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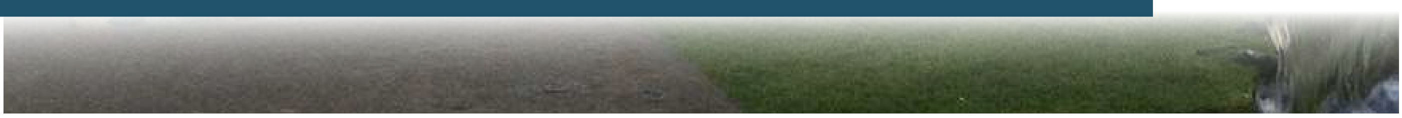
Designing Blue Green Infrastructure (BGI) for water management, human health, and wellbeing: summary of evidence and principles for design

Eun Yeong Choe
Anna Kenyon
Liz Sharp

University of Sheffield

September 2020



Designing Blue Green Infrastructure (BGI) for water management, human health, and wellbeing: summary of evidence and principles for design

Eun Yeong Choe, Anna Kenyon, Liz Sharp
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Summary

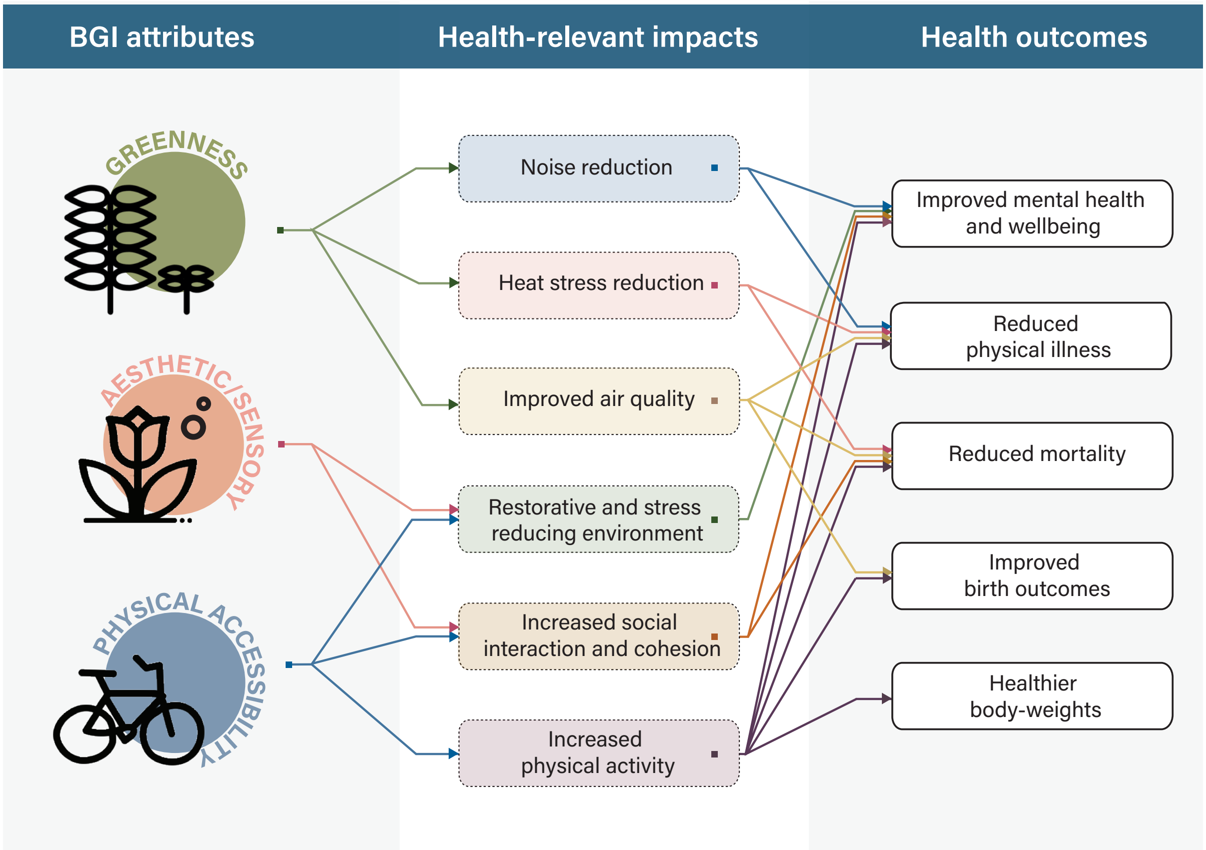
This report has been prepared by researchers from the University of Sheffield for built environment, water, and public health professionals in the UK. It collates and presents evidence about the potential benefits of designing Blue Green Infrastructure (BGI) to enhance mental health, physical health, and wellbeing. We hope it will help professionals to advocate for health-promoting BGI to policymakers; to integrate health-promoting BGI into policy, investment, and master-planning; and to design BGI in a way that maximises health benefits.

The report identifies three key attributes of BGI that provide health-relevant environmental impacts. Firstly, BGI can be used to promote a healthy physical environment: to diminish noise, reduce heat stress, and improve air quality. Secondly, BGI has beneficial aesthetic and sensory qualities: its appearance, sounds, smells, and tactile qualities can have therapeutic potential even where communities are unable to walk through the area directly (e.g. a pocket park on private land). Thirdly, there are benefits to physically accessible BGI spaces, which can promote exercise and social interaction by allowing a wide range of people with varying mobility needs to pass through them.

Together, these aspects of BGI mean that well-designed spaces can make a very real difference. As well as helping to improve general health and wellbeing, they can reduce social and health inequalities in the UK. Research suggests that such health inequalities are currently widening, at a time when the impacts of climate change are also disproportionately impacting poorer communities. We show that BGI offers the opportunity to tackle these two problems together, and thus to build a society that is fair and sustainable for future generations. The COVID-19 pandemic has reemphasised the topicality of this focus, as the quality of people's local environments is an issue that has been at the forefront of public debate during lockdown.

Sections 1 and 2 explain the scope of the report, outline key terminology, and summarise methodological issues. Sections 3-8 then review the literature on the contribution that BGI can make across six specific categories of health impact: noise reduction; heat stress reduction; improved air quality; stress reduction and cognitive restoration; decreased loneliness and enhanced social interaction; and increased physical activity. In section 9, evidence about the potential for BGI to address inequalities is considered. Section 10 then presents the evidence that these impacts can lead to improvements across five wider health outcomes: improved mental health and wellbeing; reduced physical illness; reduced mortality; improved birth outcomes; and healthier body weights. Key design findings are summarised in Section 11.

Digital abstract



Schematic pathways showing different attributes of BGI, and their relationship to health-relevant impacts and health outcomes. Kenyon, A. & Choe, E. Y.

Acknowledgements

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1. Introduction and purpose

This report has been prepared by researchers from the University of Sheffield in consultation with UK City Partners within the EU Interreg NSR project, BluE Green Infrastructure through social iNnovation (BEGIN). Our aim is to collate and present evidence about the health and wellbeing impacts and outcomes associated with Blue Green Infrastructure in the UK. Although the report's original target audience was water professionals in local authorities and water companies, we hope it will also be useful for other built environment professionals, including those focused on highways, landscape, engineering, urban design, and public health.

The aim of the report is to select, collate, and present evidence about the ways in which enhancing green features of the local environment to improve water management (creating 'Blue Green Infrastructure', or BGI) can also improve health and wellbeing within a host community. Our central argument is that through careful design BGI can have positive health benefits. Such benefits are particularly crucial in areas suffering health inequalities, which we define as avoidable, unfair, and systematic differences in health between different groups of people (The Kings Fund, 2020). Research suggests that such health inequalities are widening, at a time when the impacts of climate change are also disproportionately impacting poorer communities (Marmot et al, 2020). BGI offers the opportunity to tackle these two problems together, and thus to build a society that is fair and sustainable for future generations. The COVID-19 pandemic has reemphasised the topicality of this focus, highlighting both the importance of public health, and the critical nature of people's local environments during lockdown.

The report is designed to serve three purposes. First, it can be used to advocate for the health-promoting impacts of BGI to policymakers. Second, it provides an evidence base to integrate BGI and its associated health benefits into a wide variety of policies, schemes, and investments; for example, by supporting discussion between different professionals about the use of BGI in a masterplan. Third, by explaining how various features of BGI impact on local health and wellbeing, it supports detailed BGI design, highlighting elements that can be varied to address specific local challenges.

Evidence in this report can enable practitioners...

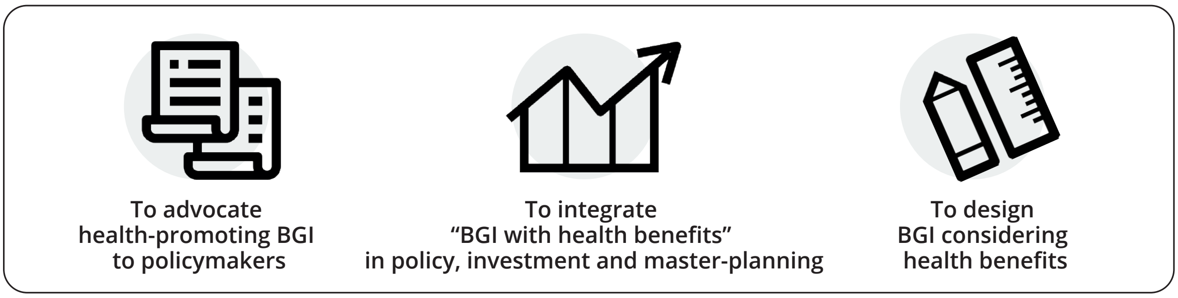


Figure 1: Infographic showing how we expect the report to be used

The report that follows has been developed through a combination of literature review and expert consultation.

The initial concept came from water professionals in Kent and Enfield Councils, who highlighted the need for accessible information on the health impacts on BGI. Relevant literature was identified through search processes using combinations of keywords relating to BGI features and health-relevant impacts. The research we used derived from a wide variety of disciplines, including environmental and social epidemiology, environmental psychology, geography, landscape studies, and urban planning. Rather than covering this very extensive set of relevant publications in detail, we used reviews and meta-analyses to summarise and collate information, seeking out additional sources as and when as it seemed pertinent to answer specific questions about the impacts of BGI. The review was carried out within the UK context; however, multiple recent global reviews have reported that researchers in continental Europe and North America are also finding associations between blue-green spaces and health-relevant impacts (Hegetschweiler et al., 2017). For this reason, the review includes some European and American studies, especially for green roofs and green walls. The report has undergone two rounds of rigorous review by a combination of professional and academic experts with specialist knowledge of BGI, engineering, functional ecology, and public health, a process that challenged the findings and prompted significant improvements. The authors are very grateful for all the help and advice received, in relation to both the content and framing of the report. Nevertheless, all errors remain our own.

The report begins by discussing key concepts and terminology (Section 2). Sections 3-8 then present a discussion of the associations between BGI features and health-related impacts. In section 9, evidence concerning the potential of BGI to address inequalities is considered. The associations between BGI impacts and health outcomes are then addressed in Section 10. Section 11 draws out the implications for BGI design, before a conclusion in which we reflect on the information presented and the gaps in current knowledge.

2. Concepts and terminology

This section explores the key concepts used in this report, and clarifies its scope. We begin by examining the meanings of 'blue green infrastructure' and 'local health and well-being benefits'; we then define important BGI attributes, health-promoting impacts, and health outcomes.

2.1 Blue Green Infrastructure (BGI)

'Green infrastructure' is a hybrid concept, combining green space and semi-green built systems (including fields, woods, rivers, lakes, and gardens) that are found between and within our built-up areas. Together, these features enable ecosystem resilience, as well as supporting human wellbeing (POST, 2013; Demuzere et al, 2014; Natural England, 2014; Barker et al., 2019). In this report, we use the term 'Blue Green Infrastructure' (BGI) to emphasize the water-related services that are also provided by these green spaces. It includes evidence on a range of 'designed BGIs' that have been developed (or substantially redesigned) for the explicit purpose of managing water more sustainably. In the UK, these are referred to using a variety of terms, including 'Sustainable Drainage Systems' (SuDS) (CIRIA, 2015), 'Nature Based Solutions' (Raymond et al., 2017), and 'Natural Flood Management' (Wingfield et al, 2019), though they have numerous other names elsewhere (Fletcher et al, 2014).

