovery is also highlighted (UNEP, 2014).
- Improved water quality from **forests** (UNEP, 2014), **riparian buffers** and **GI** (UNEP, 2014; FAO, 2016). Again, this was found to be more cost effective than treatment plants (UNEP, 2014), example in San Diego, Philadelphia, US.
- Increased carbon sequestration and storage by **trees** (American Rivers et al., 2012; EEA, 2015), for example, in Lisbon, Italy; Washington, US, Johannesburg, South Africa.
- Reduced soil erosion (The Trust for Public Land, 2006) and wind speed (Curtin University and WHO, 2013) by **trees**, for example in the US.

The economic impact of green infrastructure in delivering **cultural services** appears to receive far less attention in the research and/or grey literature compared with regulating

services. However, some studies are cited in the grey literature that provide a value for these services including:

- Increased landscape value from a new **forested** area (Science for Environment Policy, 2012).
- Recreation from **green infrastructure** (CNT, 2010), **riparian buffers** (UNEP, 2014), **parks** (Parks Forum, 2008), in studies in Philadelphia, US; Australia and New Zealand.
- Tourism and related employment from a new **forested** area (Science for Environment Policy, 2012), **parks**, **green spaces** (Parks Forum, 2008; Regional Public Health, 2010; WHO, 2016), and **coral reefs** (UNEP, 2014), for example, in Australia and New Zealand.
- Public health benefits from **urban greening** (Griffith University, 2010; Regional Public Health, 2010; WHO, 2016).
- Reduced transmission of sound using **trees** (USDA, 2010; Curtin University and WHO, 2013; FAO, 2016), **green roofs** and **porous concrete pavement** (CNT, 2010).

Property value

The grey literature also cites numerous studies that have provided estimates of increased property value as a result of GI. There are various mechanisms for this; they can be summarised as follows:

- Increased commercial and residential property value related to improved aesthetic experience, thermal comfort and liveability related to greater levels of, or proximity to, **urban greening**, **trees**, **parks**, **green spaces**, **green belt** and **community gardens** (The Trust for Public Land, 2006; Parks Forum, 2008; CNT, 2010; Griffith University, 2010; USDA, 2010; Regional Public Health, 2010; American Rivers et al., 2012; Curtin University and WHO, 2013; Walga, 2014; EEA, 2015; FAO, 2016; WHO, 2016; World Bank, 2016). Where a location for the study was provided it was the US.
- The effect on property value is stronger in denser urban neighbourhoods, and is independent of levels of neighbourhood deprivation (The Trust for Public Land, 2006), but may benefit deprived areas more (WHO, 2016).
- Increased residential property prices associated with improved water quality and stormwater management in neighbourhoods in the US that had adopted a GI approach (CNT, 2010; American Rivers et al., 2012).
- Increased income for landowners through **payment for ecosystem services** provided by their GI, for example, water management (The Nature Conservancy, 2014).
- Increased retail activity associated with higher quality landscaping (FAO, 2016).

However, a small number of studies also highlight the damage caused to property by tree roots in the built environment. This includes damage to pavements, sewers and the foundations of buildings and can cost substantial amounts to rectify (USDA, 2010; Walga, 2014; WHO, 2016). This links to maintenance and management of GI discussed below.

There was more economic evidence presented in the international grey literature than that with a UK focus, especially for the supporting and regulating services. This is particularly the case in those documents primarily concerned with water and flood risk management, particularly from the US. This may be due to there being a direct comparison available with the performance and cost of existing grey infrastructure. It appears that the majority of the evidence is from the US which may explain why this is absent from the UK-focussed grey literature where it is difficult to draw comparisons between different business environments.

Green infrastructure planning and maintenance

There is a strong focus on the planning and long-term management of GI in a small number of the documents reviewed. These tend to position GI in the context of wider planning theory and good practice as well as literature specifically related to the planning of GI including:

- The integration of GI into spatial planning as a mechanism to deliver sustainable development, and ecosystem services in the urban environment (WALGA, 2014; EPA, 2016);
- The integral role of a strong evidence base on both the needs of the area and the potential outcomes, and collaboration between disciplines and across sectors and geographical locations (Griffiths University, 2010; EPA, 2016);
- The fundamental role of GI in high quality places (WALGA, 2014; EPA, 2016);
- The emphasis on a strategic multifunctional network working across different spatial scales (Griffiths University, 2010; EPA, 2016);
- The role of the planning and design of GI in responding to environmental and demographic change (Griffiths University, 2010; EPA, 2016);
- The role of GI in the wider built environment and its integration with other amenities, facilities and types of infrastructure (Griffiths University, 2010; WALGA, 2014; EPA, 2016), in particular in increasing access to these (EPA, 2016);
- Lack of, or inadequate, provision of high quality GI and mechanisms to overcome this (Griffith University, 2010; EPA, 2016).

The evidence related to the delivery of cultural services suggests that the quality of GI can influence the outcomes. Several pieces of grey literature refer to evidence related to the maintenance and long-term management of GI, including:

- Budgetary constraints, shortage of skills and lack of volunteer time can severely hamper the maintenance of GI (Nowak et al., 2010);
- The impact of poorly maintained green spaces on the image of a neighbourhood and property value (The Trust for Public Land, 2006);
- The need to recognise maintenance costs at the outset and taking these into account in the design and characteristics of the GI (UNEP, 2014);

- The importance of collaboration with a range of sectors, including the local community to ensure maintenance requirements are minimised and there are opportunities for community involvement (Nowak et al., 2010; EPA, 2016);
- Challenges posed by complex land ownership, mixed uses, densification, urbanisation and conflicting priorities for GI (e.g. biodiversity, amenity, timber) can affect management and, in the case of forests, timber supply (Nowak et al., 2010; Brown et al., 2013).

Summary and observations

The grey literature reviewed here predominantly focuses on a few key regulating and cultural services provided by GI. These are improvements to air quality, local climate regulation, water management, and the relationship between GI, and quality of life and health outcomes. As with the UK-focussed study **trees**, **parks** and **greenspaces** receive the most attention, with strong advocates of these features. However, documents from the US, or with a global audience also champion the benefits of **SuDS**, and coastal systems such as **wetlands**, **mangroves** and **coral reefs**. It should be noted, however, that these differences may be a reflection of the grey literature reviewed, for example the focus on English language documents. Similarly, the inclusion of a few very thorough reviews of the health outcomes associated with GI has exposed nuances in the evidence that were not apparent from the UK-focussed review which only contained one such document. The evidence presented in the grey literature is summarised in Table 2.

There appeared to be a tendency for the grey literature to prioritise evidence from the country or region of the document's author. This was particularly true in the more guidance-orientated documents, for example from the US where the GI practices and valuations can be directly applied from real examples (e.g. CNT, 2010; USDA, 2010), or from Australia and New Zealand where these factors and climatic conditions mean that research from these countries is prioritised (e.g. Parks forum, 2008; WALGA, 2014). Other sources use the global evidence but still place an emphasis on the home country (e.g. Bowen and Parry, 2015; NCCEH, 2015). Other grey literature were more global in scope, including WHO (2016), Centre for Health and the Global Environment (2014), FAO (2016) and World Bank (2016a,b). FAO (2016) and World Bank (2016a,b) are particularly wide ranging and are unusual in drawing on sources from South America, Asia and particularly Africa, in addition to Europe, the US and Australia.

The vast majority of sources cited were in English language, and often from English speaking or European countries, and, to a lesser extent, Asia. The main exception to this is Health Council for the Netherlands (2008), which cites sources in Dutch. This is likely to be a reflection of the maturity of GI as a research area in these regions and that English is the dominant language in academic publishing. We also only reviewed English language documents.

