VICTORIA INSTITUTE OF STRATEGIC ECONOMIC STUDIES

Assessing the Economic Value of Green Infrastructure: Literature Review

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Contents

1. Study background, scope and methodology

This project will produce an economic framework to value the benefits of green infrastructure, in order to develop the business case for embarking on a process of adaptation to climate change. Green infrastructure (GI) builds resilience to drought, extreme heat and flood, improves health and liveability, and provides ecosystem services (Roaf et al., 2010, Brugmann, 2012). As much as is feasible, the project is exploring the multiple benefits of green infrastructure in order to develop an understanding of potential returns on investment by adapting urban environments at the local government scale. The ultimate goal of the project is to put investment in green infrastructure at the local government level on a more even footing with investment in grey infrastructure.

A lack of understanding regarding the cost of adaptation and the benefits associated with action is a primary barrier to climate adaptation action. Adaptation is often perceived as costly for local governments with few immediate returns on investment. The issue of who will pay for adaptation activities is also a major barrier. The costs of climate change, particularly at the local level, are uncertain both with respect to timing and magnitude. They range from minor to catastrophic, increasing the valuation difficulties.

We consider that existing Council resources can be repurposed to support the adaptation of our municipalities to a changing climate (Gasper et al., 2011). For example, most Councils have existing annual capital works budgets allocated for traditional infrastructure works that maintain the status quo of our municipalities. Traditional cost benefit and return on investment calculations are used to determine which projects will be undertaken.

For adaptation, we need to expand the way we cost projects to build in long-term benefits (BOM, 2013). Adaptation investment is often deferred to some undetermined future time because 'avoided damages' are assessed as being too low to guarantee a sufficient return. If we improved our understanding of the social and environmental returns associated with adaptive interventions for our municipalities, then we might act sooner.

The traditional view of many intangible benefits is that they cannot be used to justify economic returns on investment – for example the health and wellbeing benefits provided by access to parks and waterways or the ecosystem services provided by trees. Until now, development of stormwater harvesting projects have been justified only through water price savings rather than by a fuller understanding of the benefits they can provide; for example, maintaining the longevity and health of the green infrastructure in the urban landscape, the associated cooling benefit for the local microclimate or support for biodiversity (Elmqvist et al., 2013).

There have been many previous attempts to expand the way we value nature, but very little of this research has been applied, resulting in limited uptake within existing methods and tools. This project aims to develop a foundation that can assist in bridging the gap between policy and practice.

1.1. Planned outputs

- An economic framework that assists costing the intangible benefits associated with green infrastructure adaptations for urban municipalities.

- A series of workshops and seminars.
- A report that will be distributed and used for advocacy purposes.
- A communications strategy to help Council staff engage with Councillors and community.
- A tool that enables local Council asset managers and officers to understand the multiple benefits of green infrastructure projects.

1.2. Key activities

- Develop a plan for the project and appoint tasks to all partners.
- Develop communications and stakeholder engagement strategy.
- Audit data, research and information available.
- Stakeholder meetings and workshops with key agencies.

2. History of urban form

2.1. Urban ancient cities

The first recorded description of urban planning is described in the Epic of Gilgamesh (Dalley, 1989). The streets of many ancient cities were paved and laid out at right angles in a grid pattern, with a hierarchy of streets from major boulevards to residential alleys. For example, archaeological evidence suggests that many Harappan houses (situated in modern day Pakistan) were laid out to protect from noise and enhance residential privacy (Smith, 2005).

2.2. Classical and Medieval Europe

Traditionally, the Greek philosopher Hippodamus (5th century BC) is considered to be the originator of the orthogonal town plan, however, an orthogonal urban layout with more or less square street blocks has been found in earlier civilisations such as Harappa and ancient Egypt (Kemp, 1977).The ancient Romans also employed regular orthogonal structures on which they built their colonies (Higgins, 2009). This design probably was probably heavily influenced by Greek and Hellenic examples, as well as by regularly planned cities built by the Etruscans in Italy. The basic plan consisted of a central forum with city services, surrounded by a compact, rectilinear grid of streets, and surrounded by a wall for defense (Harris, 1989).

Urban development in the early Middle Ages (usually centred around a fortress or a Roman nucleus) occurred like the rings of a tree, whether in an extended village or the center of a larger city. Since the new center was often on high, defensible ground, the city plan took on an organic character, following the irregularities of elevation contours (Bartlett, 1993, Grenville, 1997).

2.3. Enlightenment Europe

Ambitious attempts at remodelling urban forms occurred during this period either to follow the scientific ideas of the age or as a showpiece for national grandeur. Natural disasters were often a catalyst for remodelling and reconstruction. Examples include Lisbon after the 1755 Lisbon earthquake with the construction of large squares and avenues as well as widened streets (Shrady, 2008). Paris was remodelled on a larger scale by Baron Haussmann. This involved demolishing large sections of the mediaeval streets and replacing them with wide boulevards. This remodelling also involved water works, public monuments and public parks (Girouard, 1985).

