Part 4

Green infrastructure and climate change

Introduction

Green infrastructure is defined in the **National Planning Policy Framework** (2012) as "A network of multi-functional green space, urban and rural, which is capable of delivering a wide range of environmental and quality of life benefits for local communities".

This section of the manual considers how green infrastructure can support climate change adaptation within urban areas. It describes the most likely impacts of climate change, and sets out information and evidence on how different forms of green infrastructure can help to address these issues. The section is aimed at the conservation sector as well as others who work in planning, sustainable development and who work in and with local partnerships and Local Planning Authorities.

Within towns and cities, the natural environment is often degraded and fragmented. The incorporation of new green infrastructure (including green space, open water – often referred to as blue space - and brownfield land) within settlements can help to provide new habitats for wildlife, while also improving the quality of life for urban communities and helping us to adapt to some of the effects of climate change. For a general overview of green infrastructure and its multi-functional benefits, Natural England has published **guidance** on green infrastructure planning and delivery.

The natural environment also has a crucial role in making urban landscapes liveable. Using nature based solutions, through the delivery of green infrastructure, to create successful places, for both humans and wildlife, is becoming increasingly understood and recognised as an essential component of nature conservation and ecosystem based adaptation.

Planning for and delivering green infrastructure is a key way to deliver and support climate change adaptation. If designed and located well, green infrastructure can provide multiple ecological benefits, such as creating and improving wildlife sites and enhancing ecological networks. It can also provide societal benefits such as increased recreation resources, flood risk management, and bringing people into contact with nature, thereby improving quality of life. Key adaptation benefits of green infrastructure include (**Natural England 2009**; **North West climate change action plan & GRaBS report 2010**):

- Managing temperature
- Managing water supply
- Managing river and coastal flooding
- Managing surface water
- Reducing soil erosion
- Helping species adapt
- Managing visitor pressure.

Green infrastructure can include a wide range of measures that enhance both the natural environment and the built environment. These include green roofs and walls, green and blue spaces and green travel routes. Green infrastructure can also include street trees, gardens, parks, rivers, wetlands and coastal areas. Sustainable urban development, including through green infrastructure delivery, is a key and growing adaptation delivery mechanism, and as such forms a significant area of work for Natural England and its partners.

Urban climate change impacts

Climate change will impact on urban areas in a number of ways. Many urban areas are already vulnerable to extreme weather events such as high rainfall and heatwaves. These events can lead to flooding and problems with localised areas of higher temperatures caused by modifications to the land surface and waste heat generated by energy use, often known as urban heat islands. Climate change will increase the severity and frequency of these extreme events. Impacts are likely to be greatest in areas that lack green open spaces and where natural processes such as drainage have been disrupted (**UK Climate Change Risk Assessment Evidence Report 2017**).

Biodiversity in urban areas will also be affected by climate change. As with rural areas, individual species may experience shifts in their range and distribution, and changes in the timing of natural events (e.g. as a result of earlier springs) could have important consequences for the interactions between species (Morecroft & Speakman 2015). These impacts could lead to changes in the composition of species' communities. Some urban areas can be quite hostile to wildlife, with small, fragmented areas of habitat and many physical barriers to movement, and the ability of species to move and adapt to change may be restricted.

The table below summarises the most significant potential impacts of climate change on urban biodiversity and urban communities. These are addressed in more detail in the following sections. Many of the impacts on biodiversity will also be experienced outside of urban areas, and are covered in more detail in the habitats and species sections of this manual.

Cause	Consequence	Potential impacts on urban biodiversity	Potential impacts on urban communities
More severe and more frequent rainfall events.	Flooding – surface water, coastal, and fluvial.	Increased frequency and intensity of rainfall causes flooding, waterlogging and longer periods of inundation, reducing the available habitat area available for various life cycle stages (e.g. foraging, breeding and hibernating). This is a particular issue for urban rivers and watercourses, many of which are heavily modified and canalised. Sudden downpours can lead to surges of water which wash species out as there are no backwaters etc. in which to hide from the current. Increased soil/sediment erosion and deposition. Changes in species composition due to changes in climatic factors that affect breeding success or mortality rates. Increased risk of pollution, especially if sewers and waste water treatment facilities flood.	Costs and disruption caused by flooding of residential, business and recreational areas, and to transport and energy infrastructure. One of the biggest challenges is surface water flooding due to lack of permeability and inundation of drainage systems. Reduction in service provision due to flooding e.g. emergency services, schools, hospitals, etc. Mortalities, injuries and mental health impacts of flooding. Increased soil erosion or sediment deposition affecting infrastructure. Impacts on drinking water provision and the costs associated with sewage removal and damage repair.

Cause	Consequence	Potential impacts on urban biodiversity	Potential impacts on urban communities
Reduced summer rainfall	Drought	Changes in species composition, as species that require specific hydrological conditions may be affected. Increased fire risk due to dry vegetation and ground conditions. Increased individual mortality, especially if water availability is severely reduced. Low water flows/volume and resultant pollution concentrations could affect freshwater habitats and species. Low water flows/volume can also result in a reduced oxygen content within the water and an increased risk of algal blooms, which can have a detrimental effect on freshwater habitats and species.	Increased fire risk to dried out vegetation (e.g. heathlands, grasslands and woodlands) and proximity to built-up areas. Low flows/volume could affect water availability and lead to restrictions on use. Pollution concentration and algal blooms in water bodies could restrict recreational use. Water shortages and restrictions on use. The ability of green infrastructure to provide some ecosystem services will decrease if it is drought stressed.
Increased mean temperatures	Urban Heat Island effect Seasonal changes	Changes in species distribution and community composition as some species may not survive in higher temperatures. Higher temperatures may facilitate the spread of invasive species and diseases. Higher temperatures will lead to a longer growing season, which could lead to increased vegetation growth. Altered phenology and species interactions, e.g. the timing of birds hatching and the availability of food supplies may be mismatched. Increased water temperatures could affect aquatic species with specific temperature requirements. Species with winter chill requirements may be affected e.g. some trees require a winter chill period in order to fruit well in the following season.	Travel disruption caused by damage to transport infrastructure (e.g. rail buckling, road melting), and the resulting repair needs. Impacts on health and wellbeing due to heatwaves e.g. increased instances of heat stroke and respiratory illness. Overheating in buildings in the summer could lead to a loss of productivity (UK CCRA Evidence Report 2017). Warmer summers could exacerbate air pollution issues. For example, air pollution can rise in periods of hot, calm weather, particularly ground level ozone concentrations (UK CCRA Evidence Report 2017). Increased energy demand for summer cooling, and potentially reduced energy demand for heating in the winter. Heat-related damage and disruption to energy infrastructure, and energy transmission efficiency losses.

Cause	Consequence	Potential impacts on urban biodiversity	Potential impacts on urban communities
Sea level rise	Increased risk of coastal flooding and erosion	Loss of inter-tidal habitats due to coastal squeeze. This is very likely in urban coastal locations, where natural processes of coastal change are often impeded by hard sea defences. Erosion and loss of sediments in areas defended by hard structures can have knock-on effects in other locations as natural processes of sediment transportation are disrupted. Potential changes to fresh water coastal habitats due to inundation and saline intrusion.	Urban areas at the coast or located on tidal rivers will be at greater risk of flooding from extreme events e.g. storm surges if adaptation measures are not taken. This will lead to knock on impacts for communities living in affected areas. Saline inundation of potable ground water used for human consumption, industry and crop irrigation
Increased frequency of extreme events.	Drought, flooding, storms, coastal storm surges	Increased stress for sensitive species, leading to reduced breeding success and greater susceptibility to other pressures. Increased individual mortality e.g. by drowning, desiccation, and wind throw. Potential changes to fresh water coastal habitats due to inundation and saline intrusion.	Extreme events have the potential to cause death and injury, and can disrupt lives; and those affected can experience mental health problems. These impacts are likely to intensify as the severity and frequency of extreme events increases, and recovery times between disruption events is reduced.

How can green infrastructure assist adaptation to climate change?