One of the reasons that this report is important is that BGI is becoming an increasingly crucial part of modern urban water systems. In the past, water professionals largely used 'grey' (concrete) infrastructure, such as pipes and pumps, to provide drainage and flood risk management services, but contemporary best practice increasingly supplements this with designed BGI elements feeding into a wider BGI system. This approach can significantly reduce flood risk by slowing water down and reducing the total quantity that needs to be conveyed at any one time, while also improving water quality by utilising and mimicking natural systems and therefore allowing natural treatment to occur. Finally, by providing space for vegetation, which it also irrigates, BGI supports biodiversity.

The trend towards greater use of BGI means that water professionals are increasingly concerned with features on the surface of the ground, rather than underneath it. As a result, they must work with other professionals and the public to create landscapes that serve multiple agendas. To understand how they can do this, it is important first to know the circumstances in which plans for new or enhanced BGI are developed (Willems et al, 2020a). One common scenario occurs when water professionals working for a local authority or water company realise that they face a significant risk (for example of flooding, or non-compliance with environmental water quality regulations), which can be mitigated by retrofitting designed BGI in locations where there is available space. In another frequently occurring scenario, sites for BGI are identified to address predicted hydrological risks within the context of wider development processes, e.g. housing, regeneration, or masterplanning. In either circumstance, while existing guidance such as the SUDS

Manual (CIRIA, 2015) already supports water professionals in considering designed BGI's water-related benefits, there is less support available to help other professional groups to understand the potential non-water 'amenity' impacts. This report fills this gap by focusing on the health and wellbeing benefits that well-designed BGI offer to their host communities.

2.2 Local health and wellbeing benefits

Health and wellbeing benefits are defined as effects that contribute positively to the condition of an individual, group, or community. They include factors that impact on lifestyle, mental and physical health and wider socioeconomic determinants of health, e.g. access to employment (Farrier et al., 2019). This report focuses on human health and wellbeing, and is therefore explicitly anthropocentric: the biodiversity benefits of creating habitats are only 'within scope' insofar as they enhance people's experience of the BGI.

The focus on local health and wellbeing refers to the ways in which these benefits are felt in the location where the BGI is situated, i.e. in the BGI's 'host community'. The report's scope does not include the health and wellbeing benefits of improved water management for downstream communities (for example, the mental and physical health benefits of flood prevention, or the reduced disease risk attendant on the removal of pollution from receiving waters). Such benefits are excluded because they are geographically and analytically separate from those enjoyed by the host community; some are also accounted for within existing metrics of BGI water benefits, such as Susdrain's Benefits Estimate Tool (B£ST) (Susdrain, 2019).

As we catalogue in detail below, proximity to BGI is widely recognised to be associated with health benefits (Natural England, 2014; POST, 2016). As we have gained an increased understanding of the underlying social and environmental determinants of health, local authorities have been urged to improve public health by ensuring that communities have access to high quality BGI (PHE, 2020a). The lockdowns associated with the coronavirus pandemic have drawn attention to the importance of access to green space, and hence also to inequalities of such access between different places (PHE, 2020b; SEI, 2020). Residential environments have never seemed so important, and unequal access to nature is now being subjected to a greater degree of public scrutiny and debate (Haxworth, 2020; Plummer et al., 2020). Consequently, the creation of healthy environments is likely to drive regeneration and development efforts during the 2020s and 2030s. As well as the functional linkages between public health and BGI, there is likely to be a place-based coincidence of needs. Recent statistics suggest that there is an almost 20-year difference between the healthy life expectancy of people living in the richest and poorest UK census districts (ONS, 2020), and health-related calls for BGI may have a distinctive local geography. Indeed, the need to generate more healthy environments may be particularly important in densely-occupied urban locations where residents' have limited opportunities for interaction with nature through private gardens and/or where there is little public green space or parkland (POST, 2016). As these dense urban environments usually confine water to grey infrastructure, such as culverts and sewers, it is probable that BGI in the same locations could serve useful water-related functions. We will return to this issue of health inequalities and sites for BGI development through the report.

Just as BGI measures initiated to address water issues may provide opportunities to create healthy environments for people, so creating a healthy environment may offer opportunities for enhanced water management. For example, involving water experts in the design of sites for food growing or green routes for more active travel can lead to a significant water benefit. There are therefore gains to fostering close cooperation between urban planners, public health officials, and water professionals over the coming decades.

2.3 BGI attributes, health-relevant impacts, and health outcomes

Our conceptualisation of BGI and health hinges on the relationships between three different categories of phenomena: BGI attributes, health-relevant impacts, and health outcomes. BGI attributes refer to the characteristics of BGI that might have health-relevant impacts, e.g. greenness, aesthetic and sensory qualities, and accessibility. Health-relevant impacts consist of the positive effects BGI can have on local environments and people, for example, reduced air and noise pollution and decreases in stress levels. Health outcomes are defined as reported or self-reported changes to the physical or mental health of individuals produced directly or indirectly by BGI, for example, reductions in respiratory disease incidence or decreased stress and anxiety levels.

The relationship between BGI attributes, health-relevant impacts, and health outcomes varies depending on what the BGI 'offers' the local population. We identified three potential attributes of BGI: greenness; sensory accessibility and aesthetic qualities; and physical accessibility. To begin with 'greenness', some health-relevant impacts derive simply from the physical existence of BGI: for example, vegetation reduces urban heat effects, regardless of whether the BGI can be seen or physically accessed. By contrast, benefits from the sensory and aesthetic attributes of BGI need to be experienced directly, i.e. seen, heard, or smelt, to impact the local population. Research suggests that sensing BGI yields benefits to the individual in terms of reduced stress, and sharing this experience with others can also enable health-beneficial forms of social interaction. BGI does not necessarily have to be in the public realm to have this sensory and aesthetic impact: features on private land in front of a commercial office block can affect those walking past, even if they cannot walk directly through the green area in question. To a large extent, it is the natural features of BGI (including literal greenness) that yield these sensory benefits. Finally, physical accessibility refers to the ability people have to pass through, under, or around BGI; this attribute offers some incentives for physical activity, which can result in improved health outcomes. For example, a pathway through a green area (or a series of small BGI 'greening' a previously grey street) can provide these accessibility qualities. These distinctions between BGIs' greenness, its sensory/

aesthetic aspects, and its physical accessibility attributes are important because they enable planners to consider the potential of different types of BGI to leverage health improvements.

Figure 2 depicts potential connections between these three BGI attributes and potential health impacts and outcomes. It does not imply a linear or causal relationship, but merely indicates potential pathways from attributes to health-relevant impacts such as reductions in heat, noise, and air pollution; decreases in reported stress; and increased opportunities for social interaction and physical activity. Each of these health-relevant impacts can have a number of different effects on human health. Noise reduction, for example, can improve mental health, but it can also reduce physical illness.

Such complex interactions illustrate the challenges of tracing relationships between BGI and health outcomes. In common with most scientific studies of the 'real' social and physical environment, it is not possible to hold one aspect of the environment constant while varying another. Evidence of mechanisms and associations must therefore be collected where possible, and inferences drawn about probable causal links (POST, 2016). In this context, Sections 3-8 discuss the evidence for correlations between BGI and health improvements, while Section 10 shows where BGI attributes and outcomes have coincided, indicating a causal connection.

Finally, it should be noted that the field of public health faces evidential challenges. Because it is closely connected to medicine, yet far more social in its scope, public health is sometimes unfairly judged by scientific standards of evidence that it cannot possibly meet (e.g. those associated with randomised control trials). In practice, there are three reasons why interventions like BGI should never be evaluated in the same way as medical interventions. First, there is virtually no risk of harm, only the opportunity cost of committing resources to one project rather than another; second, it involves many interrelated variables that cannot be held constant (Gross and Hoffmann-Riem, 2005); and third, it involves debates about how we 'measure' outcomes (e.g. should wellbeing be measured subjectively, in terms of people's reports about how they feel, or objectively, in terms of physiological indicators). In our discussions below we draw on a variety of studies that take different approaches to these issues. Some control for variables such as socio-economic status but others do not; some use subjective, self-reported data, others assess impacts through more 'objective' processes. Our overall argument is that this weight of evidence supports a clear case for investing in BGI, not just for its contributions to water management but also for the health and wellbeing benefits it can deliver.

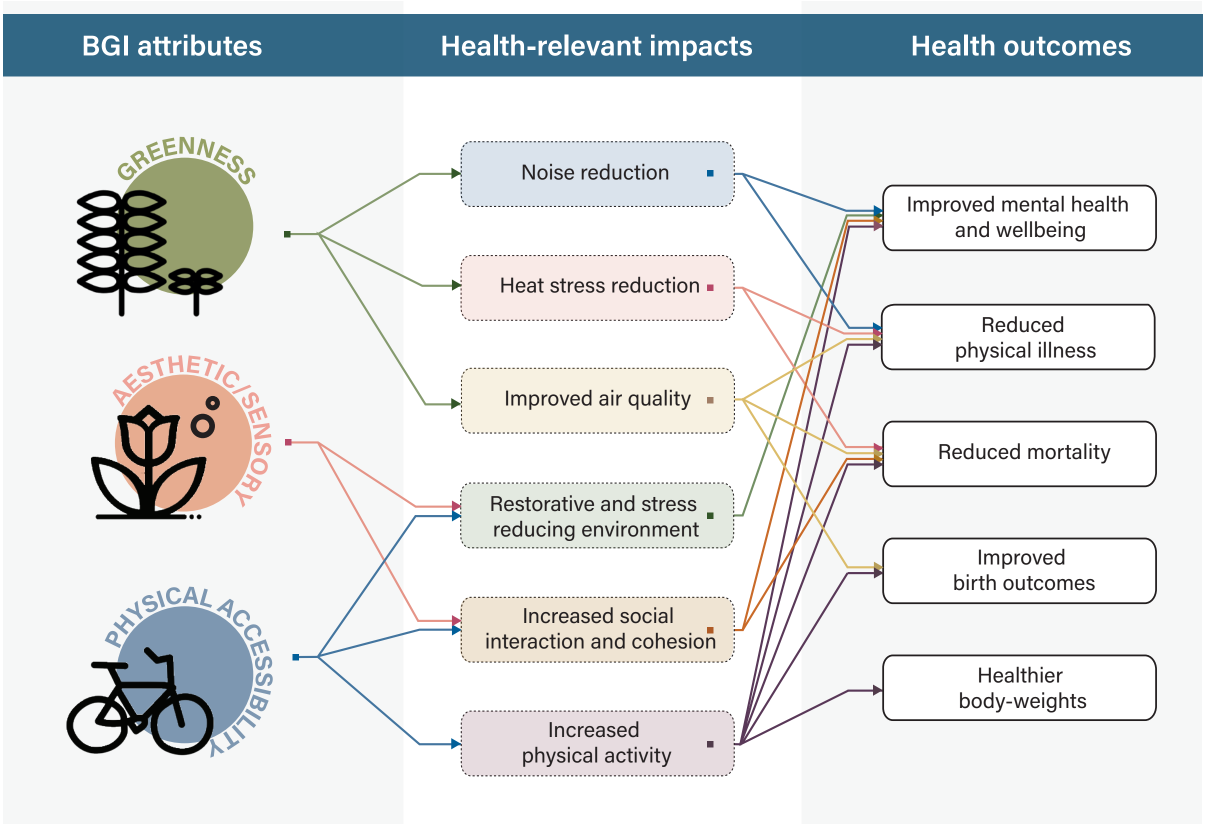


Figure 2: Schematic pathways showing different forms of BGI exposure, with potential for health-relevant impacts and health outcomes. Kenyon, A. & Choe, E. Y.

3. Noise reduction

3.1 The public health burden from noise pollution

Noise pollution poses a major and increasing threat to the health of urban residents, due to rising industrial activity and traffic volumes. Traffic noise exposure is associated with adverse health effects: the *Environmental Noise Guidelines for the European Region* (WHO Regional Office for Europe, 2018) proposed a guide value for traffic noise of 53 dB, falling to 45 dB at night. However, 40% of the population in European countries is exposed to traffic noise at levels exceeding 55 dB, resulting in health problems including cardiovascular disease, cognitive impairment, and sleep disturbance. A report by the WHO Regional Office for Europe (2011) quantified the disease burden caused by noise pollution in terms of disability-adjusted life years (DALYs), where one DALY equals one lost year of healthy life[1]. It calculated that noise pollution in western European countries costs the equivalent of 61,000 years lost to ischaemic heart disease (IHD); 45,000 years lost to cognitive impairment in children; 903,000 years lost to sleep disturbance; 22,000 years lost to tinnitus; and 654,000 years lost to annoyance. Overall, at least one million healthy years of life are lost every year from traffic-related noise in Western Europe. In the UK, the annual social costs[2] of noise pollution are estimated at £7 to 10 billion (Defra, 2013).