Table 2 Overview of the amount of evidence presented in the grey literature (red=evidence in academic literature but largely absent from grey literature; orange=academic evidence reported in some of the grey literature; green=academic evidence featured in a range of grey literature)

Scale	Green infrastructure type and examples	Biodiversity	Supporting services				Provisioning services		Regulating services							Cultural services							Economic benefits
			Soil formation	Photo synthesis	Primary production	Nutrient/water cycling	Food, fibre, fuel	Fresh water	Air quality	Climate regulation (local)	Water regulation/ purification	Pollination	Noise abatement	Carbon storage	Soil regulation	Aesthetic experience, sense of place	Social cohesion, social capital	Psychological, mental health	Physical activity, physical health	Crime and perception of crime	Recreation and tourism	Pro-environmental attitudes	
Micro	Street trees (e.g. retained mature or newly planted tree/s; green verges)																						
Building	Green walls/roofs (e.g. vertical/ rooftop garden; private garden)																						
Site	Derelict/'waste' land (e.g. brownfield land; temporary green)																						
	Water management space (e.g. SuDS; flood storage area)																						
Neighbourhood	Parks and gardens (e.g. urban park; country park; playground)																						
	Urban agriculture (e.g. allotments; community garden; urban farm)																						
	Civic spaces (e.g. square; public open space; outdoor market place)																						
	Institutional (e.g. school/ hospital grounds; cemetery, sports facility)																						
Settlement	Green/blue corridor (e.g. riverbank; cycle/foot path; railway cutting)																						
	Natural and semi-natural space (e.g. meadow; wetland; floodplain)																						
Landscape	Agricultural/productive land (e.g. farmland; vineyard; orchard; forest)																						
	Coastal/wilderness (e.g. mangrove, coral reef; moorland; mountains)																						
GI with scale not specified or of mixed scales																							

Case studies

A selection of case studies are provided to give an indication of the different types of international GI projects and initiatives. They have been selected to represent a range of initiatives from policy to implementation, scales, types of GI, geographical coverage, and anticipated outcomes. These are summarised in Table 3 and Figure 1.

Table 3 Summary of international green infrastructure case studies

Case study	Scale	Type	Primary driver	Funding & delivery	Outcomes
Urban Agriculture Casablanca, Morocco, 2005-2014 Further information	City	Retrofitting	Local food supply	German Government's Ministry of Education and Research	Improved skills, ccess to healthy food, water cycle efficiencies
Urban greening Johannesburg, South Africa, 2006- Further information	Neighbourhood	Regeneration	Environmental improvement	Johannesburg Parks Department	Additional trees planted, cleaner rivers, new parks on previous wasteland
Lingang Eco Park Tianjin, China, 2017-2018 Further information	Neighbourhood (60ha)	Regeneration	Wildlife habitat	Asian Development Bank; Port of Tianjin	Habitat for migratory birds
Water retention green space Bangkok, Thailand, 2012	Site	Retrofitting	Water management	Chulalongkorn University	Water retention, enhanced amenity green space
Da Nang Garden Walk Da Nang, Viet Nam, 2012	City	Retrofitting	Environmental quality	Da Nang People's Committee; Da Nang Company of Green Park	Improved outdoor spaces, promoting healthy lifestyles
GreenWay Sydney, Australia, 2001- Further information	Linear	Regeneration	Recreation Environmental	Ashfield, Leichhardt and Marrickville Councils, City of Canterbury, NSW Government, New Environmental Trust.	
The Goods Line Sydney, Australia, 2015 Further information	Neighbourhood	Regeneration	Connectivity; creating civic space	Property NSW	Urban greening, improved connections, high quality public realm
Green Alley Project, Chicago, USA, 1989- Further information	City	New build; retrofitting	Climate change adaptation	City of Chicago	Stormwater management, improved public realm
Stormwater Management Grants, Philadelphia, USA, 2012- Further Information	City	Retrofitting	Stormwater management	Philadelphia Water Department	Reduced water run-off, increased permeable surfacing
ADDITIONAL CASE STUDIES					
Case study	Scale	Type	Primary driver	Funding & delivery	Outcomes
Urban green space Al-Azhar, Cairo, Egypt, 1998–2005 Further information	Site (30ha)	Retrofitting	Environmental improvement	Aga Khan Development Network	Valued recreational space, high aesthetic quality, improved environmental conditions, protection of historic wall
Green Line Nairobi, Kenya, 2010 – Further information	Linear (30km long)	Retrofitting	Urban containment	Kenya Association of Manufacturers and Kenya Wildlife Service	Native species planted in a 50m buffer along the Nairobi National Park boundary

ADDITIONAL CASE STUDIES CONTINUED

Case study	Scale	Type	Primary driver	Funding & delivery	Outcomes
Nairobi River Basin Rehabilitation Program Nairobi, Kenya Further information	City	Regeneration	Water quality	Kenya Ministry of Environment, development partners, private sector, civic society	Water quality improvement, creation of recreation land along river
Mozambique Cities and Climate Change Project Mozambique, 2012-2018 Further information	National	Strategy	Climate change	Mozambique Ministry of Planning and Development and World Bank	Improving natural drainage systems, coastal protection, additional urban green space
Urban Greening Lagos, Nigeria, 2008- Further information	City	Regeneration	Climate Change; air quality	Lagos State Parks and Gardens Agency Clinton Climate Initiative	Establishment of Gardens Agency, 500,000 trees planted by 2010, greening of public spaces
Durban Metropolitan Open Space System (D'MOSS), Durban, South Africa, 2010- Further information	City (74,000ha)	Strategy	Ecological protection	eThekwini Metropolitan Municipality	Protection of environmentally sensitive areas, raised awareness of the City's biodiversity, reduction of alien species
Greening Durban Durban, South Africa, 2010 Further information	City	Strategy	FIFA World Cup 2010 green commitment	eThekwini Metropolitan Municipality, Danish International Development Agency, other corporate sponsors	Reforestation with locally grown native species, removal of invasive species, community involvement
Sponge Cities China, 2015- Further information	National	Retrofitting	Flooding and water shortage	Central Government demonstration funding and public-private partnership	Increased use of low-impact/water sensitive urban design in urban areas (16 pilot cities)
Tree planting Beijing, China, 2000- Further information	City	Retrofitting	Air quality and sandstorms	Beijing Government	Additional shading, green space increased from 36% in 2000 to 43% in 2007
Urban greening, canal parks and wetlands, Hangzhou, China Further information	City	Regeneration	Ecological restoration	China Sports Lottery (canal improvements), Hangzhou Municipal Government (urban greening)	Ecological restoration, China's first urban wetlands (Xi Xi wetlands), agricultural park, social revitalisation, improved aesthetics
Mangrove Restoration, Gujarat, India, 2002-2010 Further information	Regional	Restoration	Ecological restoration	State Forest Department, Gujarat Ecology Commission, India-Canada Environment Facility	Community-Based mangrove restoration, increase biodiversity, public participation.
Urban greening and growth boundary Delhi, India, 2009- Further information	City	Retrofitting	Biodiversity	Delhi Government	Increased green space, forests and biodiversity parks, protection of Delhi Ridge (wildlife sanctuary) from urban encroachment
Green walls and roofs Osaka, Japan, 2010- Further information	Site	Retrofitting	Urban heat island effect	Osaka Prefecture Government	Additional green space, reduced urban heat island, opportunities for food growing