The following sections examine the main climate change impacts on urban areas and show how different approaches to green infrastructure provision can help address these impacts, while also delivering benefits for biodiversity, recreation and landscape enhancement. These sections cover:

- Flooding
- Drought
- The Urban Heat Island effect
- Biodiversity enhancement
- Coastal flooding
- Conservation of soil function

Flooding

The issue

Climate change projections show that while the total amount of annual precipitation may stay roughly the same, its seasonal distribution may change and precipitation events may become more intense. Increases in extreme precipitation events, coupled with large areas of hard, non-permeable surfaces in urban areas and degraded catchment habitats upstream, will lead to increased water run-off and reduced infiltration to groundwater stores. In addition, increases in peak flows and reduced lag times in rivers can lead to flooding, with associated erosion and pollution. Heavy metals such as cadmium, chromium, copper, lead and zinc can be washed off road surfaces and into natural water bodies, if well designed detention basins or retention ponds are not present (Barbosa & Hvitved-Jacobsen, 1999). Along with nutrient pollution from overloaded sewer networks, this will further degrade urban ecosystems.

What can green infrastructure do?

Well-designed green infrastructure can help provide flood management services as an adaptation response to climate change. This includes reconnecting rivers with their floodplains, reducing run-off, slowing the flow of floodwaters, directing and storing water temporarily so that it causes less damage, filtering water to remove pollutants, and modifying infiltration. It can also help to improve the quality of water flowing into watercourses and underground aquifers, and provide wider biodiversity, landscape and amenity benefits. Specific elements of green infrastructure that can address the increased risk of flooding expected as a result of climate change include:

- Sustainable drainage systems (SuDS).
- Green roofs.
- Wetlands.
- Street trees, parks and gardens.

Sustainable Drainage Systems

SuDS aim to intercept and manage water run-off, so as to reduce flood risks, both within urban areas and further downstream. They can also help to remove contaminants from run-off. They generally aim to mimic natural processes by intercepting water close to its source and allowing it to infiltrate into the ground, or be retained in storage areas. SuDS can use a range of techniques to deliver water harvesting, infiltration, conveyance, storage, and treatment. Components of SuDS can include artificially created wetlands and retention ponds, vegetation-based systems such as reed beds, permeable surfaces, dry ponds, infiltration trenches, soakaways and rain gardens (see table below). They can be particularly important if created in areas with a high number of minor developments (such as paved impermeable driveways) where the cumulative impact of such developments has not been considered. SuDS can be incorporated into a wide range of new development schemes, and can also be successfully retrofitted to existing developments.

Some SuDS, such as water retention ponds and wetlands, can also improve water quality by acting as filters and trapping polluting particulates which would otherwise enter urban streams and harm biodiversity (Charlesworth 2003). Different SuDS components are capable of offering a range of different treatment functions and service levels, depending on their design.

Example SuDS components and purposes	
Wetlands	Shallow ponds and wetlands, including reed beds, covered with aquatic vegetation, that provide storm attenuation, sediment settlement, and pollutant removal.
Swales	Vegetated drainage channels or troughs with a shallow gradient to reduce flows. They provide storage and/or conveyance of surface water, infiltration and settlement of particulate pollutants.
Retention ponds	Ponds near to hard surfaces that provide storm attenuation, sediment settlement and pollutant removal
Trees	Trees can help surface water management through processes of transpiration, interception, increased filtration and phytoremediation[41].
Permeable pavements	Pavements and hard surfaces that allow infiltration or temporary water storage prior to discharge.
Infiltration trenches	Shallow trenches filled with stone/rubble located to receive lateral flow from an adjacent impermeable surface; they create temporary storage, filtration, and infiltration if unlined.
Soakaways	Lined or loose-filled excavated pits that provide better infiltration, storm-water attenuation and groundwater recharge.
Rain gardens or filter strips	Vegetated strips which accept runoff as overland sheet flow from upstream development, and are located between a hard surface and a receiving component. They provide vegetative filtering, settlement of particulate pollutants and infiltration.
Green roofs	A roof of a building that is partially or completely covered with vegetation and a growing medium, which can reduce run-off and attenuate peak flows.
Bioretention	Shallow, depressed landscaped areas, which use engineered soils and enhanced vegetation to filter pollution and reduce runoff; for example, planted areas in car parks.
Detention basins or dry ponds	Excavated areas close to rivers, streams and lakes used to intercept and store water for a limited period of time and protect against flooding.
Geocellular systems or below ground storage/ infiltration	It is generally recommended to handle run-off at surface, but at some sites this is not possible, so modular plastic systems with a high void ratio can be inserted, for example under street tree trenches, to help capture and slowly release run-off.

41 The use of plants to remove pollutants from soil, air or water.

Wetland restoration case study:

Beam Parklands, biodiverse community flood risk management.

Beam Parklands is a multifunctional wetland park in East London that opened in 2011. It sits on the floodplain of the River Beam, a tributary of the River Thames that forms the boundary between the London Boroughs of Barking and Dagenham, and Havering.

Single issue green infrastructure vs. multifunctional flood storage at Beam Parklands. © S.Davenport

Prior to the creation of Beam Parklands, the site had functioned as an Environment Agency flood storage reservoir, protecting local homes, schools and businesses, including Barking Power Station. However, during upgrade works a more ambitious flood protection scheme was conceived. The exceptionally biodiverse but under-used site was redesigned and connected to other areas, changing it from a single function piece of green infrastructure to a much more multifunctional area of green space that contributes to the All London Green Grid. The local community was involved from the beginning of the project, ensuring they benefit from the recreational provision as well as the flood storage function.

Green roofs

A green roof is a roof of a building that is partially or completely covered with vegetation and a growing medium, planted over a waterproof membrane. It may also include additional layers such as a root barrier and drainage and irrigation systems. Green roofs are loosely categorised by the type of vegetation they support, from 'intensive' roofs used for food growing and formal green spaces, through to 'extensive' roofs which are more naturalistic and can support a range of wildflowers.

Green roofs serve several purposes, such as absorbing rainwater, providing insulation, creating a habitat for wildlife, providing an aesthetically pleasing environment, and helping to lower urban air temperatures (The GRO Green Roof Code 2014). Green roofs can also be combined with solar panels to enhance the performance of the panels (Chemisana & Lamnatou 2014; Tomazin 2016).

Rain falling on conventional roofs moves rapidly towards drains. Green roofs use the natural functions of plants to slow down run-off and retain water in the roof's substrate before evaporating it back into the atmosphere. By retaining and slowing the release of water in periods of heavy rainfall, green roofs help to reduce peak flows. They can also retain and treat contaminants that are introduced to the surface either as dust or suspended in rainwater (Living Roofs Code of Practice) and can help to neutralise acidic rainwater (Berndtsson 2010). Roofs that are designed to provide heterogeneous wildlife habitat perform as well or better at water attenuation than less diverse vegetated roofs, while supporting greater biodiversity (Connop & Nash 2016).

Wetlands

Establishing wetlands, and riparian and floodplain woodlands, can help to reduce peak flood volumes and provide areas where rivers can flood without causing damage. There may be significant opportunities for wetland creation in rural areas that will reduce the effect of flooding on settlements. In urban areas, existing green infrastructure within flood zones can be safeguarded to help manage riverine flooding, and artificially constrained waterways can be restored to a more natural state.

Restoring floodplains, widening river corridors and setting back flood banks can provide space for excess water to be redirected and stored. This can help to re-establish a more natural flood management process upstream, thereby reducing flood risk for settlements and infrastructure downstream.

The restoration of floodplains also helps to reduce water pollution by metabolising pollutants, and can contribute to managing water availability by storing water in periods of heavy rainfall, then releasing it in dryer periods. This can help support river flows and water availability in summer by recharging aquifers and ground water.

Larger flood plain restoration projects that enable greater floodwater storage are very important. However, in the urban context, a matrix of different SuDS for rainwater run-off retention can be very effective by applying the same fundamental principles of intercepting flows and improving infiltration at a more localised scale.

The physical and functional connections between habitats made by green infrastructure can provide routes for species movement and can help improve the resilience of native biodiversity. Canals and rivers, alongside flood storage areas, can support this function. In urban areas they can play an important role in providing a refuge for species that may have lost their original, natural habitat.