3.2 Optimal roadside vegetation for noise reduction

Roadside vegetation, if sufficiently wide, high, and dense, can reduce road traffic noise. A study by Fang and Ling (2005) found that a dense vegetation belt of a 30 m width next to a road with light traffic reduced noise by 4 to 8 dB. This finding is supported by earlier studies conducted by Fujiwara et al. (1998) and Harris and Cohn (1985). Fang and Ling (2005) also suggest that street trees and hedgerows can effectively reduce noise when the ratio of noise source height to tree height is 1:6.6 within a short distance of the noise source. A recent study found that a dense 5 m vegetation barrier next to a two-lane highway (15 m wide) reduced noise levels by 9-11 dB at a distance of 20 m from the highway (Ow and Ghosh, 2017). In addition, Azkorra et al. (2015) suggest that green walls are very effective absorbing the sound of the human voice (60 dB), meaning that they can be used to mitigate noise in public places e.g. restaurants, hotels, and high street shops.

3.3 The use of natural sounds

Well-designed green and blue spaces can also be used to generate natural sounds, which can mask

[1] Disability-adjusted life year (DALY) is a measure of overall disease burden. It is calculated by adding the number of years of life lost due to premature mortality in the population and the number of years lost to disability for people living with a health condition or its consequences.

[2] Social costs are related to health problems, such as cardiovascular disease, sleep disturbances, psychological stress-related illness, and poor cognitive performance (e.g. memory and attention problems).

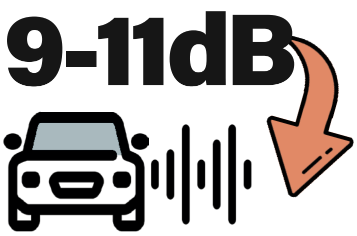
or distract attention away from unwanted sounds. Coensel, Vanwetswinkel, and Botteldooren (2011) showed that adding natural sounds (e.g. bird song, or the splashing of stream and fountains) significantly reduced perceptions of road traffic noise, improving soundscape quality. Similarly, Jeon et al. (2012) found that water sounds screened urban noises: they suggest that water noises could be effective in mitigating noise pollution provided that they were no less than 3 dB below the urban noise level.

These findings indicate that well-designed BGI can both moderate and mask traffic noise.

3.4 Green space, perceived noise reduction, and wellbeing

Some studies suggest that the presence of green space can also reduce the perception/processing of noise, thereby improving wellbeing. Gidlöf-Gunnarsson and Öhrström (2007) found that easy access to green spaces in residential areas reduces the adverse effect of high traffic noise exposure and prevents stress-related symptoms. Yang, Bao, and Zhu (2011) have shown that the presence of natural elements in areas that are exposed to noise pollution positively influences the emotional processing of the noise by residents.

BGI design tips for noise reduction



- **Design '5m depth of vegetation belt' next to a highway for effective traffic noise reduction.**
- **Use green walls to absorb sound of human voice (60dB) in public spaces.**
- **Add natural sounds (e.g. bird song, stream/fountain sound) to mask urban noises.**

Figure 3: BGI design tips for noise reduction

4. Heat stress reduction

4.1 The public health burden from heat stress

According to current climate change projections (Met Office, 2019), UK summers are expected to become longer and hotter. By 2070, under a high emissions scenario, the temperature of hot summer days is expected to increase by between 3.7 °C and 6.8 °C. There will also be an increase in the frequency of hot spells, defined as a period when the maximum daytime temperatures exceeds 30 °C for two or more consecutive days[3]. The effects of extreme events have already been experienced in many European countries: the 2003 heatwave posed a significant risk to the health of the European population and heat-related deaths during the heatwave period increased by 70,000. In England, the Office for National Statistics (ONS, 2005) estimated that 2,091 excess deaths were associated with this heatwave, of which 616 are estimated to have occurred in London. Importantly, urban heat island (UHI) effects increased heat-related mortality by around 50%.

Heaviside, Vardoulakis, and Cai (2016) have estimated the excess mortality that could be caused by UHIs across a range of projected temperature scenarios based on the UK Climate Projections. For a medium emissions scenario, a typical heatwave in 2080 could lead to a mortality rate around three times that of 2003. For city planners and public health officials, such predictions can indicate the impact of heat extremes; with microclimatic factors like the nature of the built environment and the extent of existing BGI infrastructure playing a significant role in the exposure of populations to extreme heat. In terms of associations between perceived heat stress and poverty, drawing on data from across the EU, Thomson et al. (2019) note a strong 'deprivation effect', with a significantly higher proportion of low income households finding their properties too warm in the summer.

4.2 Cooling effects of urban green spaces

The presence of green spaces in urban areas can mitigate the negative impacts of urban heat stress. BGI can create buffer zones, where the evaporative cooling effect of green space significantly reduces the temperature in comparison to areas heated by direct solar radiation (Park et al., 2017). A review of the empirical evidence suggests that, on average, green spaces are 0.94 °C cooler than the surrounding urban environment during the day (Bowler et al., 2010a). A research project by Doick, Peace, and Hutchings (2014) showed that Kensington Gardens significantly cooled central London's heat island, with areas between 20 m and 440 m of the park boundary experiencing a mean temperature reduction of 1.1 °C, and a maximum reduction of 4 °C on some nights. The evidence therefore supports the practice of replacing impervious heat-absorbing surfaces with

[3] The frequency of hot spells is predicted to rise from an average of 0.25 occurrences per annum in the present to 4.3 per annum by 2070 in the UK (Met Office, 2019).

vegetation in urban areas to reduce vulnerability to heat island effects. Völker et al. (2013) suggest that the inclusion of water bodies within the urban green space might lead to an even stronger cooling effect. These benefits are recognised in the Heatwave Plan for England, which advises the use of BGI around hospitals and residential care homes (NHS England, 2018).

4.3 Tree species for heat stress reduction

BGI may therefore have a role to play in reducing heat island effects. Based on previous studies, this review recommends some design considerations to maximise the cooling effects of green spaces. In terms of the choice of tree species, a study by Gillner et al. (2015) suggests that those with high leaf-area-density (LAD) and high rates of transpiration may be preferable, e.g. *Corylus colurna* and *Tilia cordata*. Differences in canopy structure, and the wider thermal and optical properties of the tree, may therefore impact on cooling efficiency.

4.4 Optimal BGI shapes for heat stress reduction

It seems logical that the precise impact of BGI on heat reduction will vary with details of the site, including shape and scale. However, there is as yet very little evidence to support a correlation between vegetation area and heat reduction effects. Aram et al. (2019) found that larger parks had a greater cooling effect, while Park et al. (2017) propose that green spaces arranged in circular or regular polygonal shapes have a greater cooling effect than linear shapes (the difference could be as much as 4 °C). Feyisa, Dons, and Meilby (2014) also found that more irregularly shaped green spaces have greater effects on cooling intensity and cooling distance. This may be because linear green spaces generally have a single-layer structure composed of identical species of tall trees, without smaller trees and shrubs. Though such designs still produce shade, they may allow a greater degree of heat flow.

4.5 The use of green roofs and green walls

Green roofs and green walls can supplement the use of urban trees and shrubs in heat stress reduction, especially in situations where land is not available. Green roofs and walls have been used as a solution to offset the impacts of urban heat stress: they maintain comfortable internal temperatures by providing a layer of insulation that avoids heat absorption across building facades and rooftops, thus mitigating the urban heat island effect (Coutts et al., 2013) and reducing the need for air conditioning. Lin et al. (2013) found that green roofs reduced the temperature of the outdoor environment by approximately 42%, contributing to the attenuation of indoor temperatures during the daytime.

Over the longer term, and at a wider scale, green roofs and walls can lessen the need for air conditioning, and thus also reduce energy consumption, greenhouse gas emissions, and pollution. They can therefore play a wider role in mitigating climate change and the attendant health-related risks associated with heat exposure (Coutts et al., 2013). Feng and Hewage (2014) also suggest that green walls can improve the thermal performance of buildings, due to the insulating effect of the air between the facade and the living wall. Recently, Castiglia Feitosa and Wilkinson (2018) found that the greatest improvement in thermal performance was observed through a combination of green roofs and green walls.

BGI design tips for heat stress reduction

- **Plant tree species having a high leaf-area-density (LAD) and high rates of transpiration e.g. *Corylus colurna and Tilia cordata*.**
- **Add bodies of water (e.g. ponds, streams) to green spaces.**
- **Design irregularly shaped green spaces.**
- **Use green roofs or green walls to supplement street trees and shrubs for heat stress reduction.**

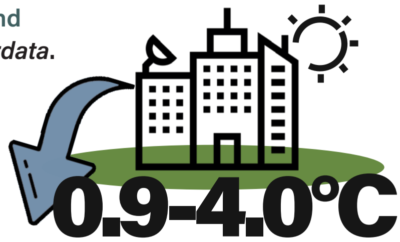


Figure 4: BGI design tips for heat stress reduction

5. Improved air quality

5.1 *The public health burden from air pollution*

Many city dwellers in the UK are exposed to illegal concentrations of nitrogen dioxide (NO2) and other traffic-related pollutants. A report by Birchby et al. (2014) estimated that long-term exposure to air pollution reduces average life expectancy in the UK by around 6 months per person, an impact valued at £16 billion per year.

5.2 *Reduced traffic-related pollution and road vegetation*

Increasing evidence indicates that the presence of trees and other vegetation in urban areas enhances air quality, improving residents' health and wellbeing (e.g. Dadvand et al., 2012). However, the effects are complex. Roadside trees and vegetation can reduce the spread of air pollution locally by preventing air movement in urban street canyons, thus focusing emissions in one location[4] (Salmond et al., 2013; Janhäll, 2015). Expansion of BGI in key locations can also produce a filter effect, enabling the dilution concentrated pollutants in traffic emissions before humans are exposed to them (Cohen et al., 2005). Brantley et al. (2014) found that a stand of trees significantly reduced transmission of traffic-related air pollution, such as NO_2, black carbon, and particulate matter concentrations, by between 7.8 and 22%. Mori et al. (2018) showed that a 1.5 to 3 m high vegetation barrier reduced the deposition of pollutants compared to an open lawn area, while Baldauf (2017) recommends extending dense roadside vegetation 50m beyond the source of pollution to prevent a 'meandering' effect and to reduce noise.

Evergreen species intercept higher quantities of pollutants compared to deciduous species, especially during the winter season when the concentration of air pollutants is generally higher. Sæbø et al. (2012) also found that evergreen species with smaller leaves, hairs, waxes, or more complex shoot structures are more efficient at capturing particulate matter. Among deciduous species, plants with a longer leaf life span are usually more effective (Pikridas et al., 2013). As trees and shrubs vary in their capacity to deal with different pollutants, species should be carefully selected to target specific air quality problems at vulnerable sites in the urban environment (Sæbø et al., 2012). It is also worth noting that BGI can be used to create alternative routes to increase carbon neutral active travel (reducing pollution at its source), and can also be deployed to protect pedestrians from exposure to pollution from major roads, where it is most concentrated (POST, 2013).

[4] Urban street canyons are formed by parallel rows of buildings enclosing a vehicular roadway. The street canyons are often the location of substantial primary pollutant emissions, usually dominated by traffic source (Bright, Bloss and Cai, 2013).

5.3 Potential pathogenic effects of green spaces

As noted in Section 5.2, trees can increase local concentrations of air pollution by preventing air movement and lowering wind speeds in urban street canyons (Gromke and Ruck, 2012). Furthermore, airborne pollen is a major concern in urban green spaces. An overabundance of a small number of tree species that release large amounts of allergenic pollen, such as birches, poplars, willows, elms, cypresses, and palm trees can be problematic for children and vulnerable individuals with allergies or asthma (Cariñanos and Casares-Porcel, 2011; Dellavalle et al., 2012). A review by Cariñanos and Casares-Porcel (2011) suggests some useful guidelines for designing urban green spaces to lower potential impacts for those with allergies: 1) Increase plant biodiversity, 2) Control invasive species, 3) Avoid overuse of male individuals of dioecious species, 4) Choose species with low-to-moderate pollen production (e.g. entomophilous or insect-pollinated species), 5) Adopt appropriate management, maintenance, and gardening strategies, and 6) Avoid forming large focal pollen sources and screens by respecting planting distances.