ADDITIONAL CASE STUDIES CONTINUED

Case study	Scale	Type	Primary driver	Funding & delivery	Outcomes
Green Up Yokohama, Japan, 2009-2018 Further information	City	Retrofitting	Increase urban green space	Local tax of businesses and residents (City of Yokohama)	Conservation of forests, farmland, implementation and improvement of green spaces
Kids Mayumi Kindergarten Osaka, Japan, 2016 Further information	Site	Retrofitting	Education	Private	Children's exploratory play, greater exposure to fresh air, daylight and green space
National Coastal Greenbelt Action Plan Philippines, 2014- Further information	National	Strategy	Coastal protection	Philippines Government	Adoption of the National Coastal Greenbelt Act of 2014
Active, Beautiful, Clean Waters Singapore Further information	City	Strategy	Stormwater management	Singapore Government, PUB (national water agency), public-Private partnerships	Decrease flood-prone areas, aesthetic and environmental improvements
Eco-links between parks Singapore, 2007-2020 Further information	City	Retrofitting	Ecological connectivity	Singapore Government	Additional parkland, rooftop gardens
Henderson Waves Bridge Singapore, 2008 Further information	Site (Bridge, 274m long)	Infrastructure	Connectivity and additional green space	Urban Redevelopment Authority of Singapore	Improved connectivity; additional social spaces with shade and shelter, wildlife habitat; civic identity
Metro Colombo Urban Development Project Colombo, Sri Lanka, 2012-2017 Further information	Region	Retrofit	Stormwater management	World Bank, local authorities in the Colombo Metropolitan Area	Canal rehabilitation, integrated flood management systems
Green Infrastructure Plan Bangkok, Thailand Further information	City	Strategy	Improve accessibility	Bangkok Metropolitan Administration	Increased shading of public realm, aesthetic improvement, additional recreational areas, improved water quality
Community-based Mangrove Reforestation and Disaster Preparedness Program Viet Nam, 1994-2010 Further information	Region	Restoration	Coastal protection	International Federation of Red Cross and Red Crescent Societies	Disaster reduction, habitat preservation/ restoration, carbon sequestration, improved community livelihoods
Central Park Sydney, Australia, 2010-2015 Further information	Site (Building 34 storeys)	Regeneration	Sustainable design	Private sector	Vertical gardens, greywater reuse for irrigation.
GWL Terrein Amsterdam, The Netherlands, 1993 Further information	Neighbourhood 6 ha	Regeneration ; retrofitting	Provide a car-free residential development	Amsterdam City Council, KCAP, West8 Landscape Architects	High density, car free, ecologically sensitive development

ADDITIONAL CASE STUDIES CONTINUED

Case study	Scale	Type	Primary driver	Funding & delivery	Outcomes
Ecolonia The Netherlands, 1989-1992 Further information	Neighbourhood 2.7 ha	Regeneration	Demonstration of sustainable urban planning	SenterNovem, Bouwfonds, Netherlands Ministry of Housing, Spatial Planning and the Environment, Ministry of Economic Affairs	Sustainable energy and improved water management, durability, sound insulation, health, wellbeing
Green Ventilation Corridors Stuttgart, Germany, 1980s Further information	City	New build; retrofitting	Air quality improvement	City of Stuttgart, Verband Region, EC	New development prevented in corridors to ensure adequate ventilation to the city
Green Roofs Basel, Switzerland, 1996- Further information	City	New build; retrofitting	Climate change mitigation	City of Basel, Energy Saving Fund	Standards for green roofs, reduced energy use, increased biodiversity
Copenhagen, Denmark, 1960s– Further information	City	Retrofitting	Climate change mitigation	Copenhagen City Council	Increased green infrastructure, walking and cycling levels, reduced energy use
National Adaptation Program of Action Dominican Republic, 2008– Further information	National	Strategy	Climate change	Dominican Republic Government	Reef restoration, preservation/ restoration of wetlands and mangroves
Green Plan Mexico City, Mexico, 2007-2011 Further information	City	Strategy	Climate change	World Bank, United Nations, Mexico City	75% of 113 action points had been started in 2009
Urban Reforesting and Green City Programme, Puebla, Mexico, 2009– Further information	City	Regeneration	Ecological protection	Puebla City	50 acres of green space created and 37,700 trees planted
Augustus F. Hawkins Natural Park Los Angeles, US, 2000 Further information	Site (3.4ha)	Regeneration	Increase urban green space, biodiversity	California Parks	Improved conviviality, valued by local communities; increase in wetlands, habitat, and community gardening
Taylors Yard Los Angeles, US, 2001-2007 Further information	Site (40ha)	Regeneration	Recreation	State of California Parks Department, City of Los Angeles	Created riparian habitat, provided playgrounds, outdoor classrooms and picnic facilities within a new inner city park
Rooftops to Rivers Aurora, Illinois, US, 2009- Further information	City	Strategy	Stormwater management	Illinois Environmental Protection Agency, Local stormwater management fees to residents and businesses	Reduced water run-off Increased permeable surfacing
Stormwater management Portland, US, 2007- Further information	City	Retrofit	Stormwater management	City of Portland regulations, development incentives	Increased permeable surfaces, green roofs, reduced cost of stormwater infrastructure and combined sewer overflow costs
Urban agrihood Detroit, US, 2016- Further information	Neighbourhood	Regeneration	Urban agriculture	Michigan Urban Farming Initiative	Community gardens, orchards, sensory garden; since 2012 distribution of over 50,000 pounds of free fresh produce

ADDITIONAL CASE STUDIES CONTINUED

Case study	Scale	Type	Primary driver	Funding & delivery	Outcomes
Urban agrihood Detroit, US, 2016- Further information	Neighbourhood	Regeneration	Urban agriculture	Michigan Urban Farming Initiative	Community gardens, orchards, sensory garden; since 2012 distribution of over 50,000 pounds of free fresh produce
Urban greening and management Curitiba, Brazil, 1970s- Further information	City 43,202 ha	Retrofitting	Population growth	Federal Grants, Public-Private collaboration	Sustainable development at the city scale
Green corridors Plan Rio de Janeiro, Brazil, 2012- Further information	City	Strategy	Ecological connectivity	Municipality of Rio de Janiero Environmental Department, State Government	Reforestation and restoration of degraded areas, wildlife protection
Metropolitan Regulation Plan Santiago, Chile, 2010-2030 Further information	Region	Strategy	Increase urban green space	Santiago Metropolitan Region	Additional urban green space and tree planting
Forestation and Reforestation Project Quito, Ecuador, 2008- Further information	City	Retrofitting	Environmental benefits	Departmental and institutional cooperation	Increased green space and tree cover
Green Lima and Callao Pact Lima, Peru, 2007- Further information	Regional	Strategy	Access to urban green space	Pact signed by 49 districts, UN Habitat and UNEP	58% increase in parks between 2004 and 2010; improved health and wellbeing; shared civic identity
Urban Sustainability Plan Montevideo, Uruguay, 2010-2020 Further information	City	Strategy	Environmental improvement	Intendencia de Montevideo, University of the Republic	Creation of urban green spaces, wetlands and beaches