Mayesbrook Park, London

The intention at Mayesbrook Park was to update 50 year old flood management infrastructure in an area of East London suffering from localised flooding and lack of natural green space. The project used a more 'nature based' approach to flood management, while providing a multifunctional landscape that is more resilient to climate change for people and wildlife. The works restored natural meanders to the Mayes Brook, through the creation of 500 m of new sinuous water channels, which help to slow high flows and improve habitat diversity, while 450 m of re-graded banks help to increase the capacity of the river and improve the riverside habitat. The work has created 1.5 ha of new floodplain and provided areas of wetland, meadow and woodland habitat.


Before


During works


The restored river at Mayesbrook Park

An ecosystem services assessment helped build the case for investment showing the integrated urban river restoration provides a long-term return to society of at least £7 for every £1 spent. Extensive public consultation helped the partners address local concerns and the area is now a well-loved and used urban greenspace. There are future plans to link this park with another nearby park to provide connections for people and nature.

Street trees, parks and gardens
Street trees, in association with sub-surface retention systems (areas under streets and pavements where water can be collected and used by street trees or passed slowly in to the sewerage system) can help manage surface water and urban diffuse pollution, as shown by the **Howard Street** experiment in Salford. Parks and gardens are also important for climate change adaptation, and green elements associated with hard infrastructure, e.g. road verges, also provide important support to managing flood risks and pollution.

The Forestry Commission's **i-tree Eco Tool** assessment of London found that, among other ecosystem services, London's 'urban forest' (which consists of nearly 8.5 million individual trees with a leaf area of some 1047 km^2) currently prevents 3,414,000 cubic metres of run-off per year and provides £2.8 million worth of flood alleviation benefits (Treeconomics 2015).

Natural Flood Risk Management Evidence Base

The Environment Agency (2017) has published **Working with Natural Processes – the evidence behind Natural Flood Management** which synthesises the evidence base for natural flood risk management. It includes an evidence directory, maps and supporting guides to help flood risk managers to access up-to-date information and to fully understand the potential benefits.

Drought

The issue

Higher temperatures and reduced summer rainfall are likely to lead to more frequent periods of drought and pressures on existing water resources.

What can green infrastructure do?

Green infrastructure has the potential to:

- Help retain water.
- Increase biodiversity survival in times of heat and water stress.
- Provide shade and cooling.
- Be incorporated into rainwater harvesting systems to improve water use efficiency and reduce demand on natural sources.

Well-designed green infrastructure can help vulnerable species to survive in periods of drought. For example, a green space designed with a matrix of habitats, species diversity, and drought tolerant planting will be more likely to survive drought and provide cool and shaded refuges for species during hot, dry periods. Water bodies can provide much needed water for animals and people (e.g. recreation) in times of drought and provide a cooling effect in the local area. Furthermore, green infrastructure such as parks, with deep soil bases, can act as natural water reserves, with trees helping to increase the infiltration of water into the soil.

However, green infrastructure can be vulnerable to drought itself, which can affect its functionality and biodiversity (Gill *et al* 2013; Speak *et al* 2013). It is also important to note that if large amounts of artificially provided water are required to keep green infrastructure functioning, it could cause an added water stress. Therefore, the right design and scale in the right place is required, in order to provide green infrastructure that is sustainable under drought conditions. Integrating water capture and retention techniques, suitable planting and appropriate design can help ensure this.

The Urban Heat Island effect

The issue

The urban heat island effect is what causes urban areas to be warmer than the surrounding countryside. In contrast to rural areas, where night-time relief from high daytime temperatures occurs as heat is lost to the sky, the urban environment traps and stores more heat, which is re-emitted overnight, keeping temperatures higher than the surrounding countryside (Smith & Levermore 2008). Areas with limited vegetation, hard artificial surfaces and anthropogenic heat sources all contribute to this, as do high buildings and complex topography, which can restrict air flows and trap hot air (Brown 2015). In the UK, temperature differences between cities and rural areas can be more than 70°C (Smith & Levermore 2008), and increases in mean air temperatures and more frequent heatwaves mean that heat related issues in built-up areas are likely to become more of a problem in the future (Hathway & Sharples 2012; **UK Climate Change Risk Assessment Evidence Report 2017**).

What can green infrastructure do?

Green infrastructure can help to reduce ambient temperatures in urban areas by providing shade from the sun, and natural cooling as a result of evapotranspiration. This can be achieved by creating areas of green and blue space and tree planting, and by installing green roofs and walls. These approaches are likely to become more important in built up areas as average temperatures rise and periods of extreme high temperatures become more frequent.

Green and blue spaces and tree planting

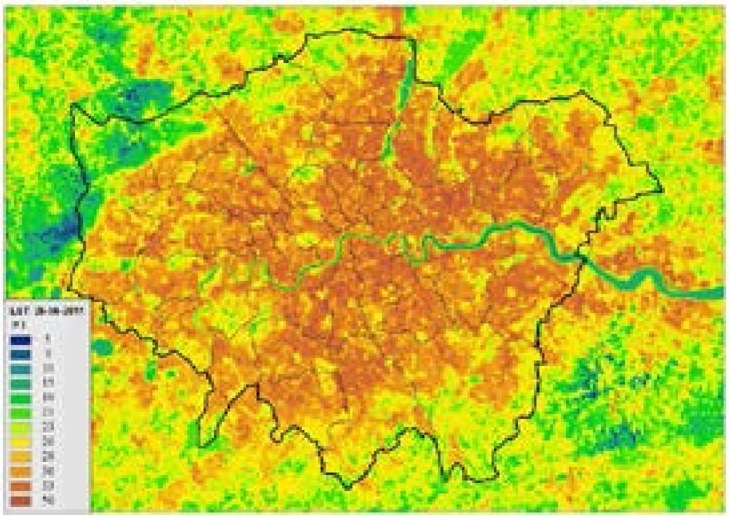
Green spaces create cooler microclimates through evapotranspiration; when water evaporates from leaves and the earth's surface, energy is absorbed from the air, creating a cooling effect. The shade provided by mature trees on streets and in parks and gardens reduces temperatures locally and can shield building facades and street surfaces from the sun. The amount of energy stored by the built fabric during the day is therefore reduced, and so the urban heat island effect is reduced. Gill *et al* (2007) performed a study on the cooling effect of green spaces in Manchester using modelling techniques and based on the UK Climate Projections 2002. They found that adding 10% green cover to areas with little green space, such as town centres and high-density residential areas would reduce maximum surface temperatures by 0.7-1.20°C (low emissions-high emissions scenarios, 2080s). If the green space was not added, the surface temperature would increase by 1.7-3.70°C (low emissions-high emissions scenarios, 2080s). In contrast, removing 10% of existing green cover in town centres would lead to an increase in temperature of 7-8.20°C by 2080 under the low-high emissions scenarios (all changes are in relation to the 1961-1990 baseline).

Water bodies complement the role of trees and green space by further moderating surface temperatures through evaporative cooling. In drought conditions, when the cooling effects of vegetation in green spaces are impaired, the role of urban water becomes more pronounced.

In clear sky conditions, shade provides an important cooling effect for individuals, and broad leaved deciduous trees provide the greatest benefit. They reduce not only the solar radiation felt directly by people, but also the amount of radiation absorbed by the ground, which would otherwise be re-emitted. It is therefore important to plan ahead to enhance and replace existing stocks and allow trees to grow to maturity. Leafy shrubs and hedges also further reduce thermal re-emission from the ground compared to lawn surfaces. This highlights the need to provide a variety of vegetation in green spaces, which will also generally enhance their biodiversity value.

As well as cooling the air locally, green spaces can also create air movement, causing cooler air to be blown towards surrounding neighbourhoods, creating statistically significant cooler temperatures in these areas too (Brown *et al* 2015). Modelling suggests that green spaces can have a city-wide cooling effect (Gill *et al* 2007).

Green and blue spaces will be most effective in urban areas with sparse existing vegetation, little open space, and high building density. The cooling services of green infrastructure can be particularly significant for vulnerable people during periods of heat stress (**Doick** *et al* **2017**). Design should ideally focus on shaded green space. Tree species with dense foliage (high leaf area index) or which produce dappled shade are most useful. The size of the green space is also important. It has been found that green spaces develop a distinctive climatic effect when they are greater than 1 ha in size (von Stülpnagel *et al* 1990), and that a cooling service on calm warm nights within cities with similar climate and characteristics to London may be provided by green spaces of 3–5 ha, situated 100–150 m apart (Vaz Monteiro *et al* 2016).