5.4 The use of green roofs and green walls

Although street trees and shrubs are more effective at reducing pollutants, green roofs and green walls can play a supplementary role in producing air quality improvements under a range of environmental conditions e.g. high-level traffic and industrial emissions sites, and pedestrian pollutant exposure hotspots (Rowe, 2011). They may prove particularly useful where there are limited opportunities to implement urban greenery on the ground (Dimitrijević et al., 2018). The City of Los Angeles Environmental Affairs Department (2006) estimated that 2,000 m^2 of uncut grass on a green roof can remove up to 0.98 tonnes of particulate matter: in other words, one square meter of green roof can offset the annual particulate matter emissions of one car. Speak et al. (2012) found 0.21 tonnes of particulate matter per year could be removed from the air in Manchester if all rooftops in the city centre were covered with green roofs (the equivalent of 2.3% of the particulate matter emissions of this area). Similarly, Pugh et al. (2012) showed that green walls in street canyons can reduce street-level concentrations of pollutants by as much as 40% for NO_2 and 60% for PM_{10}.

Vegetation can significantly improve urban air quality; however, schemes need to be carefully considered to ensure that the effects are positive. Selecting low pollen producing species, adopting appropriate planting strategies, and ensuring proper maintenance can maximise the beneficial impacts on air quality and therefore on health and wellbeing (Hartig et al., 2014).

BGI design tips for improved air quality

- Plant evergreen shrubs, evergreen tree species with smaller leaves, hairs or more complex shoot structures to capture particulate matter.
- Guidelines for low allergy impact: Increase plant biodiversity, control invasive species and select species with low-to-moderate pollen production.
- Use urban trees for air pollution control supplemented by green roofs or green walls.

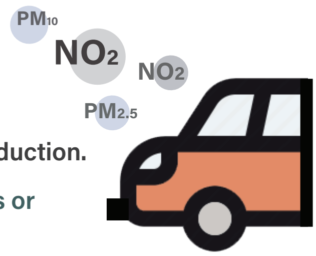


Figure 5: BGI design tips for improved air quality

6. Restorative and stress-reducing environments

6.1 The public health burden from mental health issues

A survey from the Mental Health Foundation (2018) showed that 74% of UK adults have felt so stressed they have been overwhelmed or unable to cope. Increased levels of stress can lead to burn-out or mental health problems (i.e. anxiety and depression). In the UK, 70 million sick days are taken each year due to mental ill health, making it the leading cause of long-term sickness leave, with an estimated economic cost of £105 billion per year (Mental Health Taskforce, 2016).

6.2 The relationship between green spaces, mental health, and wellbeing

The positive link between nature, mental health, and wellbeing has been extensively established. Roe et al. (2013) and Tyrväinen et al. (2014) found that even a short visit to a natural area has significant benefits in terms of stress reduction. Ewert and Chang (2018) also indicate that visitors to natural environments have noticeably reduced physical and psychological stress levels.

A number of theories seek to explain this connection between green space and better mental health:

- The influence of physical and biotic aspects of the natural environment on human physiology. This includes processes, compounds, or organisms that elicit positive responses in humans, including those that ultimately affect mood, such as phytoncides (volatile aromatic compounds derived from trees, see Hansen, Jones and Tocchini, 2017); and microbial species found in natural environments that influence human immune and mental health responses (Lowry et al., 2016).
- Positive affect (happiness). Natural environments and exposure to nature can bring about positive emotional states (McMahan and Estes, 2015; Richardson et al., 2016) beyond restoration or the countering of negative affect (Ulrich 1984; Kaplan and Kaplan 1989). Experimental evidence demonstrates that positive mental states broaden attention, improve thoughts, and positively impact behaviour and mental health (Fredrickson and Branigan, 2005). Finally, there is a link between positive affect and immune function through up-regulation of immune components (Marsland et al., 2006).
- The absence of directed attention when brain capacity is exhausted results in mental fatigue and tiredness (Kaplan, 1995), which can cause poor decision-making and weakened self-control, leading to various health-related problems (Ohly et al., 2016). Attention Restoration Theory (ART) suggests that specific settings, and particular natural environmental settings,

can offer a "*restorative environment*" (Kaplan 2001; Herzog et al. 2003; Kaplan, 1995). Such environments provide (1) a feeling of escape from daily routine (2) opportunities for involuntary "*soft fascination*" without cognitive effort, which reduces mental fatigue (3) a sense of "*extent*" i.e. a place that is physically or conceptually large enough that one's mind can wander within it, and (4) a harmonious relationship between one's predispositions and the attributes of the surroundings (Kaplan, 1995; Ohly et al., 2016). These four characteristics of the restorative environment allow people to recuperate by reducing fatigue and stress, increasing resilience to stressors, and allowing people to regain the capacity for more strenuous mental effort that requires directed attention.

- Stress Reduction Theory (SRT) suggests that the restorative influence of the natural environment can change a person's emotional state (Ulrich et al., 1991). Ulrich (1984) experimentally compared the recovery from surgery of two groups of patients: the first group was exposed to views of natural environment, the second to non-natural views, such as brick walls. The first group required less medication, experienced fewer post-surgical problems, and were discharged earlier than the second. Similarly, Diette et al. (2003) showed that exposure to natural environments (i.e. natural sights and sounds) effectively distracted patients from stress and pain. Numerous studies link exposure to natural environments and restorative psycho-physiological responses, such as reduced heart rate (Jung, Woo, and Ryu, 2015), decreased blood pressure (Song, Ikei, and Miyazaki, 2017), and diminished stress hormone levels (Ewert and Chang, 2018).

6.3 Biodiversity, mental health, and wellbeing

These studies suggest that the presence of BGI is likely to have beneficial effects on people who live nearby, by providing a natural environment that can reduce stress and restore cognitive function. However, not all BGIs are equally beneficial for psychological restoration. A study by Wood et al. (2018) found that botanical or floral diversity was strongly associated with a restorative benefit from urban green spaces. Cameron et al. (2020) correlated positive affect with green spaces that were richer in bird biodiversity (perhaps an indicator of a more diverse habitat). In addition, Stigsdotter et al.'s (2017) study showed that a biodiverse forest environment with areas of dense growth mixed with more open views was optimal for psychological restoration, as the openness provided varied sensory experiences while enclosure offered privacy. Recent studies suggest that the presence of water is likely to be the most restorative element in green spaces (Deng et al., 2020), and that environments with water features are associated with greater positive affect and restoration than those without (White et al., 2010).

Recent studies in the UK have begun to move outside of ART and SRT frameworks to conceptualise other routes to the mental health benefits of urban nature. However, there are significant overlaps between their practical findings and those of the restoration studies. A qualitative study exploring the mental health and wellbeing benefits of urban natural environments for young urban residents found that they valued trees, water, open spaces, and views in particular (Birch et al., 2020). Correspondingly, McEwan et al. (2020) found that wonder at wildlife, appreciation of street trees, and awe at views supported positive mental health for city dwellers.

BGI design tips for restorative and stress reducing environments

- **Increase biodiversity (e.g. colour, floral diversity, high vegetation cover, plant richness, bird richness, and habitat diversity) in urban green spaces.**
- **Offer a variety of spaces and vegetation types e.g. balance enclosed dense growth with more open views.**
- **Add water features to create spaces for restoration and relaxation.**

Figure 6: BGI design tips for restorative and stress reducing environment

7. Increased social interaction and cohesion

7.1 The public health burden from social isolation

A report by the British Red Cross (2016) showed that over 9 million people in the UK, almost a fifth of the population, reported they are always or often lonely. The effect of loneliness and isolation on mortality is comparable to the impact of well-known risk factors, such as obesity or smoking. Studies suggest loneliness can be as harmful to health as smoking 15 cigarettes a day (Holt-Lunstad, Smith, and Layton, 2010).

7.2 Social interactions in green spaces

BGI may provide attractive places for social contact and interaction, including neighbour contact, which can promote a sense of community. A study in Kentlands (in the US) indicated that residents living in areas with a greater variety of natural open spaces had an increased sense of community and a stronger attachment to their community (Kim and Kaplan, 2004). De Bell et al. (2017) also found that visiting blue spaces enhanced social interaction and psychological benefits. Peters, Elands, and Buijs (2010) and Kaźmierczak (2013) suggest that local parks provide opportunities for social interaction that may help residents to establish recognition and develop social ties. Embedding green space in a highly urbanised environment (Salford, UK) was associated with increased social and psychological benefits also, including sense of pride in the neighbourhood, motivation, and a more positive attitude (Chalmin-Pui et al., in press). Reductions in crime are associated with the presence of green space, including domestic violence (Kuo and Sullivan, 2001) and gun crime (Branas et al., 2011). The work of Rishbeth et al. highlights the value of natural environments and green spaces for developing a sense of place, sociability, and social connection among migrants (Rishbeth and Powell, 2013; Rishbeth et al., 2019). Conversely, Maas et al. (2009) argue that places without natural environmental attributes correlate with increased feelings of loneliness and inadequate social support, which result in poorer mental health and wellbeing.

Some studies suggest that social interaction may mediate the association between BGI and mental health benefits (De Vries et al., 2013). Similarly, Sugiyama et al. (2008) found that the relationship between neighbourhood greenness and health outcomes was partially mediated by an increase in walking for recreation and social cohesion. In the UK, the recent 'Living Streets' project (2020) aimed to create a better walking environment in order to encourage physical activity, but it also revealed that increased opportunities for walking encouraged a more social and cultural experience of place, and enhanced mental health and wellbeing, by connecting neighbours and reducing social isolation. As part of the project, a carriageway and parking spaces were transformed into a community space that included play areas and green spaces (including wildflower plantings and sustainable urban drainage). However, while aesthetically attractive BGI can be a pleasant backdrop for activity and social interaction, social engagement is more effectively supported by ensuring that BGI is accessible, e.g. by providing seating areas (Kawachi and Berkman, 2001).

7.3 Community engagement and volunteering for BGI maintenance

BGI maintenance is crucial to maximise its benefits. For example, while well-maintained green spaces can improve health and wellbeing, overgrown vegetation can have a negative impact by increasing the fear of crime. Some types of BGI, such as green roofs, green walls and rain gardens require minimal maintenance once installed. Others, such as urban parks, require most costly forms of maintenance such as mowing, weeding, watering and litter removal. These costs often fall to local authorities, who have experienced significant budgetary cuts in recent years (POST, 2013). Community engagement for co-development and maintenance could improve the sustainability of a project by minimising these costs, although it is important to recognise that such engagement itself is not entirely cost-free. Long term, stable funding is important to ensure both community- and local authority-led management, and a paid programme facilitator can play a particularly important role (Hunsberger et al., 2005).

Everett and Lamond (2018) have highlighted the potential value of public engagement in BGI design and maintenance. It can create a heightened awareness and understanding of how BGI works to manage water, generate a sense of site ownership by local people, and improve community coherence and cohesion. In addition, volunteering in local BGI maintenance improves participants' health and wellbeing, builds sustainable communities, conserves the environment, creates a connection with nature, and offers opportunities for learning around environmental issues (O'Brien, Townsend, and Ebden, 2010; Molsher and Townsend, 2016; Defra, 2011; Willems, 2020b).

In conclusion, BGI can make a clear contribution to social interaction, with a positive impact on health.