Barcelona also built an orthogonal pattern of urban design beyond the city walls which were demolished in the 1850s. Each block was built around central gardens which were orientated to maximise sunlight and assist social integration (Busquets, 2005).

In the 19^{th} century the growth of cities of the industrial revolution increased at a much faster rate than in previous centuries with the vast majority of urban design dictated by business concerns. This led to poor quality housing, disease and public health issues as well as almost no open spaces for recreation and fresh air. Crowding in cities such as London was extreme, with one example in St Giles, of 54,000 people living in a few streets (Davin, 1996).

Concurrently, by the 19th century cemeteries in cities such as London accommodated enormous numbers of bodies. For the whole of London, there were only 218 acres of cemeteries with accordingly extremely high densities of bodies. For example, St Martins in the Field at Trafalgar Square had approximately 70,000 bodies in the area approximately the size of two tennis courts (Halliday, 1999, Beach, 2006).

This led to the proposal by John Claudius Loudon for suburban cemeteries on the outskirts of London. Loudon observed that London was built on heavy clay soils which did not drain well which promoted festering and stagnation. Loudon suggested sandy soils where the bodies would in effect become compost and extensive planting of trees and shrubs would absorb the 'miasmas' leaking out of the graves. Loudon designed several cemeteries which were almost identical to parks. Consequently cemeteries became de facto parks where families went on Sunday walks to visit graves as well as have picnics (Wickham, 2007).

The popularity of cemeteries as parks eventually led to the development of parks themselves with the first public municipal park, at Birkenhead in Liverpool, being opened in 1847. Parks already existed at this time; however, they were not parks as they are understood today. Previously parks were private with Regent's Park in London charging an admission fee until 1835. Most of the new industrial cities did not have parks so working people had nowhere to go for recreation and fresh air (Brocklebank, 2003).

An American journalist, Frederick Law Olmsted travelled to the north of England in 1851 where he visited Birkenhead Park. Inspired by this visit, six years later Olmsted designed Central Park in New York (Beveridge and Rocheleau, 1998).

2.4. 20th Century

Urban planning underwent a paradigm shift at the turn of the 20th century. The poor quality housing and disease in industrial cities together with the increasing construction and popularity of public parks generated support for intervention on behalf of the poorer parts of society. Urban planning theories and models were developed to mitigate the impacts of the industrialisation by providing the working population with healthier environments.

The first significant urban planning theorist was Ebenezer Howard with his Garden City Movement in 1898. Howard drew inspiration from planned industrial communities such as Saltaire and Ripley Ville in England which provided a healthy living space for the factory workers (Steuer, 2000, Holroyd, 2000)..

Howard's garden cities were intended to be planned, self-contained communities surrounded by parks like Birkenhead Park. Howard proposed separate areas of residences, industry, and agriculture and consequently introduced the concept of planning zones. Such a garden city would be self-sufficient and when it reached full population, another garden city would be developed nearby connected by rail or road. Howard envisaged a cluster of several garden cities as satellites of a central city of 50,000 people. The influence of the Garden City idea can be clearly seen in Walter Burley-Griffin's design for Canberra (MacMahon, 2001).

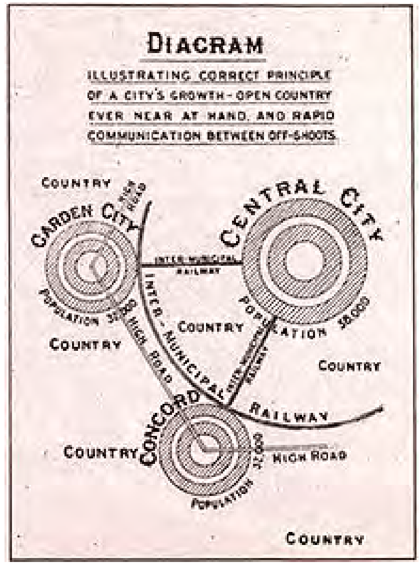

Figure 1: Ebenezer Howard's influential 1902 diagram, illustrating urban growth through garden city "off-shoots" (Howard, 1902)

2.4.1. Modernism

In the 1920s, the ideas of modernism began to influence urban planning. The well-known modernist architect Le Corbusier presented his scheme for a 'Contemporary City' for three million inhabitants in 1922. The centrepiece of this plan was a group of sixty-story cruciform skyscrapers, steel-framed office buildings encased in huge curtain walls of glass. These skyscrapers were set within large, rectangular, park-like green spaces. At the centre was a huge transportation hub that on different levels included depots for buses and trains, as well as highway intersections, and at the top, surprisingly, an airport (Evenson, 1969).