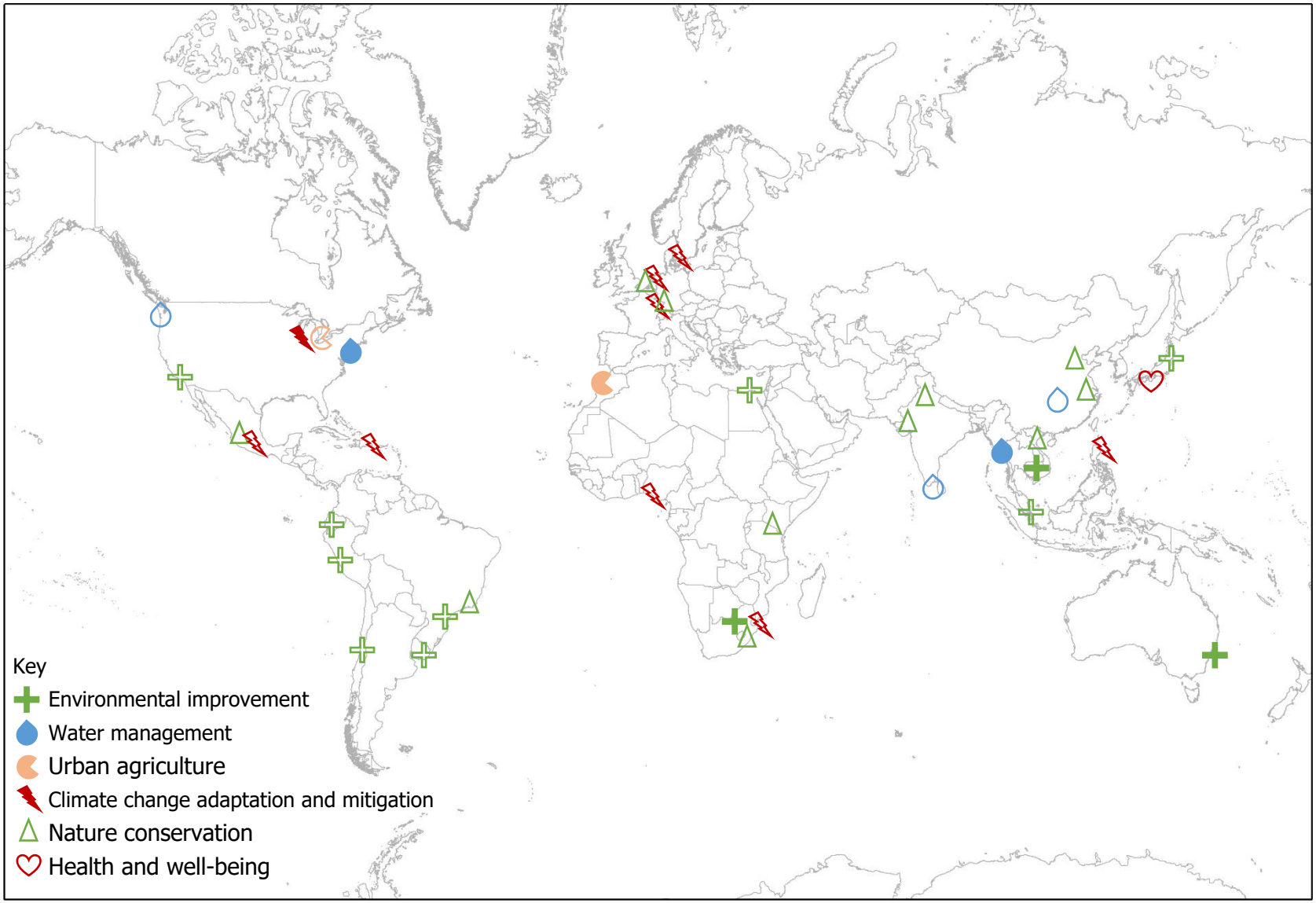


Figure 1. Map of detailed (closed symbols) and additional (open symbols) case studies.

Urban Agriculture, Casablanca, Morocco

Dates	Scale	Type	Primary driver	Funding & delivery	Outcome
2008-2014	Region	Retrofitting	Climate change adaptation	German Government's Ministry of Education and Research	Improved skills; access to healthy food; water cycle efficiencies

An example of a garden design. Source: Urban Agriculture Casablanca

Context

Casablanca is Morocco's largest and most populated region, accommodating 22% of the nation's population and 60% of industry. The Urban Agriculture Casablanca project explored the role of urban agriculture in contributing to a sustainable and climate-optimised city. The project is part of a wider global research programme exploring megacities and features of energy and climate efficient urban areas. Urban Agriculture Casablanca recognises the multiple benefits of urban agriculture as an integral part of a city's green infrastructure and conceptualizes it as a productive green infrastructure. This includes the local supply of healthy food, opportunities for recreation and leisure, improved resource management, contribution to ecosystem services, improved residential environments and aesthetic quality. The nine-year research project included four pilot projects that explored how urban agriculture can be integrated into urban development processes and how it can contribute to climate change adaptation. Each pilot project looked at the challenge from a different perspective; industry, informal settlements, peri-urban tourism and healthy food production.

Green infrastructure features

- Community agriculture gardens: focus on community interaction and to empower local women in informal settlements to learn new skills in growing food and to create efficiencies through grey water reuse from adjoining land uses
- Educational agriculture farms: food production and training for local farmers in agro-ecological practices, provide opportunities for food production, establish a producer-consumer network to deliver food baskets to urban dwellers
- Constructed wetlands: to address water scarcity and quality issues, test and facilitate greywater water reuse for irrigation in urban agriculture.

Educational farm in Dar Bouazza. Source: Urban Agriculture Casablanca

Progress

In a transdisciplinary approach, the pilot projects demonstrated a range of benefits of urban agriculture for the local communities and the environment. A new temporary training garden was formed within the existing urban area of an informal settlement in cooperation with local partners from the neighbouring school, a private land owner, women from the settlement and the university. A wetland was constructed adjacent to the garden and a school to enable water reuse for irrigation of the garden where women were trained in food cultivation techniques. Environmental benefits of urban food production were also explored in connection to waste water from an urban waste water treatment plant collected and reused for agricultural irrigation.

As part of the healthy food production pilot, locally grown food from a training farm and a farmer's cooperative w sold as weekly delivered food baskets to local consumers at a newly created selling point in the urban area.

The project successfully collaborated with citizens, private owners, NGOs, farmers, urban planning administrations and universities to establish efficient, sustainable and integrated urban agricultural practices and spaces within a growing urban region that provided opportunities for leisure and recreation, as well as new avenues for economic income, efficiencies in the water cycle and access to healthy food.

Further information

http://www.uac-m.org/home/index.html

http://future-megacities.org/fileadmin/documents/forschungsergebnisse/aktuell/8CAS-PB.pdf

http://future-megacities.org/fileadmin/documents/forschungsergebnisse/aktuell/CAS-AB1.pdf

http://www.uac-m.org/fileadmin/user_upload/public/1_Home/UAC_Publication_Topos.pdf

http://uac-darbouazza.blog4ever.com/articles

Green City, Johannesburg, South Africa

Dates	Scale	Type	Primary driver	Funding & delivery	Outcomes
2006 - ongoing	City	Retrofitting	Environmental quality	City of Johannesburg Metropolitan Municipal Authority, Johannesburg City Parks and Zoo	Improved outdoor spaces, promoting healthy lifestyles

Context

The City of Johannesburg aims to be a world-class green city. There were historically large variations in the green infrastructure provision across the city and *The State of the Environment* report provided the evidence base that highlighted a number of challenges facing the city. This covered a wide range of issues related to sustainable development, but in terms of green infrastructure the variation in green infrastructure, lack of and loss of public open spaces, pressures on habitats for protected species, and a reduction in the quality of the landscape are particularly pertinent (City of Johannesburg, 2008). As well as developing a suite of policies and frameworks to manage development and provide a network of public open spaces the city's green infrastructure is also a feature of the wider Green City programme. This programme includes a range of initiatives including producing energy from landfill gas, improving waste and water management and providing transport infrastructure and smart buildings.