BGI design tips for increased social interaction and cohesion

- **Create community space, such as a resting point for people, a play area for children, alongside green planting.**
- **More community engagement for co-development and maintenance of BGI.**
- **Provide a range of environmental volunteer opportunities to suit participants' age, interests and ability.**

Figure 7: BGI design tips for increased social interaction and cohesion

8. Increased physical activity

8.1 The public health burden from physical inactivity

UK physical activity guidelines (CMO, 2019) recommend that adults aged 19 and over should spend at least 150 minutes per week doing moderate intensive physical activity (e.g. cycling) or 75 minutes per week doing vigorous physical activity (e.g. running or swimming). However, PHE (2014) report that one in four women and one in five men do less than 30 minutes of physical activity a week. Lack of physical activity is responsible for 3% of the disability-adjusted life years (DALY) lost annually in the global north, at a direct cost to the NHS of £1.06 billion per year. It is the fourth largest cause of disease and disability in the UK (Allender et al., 2007). In summarising the impact of physical activity on health, the Chief Medical Officer stated: "*If physical activity were a drug, we would refer to it as a miracle cure, due to the great many illnesses it can prevent and help treat*." (PHE, 2020b)

8.2 Health benefits of physical activities in green spaces

Regular physical activity is associated with physical and mental health benefits, such as a reduced risk of diabetes, obesity, heart disease, and depression (Lee et al., 2012). Several studies suggest that the outdoor environment may influence levels of physical activity by offering suitable spaces for exercise, and natural environments are recognised as being particularly good places to promote healthy activity (Ward Thompson and Aspinall, 2011). For example, Ellaway, Macintyre, and Bonnefoy's (2005) European cross-sectional survey found that higher levels of greenery in residential environments are associated with being physically active: residents of environments with the highest levels of greenery were three times more active than those who lived in areas with the lowest levels of greenery. A study by De Jong et al. (2012) found a positive relationship between quality of green space in a neighbourhood and physical activity, with impacts on residents' health and wellbeing. Interest in gardening has also been closely correlated with increased frequency of moderate physical activity (Chalmin-Pui et al., in press). Accessible and amenity-rich BGI can provide a pleasant environment for physically and mentally beneficial forms of outdoor exercise and activity (De Vries et al., 2013; Hartig et al., 2014).

8.3 The quality of green space

The literature does not show a consistent relationship between a provision of green space and increases in physical activity. For example, Troped et al. (2010) measured an area's 'greenness' using satellite imaging and found that adults' physical activity was inversely associated with the percentage of vegetated ground cover in a 1 km buffer zone around their residences; hence, people living in very green rural areas tended to do less activity than those living in dense urban areas. The authors suggest that these counter-intuitive associations may be due to a strong negative correlation between greenness and other built environment variables included in the study (intersection density, residential population density, housing density, and land use mix). In other words, they suggest that the relative influence of green space may be subordinate to other features of the built environment, such as density and connectivity.

The quality of green spaces may also be relevant. Day (2008) found that natural landscapes generally encouraged walking among older adults in Scotland, but poorly maintained parks acted as a deterrent to use of these spaces. Cultivated rural landscapes with limited footpaths could likewise discourage exercise due to the need to use a vehicle to access services. Ord, Mitchell, and Pearce (2013) considered data on 3,679 adults living in urban areas across Scotland with green space nearby. The authors found no evidence of a relationship between availability of green space and either increased total physical activity or increased physical activity within the green space. Wheeler et al. (2015) suggest that these results may be a consequence of the tendency to treat green space as a homogenous entity, paying insufficient attention to its type, quality, and context.

8.4 Public facilities in green spaces

Van Dillen et al. (2012) show that access to high-quality green space (i.e. accessible, well-maintained, clean, safe places) was positively associated with general health. Schipperijn et al. (2013) also found that levels of physical activity in green space were positively correlated with features such as provision of a walking and/or cycling route, the presence of a water feature (i.e. pond, stream), lights along trails, a pleasant view, a bike rack, and a car park. In a study involving older women, Chastin et al. (2014) found that a lack of seating and resting facilities outside the home limited participants' motivation or confidence to be active. Most stated that they would walk more if they could find seating places at staggered intervals in public spaces, enabling them to rest when needed and giving them increased confidence to venture further outside. Other research also suggests that greenery can attract older people into the outdoor environment in tandem with the provision of facilities such as benches or toilets (Aspinall et al., 2010).

8.5 The enhanced benefits of physical activity in green spaces

Researchers are now encouraging doctors to use 'green' or 'social' prescriptions to give patients a 'dose of nature' alongside more conventional forms of medication, a shift that emphasizes the physical and mental health benefits of outdoor physical activity (POST, 2016). NICE guidance (2014) also now recommends exercise referral schemes as an intervention for sedentary or inactive patients who have existing health conditions or other factors that put them at increased risk of ill health.

A number of experimental studies on the concept of "*green exercise*" have found possible synergistic benefits in being physically active in a natural environmental setting, as opposed to being in a natural environment without exercising, or exercising in a non-natural environment (see Pretty et al., 2006). Bowler et al. (2010b) found that participants who walked/ran in a natural outdoor environment reported a reduction of negative emotions, compared to those who performed similar activities in an indoor environment, while a systematic literature review by Thompson-Coon et al., 2011 found that outdoor exercise in green space yielded greater feelings of revitalisation, vitality, and positive engagement compared to indoor exercise, as well as reducing stress, anger, and sadness (though the authors also concluded that more research was needed in this area). It is possible that the "*soft fascination*" provided by natural environments, i.e. the feeling of being effortlessly engrossed, interested, and distracted from pain and boredom, may be at work during physical activity in green space (Kaplan, 1995).

There is little research to date on whether exercise in a partially natural environment, for example, a street with many natural-looking sustainable drainage features, has similar benefits. However, the selection of such spaces for exercise by walkers, runners, and cyclists might suggest that they confer benefits that conventional streets lack. It is also possible that some people who would not otherwise choose to exercise do so in these spaces because of additional features like shade or fresher air. Finally, it is notable that some BGI developments are explicitly linked with local programmes of gardening and maintenance, which contribute directly to increased physical activity.

BGI design tips for increased physical activity

- **Increase exercise opportunities by creating walking trails, cycle lanes, fitness equipment, lights along trails or pleasant views in green spaces.**
- **Offer greener sitting and resting facilities at staggered intervals in public spaces.**
- **Create green travel routes to everyday destinations such as grocery stores, schools, work or libraries.**

Figure 8: BGI design tips for increased physical activity

9. Health inequalities and health-supporting blue and green environments

There is mounting evidence that noise, heat, and air pollution are unequally distributed. This can be a result of spatial inequalities (where people living in particular places are more likely to experience a particular type of environment) or health inequalities (where certain groups of people are more susceptible to the effects of pollutants). There is also mounting evidence that socio-economically deprived and vulnerable groups have lower provision of BGI in their local area, and that they may be less able than other groups to access such places even when they are present. This section discusses this evidence. Since these inequalities in health and wellbeing can be mitigated by increasing access to BGI, provision of such spaces should be a goal for policymakers and planners.

9.1 Noise, heat and air pollution

According to the annual report of England's Chief Medical Officer (CMO, 2017), a greater number air pollution sources and a higher concentration of emissions are typically found in more socially disadvantaged areas. People living in these places are also likely to be more vulnerable to the effects of air pollution. Ethnic minority populations in the UK are also exposed to higher concentrations of NO_2 and PM_{10} but there is no consensus on whether this is a causal association between ethnicity and pollution exposure or a part of an association between deprivation and ethnicity. Fetuses, babies, and children are known to be more susceptible to poor air quality than adults and are thus disproportionately affected by exposure (CMO, 2017).

Some evidence also suggests that people living in more deprived areas have higher levels of exposure to noise pollution (EC, 2016). A Belgian study found a positive association between rising noise pollution and subjective ratings of poor health, particularly in urban areas. This relationship that was particularly significant for those in lower socio-economic groups living in poorer quality neighbourhoods (Schmit and Lorant, 2009).

The Urban Heat Island effect means that urbanised areas are more susceptible to high temperatures (Tomlinson et al, 2011, Wolf and McGregor, 2013). The effects of heat stress are more dangerous for specific vulnerable sections of the population:

- Older adults: especially those over 75 years old, those living on their own, those who are socially isolated, and those living in a care home.
- People with chronic and severe illness including heart or lung conditions, diabetes, renal insufficiency, Parkinson's disease, or severe mental illness.

- Groups who are unable to adapt their behaviour to keep cool such as babies and the very young, those with disabilities, bed-bound people, and those with Alzheimer's disease.
- People with specific environmental exposure: those who live in a top floor flat, the homeless, those with activities or jobs that are in hot places or outdoors, particularly if they cannot avoid high levels of physical exertion (Source: Landeg et al. 2020).

In the contemporary context, it is worth noting that there are overlaps between these heat risk factors and those for severe COVID-19 disease. Due to COVID-19 restrictions, many vulnerable people may spend more time indoors, and those managing COVID-19 symptoms at home may struggle to keep cool during an extreme heat event, particularly if they have a fever. Those recovering at home after a severe COVID-19 infection may also have ongoing organ damage, which means that they will be more vulnerable to the effects of heat than usual (Landeg et al., 2020).
This evidence that these environmental problems are concentrated in deprived neighbourhoods highlights an opportunity to place BGI strategically to mitigate unequal exposure to noise, heat, and air pollution.

9.2 Deprivation

A recent scoping review by Hands et al. (2019) reviewed 24 studies to conclude that there was a correlation between access to green space, lower levels of deprivation, and higher socioeconomic status. Even where green space was present, people in the lowest socioeconomic groups visited it less often, perhaps because such places in their areas were perceived as of a low quality aesthetically, and as foci for unsafe and antisocial behaviours. Provision of green space alone may therefore not be sufficient to reduce persistent health inequalities, since usage depends on additional factors, including aesthetics and other amenities (Estabrooks et al. 2003; Ellaway et al. 2007; Mitchell and Popham 2007; Day, 2008; Nagel et al. 2008; Jones et al. 2009). Designing open spaces that take account of this is important to securing health and wellbeing outcomes: a multi-ethnic, Bradford based study of childhood wellbeing concluded that satisfaction with the quality of green space was a more critical factor than its quantity in ensuring better wellbeing outcomes (McEachan et al., 2018).

Lengen and Kistemann (2012) have shown that place constitutes a distinct dimension in neuronal processing, and that emotional bonds with places contribute to sustain health and wellbeing. Factors such as a place's meaning and value, symbolic landscapes, past experiences and emotional ties with place are therefore important as components of human wellbeing. Positive experiences and emotional bonds may be stronger in the natural environment.

9.3 An equigenic effect

There is evidence that access to blue and green spaces can be "*equigenic*", which means that it can reverse the usual conversion of social inequality to health inequality (Wheeler et al., 2015).

Improving green space can confer physical and mental health benefits in disadvantaged areas and its use may promote social cohesion by allowing groups from different social backgrounds to interact, which has health benefits, such as reducing stress and depression (POST, 2016; Hands et al., 2019). Ward Thompson et al. (2013) show that improvements in access to green space near deprived urban communities increased green space use and activity levels, and improved perceived quality of life. The creation of new green spaces in disadvantaged neighbourhoods (e.g. greening of unused lands) can even help reduce the incidence of certain crimes (Branas et al., 2011; Chong et al., 2013). There is less literature studying the relationship between access to blue space and inequality, but a review by Gascon et al. (2017) found one study reporting that the beneficial effects of outdoor blue spaces were largest in more deprived socioeconomic areas (Wheeler et al., 2015; Gascon et al., 2017).

9.4 Different demographic groups

Some groups are more likely to experience health benefits when they access blue and green spaces than others. They include females, older adults, people from ethnic or cultural minority groups, and people who have disabilities, which highlights the importance and potential of ensuring equitable access to health-promoting BGI for diverse groups.

- Ethnicity: Maruthaveeran and Van den Bosch (2014) found that certain groups of people, particularly older people, women, and ethnic minorities, were more fearful in local green spaces because of a heightened perception of their vulnerability or past experiences of crime. This negative perception of local green space can be addressed by proper management and maintenance (WHO, 2016) which is discussed in more detail in Section 11 of this report. Additionally, a scoping review by Hands et al. (2019) found that people of white British ethnicity were less likely to report insufficient time as a barrier to visiting green space than residents of more ethnically diverse areas, with the latter also suffering lower levels of both access to, and satisfaction with, green space (satisfaction with the quality of such places was particularly low amongst the Bangladeshi community).
- Gender: Hands et al. (2019) found that women are more likely to visit green space than men and that conditions of self-reported stress and major depressive disorder were inversely associated with the provision of green space. This suggests that women may be more likely than men to suffer adverse health effects from lack of BGI.
- Age: Hands et al. (2019) found that older adults were less likely to use green space, but those who did experienced lower objectively-measured stress. For younger and middle-aged adults, those with greater access to green space were less likely to experience major depressive disorder.
- Disability: Studies from Denmark indicate lower use of blue and green spaces by disabled people (Corazon et al., 2019). A Scottish review found that access to blue and green spaces was lower for disabled people (60%) compared to non-disabled people (70%) (Scottish

Government, 2019). A variety of reasons may explain this, including insufficient or inaccessible public transport (Corazon et al. 2019).