London, June 2011, Land Surface Temperature. © Arup (2014)

Illustration of green and blue spaces in London
Source: https://maps.london.gov.uk/green-infrastructure/ Open Government Licence v3

The map opposite shows how urban green infrastructure can reduce the urban heat island effect through the cooling effects of evapotranspiration and shade. The map shows the surface temperature of London on the night of 26 June 2011 (in °C). The red areas are hottest and the green, the coolest. The densely built up West End (theatres/shops/tourist attractions) is 8% hotter, at 31 °C, than Richmond Park, a large area of urban green space, which is much cooler at 23 °C. When you overlay the vegetation map of London, it shows a strong correlation between green areas and the lowest temperatures.

Green roofs and walls

Green roofs and walls can provide cooling, flood management, and biodiversity benefits (**Greater London Authority 2008**). They have also been shown to lower ambient temperatures by reducing night-time heat radiation, shielding building materials from the sun, and storing water in substrates, which provides evapotranspirative cooling (Alexandria & Jones 2008). Greening roofs in areas with a high proportion of buildings is an effective strategy to reduce surface temperatures (Gill *et al* 2007). Green roofs can also increase insulation, making buildings more efficient and reducing energy use e.g. helping to reduce the energy use for air-conditioning in buildings in summer and heating in winter (Smith & Levermore 2008; Castleton *et al* 2010).

Green walls work in a similar way to green roofs. They can help reduce the urban heat island effect through the interception of light and heat radiation which would otherwise be largely absorbed and converted to heat by building surfaces and then radiated back into the surrounding streetscape. They can also play a role in intercepting and temporarily holding water during rainstorms, in the same way that green roofs do. They also trap dust and filter out harmful pollutants in the atmosphere, as well as helping tackle noise pollution both inside and outside of buildings.

When modelling the cooling effects of green roofs and walls in the spaces between buildings, Jones & Alexandri (2008) found that air and surface temperatures lower significantly when walls and roofs are covered with vegetation. Green roofs act as a constant heat sink through evaporative heat transfer. They also absorb less radiation, which means less heat is absorbed by buildings in the day, and less is re-emitted at night.

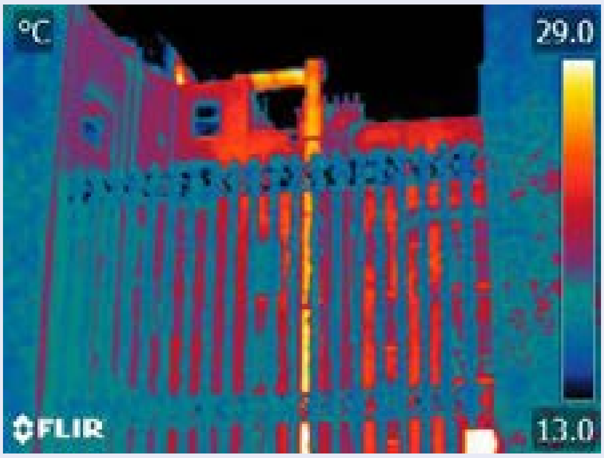
Green roof at Canary Wharf, London.

Victoria Business Improvement District (BID), London

The objective here is to retrofit the area of the Victoria BID in Central London with green infrastructure to deliver a range of ecosystem services which underpin economic growth. A BID is a geographically defined area in which businesses make financial contributions to be spent in the area on projects determined by the local business community. The Victoria BID wanted to use natural environment features and biodiversity to create a sense of place and identity, to provide localised adaptation to climate change, and to be an exemplar green infrastructure project in a highly developed area. A baseline green infrastructure audit found that most of the potential for green infrastructure delivery was at roof level. Roofs were assessed to establish their potential to support a range of green roof types, and a plan was developed to identify the best opportunities and to help prioritise approaches to building owners. If the mapped potential for green roofs is delivered in this area, the green cover in Victoria would increase by 80% and 25 hectares of green space would be created, providing increased wildlife habitat and helping to reduce surface water run-off.

The Rubens Green wall

The Rubens Green Wall covers 350 m2 and comprises 10,000 plants, which provide a range of biodiversity, cooling, noise reduction and air pollution benefits. It also incorporates a rainwater attenuation tank and irrigation system to distribute the collected rainwater to the plants. The location was highlighted through the Victoria BID green infrastructure audit. The thermal images below illustrate the cooling properties of the wall.



Thermal Image of green wall on the Rubens Hotel in Victoria. © Thomas Chung, University of Reading/Forest Research

Retro-fitted green wall on the Rubens Hotel in Victoria. © Natural England/Sarah Taylor

Biodiversity enhancement

The issue

Biodiversity is subject to a range of climate change related impacts, as discussed elsewhere in this manual. These include population range shifts, changes in the timing of seasonal events and the interactions between species, vulnerability to extreme weather events, and indirect impacts from our responses to climate change.

Our traditional framework for valuing habitats and sites may not always work in an urban context, and it might be more useful to think of urban areas as having their own characteristic suite of habitats and species, reflecting the physical environment and cultural history of developed areas. In some instances, urban areas may be more biodiverse than surrounding agricultural land. It is not just large open spaces that are important; the matrix of smaller bits of habitat and green space can also be valuable for nature conservation in a changing climate, and the potential for green infrastructure within urban areas to deliver benefits for both nature and people should be recognised.

What can green infrastructure do?

Good quality and well planned green infrastructure can contribute to our network of ecologically rich sites, and has the potential to help nature to adapt to climate change by:

- Providing new areas of valuable habitat.
- Reinstating natural functions such as water and nutrient cycling.
- Providing increased connectivity between fragmented areas of habitat.
- Allowing people to access and enjoy nature and learn about the importance of the natural environment.

These biodiversity benefits can often be delivered in combination with flood and heat regulation. Examples of green infrastructure that benefit biodiversity include:

- Conventional green spaces and wetlands, which provide semi-natural features and can increase habitat size and connectivity;
- Soft Infrastructure, including green roofs and walls, gardens, and flood alleviation features.

Conventional green spaces

These include informal areas of open space, parks and wetlands that contain areas of semi-natural habitat, as well as more formal nature reserves and other designated sites. Such areas will often provide a range of ecosystem services, as previously discussed, as well as providing valuable wildlife habitat, and will be vulnerable to the impacts of climate change as well as helping provide nature-based solutions to some of the impacts likely to be felt.

When creating or improving an area of green space it is important to consider how the effectiveness of any biodiversity enhancements could be influenced by the surrounding area. For example, there may be a risk that storm water runoff could flood the habitat and carry pollutants into sensitive habitats, or that invasive species could colonise from nearby gardens. Green infrastructure can be considered to be an arrangement of semi-natural features that work best when connected and functioning in a network that extends through and across the urban area and out into peri-urban and rural areas.

The principles of design and scale for green infrastructure are discussed further later in this section.

Soft infrastructure

Green infrastructure that is designed to provide another service to urban areas, such as floodwater attenuation or urban cooling, can also be designed to enhance biodiversity. For example, it can be designed to maximise the benefits for known local wildlife or species that struggle in urban situations, or to provide greater permeability between habitats within an otherwise hostile environment. However, in order to provide biodiversity benefits, this needs to be considered and incorporated into the design at an early stage, or opportunities to enhance biodiversity could be missed.

The potential for any form of green infrastructure to enhance biodiversity should be a primary design consideration. Creating a range of habitat and vegetation types, ensuring variation in topography and vegetation height, and providing specific features such as areas of wetland and woodland will all help to maximise biodiversity potential. More information about this can be found in Natural England's guide series on the **Mosaic Approach** (Natural England 2017).

Green roofs can provide habitat for many invertebrates, including those listed as rare or scarce (Kadas 2006). It is also possible that green roofs, if designed and located well, may also provide new links in an often fragmented network of habitats, thereby facilitating movement and dispersal of wildlife through urban areas. This is more likely to be beneficial for mobile groups such as flying insects and birds, but more research is required to assess their contribution to connectivity (Williams *et al* 2014). As species' ranges change in response to climate, green roofs may provide important stepping stones to aid this movement. Green roofs can also provide new habitat in areas which are currently lacking in wildlife interest.