This programme has a number of green infrastructure projects. These include street planting in specific townships to reduce the disparity in green infrastructure between different neighbourhoods, providing new parks and public open spaces as well as improving existing ones, and consolidating the management of green infrastructure assets into the Johannesburg City Parks and Zoo not-for-profit in 2013. In addition to a management role that includes nature conservation, arboricultural and botanical services, they also provide an eco-tourism and environmental education programme, community projects and walking trails. This means that one agency is responsible for all publicly owned and managed GI in the city.

Green infrastructure features

- 2.5 million trees in the public realm;
- 35 cemeteries, including 5 recognised for their cultural significance;
- 2,000 parks, sports and leisure facilities and public open spaces covering 20,000 ha;
- Nature reserves and botanical gardens;
- 55 ha Johannesburg zoo.

Progress

This is an ongoing programme with many individual initiatives. For example, removal of invasive species such as weeping willow bug weed, grey poplars and black wattles that can

restrict water flow and cause localised flooding. The Greening Soweto project was funded and delivered by the business community and residents to increase the coverage of street trees in the township. It started in 2006 in preparation for the 2010 FIFA World Cup and planted 200,000 new trees in the public realm.

Green City Johannesburg from top to bottom, left to right: Diepkloof Park; Dorothy Nyembe Environmental Education Centre; Rietfontein Nature Reserve and Zoo Lake (Source: City Parks and Zoo)

Another initiative is Xtreme Park Makeover this transforms underused and rundown spaces into city parks in 24 hours including all landscaping and amenities such as sports facilities, seating areas, and water features. In 2008, one improved park in Diepkloof won gold at the United Nations' Liveable Communities Awards.

References and further information

City of Johannesburg:
http://www.joburg.org.za/index.php?option=com_content&id=5497&Itemid=339

City Parks Greening Programme: http://www.jhbcityparks.com/index.php/what-we-do-contents-31

City of Johannesburg (2008) State of Environment Report: http://www.joburg.org.za/index.php?option=com_content&task=view&id=3959&Itemid=114

African Green City Index: http://www.siemens.co.za/sustainable-development/pdf/African-Green-City-Index.pdf

Lingang Eco Park, Tianjin, China

Dates	Scale	Type	Primary driver	Funding & delivery	Outcomes
2017-2018	Neighbourhood (60ha)	Regeneration	Wildlife habitat	Asian Development Bank; Port of Tianjin	Habitat for migratory birds

Context

China launched *Sponge City* an ambitious national programme in 2015. It seeks to increase the amount of permeable surfacing and green space in cities to reduce flooding in urban areas. Tianjin, in China's north, is one of sixteen pilot cities selected to initiate this programme. Working with the Asian Development Bank and the Port of Tianjin, a design competition to create a new Eco Park on a previous landfill site was held in 2015. The location of the site is in the East Asian-Australasian Flyway, a migration route between Australia and New Zealand to the Arctic Circle that 50 million birds use each year. Due to the loss of bird foraging habitat along coastal areas due to urbanisation, this corridor is now the world's most threatened bird migratory route. Recognising the importance of this route to threatened waterbirds, the project sought to reinstate important coastal resting and foraging habitats for migratory birds. The design competition brief included the need for wetlands, parkland and an urban forest on the 60-hectare site.

The 'bird airport' to be built on an old landfill site in Tianjin, China. Source: McGregor Coxall

The winners of this competition were landscape architects McGregor Coxall, who have designed a 'Bird Airport' for the site. The design provides three different types of water habitats that cater for the diverse range of migratory birds that travel through this area. The site will also have a visitor and research centre and 7 kilometres of wetland trails, a forest walk and cycle circuit. Birdwatching hides will also allow visitors to view the birds in this new

habitat. The wetland will also capture recycled wastewater and harvested rainwater, providing a water management function. The masterplan area is part of a wider 'necklace' of GI projects that the city is implementing.

Green infrastructure features

- Wetlands, including an island lake with shallow rapids, reed beds and mudflats;
- Green roof on the visitor and research centre;
- 20-hectare forest;
- 7 kilometres of walking and cycling trails.

Progress

Construction of the winning masterplan from the design competition will commence in 2017, with a completion date in 2018.

The 60-hectare site will provide an important wetland habitat for migrating birds. Source: McGregor Coxall

Further information

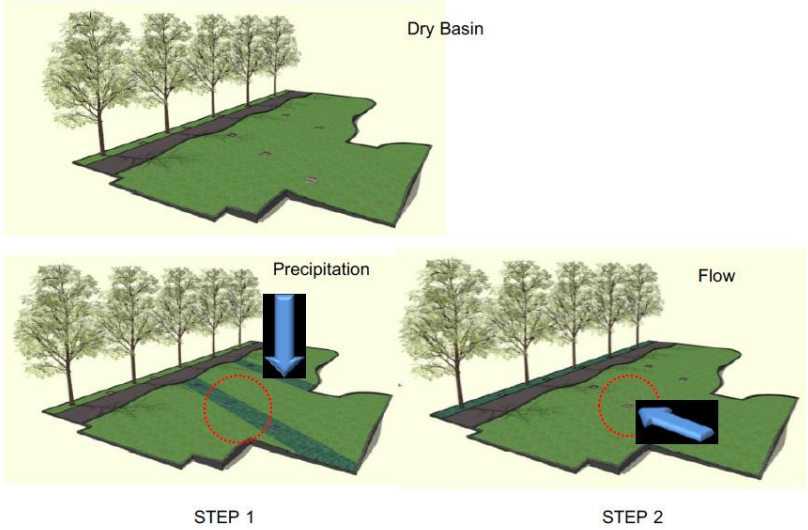
https://mcgregorcoxall.com/news-detail/231

https://www.dezeen.com/2017/02/15/lingang-eco-park-mcgregor-coxall-wetland-bird-airport-tianjin-china/

http://uk.archinect.com/news/gallery/149992403/5/mcgregor-coxall-to-design-bird-airport-wetland-park-in-tianjin

Water retention green space, Chulalongkorn University, Bangkok, Thailand

Date	Scale	Type	Primary driver	Funding & delivery	Outcome
2012	Site	Retrofit	Water management	Chulalongkorn University	Water retention and enhanced amenity green space



The design principles behind the water retention green space. Source: Kangwarn Pipitpongson

Context

Bangkok, like much of Southeast Asia is subject to annual monsoons. The impacts of a changing climate as well as the city's predominantly low-lying terrain increases the risk of flooding in the city during the wet season, as well as periods of drought in the dry season. In 2011, the city experienced the worst flooding in modern times. Due to these growing pressures, researchers and designers in the city are looking to integrate green infrastructure in to the urban environment to assist with water management. At Chulalongkorn University, to the east of the Bangkok city centre, landscape architects have redesigned an existing car park to implement a water retention green space. Based on the principles of hydro-agricultural drainage structures used in rural areas of Thailand, a series of swales capture rainwater and direct the flow of water to drainage points. Water is then slowly released to the main drainage system of the Chula campus before final release to the city's stormwater drainage system. This helps to mitigate flooding during heavy rainfall and reduces the amount of water that goes to the city's stormwater drainage system.