- COVID-19: The outbreak of COVID 19 has disproportionately affected the health of people from disadvantaged or marginalised groups (Royal College of Physicians, 2020). Improving access to BGI for these groups is now a pressing concern, and should form part of local authorities' COVID-19 recovery plans. Social distancing and self-isolation, particularly among vulnerable groups such as the over-70s can make taking part in physical activity difficult and are associated with negative mental health impacts (PHE, 2020a).

10. Health outcomes

10.1 Improved mental health and wellbeing

Over the past decade, there has been a dramatic increase in the evidence for the benefits of natural environments on mental health and wellbeing. The British Household Panel Survey (which ran from 1991 to 2008) showed a sustained improvement in the mental health of those who moved to a greener neighbourhood, compared to those who moved to a less green place (Alcock et al., 2014). Van den Berg et al. (2016) found that more time spent in green space is associated with greater mental health and vitality. Beyer et al. (2014) found that higher levels of neighbourhood greenness were associated with lower levels of depression, anxiety, and stress, while Völker and Kistemann (2015) showed that blue spaces are particularly linked to psychological benefits.

Stress is a significant health issue that is closely linked to psychiatric morbidity, such as depression and burnout syndrome (Tyrväinen et al., 2014). Roe et al. (2013) and Tyrväinen et al. (2014) found that even a short visit to a natural area has a significant benefit in terms of stress reduction, compared to a non-natural area. A recent experimental study by Ewert and Chang (2018) also showed that visitors to natural environments experienced significantly reduced physical and psychological stress levels, as opposed to those who visited a more built-up outdoor setting or indoor sports centre. In another study, an eight-week experiment followed 94 office employees who took walks during their lunch break, either in the natural environment (i.e. along a path with trees and well-kept grass) or in the built environment (i.e. along a path through residential and industrial zones). Their findings showed that the mental health of those who walked in the natural environment was substantially improved, compared with those who walked in the built environment (Brown et al., 2014). Natural environments may also have indirect effects on stress, by serving as a buffer against its adverse health-related effects. For example, Brown et al. (2013) found that participants who viewed the natural environment prior to being subjected to a mental stressor demonstrated greater recovery compared to those who had a view of the built environment.

In addition, a growing body of literature recognises the benefits of natural environments for mental health and cognitive development. Berman et al. (2012) found that individuals who were diagnosed with major depressive disorder (MDD) demonstrated significant improvement in short-term memory and working memory capacity after they took a walk in the natural environment. Dadvand et al. (2015) showed that surrounding greenness at home and school improved working memory and attention in children. Similarly, Amoly et al. (2014) demonstrated that children who spent longer periods of time in blue and green spaces had reduced behavioural difficulties, lower levels of peer relationship problems, and diminished symptoms of attention deficit/hyperactivity disorder (ADHD).

The evidence shows that mental health outcomes are positively impacted by contact with natural spaces, with the potential to yield substantial benefits. In terms of the implications for the design of natural spaces, these benefits can to be gained from large natural areas such as urban woodland but also from smaller-scale BGI features, such as the existence of pocket parks and street trees.

10.2 Reduced physical illness

Several studies have shown a strong association between use of urban green spaces and lowered risks of cardiovascular morbidity (e.g. Gascon et al., 2016; Yeager et al., 2018). A significant increase in risk of cardiovascular disease was observed for people who were not park users and for those who lived further from parks, compared to those living near them (Tamosiunas et al., 2014). Pereira et al. (2012) also found that variability in neighbourhood greenness was negatively associated with coronary heart disease and stroke. The odds of hospitalization for heart disease or stroke were 37% lower amongst adults in neighbourhoods with highly variable greenness, compared to those in predominantly green (i.e. rural), or non-green (i.e. very urban) neighbourhoods. The authors explain that "*variability in neighborhood greenness is a single metric that encapsulates two potential promoters of physical activity - an aesthetically pleasing natural environment and access to urban destinations*", and they suggest that the best heart health occurred where both factors were present. An experimental study by Grazuleviciene et al. (2015b) found that walking in a park had a greater effect on cardiac function in patients with coronary artery disease than walking in a busy urban street.

A number of gaseous and particulate air pollutants are associated with pulmonary morbidity and mortality. Air pollution enhances pulmonary disease (accelerating decline in pulmonary function) and asthma, and harms are greater for vulnerable populations, such as children and the elderly (Kurt et al., 2016). It is therefore plausible that neighbourhood greenness can prevent pulmonary disease by reducing exposure to traffic-related air pollutants. Furthermore, recent studies showed a relationship between diabetes and neighbourhood greenness. Astell-burt et al. (2014) and Bodicoat et al. (2014) found that the risk of type 2 diabetes mellitus was significantly lower in greener neighbourhoods.

In summary, there is evidence that neighbourhoods with more green space show decreased levels of cardiovascular illness, asthma, and diabetes.

10.3 Reduced mortality

A body of evidence, including a recent review of nine studies in The Lancet found evidence of an inverse association between neighbourhood greenness and all-cause mortality (Rojas-Rueda et al., 2019 see also Gascon et al., 2016). This may be due to a variety of mechanisms. As depicted in Figure 2, BGI may be associated with lower levels of exposure to air pollution, extreme heat, and noise which may lead to better mental and physical health (e.g. Yang et al., 2011; Brantley et al., 2014). Furthermore, access to green space has been associated with lower levels of perceived stress and reduced physiological indicators of stress (Ewert and Chang, 2018), which are associated with improved prognosis and quality of life in patients with existing psychological or physical health problems (Arnold et al., 2012).

Villeneuve et al. (2012) studied associations between green space and mortality in a 22-year follow-up study of 575,000 adults in Ontario, Canada. They found that green space in residential areas was associated with a long-term reduction in mortality, particularly from respiratory disease. Gascon et al. (2016) also showed a reduction in cardiovascular disease (CVD) mortality in areas with higher residential greenness, while Wilker et al. (2014) found that green space in residential areas was associated with higher survival rates after ischemic stroke. Xu et al. (2013) showed that greener neighbourhoods were associated with lower mortality risk during heat waves.

10.4 Improved birth outcomes

Birth weight is an important indicator of health in early life: low birthweight is associated with higher levels of infant mortality, as well as long-term adverse effects on childhood psycho-physiological development (WHO, 2006). Dzhambov et al. (2014) and Yin (2019) found that pregnant women living in greener environments gave birth to babies with higher birthweights. Similarly, Grazuleviciene et al. (2015a) showed that babies born to pregnant women living in areas with low levels of surrounding greenness and at greater distances to city parks had an increased risk of preterm birth (defined as birth before 37 weeks of pregnancy has been completed) and a reduced gestational age at birth.

10.5 Healthier bodyweights

The rapid increase in the number of obese people in the UK is a major challenge. According to the government's Foresight programme, over half of the UK adult population could be obese by 2050. The NHS costs associated with people being overweight and obese are projected to double to £10 billion per year by 2050, with the wider costs to society and business estimated at £49.9 billion per year (Government Office for Science, 2007).

A review by Mackenbach et al. (2014) indicates that several factors within the physical environment may affect adult obesity, including urban sprawl, land-use mix, walkability, and provision of green space (which can impact obesity through increased physical activity). A US study found that the type of natural environment within a county mattered: cropland and rangeland had no positive impact on Body Mass Index (BMI), but forests, parks, and recreational land were associated with reductions in BMI in the population (Ghimire et al., 2017). Lovasi et al. (2013) also found that a higher density of street trees was associated with lower prevalence of obesity among preschool children in New York City. The findings suggest that green and blue spaces, such as urban parks, street trees, woodlands, and natural outdoor recreational spaces can play a valuable role in reducing obesity and associated public health problems (Ghimire et al., 2017).

However, some researchers have highlighted that the relationship between bodyweight and green space is not straightforwardly linear. A longitudinal study in Ireland by Dempsey, Lyons, and Nolan (2018) indicated that people living in urban areas with both very high and very low proportions of green space have a higher probability of being obese than those in urban areas with a medium amount of green space. The reason for this finding is unclear, but (echoing the conclusions of Pierera et al., (2012) noted in Section 10.2 above) it might be that those living in the greenest areas had fewer opportunities for either recreational or routine walking (e.g. to shops). An English study by Cummins and Fagg (2011) also found that residents in the greenest areas were more likely to be overweight or obese between 2002-2003, though their data suggested that by 2004-2007 there was no statistically significant association between green space and BMI.

These results indicate some ambiguity about whether provision of green space can be associated with reductions in BMI. Although greener areas may allow and encourage more active travel, a direct association with BMI is not always observable, perhaps because of other complex intervening factors. Notwithstanding this ambiguity, there is some evidence of a positive influence between BGI and physical activity.

10.6 Inequalities

All of the health outcomes discussed above are unequally distributed in society. For example, people from socially disadvantaged backgrounds, those with disabilities, and those from minority ethnic backgrounds are more likely to experience mental and physical illness. Further, people with these characteristics are also more likely to live in more deprived areas (PHE, 2018). People with additional health needs or those from minority groups often seem to experience a form of 'double jeopardy': higher deprivation and greater susceptibility to adverse health outcomes (POST, 2016). There is also evidence that deprivation-related health inequalities are worsening: the healthy life expectancy for women aged 65 in the most deprived parts of the UK recently fell from 18.5 years (2013-15) to 18.3 years (2016-18), at a time when healthy life expectancy increased for women from less deprived areas (ONS 2020). There are also substantial disparities in birth outcomes for babies born to mothers from lower incomes and mothers from ethnic minorities, with data from the UK Millennium Cohort study showing that Pakistani, Bangladeshi, black Caribbean, and black African babies had significantly lower birthweights than their white counterparts, a difference that is largely explained by socioeconomic factors (Kelly et al., 2009).

It would be impossible to examine the full extent of inequalities in health outcomes here or to do justice to the highly complex and interrelated causal mechanisms behind such trends, but the brief discussion above serves to highlight some of the complexities of the relationship between place, deprivation, and health inequalities. BGI represents a particularly important intervention that can be potentially used to improve the health outcomes for deprived areas, thanks to its equigenic effect (see Section 9.3). Such differential improvements are more likely if interventions are targeted at particular places, and made accessible to vulnerable population groups. Section 11 includes strategies for developing inclusive BGI interventions that can reach those who have the highest need.

10.7 Conclusion: health outcomes

This section has explored a variety of associations between access to BGI and health outcomes, including the maintenance of a healthy weight, a reduction in physical and mental illness, reduced mortality, and improved birth outcomes. It also highlights the need to target improvements at particularly deprived areas, for maximum positive impact.

11. Implications for BGI design

This section focuses on the way that BGI can be designed to leverage health outcomes and health impacts, based on the evidence discussed in Sections 3 to 10. Many local authorities and water companies recognise BGI design as an integral part of water management practice, but here we suggest that the design process also provides local authorities with the opportunity to maximise synergies between water management benefits (largely experienced by providers, ecosystems, or the downstream community) and potential health and wellbeing impacts for the community hosting the BGI. There may be a particularly strong policy driver for this if the host community is one suffering health inequalities. In exploring the design implications, it is important to recognise that there are synergies and trade-offs between the different health and wellbeing benefits, as well as between these benefits and water management objectives. Ultimately, decisions about the right balance of benefits depend on local needs and the constraints of the development sites as well as the policy drivers providing funding for BGI.

How can designers set about maximising the benefits of BGI? To address this question, this section first considers whether and how BGI can be used to target health inequalities. The subsequent subsections enumerate the factors that need to be considered in 'small-scale', 'large-scale', and 'linear' BGI design. The 'small-scale BGI' scenario envisages the chance to create pockets of BGI (each imagined to be around 2 metres by 4 metres) within a street, around a parking area, or within an otherwise built-up context. Here, each BGI has a small impact on local health and wellbeing, but the cumulative impact of many of these small BGI is potentially substantial. Such small-scale BGI might be developed in a retrofit or new development context. By contrast, when discussing large-scale BGI, we are imagining an open space of at least 20 metres by 40 metres (but quite possibly considerably larger). Effectively this scenario provides the opportunity to repurpose a patch of urban land entirely for BGI, with considerable potential impacts on neighbourhood health and wellbeing. It might involve the repurposing of parkland or derelict land within a retrofitting project; equally, it might involve an area of green space created within a large new development.
We define 'linear BGI' as linear blue and green spaces in cities. Examples include rows of street trees, hedgerows along pedestrian or bicycle paths, or a riverfront or other natural corridor. Linear BGIs can be important in creating routes linking BGIs within a city, or in connecting BGIs in and outside of urban areas. We envisage that water professionals may have the opportunity to create or enhance some linear BGI in either a retrofitting or new development context.