Within cities, some of the most biodiverse areas can be previously developed brownfield sites, which are often at risk of redevelopment. The London Wildlife Trust has estimated that about a quarter of the city's wildlife sites are wholly or partly brownfield in character and if they were redeveloped it could mean a significant loss of urban biodiversity. They note that some London brownfield sites have already been so damaged or destroyed that they can no longer support the wildlife they were noted for (London Wildlife Trust 2002). The London Wildlife Trust also highlights that rapid growth in London puts considerable direct and indirect pressure on the locally important wildlife sites in the city (London Wildlife Trust 2015).

Green roofs can provide some compensation for lost brownfield habitats. For example, there is good evidence that the black redstart *Phoenicurus ochruros*, which is rare in the UK, uses extensive green roofs as nesting sites (Frith, Sinnadurai & Gedge undated). Designing green roofs that include varying substrate depths and drainage regimes creates a mosaic of habitats and can help the green roof avoid the negative impacts of drought that can be found on roofs with shallow substrates, and can facilitate colonisation by a more diverse flora and fauna (Brenneissen 2006). At the Queen Elizabeth Olympic Park in London, bio-solar roofs, which combine biodiversity benefits and photovoltaic energy systems, supported 92 plant species, with a variety of vegetation structure, and many invertebrate species of conservation concern (Nash *et al* 2015). Appropriate design and location is crucial in order to realise these benefits.

A bee's eye view of sustainable living (Davenport, in Dales, Doran & McGregor 2016)

Barking Riverside in East London is one of the largest redevelopment sites in the country. It covers 180 hectares and the site is home to protected and notable species, including rare and scarce invertebrates that are often found on the early successional habitat mosaics of brownfield sites. The redevelopment will deliver nearly 11,000 new homes, but it will also weave in green infrastructure and recognise the ecosystem services the site provides, including conserving the site's valuable biodiversity, retaining 40% of the site as green space, and developing a Sustainable Urban Drainage Systems plan.

Wetland habitats created on green roofs. © Caroline Nash

Research was conducted to test how a development can be designed to deliver truly multi-functional green infrastructure, including an ecologically led approach to green roof design. New roofs on site incorporate ephemeral wetland habitats that are typical of high quality brownfield habitats, and a niche often missing from green roof designs used to compensate for the loss of biodiverse brownfield habitats. The work also trialled a range of terrestrial landscaping options designed to incorporate ecological niches required by the species at Barking.

Monitoring showed the habitats were quickly colonised by notable invertebrate species, such as the shrill carder bee, and species diversity was found to be much greater on the ecologically designed areas than the traditionally landscaped control areas. The aspiration is for Barking Riverside to become a benchmark for sustainable design and the best way to deliver multifunctional green infrastructure.

For more detail see Natural England's **Chief Scientists Report 2015 - 2016** pp. 51-52

Gardens can provide a valuable refuge from the impacts of climate change for urban wildlife, by providing pockets of vegetation and shade, and can be particularly important for drought sensitive animals such as amphibians. Their usefulness will depend on their design and the way they are managed, and to be most beneficial to wildlife, gardens should provide a good range of food sources, water, shelter and nesting sites. As with other types of green infrastructure, if designed well, urban gardens can provide a valuable addition to the mosaic of green and blue spaces that contribute to climate change adaptation within urban areas.

Coastal flooding

The issue

Coastal flooding is likely to become more frequent as sea levels rise, and will impact on the people, buildings, infrastructure and wildlife of coastal settlements. Where inter-tidal habitats, which would otherwise provide a degree of flood protection, are constrained by artificial structures, leading to increased erosion and coastal squeeze, the ability to mitigate flooding of built up areas inland will be reduced.

What can green infrastructure do?

Just as various forms of green infrastructure can help protect urban areas from fluvial flooding, green infrastructure at the coast can help to address coastal flooding. At the coast, the term green infrastructure can be applied to both naturally occurring habitats, such as sand dunes and salt marshes, which can provide a buffer between coastal settlements and the sea, and to designed structures such as sea defences that may incorporate elements of green infrastructure. Specific elements of green infrastructure that may address coastal flooding and erosion include restoration of coastal and wetland habitats, managed realignment to create new areas of coastal habitat, and the incorporation of green infrastructure elements within hard sea defences.

Green infrastructure at the Coast

Actions at the coast that can help provide protection and adaptation for coastal settlements include protecting, enhancing and increasing coastal wetlands, which provide natural storage areas and can accommodate coastal floodwaters, potentially preventing other areas from flooding. In addition, dune systems and salt marshes provide a natural buffer against coastal flooding, by helping to dissipate wave energy and thus reduce erosion. Green infrastructure can also be incorporated into hard coastal defences, where evidence suggests it can enhance the performance of a seawall, as well as providing habitat niches and features for biodiversity (**CIRIA** 2014). Where engineered sea defences are still required, this hybrid approach, using both green and grey infrastructure, can provide effective and affordable options and often have positive additional benefits (The Royal Society 2014).

Green infrastructure interventions to manage coastal flooding will, to a large extent, involve safeguarding and enhancing existing habitats, which provide a natural buffer from the sea and provide space to enable habitats to roll back naturally. Creating new habitats, for example through managed realignment, will be possible, but these will generally take time to function as well as established habitats. However, in many instances, the service provided by green infrastructure in managing coastal flooding could be enhanced by the creation of areas of marsh and other wetland habitats, alongside other multifunctional green spaces. This can help to relieve the problems of coastal squeeze and create a more natural coastline, which is better able to absorb the sea’s energy and withstand major flood events, while providing wider recreational and biodiversity benefits.

Managed realignment at Freiston Shore, Lincolnshire

There is a range of examples of managed realignment providing ecosystem-based adaptation alongside hard sea defences to reduce vulnerability to coastal flooding. Freiston Shore, Lincolnshire, was selected for managed realignment in 2002, because erosion rates at the base of the sea wall were increasing, leading to escalating repair and maintenance costs. The measures at Freiston Shore were found to be very cost effective; the wave attenuation function of the saltmarsh vegetation is predicted to decrease the overall costs of the sea defence structures. The Environment Agency estimated that an 80 m wide saltmarsh margin could reduce a sea defence height from 12m to 3m, with a financial saving greater than an order of magnitude (Colls, Ash & Ikkala 2009). There are many benefits of the realignment at this **RSPB reserve**, as it attracts thousands of wetland birds throughout the year and provides a recreation resource.

New York City Green Infrastructure Plan, (Mayor of New York City 2010)

The majority of New York City's key infrastructure lies less than 3 metres above sea level. This highlighted a problem during extensive coastal flooding by Hurricane Sandy. The frequency of extreme weather such as hurricanes and storms is likely to increase with climate change. The city published its Sustainable Storm Water Management Plan in 2008 and its Green Infrastructure plan in 2010 to address these issues. Plans include increased vegetated areas along the coast and permeable pavement material to absorb water and slow run off times. The city already uses beach nourishment and restoration of sand dunes to combat flooding. See New York Green Infrastructure Plan for more information.

Conservation of soil function

The issue

There is growing awareness of the role soils play in providing a range of ecosystem services and supporting human activities, as recognised by the Millennium Ecosystem Assessment and the UK National Ecosystem Assessment. Soils form slowly, taking on average 100 years to make 1 cm of topsoil, and should therefore be considered a non-renewable resource (Environmental Audit Committee 2016). Despite this understanding, their use and mismanagement can result in the degradation of their physical, chemical and biological properties, potentially affecting their function and the services they provide. By taking into account the effect of soil degradation on soil properties and the ecosystem services they provide, Graves *et al* (2015) estimated the current total cost of soil degradation in England and Wales at between £0.9 billion and £1.2 billion. Despite these high estimates, there are significant evidence gaps concerning degradation of urban soil, particularly in association with urban green space and the sealing of soil under impermeable materials (Graves *et al* 2015).

Climate change is expected to have an impact on soils (UK Climate Change Risk Assessment 2017), with both direct and indirect effects on soil properties and processes. The interaction between these are complex, but the balance between soil temperature and moisture exerts a significant control, causing soil processes, properties and functions to be sensitive to changes in climatic conditions. While there are still significant evidence gaps in this area, it is clear that effective climate change adaptation methods require an understanding of the multifunctional role soils can play.