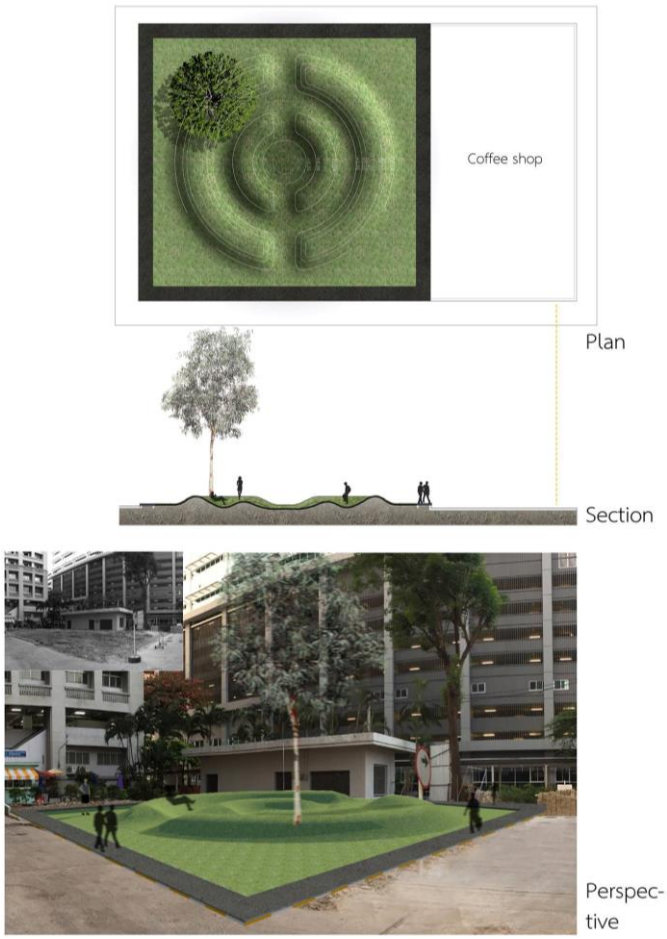
Green infrastructure features

- Rain gardens: slow down storm water runoff and to harvest water for controlled irrigation;
- Tree planting: create shade and reduce heat, addressing Urban Heat Island effect.

Attractive and functional green space. Source: Kangwarn Pipitpongson

Progress

The water retention green space was a retrofit project in the University campus. During the monsoon season, the swales provide a natural catchment for rainwater, capturing runoff and directing it to the drainage points. The swales also provide an attractive green space that staff and students can utilise outside periods of heavy rain. Trees are planted in appropriate locations within the green space to contribute to the amenity and usability of the space (shading), without effecting the water retention function. The car parking area adjoining the green space is paved with porous materials to allow water to permeate into the ground. The project has been particularly successful and as such the design principle is being applied to other parts of the campus.



Work on progress – turning a lost space on the University campus into green and blue infrastructure. Source: Onkamon Nilanon.

Further information

Thaitakoo, D., McGrath, B., Srithanyarat, S. and Palopakon, Y. (2012) Bangkok: The Ecology and Design of an Aqua-City. In: Picket, S.T.A., Cadenasso, M.L. and McGrath, B., ed., (2013) *Resilience in Ecology and Urban Design*. London: Springer, pp. 427-442.

Da Nang Garden Walk, Vietnam

Dates	Scale	Type	Primary driver	Funding & delivery	Outcomes
2012	City	Retrofitting	Environmental quality	Danang People's Committee; Danang Company of Green Park	Improved outdoor spaces, promoting healthy lifestyles

Context

Da Nang, Vietnam was awarded the ASEAN City of Sustainable Environment Award in 2011. It has a number of initiatives related to the sustainable development of the city including improving air and water quality, waste management and ensuring the city is resilient to climate change. This is in the context of a population that is projected to almost double between 2009 and 2020 to 1.5 million. The city has had a sustained programme of tree planting since 2012, which has included providing the expertise needed in the Danang Company of Green Park to plant and manage trees and promoting the benefits of trees to local residents.

Da Nang Garden Walk, Vietnam. Credit: Danang Company of Green Park

The Garden Walk programme is a £92K (2,637,773,000 VND; 115K USD) investment in a network of green spaces or 'pocket parks' threading through eight residential neighbourhoods of the city. The aim is to improve the landscape quality of Da Nang, provide

opportunities for rest, relaxation and children's play, and make use of abandoned or underused sites.

The Garden Walk programme had strong community involvement with the Danang Company of Green Park meeting with the local People's Committees of the Districts and Wards and residents to start the clearance and handover of the required land.

Completed in 2012, the programme cleared 2 ha of land, installed water supply systems, constructed paved areas and footpaths, imported soils followed by tree and grass establishment. In addition to the initial investment, a strong emphasis has been placed on the maintenance and long-term success of the Garden Walks.

Green infrastructure features

- 1.5 ha grassed areas;
- 183 trees;
- 0.5 ha of paving and paths;
- Fitness equipment and seating.

Da Nang Garden Walk, Vietnam. Credit: Danang Company of Green Park

Progress

The investment in the eight garden walks has changed the landscape and environment completely and has had a tremendous social impact in the residential areas. Before the Garden Walk programme, the spaces were empty lots, some of which were used for informal waste disposal. Although the size of these garden walks are compact, ranging from 0.09 to 0.4 ha, these green areas have created positive value in the landscape, benefitting local residents by providing relaxing places for taking rest and playgrounds for children.

Local communities have joined the government in the maintenance, investment and promotion of additional features of the garden walks. For example, providing funding to improve paved areas, and install benches, and, through Danang Youth Union, fitness and sports equipment.

However, in some instances, where the investment was small and scattered, local residents have not yet recognized the value of the garden walk and use this space for drying clothes and other household items, grazing or football which has an adverse effect on the landscape and damages the greenery. Danang Company of Green Park is overcoming this through enhanced maintenance.

Because of the positive and practical impact of the Garden Walk programme, in the past few years, the city has invested in constructing additional green spaces, which increases the green infrastructure and improves the built environment in crowded residential areas.

References and further information

With thanks to Danang Company of Green Park and Center for Promotion of Human Resources Development for the text.

The GreenWay, Sydney, Australia

Dates	Scale	Type	Primary driver	Funding & delivery	Outcome
1998 – ongoing	Linear	Regeneration	Recreation Environmental	Ashfield Council, Leichhardt Council, Marrickville Council, City of Canterbury, NSW Government, New Environmental Trust.	Increased biodiversity and wildlife habitat; improved social capital, quality of the urban environment, sustainable travel

Waratah Mills Community bushcare site in Dulwich Hill. Source: GreenWay

Green infrastructure features

- 5 km urban 'greenway' in Sydney's inner west: provides shared paths for recreation and transport;
- Bush Links: provide community bush care sites and habitat areas for native flora and fauna and wider integration of native flora in parks, reserves and private yards;
- Parks and playgrounds: recreation and educational use.

Context

The Cooks River to Iron Cove GreenWay is a community-led initiative to create a green corridor for local recreation, transport and wildlife in Sydney's inner west. Inspired by other green corridor projects, the local community recognised the opportunity that a redundant

railway corridor presented to create community connections, improve biodiversity and the quality of the urban environment, facilitate sustainable transport, provide opportunities for sustainability education and to raise awareness of the history and culture of the local area.

The GreenWay follows the Inner West Light Rail line and the Hawthorn Canal. It stretches across eleven suburbs and the catchment (based on the Sydney Harbour and Cooks River water catchment area) and includes almost 46,000 people, including over 5,500 school-aged children. The GreenWay includes a shared use path for cyclists and pedestrians, cultural and historical sites, foreshore walks, public art, cafes, bush care sites, parks, playgrounds and sporting facilities.