Table 1: Three types of BGI considered

Small-scale BGI	*Pocket parks, rain gardens, green roofs, and green walls*
	• Pocket parks are found in corners of the city (streets, plazas, squares, sidewalks, loading baya) or abandoned lots between buildings. They are designed to provide a 'green oasis' in an urban area. • A rain garden, often referred to as a bioretention area, is a planted depression which relies on vegetation and soils to mitigate stormwater runoff from buildings, pavements, and roads. • A green roof is a roof surfaced with plants, usually chosen for their ability to retain water and also to insulate the building. • A green wall is a vertical built structure which is designed to grow plants. It absorbs water and pollution while cooling the air and insulating the building.
Large-scale BGI	*Parks, ponds, and wetlands*
	• A park is a larger area of green space open to public use. • A pond is permanent pool of water on the ground's surface. • A wetland is an area of planting that is permanently saturated or that becomes saturated and stores water when it rains.
Linear BGI	*Street trees and hedgerows, urban streams*
	• Street trees are trees planted in the street, often for shade and aesthetic appearance. • A hedgerow is a linear feature of continuous planting which is usually shaped through regular trimming. It is often used as a boundary. • An urban stream comprises the bed and banks around a stream flowing through an urban area.

In relation to each scenario we begin by considering the overall principles that should guide design. We go on to consider the variables that are likely to influence design choices, before highlighting key trade-offs. We conclude with a few different exemplary designs for each scenario, illustrating the key choices that must be made.

11.1 Targeting interventions to address health inequalities

Vulnerable communities and people living in places with higher levels of deprivation may face a 'double jeopardy': they are more exposed to environmental factors that can negatively affect their health, and more susceptible to negative health outcomes as a consequence of that exposure. Spatially targeted approaches to planning can help to address these issues by identifying places and communities that are likely to experience high deprivation, low access to blue and green environments, or higher levels of pollutants (Kenyon and Pearce, 2019).

Even where hydrological constraints do not allow flexibility in the location of BGI, design choices can enhance access and accessibility for groups who may feel physically, culturally, or socially excluded from using blue and green spaces through the following strategies:

- Safety and quality: Designers can consider factors that are likely to affect perceptions of safety in BGI design. For example, they might include additional safety features such as good lighting, and enhanced features and facilities such as toilets, bicycle racks, cafes, signage, and information. Developing more aesthetically pleasing environments can also enhance perceptions of quality and safety (Cerin et al. 2009; Freeman et al. 2013).
- Ensuring access for people with disabilities: Inclusive green space strategies are best planned with all people in mind: an understanding of different needs can ensure that as many people as possible can enjoy the space, regardless of ability (Sensory Trust, 2017).
- Local information and people: Different groups may benefit from different types of environment. For example, people living in disadvantaged neighbourhoods may benefit from specific types of built environment, such as those that offer health and recreational resources that are easy to access on foot (King and Clarke, 2015). Using local data and knowledge can be helpful in gauging local needs and can also involve local communities in the design and planning of BGI initiatives. This also means that the concerns of specific groups can be heard and addressed at an early phase of planning (Daly et al, 2015). Involving local communities in the design and planning stage of BGI to ensure that that local needs and priorities meaningfully shape the design increases the potential for such spaces to become a resource that benefits the local community (Wolch et al. 2014; Sensory Trust, 2017)
- Additionally, certain groups may be less inclined to engage with outdoor environments for cultural or individual reasons. To support use of spaces among these groups, additional complementary strategies such as exercise promotion programmes may be needed (Kenyon, 2018) as well as structured community involvement, such as forest schools for children, local 'friends of' the area groups, community group spaces, and other activities.

11.2 Small-scale BGI

Recent developments in the field of urban BGI have led to a renewed interest in the multi-functionality and associated benefits of small-scale BGI, such as community green spaces, pocket parks, rain gardens, or temporary recreation spaces along streets. They are often scattered in patches or hidden in the structure of the city, serving local people directly. Such small-scale BGI make an important contribution to the daily life of urban residents and meet people's functional needs, providing places for leisure, relaxation, and socialising. Thus, small-scale BGI have the potential to complement the health impacts and social functions of larger scale projects and sites. More recently, research has heightened awareness of the need for community participation and engagement in the co-production of small-scale BGI projects, demonstrating how this can enhance sites and provide opportunities to build community cohesion.

In order to maximise the health impacts and outcomes outlined in this report, we propose the following design guidance:

Table 2: Design guide for small-scale BGI

Types of BGI	Health impacts	Design guide
Pocket parks	Noise reduction	• Adding water features (e.g. fountains) to provide effective natural sounds to mask road traffic noise. • Applying planting strategies for noise reduction e.g. bordering a pocket park along a road with an optimised vegetation barrier (e.g. 2 m high shrub zone with a length of 15 m, see Section 3.2).
	Heat stress reduction	• Designing a circular- or polygonal-shaped pocket park to enhance the cooling effect. • Creating many shaded areas to boost evapotranspiration inside pocket parks. • Adding water bodies within the urban green space to maximise the cooling effect.
	Improved air quality	• Planting appropriate trees and shrubs within pocket parks to improve air quality (see Section 5.2). • Combining a variety of design solutions (e.g. green roofs, green walls) to reduce air pollution.
	Restorative and stress-reducing environment	• Adding ornamental street trees to create comfort and pleasant local environments e.g. *Acer rubrum, Prunus 'Pink Perfection'*. People are also attracted to 'flat top/roof trees' e.g. *Acer palmatum, Cedrus libani, Pinus sylvestris*. • Creating more attractive local environments with seasonal plants in a pocket park (e.g. a mixture of native perennial flowers, shrubs, and trees). • Adding water features to provide attractive views and sounds while creating spaces for restoration and relaxation. • Community involvement in design and planning.
	Increased social interaction and cohesion	• Providing a variety of public places (e.g. seating/ resting areas) to allow interaction with other people through observation, communication, and leisure. • Promoting more active local community and neighbourhood involvement in management and maintenance. • Community involvement in design and planning.

	Increased physical activity	• Providing a variety of social facilities for the use and enjoyment of the area e.g. play areas for children, seating/resting facilities. • Introducing programmes to promote the use of the green space and physical activity (e.g. growing vegetables). • Encouraging active surveillance and visibility of public spaces e.g. increased lighting and active street frontages. • Community involvement in design and planning.
Rain gardens	Noise reduction	• Adding water features (e.g. fountains) to provide effective natural sounds to mask road traffic noise. • Combining possible applications e.g. bordering a pocket park or rain garden with an optimised vegetation barrier (see Section 3.2).
	Heat stress reduction	• Creating many shaded areas to boost evapotranspiration inside rain gardens.
	Improved air quality	• Planting appropriate trees and shrubs within pocket parks to improve air quality (see Section 5.2). • Combining a variety of design solutions (e.g. green roofs, green walls) to reduce air pollution.
	Restorative and stress reducing environment	• Creating more attractive local environments with seasonal plants in a rain garden (e.g. a mixture of native perennial flowers, shrubs, and trees). • Community involvement in design and planning.
	Increased social interaction and cohesion	• Providing a variety of seating/resting facilities near rain gardens to allow interaction with other people through observation, communication, and leisure. • Encouraging more active local community and neighbourhood involvement in management and maintenance. • Community involvement in design and planning.
	Increased physical activity	• Providing a variety of public facilities to encourage use and enjoyment of the area e.g. play areas for children, seating/resting facilities. • Introducing programmes to promote the use of the green space and physical activity (e.g. growing vegetables). • Community involvement in design and planning.
Green roofs and green walls	Noise reduction	• Using green walls to absorb the sound of the human voice (60 dB) around public places e.g. restaurants, hotels, or high street shops.
	Heat stress reduction	• Combining green roofs and green walls to enhance the heat stress attenuation in indoor environments.

	Improved air quality	• Planting pollution-busting tree and shrub species: an intensive green roof (with trees and shrubs) is more effective than an extensive green roof (covered with low growing plants) in producing a reduction in air pollution. • Replacing the current use of polymeric green roof layers (which release toxic substances) by re-use of waste materials to enhance sustainability of green roofs.
	Restorative and stress reducing environment	• Increasing colour and floral diversity to create more attractive environments with seasonal plants (e.g. a mixture of low-growing wildflowers, sedums, and small shrubs).
	Increased social interaction and cohesion	• Providing a variety of seating/resting facilities to allow interaction with other people. • Encouraging more active local community and neighbourhood involvement in management and maintenance. • Community involvement in design and planning.
	Increased physical activity	• Providing a variety of public facilities for the use and enjoyment of the area e.g. play areas for children, garden features. • Introducing programmes to promote the use of the green roofs (e.g. vegetable and herb gardens). • Community involvement in design and planning.

11.3 Large-scale BGI

The availability and accessibility of green space is particularly important for large-scale BGI, which can play a role in physical and mental health, exercise, and social interaction. Often, these large green sites already exist but can be enhanced to offer BGI that achieves water goals, but also promotes local health and wellbeing. Sometimes derelict sites or new developments also offer the opportunity to create completely new large-scale BGI.

The benefits of all large-scale BGI are maximised if:

- They are close to areas of deprivation, enabling easy access for local people, and include a range of facilities (e.g. walking trails)
- The spaces are protected and managed carefully so that they provide both ecological value and high-quality natural experiences. Care needs to be taken not to compromise the positive health benefits that green spaces offer to urban residents.
- They achieve naturalness without compromising safety and security. Thought needs to be given to use, sight lines, and provision of a variety of spaces, so that people can enjoy the BGI without fear.
- Local residents are involved from the design and planning stages.

In order to maximise the health impacts and outcomes outlined in this report, we propose the following design guidance:

Table 3: Design guide for large-scale BGI

Types of BGI	Health impacts	Design guide
Urban woodland	Noise reduction	Following effective planting strategies for noise reduction (see Section 3.2): • For a 15 m deep vegetation area, significant noise reduction is predicted to occur with a tree spacing of less than 3 m and a tree stem diameter of more than 0.11 m • A 2 m high shrub zone with a length of 15 m provides effective road traffic noise reduction.
	Heat stress reduction	• Considering tree species with a leaf-area-density (LAD) and high rates of transpiration e.g. Corylus colurna and Tilia cordata: the shading effects of trees and other taller vegetation along with increased evapotranspiration (ET) appear to contribute to cooling effects. • Adding water bodies within the urban green space to maximise the cooling effect.
	Improved air quality	• Planting close to pollution sources generates additional air pollution absorption benefits. • Selecting specific evergreen tree species with smaller leaves, hairs, waxes, or sticky and rough surfaces maximises removal of particulates e.g. pine trees. • Planting evergreen shrub species can capture higher quantities of pollutants, especially during the winter season when the concentration of air pollutants is generally higher. • Considering the tree life expectancy: young and smaller trees of the same species are more effective at removing pollutant particles due to their greater foliage densities compared to much larger mature specimens. Selecting species with low-to-moderate pollen production and increasing plant biodiversity to control air quality.
	Restorative and stress-reducing environment	• Reducing negative perceptions of woodland e.g. an increased use of information, signs, maps, and lights can encourage visitor confidence, as people can feel trapped and threatened otherwise. • Offering a variety of spaces and vegetation types to allow people to enjoy the woodland without compromising their personal safety or security e.g. adopting a wood pasture approach. • Adding water features to provide attractive views and sounds of water while creating spaces for restoration and relaxation. • Community involvement in design and planning.