What can green infrastructure do?

In all locations, good soil management is important to ensure soils are resilient in the face of climate change, in order for them to provide climate change adaptation benefits through water regulation, urban cooling and drought management. Soils are the foundation for many of the ecological processes discussed in this manual, such as habitat development, biogeochemical cycling, and the life cycles of many organisms. Green infrastructure can contribute to soil conservation, and thereby ecosystem services and climate change adaptation, in a number of ways:

- Preventing soil erosion.
- Creating and maintaining permeable surfaces.
- Engineered soils.

Preventing soil erosion

While erosion is a natural process, it can be exacerbated by cultivation, deforestation and pressures from overgrazing. Future climate change projections could also influence erosional processes due to predicted increases in the frequency and intensity of rainfall events (UK Climate Change Risk Assessment 2017). *In situ* soil loss affects agricultural productivity and damages semi-natural habitats, but severe impacts of degraded soils are often felt 'off-site' (Graves *et al* 2015). The transport of sediment can damage downstream infrastructure, such as roads, waterways and drains, and habitats, such as wetlands, and can carry nutrients, depositing them in areas of sensitive biodiversity.

Green infrastructure can be implemented and enhanced to target and reduce soil erosion where there is a risk and where climate change may exacerbate this risk. This is especially important in upland areas, on slopes, and along the banks and floodplains of streams and rivers or close to transport infrastructure. Woodland planting can reduce soil erosion at source, litter and roots acts to keep soils in place and limit the delivery of sediment to watercourses, protect river banks from erosion and encourage sediment deposition within the floodplain. Vegetation can also reduce nutrient loss via uptake by plants and trapping soil particulates (Broadmeadow & Nisbet 2010). While the impact on soils from climate change and land use interactions are complex and require further research, it is widely recognised that measures to maintain vegetation cover and soil structure is essential to protect soils from future erosional pressures (UK Climate Change Risk Assessment 2017).

Creating and maintaining permeable surfaces

In England, urban areas account for over a tenth of the national land surface (Davies *et al* 2011), and for much of this land the soil is sealed under hard, impermeable surfaces. Sealing soils leads to a serious loss of soil functions and the ecosystem services they provide. This includes restricting plant growth, limiting the cycling and storage of nutrients and water, and acting as a barrier at the soil-atmosphere interface, restricting gaseous exchange. The impermeable nature of most construction materials, meaning that water can no longer infiltrate the soil, often leads to severe localised flooding. Utilising woodland and other vegetation increases surface roughness, slowing run-off flow and increasing percolation into the soils, delivering not just a reduction in peak flow rates but other benefits such as retention of nutrients, trapping of pollutants and recharge of ground waters (Demuzere *et al* 2014; Spatari, Yu & Montalto 2011).

These benefits rely on soil properties to deliver effective flood management, and are further dependent on suitable siting in the urban landscape. Alongside the floodplains, SuDS and wetlands discussed elsewhere, networks of vegetated corridors and patches containing soils with a high infiltration capacity can influence the timing and quantity of run-off. In new developments and where it is impractical to replace sealed surfaces with vegetated areas, then porous paving materials could be considered. These materials significantly reduce run- off rates, increase infiltration, and reconnect urban surfaces with the hydrological benefits soils can provide (Rawlins *et al* 2013).

As discussed above, areas with extensive sealed surfaces also generally absorb more solar radiation, exacerbating the urban heat island effect (Rawlins *et al* 2013). Vegetation and green roofs can contribute significantly to reducing the impact of this by cooling the surrounding air via evapotranspiration (Demuzere *et al* 2014). However, evapotranspiration is limited by soil moisture, and rates decrease during dry periods of weather. By considering the water retention capacity of local soils and methods to maintain soil moisture levels, such as irrigation, the effectiveness of this method can be increased, as well as providing a cooling effect via evaporation from the soil itself.

Engineered soils

Soils are living, breathing systems that take millennia to form and, as such, priority should be given to preserving undisturbed sites to maintain natural processes. However, soils underpin much of the green infrastructure described in this chapter and in some cases their properties can be modified to increase their green infrastructure benefits. Engineered soils are soils that have been designed or modified to perform functions required for a specific location. These engineered soils can then be used in rain gardens, green roofs and bioswales to support the local soils in the services they provide. The core properties of engineered soil in green infrastructure are (Soil Science Society of America 2017):

- Steady infiltration of water – slowly enough to filter and adsorb contaminants, but at a rate fast enough to prevent flooding.
- Resist compaction – soil compaction can reduce infiltration rates leading to surface water retention
- Maintain nutrients and moisture to support plant communities and wider biodiversity benefits.

Engineered soils can also provide other benefits besides water management. Studies led by Newcastle University have demonstrated that such soils can sequester significant amounts of atmospheric carbon when calcium and magnesium silicates are present on urban brownfield sites due to demolition activity (e.g. cement and concrete from demolished buildings) (Washbourne, Renforth & Manning 2012). These react with atmospheric carbon dioxide, channelled underground by plant communities, forming stable, long-term carbonates. While further research is necessary, the growth and regeneration of urban areas means these areas could also act as carbon capture sites, mitigating climate change as well as providing adaptation benefits.

Engineered soils - Omaha, Nebraska, USA

In the late 1800s, and inspired by European cities, the city of Omaha, Nebraska, employed the landscape architect Horace Cleveland to design a network of parks and tree-lined boulevards for residents to enjoy. These historic sites are now being explored to help manage storm water run-off from hard-engineered surfaces, through trialling the use of engineered soils within the green infrastructure network. The approach taken is to consider the targeted use of engineered soil trenches within areas of undisturbed soils. This increases infiltration and manages storm flow where a risk has been identified, but preserves the structure and function of local soils and reduces costs (Fisher 2015).

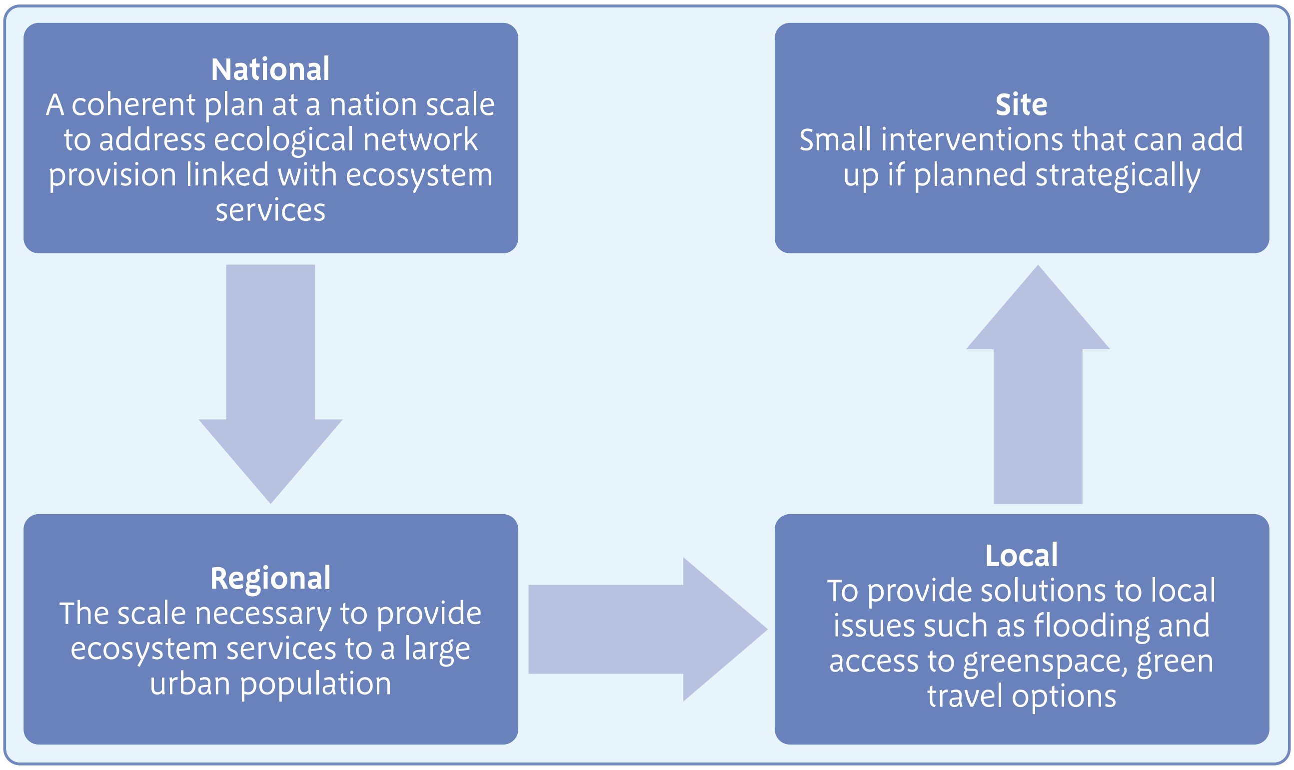
Scale and design of green infrastructure

When planning any green infrastructure in urban areas, the issues of scale, design and multi-functionality are crucial. These are considered below. More information on planning green infrastructure improvements is contained in Natural England's **Green Infrastructure Guidance** (Natural England NE176 2009).