The GreenWay route. Source: GreenWay

Progress

The origins of GreenWay began in 1998 when local community groups started bush restoration and cycle path improvements along the Hawthorn Canal in the northern section of the greenway. Consultations in the early 2000s and the formation of the 'Friends of the GreenWay' community group led to a formal GreenWay Masterplan being adopted by the

four local authorities in 2009, with support from community groups and the State Government. In 2011, the New South Wales state government began construction of a light rail service along the GreenWay. Funding for the ongoing GreenWay project and to complete the missing 3.2km of shared path along the GreenWay has been from a variety of funding sources. This includes a Memorandum of Understanding (2014-2019) between the four local authorities, and more recent funding opportunities from the local councils and state government in 2016. It is hoped that the missing links will be completed by 2020.

The GreenWay has more than 6,000 active volunteers and programmes with local schools on sustainability and active travel, as well as an Art Exhibition in 2016. A Vegetation Management Plan for the GreenWay has been developed as well as a biodiversity strategy. There is also monitoring of particular species, such as the bandicoot. The GreenWay Priorities to 2019 include completing the missing links, continuing revegetation along the Greenway, widening biodiversity monitoring activities and a focus on stormwater quality issues.

The GreenWay has improved the quality of the urban environment and improved local connectivity in the area. Environmental improvements have created new wildlife habitats and increased native flora and fauna in a highly urban environment. The grass-roots nature of the programme has developed strong community engagement and successful education, arts and cultural activities.

Further information

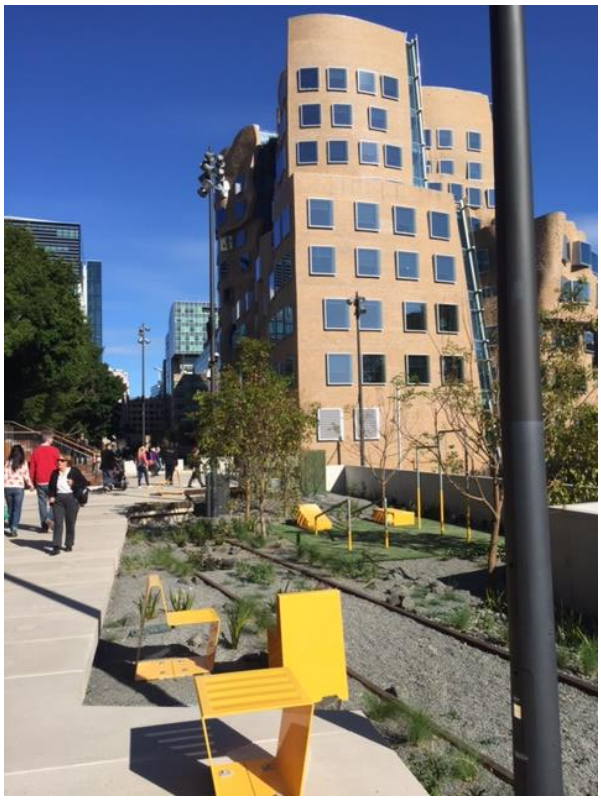
http://www.greenway.org.au/

http://friendsofthegreenway.org.au/

http://www.leichhardt.nsw.gov.au/Community-Issues/Other-Issues/The-Greenway

The Goods Line, Sydney, Australia

Dates	Scale	Type	Primary driver	Funding & delivery	Outcome
2015	Neighbourhood	Regeneration	Connectivity and creating civic space	Property NSW	Urban greening; improved connections; high quality public realm



Open Day on the Goods Line. Source: Stephen Pierce

Green infrastructure features

- Urban green spaces: creation of additional public realm that includes tree planting and native landscaping to improve aesthetic quality, provide shading and promote recreational and active travel uses.

Context

Utilising a former railway line, the Goods Line provides a key strategic link and a high quality green space in the heart of Sydney. Modelled on the High Line concept in New York, USA, the Goods Line creates an elevated public space that links Railway Square and Darling Harbour. The design incorporates a series of different spaces that facilitate a range of activities along the Line, such as play, exercise, events and study. The Goods Line also provides an important strategic connection between key educational, cultural and business

sites such as China Town, Central Station, the University of Technology Sydney, Sydney TAFE and the Australian Broadcasting Corporation.

Planting (left) and public spaces (right) along the Goods Line. Source: Property NSW

Progress

The Goods Line project was opened in 2015. This project has transformed a densely populated area of Sydney, by providing a leafy civic space for local communities and daily visitors. The linear space connects communities of Ultimo, Darling Harbour and Haymarket. The design maximises the canopies of established fig trees along the line for shade and aesthetic value, and garden beds and planters create features and define edges. Water features allow opportunities for play and reflect the heritage of the site. An amphitheatre provides an opportunity for small events. The Line is well-lit allowing night-time use of the Line.

The project has a strong narrative and identity that reflects the history of the site and its role in the growth of Sydney. The design facilitates a multifunctional series of spaces that allows movement and opportunities for social interaction within a green environment. The project has won multiple awards from concept through to implementation, for planning, design and landscaping.

Further information

http://www.darlingharbour.com/things-to-do/the-goods-line/

http://aspect.net.au/?p=384

http://thegoodsline.aspect.net.au/

The Green Alley Program, Chicago, USA

Dates	Scale	Type	Primary driver	Funding & delivery	Outcome
Pilot 2006	City	New/retrofitting	Ageing infrastructure; urban heat island; triple bottom line	Chicago City; incentive schemes	Safer water through stormwater management; green streets, roofs and alley program, green permitting

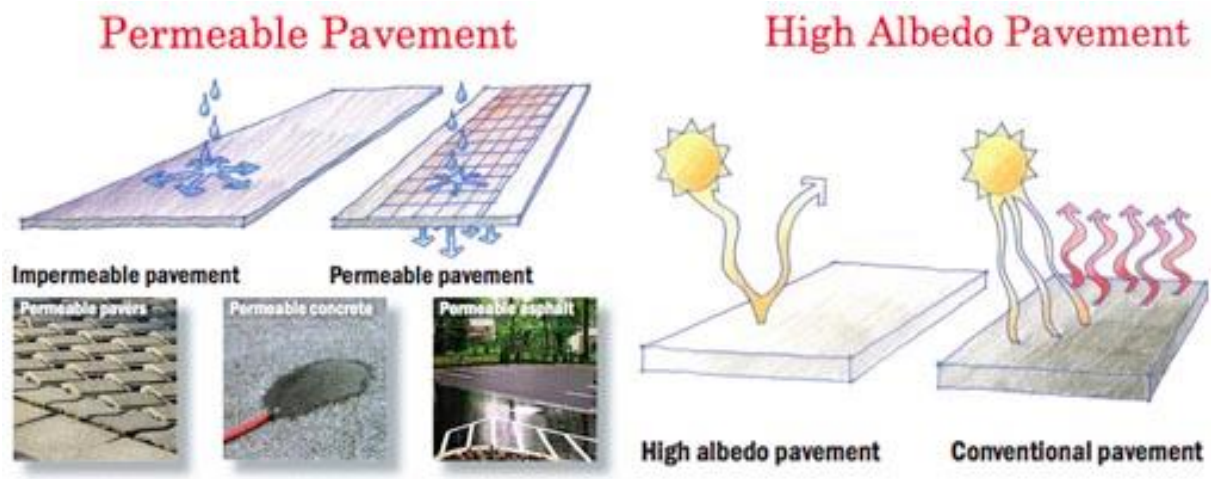
Context

The Green Alley Program ran initially as a pilot scheme in 2006. By 2010 over 100 alleys had been transformed into Green Alleys in the Chicago region. The program was developed in response to huge flooding issues caused by ageing infrastructure that could no longer cope with the rate of rainfall and the absence of connections in some parts of Chicago to any sewage system at all. This posed considerable risks to property and public health. The Green Alley Program is focussed on changing existing impermeable concrete alley surfaces into more sustainable, permeable ones that use recycled materials. These materials also reflect sunlight, helping to reduce the urban heat island in the city. City officials have taken this a stage further and have produced a handbook (see link below), for residents encouraging them to adopt as many green infrastructure approaches as possible, by using planters and building trenches to enhance the Green Alley Program further.