	Increased social interaction and cohesion	• Providing a variety of public places to allow social interaction through observation, communication, and leisure. • Maximising the opportunities for local people to take an active role in the management and development of large-scale BGI. • Offering a range of environmental volunteer opportunities to suit participants' ages, interests, and abilities. • Encouraging involvement through local social campaigns. • Community involvement in design and planning.
	Increased physical activity	• Increasing access to woodlands to encourage the use of informal activities, such as jogging, dog walking, picnics, and talking with neighbours. • Offering a variety of facilities (e.g. walking trails, fitness equipment, bike racks, seating and resting areas, picture trails for children to follow) for different recreational users and activities. • Giving more opportunities to explore woodland, such as different sizes of space, functions, experiences (open view/senses of enclosure) and vegetation types. • Designing the site to improve safety and surveillance e.g. clear sightlines to entrances and exits, increased lighting. • Improving access for most people, especially those with mobility and sensory impairments (e.g, no steps higher than 15 mm, paths at least 1 m wide, path gradient of no more than 1:20, resting places every 150 m, as advised in the British Standards). • Providing facilities/programmes to encourage people with disabilities to use the site e.g. a new touch trails for visually impaired people. • Encouraging involvement through local social campaigns • Community involvement in design and planning.
Parks	Noise reduction	• Applying planting strategies for noise reduction e.g. bordering a park along a road with an optimised vegetation barrier e.g. a 2 m high shrub zone with a length of 15 m (see Section 3.2). • Adding water features (e.g. fountains) to provide effective natural sounds to mask road traffic noise.
	Heat stress reduction	• Considering tree species with a high leaf-area-density (LAD) and high rates of transpiration e.g. *Corylus colurna* and *Tilia cordata*: shading effects of trees and other taller vegetation along with increased evapotranspiration (ET) appear to contribute to cooling effects. • Adding water bodies within the urban green space to maximise the cooling effect.

	Improved air quality	• Selecting specific evergreen tree species with smaller leaves, hairs, waxes, or sticky and rough surfaces to maximise removal of particulates. • Planting evergreen shrub species to capture higher quantities of pollutants, especially during the winter season when the concentration of air pollutants is generally higher. • Considering the tree life expectancy: young and smaller trees of the same species are more effective at removing pollutant particles due to their greater foliage densities compared to much larger mature specimens. • Selecting species with low-to-moderate pollen production and increasing plant biodiversity to control air quality.
	Restorative and stress reducing environment	• Reducing negative perceptions of public space e.g. good lighting, easy to read signs and maps. • Increasing biodiversity (e.g. increasing floral diversity, vegetation cover, and plant/flower abundance, plant richness, bird richness, and habitat diversity) to enhance the psychological benefits gained from visiting green space. • Adding water features to provide attractive views and sounds of water while creating spaces for restoration and relaxation. • Community involvement in design and planning.
	Increased social interaction and cohesion	• Exploring opportunities to encourage people to congregate in areas of green space, such as seats that people can arrange themselves, board games areas, or arts markets. • Maximising the opportunities for local people to take an active role in design, management, and development.
	Increased physical activity	• Offering a variety of facilities (e.g. walking trails, fitness equipment, bike racks, seating and resting areas, picture trails for children to follow) for different recreational users and activities. • Providing opportunities for exercise and stimulation in green space, such as different sizes of space, functions, experiences (open view/senses of enclosure), and vegetation types. • Designing the site to improve safety and surveillance e.g. clear sightlines to entrances and exits, increased lighting. • Improving access, especially for those with mobility and sensory impairments by following standards (e.g. no steps higher than 15 mm, paths at least 1 m wide, path gradient of no more than 1:20, resting places every 150 m as advised in the British Standards). • Providing facilities/programmes to encourage people with disabilities to use the site e.g. a new touch trail for visually impaired people. • Community involvement in design and planning.

Ponds and wetlands	Noise reduction	• Enhancing noise reduction by installing moving water features (e.g. a waterfall or cascading stream flows). • Planting vegetation barriers alongside ponds and wetlands to enhance noise reduction (see Section 3.2).
	Heat stress reduction	• Planting suitable trees along ponds and wetlands to maximise the heat stress reduction effect (see Section 4.2).
	Improved air quality	• Planting suitable trees and hedgerows to improve air quality (see Section 5.2).
	Restorative and stress reducing environment	• Increasing biodiversity (e.g. colour and floral diversity, high vegetation cover and plant/flower abundance, plant richness, bird richness, and habitat diversity) to enhance the psychological benefits gained from visiting green space. • Community involvement in design and planning.
	Increased social interaction and cohesion	• Providing a variety of public places (e.g. seating/ resting areas) to allow interaction with other people through observation, communication, and leisure. • Encouraging more active local community and neighbourhood involvement in management and maintenance. • Offering a range of environmental volunteer opportunities to suit participants' ages, interests, and abilities. • Community involvement in design and planning.
	Increased physical activity	• Providing facilities for informal activities e.g. walking trails, bike racks, fitness equipment, gazebos around a pond or wetland, and opportunities for pond dipping. • Improving access, especially those with mobility and sensory impairments, by following standards (e.g. no steps higher than 15 mm, paths at least 1 m wide, path gradient of no more than 1:20, resting places every 150 m as advised in the British Standards). • Designing the site to improve safety and surveillance e.g. clear sightlines to entrance and exits, increased lighting. • Community involvement in design and planning.

11.4 Linear BGI

Linear BGI can be used to connect green areas, creating corridors for the movement of both wildlife and people through an urban area. Examples include rows of street trees, hedgerows, and urban streams. Linear BGI can improve access between different green spaces within the city, or between green spaces in the city and the surrounding countryside. It offers opportunities to develop blue-green routes for walking and cycling, which contribute towards a healthy and sustainable transport plan.

In order to maximise health impacts and outcomes, we are proposing to adopt the following types of linear BGI:

Table 4: Design guide for linear BGI

Types of BGI	Health impacts	Design guide
Street trees and hedgerows	Noise reduction	Following effective planting strategies for noise reduction (see Section 3.2): • A vegetation belt more than 30 m wide next to a road effectively reduces traffic noise. • A 5 m depth of roadside vegetation reduces traffic noise. • The ideal ratio of noise source height to tree height is 1:6.6 within a short distance of the noise source.
	Heat stress reduction	• Considering tall vegetation and tree species with a high leaf area density (LAD) and high rates of transpiration e.g. *Corylus colurna* and *Tilia cordata* to maximise shading effects and evapotranspiration (ET) Combining a variety of design solutions (e.g. green roofs, green walls) to maximise heat stress reduction.
	Improved air quality	• Selecting specific evergreen tree species with smaller leaves, hairs, waxes, or sticky and rough surfaces to maximise removal of particulates. • Planting evergreen shrub species to capture higher quantities of pollutants, especially during the winter season when the concentration of air pollutants is generally higher. • Selecting species with low-to-moderate pollen production and increasing plant biodiversity to control air quality.
	Restorative and stress-reducing environment	• Adding ornamental street trees to create an attractive local environment e.g. *Ginkgo biloba* and *Koelreuteria paniculata*.
	Increased social interaction and cohesion	• Linking small pocket parks or public areas to provide greater opportunities for social engagement with neighbours. • Maximising the opportunities for local people to take an active role in management and development of local BGI • Encouraging community involvement through social campaigns
	Increased physical activity	• Promoting connectivity between BGIs, e.g. integrating them with existing walking and cycle networks. • Encouraging active surveillance of and good visibility within public spaces e.g. increased lighting and active street frontages. • Encouraging community involvement through social campaigns

Urban stream	Noise reduction	• Enhancing the masking effects of water sounds for noise reduction by creating moving water features (e.g. installing a waterfall or cascading stream flows). • Planting vegetation barriers alongside a stream to enhance noise reduction (see Section 3.2).
	Heat stress reduction	• Planting suitable trees and shrubs along a stream to maximise the heat stress reduction effect (see Section 4.2).
	Improved air quality	• Planting suitable trees and shrubs along a stream to maximise improvements in air quality (see Section 5.2).
	Restorative and stress reducing environment	• Increasing biodiversity (e.g. high vegetation cover and plant/flower abundance, plant richness, bird richness, and habitat diversity) to enhance the psychological benefits of visiting green space • Encouraging community involvement through social campaigns.
	Increased social interaction and cohesion	• Providing a variety of public places (e.g. seating/resting areas) to allow interaction with other people through observation, communication, and leisure. • Maximising the opportunity for local people to take an active role in the management and development of BGI. • Offering a range of environmental volunteer opportunities to suit participants' ages, interests, and abilities. • Encouraging community involvement through social campaigns
	Increased physical activity	• Providing a variety of facilities for the use and enjoyment of the area, e.g. lights, stepping stones, boardwalks, and other waterfront attractions. • Promoting connectivity between BGIs, e.g. integrating with existing walking and cycle networks. • Designing the site to improve safety and surveillance e.g. clear sightlines to entrance and exits, increased lighting. • Encouraging community involvement through social campaigns.

12. Conclusion

BGI offers a unique opportunity to create infrastructure which unites environmental, health, and social benefits. This report has summarised the ways in which BGI can support health and wellbeing outcomes for the communities who host them. By reviewing evidence from recent research, we have sought to create an authoritative and accessible reference report that summarises both the potential health and wellbeing benefits of BGI and the design considerations that these raise. Our key goal has been to show how the inclusion, location, and design of BGI can be attentive to local health and wellbeing outcomes without compromising the delivery of downstream water services. Our summary suggests that large-scale, small-scale, and linear BGI interventions can all play a role in promoting physical and mental health and wellbeing.

Sections 3-8 demonstrated that green space offered by BGI has a variety of health-relevant impacts. Clear evidence was highlighted in relation to six impacts: noise reduction; heat stress reduction; improved air quality; stress reduction and cognitive restoration; decreased loneliness and enhanced social interaction; and increased physical activity. While the former three are achieved by all BGI regardless of scale or access, the restorative, social, and physical exercise benefits are more dependent on access and design.

Section 10 showed evidence of associations between green space and improved health outcomes, including improved mental health and wellbeing; reduced physical illness; reduced mortality; improved birth outcomes; and healthier body weights.

Section 11 looked at questions of design, suggesting the benefits of different options in producing enhanced health and wellbeing benefits.

Throughout this report (but particularly in Sections 9, and subsections 10.6 and 11.1), we have argued that BGI represents a significant opportunity to intervene meaningfully in order to reduce social and health inequalities. Targeting BGI-related interventions to improve health and wellbeing can make a significant difference to the most vulnerable communities. BGI offers the chance to convert the 'double jeopardy' of social deprivation and health inequalities into a virtuous pairing between environmentally-focused and health-focused improvements.

The development of this report has also highlighted some gaps in relation to existing knowledge. While these gaps point to some important areas for further research, they do not take away from the overwhelming weight of evidence showing that BGI can offer synergistic benefits addressing both water risks from climate change and aiding public health and wellbeing:

- Research on the impacts of large green spaces, like parks, is more extensive than research on smaller green features. For example, how does access to multiple small green features within a neighbourhood compare to an otherwise 'grey' neighbourhood? More extensive evidence about these smaller green features could be particularly useful, as many of the opportunities for urban BGI occur in dispersed micro projects.

- While the current literature points to overall associations, it does not differentiate sufficiently between the ways in which different types of BGI are likely to impact on health and wellbeing. The processes of locating and designing BGI would be better informed if we understood how wellbeing is impacted by:
    - *the scale of BGI;*
    - *different components creating different qualities of BGI, for example inclusion of visible 'wet' features such as ponds or rain gardens, and;*
    - *the diversity of different BGI features within a green space or neighbourhood.*

  By way of illustration, one of our readers highlighted how it would be useful to draw on Ewert and Chang (2019)'s methods of measuring stress markers among visitors to different spaces to support an investigation of the impacts of a semi-natural environment, such as a street with rain gardens.
- There is some ambiguity about how the benefits of access to green space balance against issues of urban and rural isolation. While some studies point to the advantages of greater access to green space as if this were a linear relationship, others suggest that the optimal balance is 'variable' with a combination of green space and urban destinations. We suggest that such factors are also likely to be culturally and infrastructurally specific (e.g. isolation is more intense if you have no access to transport), but further research is required to expand on the nature of these relationships.

To maximise the benefits of BGI, it will be necessary for professionals in the fields of water, public health, and the built environment to work together. We hope that this report encourages them to develop synergies between their respective fields, thus ensuring a form of BGI that promotes health, social, and environmental benefits.

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CONTACT

Dr. Eun Yeong Choe (eychoe1@sheffield.ac.uk)
Department of Landscape Architecture, University of Sheffield

Dr. Anna Kenyon (akenyon10@uclan.ac.uk)
School of Medicine, University of Central Lancashire

Dr. Liz Sharp (l.sharp@sheffield.ac.uk)
Department of Urban Studies and Planning, University of Sheffield