Scale

Green infrastructure can be planned at a range of scales, from regional to district and local. In order to maximise the benefits and effectiveness of such planning, these plans should, ideally, be 'nested' so as to support each other (see diagram). In this way, regional plans might address more widespread issues and environmental features that cross administrative boundaries, whereas more local plans can provide the evidence base and policy framework to support more local green infrastructure delivery.

Green infrastructure planning at a regional scale can consider large-scale landscape connectivity and address the provision of ecosystem services, for example, working at a catchment level to address water provision and flood risk management or contributing to ecological networks to help species adapt to climate change (Lawton *et al* 2010). At a more local scale, particular issues can be addressed, such as localised flooding, re-naturalisation of river channels, and provision of green space for access and biodiversity. Planning can also take place at the site level, and in densely developed areas the cumulative benefit of many small scale individual sites can be significant.



The range of scales at which green infrastructure can be planned.

Design

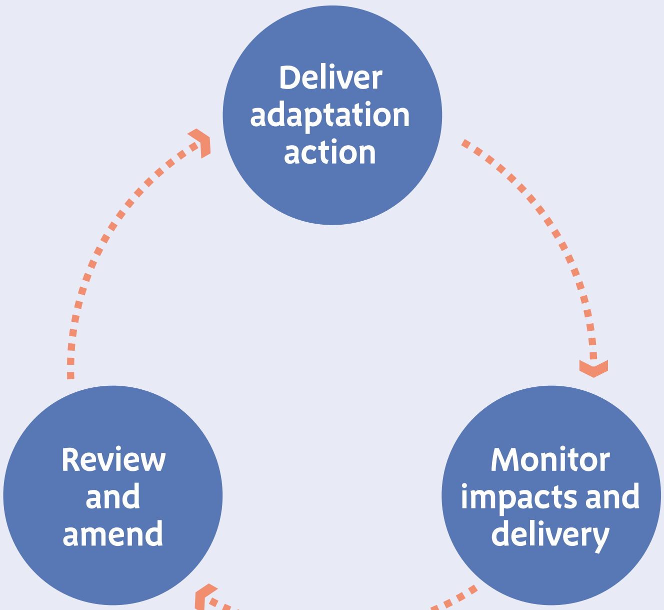
Good design is crucial to ensuring that green infrastructure provision is effective. The process of green infrastructure planning should provide the evidence needed to inform the design of green infrastructure. Such planning will help to identify the range of functions that a specific component of green infrastructure should deliver, based on the requirements of an area, and also provide evidence about the value of existing green infrastructure. Ideally, as most vegetation needs time to mature and reach full effectiveness, green infrastructure should be incorporated into developments at an early stage in order to secure maximum adaptation benefits. However, it can often be successfully retrofitted into existing developments.

Better quality of life for people and integration with the natural environment should be at the heart of any approach to green infrastructure design. The delivery of a combination of green infrastructure assets to provide nature-based climate change adaptation, is vital for sustainable development. As described above, properly designed and located, green infrastructure can help address the vulnerability of both people and wildlife to climate change in urban areas.

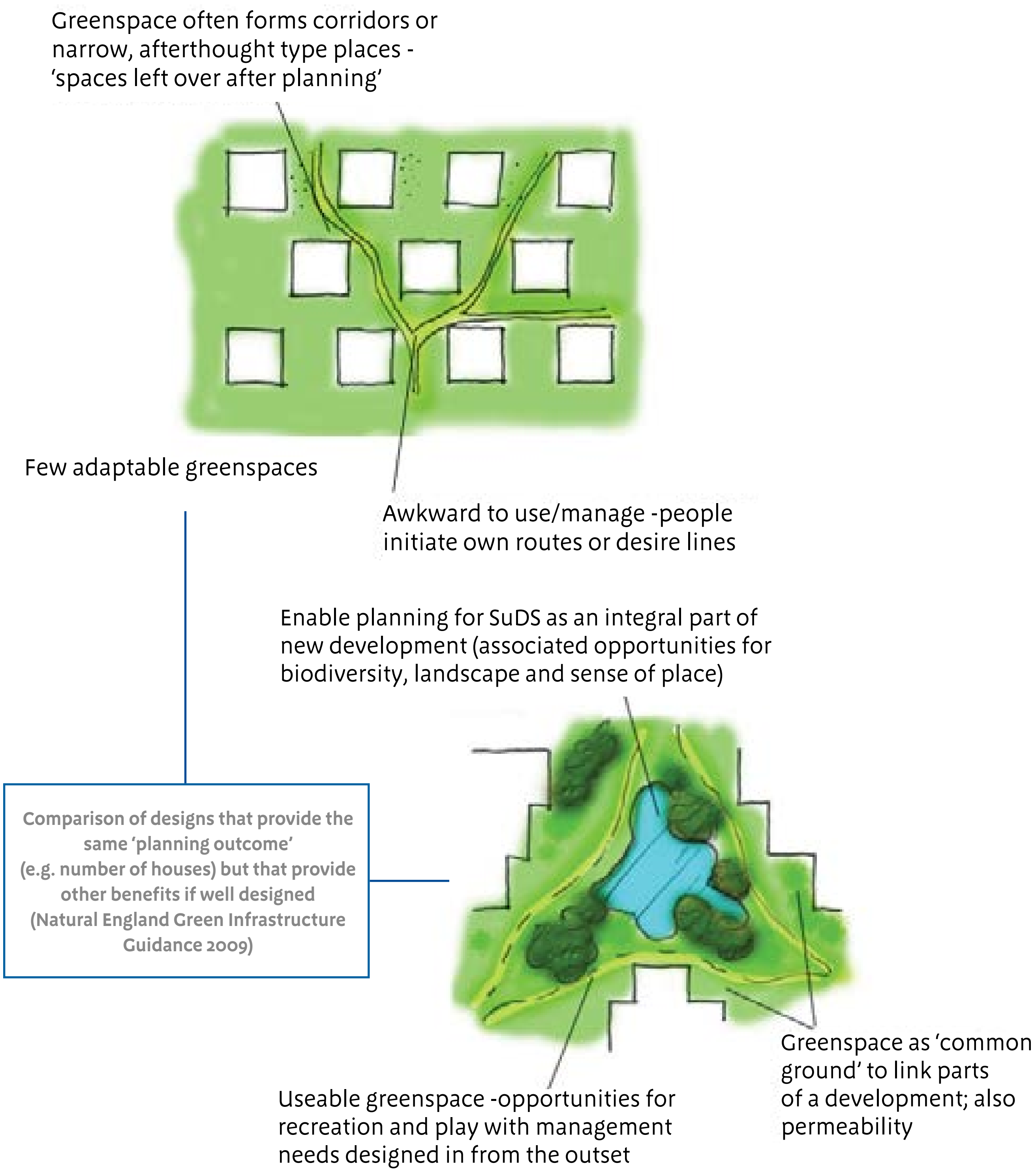
Adaptive management and maintenance

Green infrastructure will often require ongoing management to enable it to continue to function effectively, for example regular dredging of retention ponds. The need for long-term maintenance should be built into any green infrastructure planning and design project. As an example, the **CIRIA SuDS Manual**, which contains detailed information on SuDS design, also covers ongoing maintenance procedures. The need for maintenance, and the ongoing ability to provide it, must be incorporated from the beginning of the green infrastructure and climate change adaptation design period.