The Green Alley Program. Source: City of Chicago

Green infrastructure features

- Tree planting: to create shade and reduce heat, addressing urban heat island;
- Native landscaping: locally suited to weather, water and soil conditions, reducing need for high maintenance and watering;
- Rain gardens and water butts: to slow down storm water runoff and to harvest water for controlled irrigation;
- Green roofs: to reduce the rate of storm water runoff, urban heat island effect, overall reduction of energy costs;
- Naturalised detention: a pond or wetland which manages stormwater runoff and filters silts, pollutants and debris;
- Bioswales: the use of a trench planted with native plants to reduce rate of water runoff, filter it and recharge groundwater.



Permeable Alleys. Source: City of Chicago

Progress

Chicago has led the way in North America in its approach to managing water and gradually changing the surfaces of its approximately 1,900 miles of alleys. Many other cities, like Los Angeles, Boston and Seattle, have since adopted similar approaches to tackling stormwater and water quality. Between 2010 and 2013, Chicago upgraded a further 100 alleys and installed 360 green roofs. It has developed from what was a Green Alley pilot scheme into a city wide, Streetscape and Sustainable Design Program. A more holistic approach to sustainability is now in place, addressing issues beyond stormwater management such as air pollution, water conservation and health and wellbeing, all with green infrastructure at its heart. The work they have done here and in particularly in the Cermak – Blue Island Sustainable Streetscape Project has earned Chicago the title of 'City with America's Greenest Street'.

References and further information

http://www.cityofchicago.org/content/dam/city/depts/cdot/Green_Alley_Handbook_2010.pdf

https://www.cityofchicago.org/city/en/depts/cdot/provdrs/street/svcs/green_alleys.html

http://stormwater.wef.org/2013/11/chicagos-streets-alleys-islands-future/

Stormwater Management Grants, Philadelphia, USA

Dates	Scale	Type	Primary driver	Funding & delivery	Outcomes
2012 - ongoing	City	Retrofitting	Stormwater management	Philadelphia Water Department	Reduced water run-off; increased permeable surfacing

Rain garden at Popi's restaurant, Philadelphia. Photo courtesy of Phildelphia Water Department.

Context

Stormwater Management Incentives Program Grant (SMIP) and the Greened Acre Retrofit Program Grant (GARP) are two funding incentives in the city of Philadelphia to retrofit green infrastructure on private property across the city. They are part of a wider stormwater management plan for Philadelphia *Green City, Clean Waters*. This plan aims to reduced the combined sewer overflow by 60% and reduce overflow by 85%. The citywide plan includes two grant programmes (SMIP and GARP) as well as a capital investment to increase green infrastructure in the public domain (e.g. green streets and sidewalks, green roofs, bioswales, rain gardens, complete streets – see Big Green Map) and regulation control of new development.

SMIP and GARP incentivise property owners by providing funding to implement green infrastructure on private land and reduce the amount of impervious surfacing on their property. The City of Philadelphia charge property owners a monthly water bill, which includes a stormwater fee. This fee is calculated based on the size of the property and the amount of impervious surface. So the added incentive for property owners is that increasing green infrastructure on their property also means a reduction in their monthly water bill.

The difference between the two grant schemes is that SMIP funding is applied for, and the green infrastructure implemented, by individual property owners. The GARP programme targets aggregated properties (minimum of 10 acres in total) so the funding agreement and implementation is undertaken by a third party (e.g. a property management company), on behalf of property owners. Up to US$100k/impervious acre is available from the SMIP funding grant and up to US$90k/impervious acre under the GARP grant.

Stanley's Hardware, Philadelphia. Image courtesy of Philadelphia Water Department.

Green infrastructure features

- Rain gardens;
- Green roofs;
- Swales / Bioswales;
- Flow through planter boxes / tree trenches;
- Permeable pavement ('porous');
- Cisterns: capture and reuse.

Progress

SMIP was first offered in 2012 with US$5million/year available for grants. In 2014, GARP was launched and the budget was increased in 2015 to US$15million/year, which included funding for SMIP and GARP.

References and further information

Philadelphia Water Department website:
http://www.phila.gov/water/wu/stormwater/Pages/Grants.aspx
http://www.phillywatersheds.org/stormwaterpioneers
http://www.phila.gov/water/wu/stormwater/Pages/Grants.aspx
Popi's Restaurant – SMIP grant –rain gardens:
http://www.phillywatersheds.org/stormwaterpioneers
Stanley's Hardware:
http://www.phillywatersheds.org/doc/Case%20Study-Pioneers-Stanleys_WebsiteFinal.pdf

Lessons learned

We also asked the case studies for any lessons learned from their experiences of GI delivery. These can be summarised as follows:

- The objectives for the GI must be understood and communicated so that the right (multi) disciplinary teams can be commissioned and the GI effectively planned and designed;
- It is important to have local champions and experts driving the project;
- Working with communities to gain local expertise, understand their needs for the GI and how they will use it so that something is delivered that meets their requirements and reduces conflicts;
- Ensuring maintenance requirements are understood and resources are in place to deliver them from the outset;
- Ensuring that professionals have the skills needed to plan, design and delivery GI, for example through training, regulation and as GI becomes more common place. This could come from the public sector "making money available does not necessarily mean that the private sector will know how to spend it effectively";
- Similarly, providing information to residents so that they understand the purpose and benefits of the GI features and how to get the most from them;
- Combined approach between regulation and incentives for creating new GI, for example in stormwater management;
- Providing soft measures, marketing and communication to promote new GI incentives, initiatives, projects and features to maximise their success;
- Small, simple, multifunctional green spaces can be extremely effective for example, for water management, local climate regulation and recreation.

Conclusions

The grey literature and case studies demonstrate that the evidence related to GI is reaching the international practice community. There is some contrast in the focus of these; the grey literature concentrates on regulating services and their economic benefits, and the cultural services whereas the primary drivers for many of the case studies are regulating services and habitat restoration. The reasons for this are unclear but it maybe that the financial case for regulating services is easier to make and these, along with nature conservation are responding the legislative drivers. Also, there is a more mature evidence base for these outcomes of GI than those related to health and well-being which seem to be seen as secondary benefits in many of the case studies except where urban regeneration is the focus.

The challenges in the international community are different from those in the UK and this is reflected in the grey literature and case studies. For example, there is a greater focus on coastal water management, gender equality, benefits of urban agriculture for the urban poor and nature conservation, particularly in developing countries.

There does appear to be an opportunity to evaluate the outcomes of GI projects. Very few of the case studies provide a robust evaluation of the outcomes of the project. Related to

this, much of the academic literature appears to focus on small-scale projects, modelling and/or a small number of outcomes meaning that it difficult to assess trade-offs and synergies between different objectives for GI.

Overall, it is clear that GI is receiving significant attention in the international community with a number of documents published in the last two years aimed at a global audience and a vast array of projects being delivered around the world. Despite this, the lesson learned from the case studies suggest that the successful delivery of projects is challenging. There is therefore an opportunity to consolidate the academic and practice-based evidence and enhance this with consideration of the long-term delivery of GI.

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