Monitoring and maintenance is particularly important for climate change adaptation focused elements of green infrastructure. Changes in climate are not wholly predictable so it is important to ensure climate change impacts and adaptation actions are monitored and reviewed, and if necessary adjusted, to maximise their effectiveness over time.



There are many ways in which urban development can be designed. At one end of the spectrum are unimaginative designs that leave little room for open space and the provision of natural services; at the other are more integrated designs which provide a variety of open spaces and deliver a range of ecosystem services, including local climate change adaptation. Stylised examples of these two contrasting approaches are shown below:



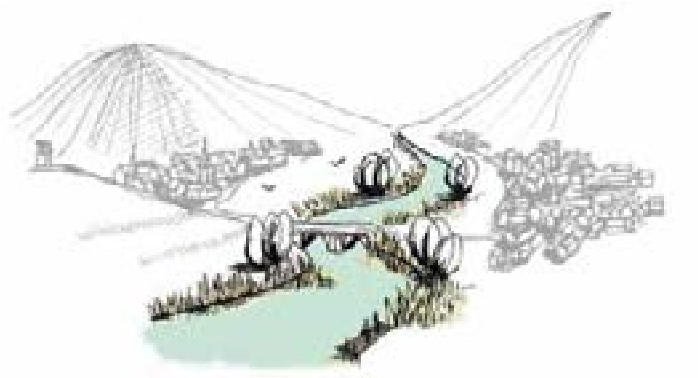
Comparison of designs that provide the same 'planning outcome' (e.g. number of houses) but that provide other benefits if well designed (Natural England Green Infrastructure Guidance 2009)

Variety and complexity should be key principles of any green infrastructure design. Heterogeneity in topography, habitat types, and surface roughness and vegetation height etc. are important factors for both biodiversity and ecosystem services such as flood risk management. The concept of surface roughness and habitat heterogeneity is starting to be explored as a flood risk management benefit. A project in Melbourne, Australia (Ossola, Hahs & Livesley 2015) selected a network of urban parks characterised by different proportions of low-complexity and high-complexity wooded patches to measure soil hydrological processes such as water infiltration, water holding capacity, and run-off. The results demonstrate that the fine-scale heterogeneity of urban landscapes had a significant influence on soil hydrology. In particular, water infiltration rates were greatest in patches with more complex and varied habitats, and these types of patches also intercepted and held more storm water than more homogeneous habitats.

The importance of multi-functionality

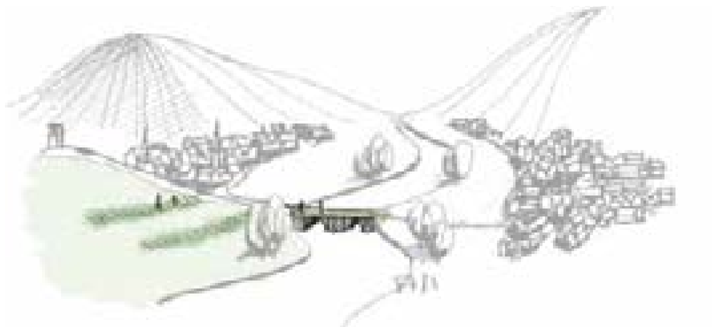
Multi-functionality – using good design to deliver multiple benefits from a single area - is the cornerstone of effective and sustainable green infrastructure. It has long been recognised that green infrastructure, particularly in busy urban areas, can provide a wide range of benefits in one place. For example, provision of biodiversity conservation can be delivered alongside ecosystem services such as recreation opportunities and green travel options, climate change adaptation such as urban cooling or flood alleviation benefits as well as a providing the mental health benefits of access to more natural spaces.

However, it should not be assumed that all functions are mutually compatible on the same piece of land; they may be mutually supportive, but they can also conflict. For example, an informal recreation area may be able to support increased biodiversity, but a sports pitch requires specific vegetation management to provide its primary function. This underscores the need to view multi-functionality as something that a whole green infrastructure system delivers (appropriate to local evidence of need for specific functions) at a range of scales, rather than a simple concept that applies all functions to the same piece of land. However, green infrastructure systems can be designed so that incompatible functions might operate on the same land but at different times, such as the formal sports field that can also act as a flood storage area in times of high rainfall.

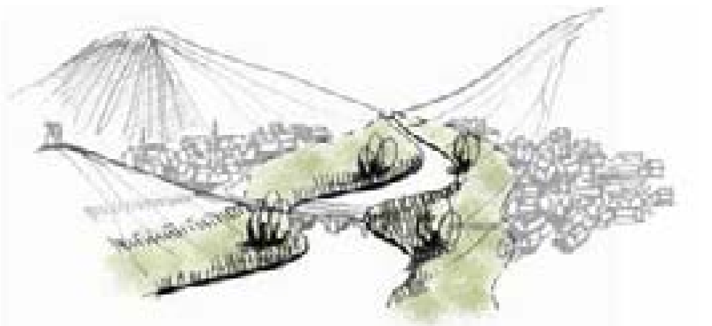


Habitat provision and access to nature

Access, recreation, movement and leisure



Landscape setting and context



Flood attenuation and water resource management

Illustration of multifunctionality form (Natural England Green Infrastructure Guidance 2009)

Queen Elizabeth Olympic Park

The [Queen Elizabeth Olympic Park] sits within the Lee Valley Regional Park, which stretches from central London out to the more rural areas of Hertfordshire and Essex. It was designed as the centrepiece of a major regeneration project linked to the London 2012 Olympic and Paralympic Games. As well as providing opportunities for sport and recreation as part of the Olympic legacy, the site has been designed to retain water in times of flooding, and to provide new areas of wildlife habitat and opportunities for public access in an area previously almost devoid of these.

Queen Elizabeth Olympic Park. © Natural England/S. Taylor

The north of the Park is shaped like a bowl, with natural flood management and drainage features such as swales and reed beds. It has been calculated that these features provide a flood risk management service for 5,000 homes (London Legacy Development Corporation 2014/15). A wide range of urban biodiversity has been recorded at the site including rare and notable species. This includes an increase in the number of breeding black redstarts; the park now provides a home for 6% of the country's population (London Legacy Development Corporation, 2014). This is achieved through a wide range of partner organisations working together to provide multiple benefits.

The importance of partnerships and funding (e.g. who is responsible for taking on assets)
Green infrastructure is most often and most successfully delivered and maintained through partnership. This allows the design to reflect the diverse needs of a location and can help to engage a wide audience, allowing representation of desires and input from many users and beneficiaries.

LOCATION
Where green infrastructure will provide the required adaptation function

PARTNERSHIPS
How we best provide the other elements

FEATURES
What green infrastructure will provide the required adaptation function, reinstating natural processes?

MULTI-FUNCTIONALITY
Ensure the best combination of functions are provided and maximised where possible and appropriate

Principles of good green infrastructure design

WWT London Wetland Centre. © Natural England/Sarah Taylor

References and further information

Further information

Useful websites and partnerships

- SuDS and green infrastructure guidance resources, Ciria
- Green Infrastructure Partnership website
- Urban Regeneration and Greenspace Partnership – including the 'benefits of green infrastructure knowledge portal' where you can search a publications database.
- European Conference on Biodiversity and Climate Change - Nature-Based Solutions to climate change in urban areas and their rural surroundings, Conference proceedings, BfN/ENCA
- Foresight, Cities Alive; rethinking green infrastructure, ARUP, 2014
- Natural England Access to Evidence Green Infrastructure Reports
- Natural England's Green Infrastructure Guidance
- Natural England report on Green Bridges: A literature review
- All London Green Grid
- Living Roofs

Trees and Woodlands

- Forest Research Benefits of Green Infrastructure summary & technical reports
- Realising the benefits of trees and woodland in the East of England

Ecosystem services and multifunctionality

- Defra, 2010. What nature can do for you? A practical introduction to making the most of natural services, assets and resources in policy and decision making
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Case Studies

Natural England Case Study - Beam Parklands

Natural England Case Study - Mayesbrook Park

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