In the 1930s, Le Corbusier expanded and reformulated his ideas on urbanism, eventually publishing them in *The Radiant City* in 1935. The most significant difference between the Contemporary City and the Radiant City is that the latter abandoned the class-based stratification of the former; housing was now assigned according to family size, not economic position. Le Corbusier's theories were sporadically adopted by the builders of public housing in Europe, the United States and Australia as witnessed by high rise public housing complexes built in the 1950s and 60s in Sydney and Melbourne (Marston, 2004).

Another important theorist was Sir Patrick Geddes who took a very different approach to Le Corbusier and emphasised the importance of taking the regional environment into account and the relationship between social issues and town planning. Geddes' ideas were a forerunner to the New Town concepts (Munshi, 2000).

2.4.2. New Towns

Howard's urban planning concepts were only adopted on a large scale after World War II. The *New Towns Act 1946* resulted in many New Towns being constructed in Britain over the following decades. New towns were also built in the United States from the 1960s, as well as in European countries such as France, Germany, Italy and Sweden. However, many New Towns combined aspects of modernism and garden cities. The lack of human scale and soul eventually generated a backlash (Hall and Ward, 1998).

2.5. New Urbanism

By the late 1960s and early 1970s, many planners felt that modernism's clean lines and lack of human scale sapped vitality from the community, blaming them for high crime rates and social problems. Modernist planning fell into decline in the 1970s when the construction of cheap, uniform tower blocks ended in most countries, such as Britain and France. Since then many have been demolished and replaced by other housing types and urban design such as New Urbanism.

Various current movements in urban design seek to create sustainable urban environments with long-lasting structures, buildings and improved liveability for its inhabitants. The most clearly defined form of walkable urbanism is known as the *Charter of New Urbanism*. It is an approach for successfully reducing environmental impacts by altering the built environment to create and preserve smart cities that support sustainable transport (Kunstler, 1998).

Critics of New Urbanism have argued that its environmental aspect is too focused on transport and excessive individual mobility. Also, the emphasis needs to shift from sustainability to resilience, and the spatial scope from the city to the whole urban region. Further criticisms include the fact that climate change already occurring and therefore it is more prudent to focus on the resilience of whole city-regions, retrofitting the existing sprawl for sustainability and self-sufficiency, and investing heavily in 'green infrastructure' (Bogunovich, 2012).

2.6. Urban design, sustainable development and sustainability

Some urban planners argue that modern lifestyles consume too many natural resources, pollute or destroy ecosystems, increase social inequality, create urban heat islands, and accentuating climate change. Consequently, many urban planners advocate sustainable cities such as Wheeler (2004) who suggests sustainable urban development is "development that improves the long-term social and ecological health of cities and towns". His suggestions include the restoration of natural systems, good living environments and social ecology, as well as efficient land use, less automobile use, better access, efficient resource use, less pollution and waste, community participation and involvement, and preservation of local culture and wisdom. These views are increasingly shared amongst planners with an emphasis on minimising the uses of energy, water, and the outputs of waste and pollution.

3. Green infrastructure definitions and concepts

There is no generally agreed definition of green infrastructure (GI), however, most definitions have common themes relating to green and blue spaces in the urban setting and the benefits they provide.

3.1. Definitions

Natural England's Green Infrastructure Guidance defines green infrastructure as follows:

> Green infrastructure is a strategically planned and delivered network comprising the broadest range of high quality green spaces and other environmental features. It should be designed and managed as a multifunctional resource capable of delivering those ecological services and quality of life benefits required by the communities it serves and needed to underpin sustainability. Its design and management should also respect and enhance the character and distinctiveness of an area with regard to habitats and landscape types. Green infrastructure includes established green spaces and new sites and should thread through and surround the built environment and connect the urban area to its wider rural hinterland. Consequently it needs to be delivered at all spatial scales from sub-regional to local neighbourhood levels, accommodating both accessible natural green spaces within local communities and often much larger sites in the urban fringe and wider countryside.
> (Natural England, 2009a p7)

Two other definitions listed below illustrate the common themes of green and blue spaces. The first, proposed by Naumann, McKenna et al (2011) emphasises biodiversity, while the Australian Institute of Landscape Architects in their Green Infrastructure Report, highlight benefits and various types of green infrastructure.

> Green infrastructure is the network of natural and semi-natural areas, features and green spaces in rural and urban, and terrestrial, freshwater, coastal and marine areas, which together enhance ecosystem health and resilience, contribute to biodiversity conservation and benefit human populations through the maintenance and enhancement of ecosystem services. Green infrastructure can be strengthened through strategic and co-ordinated initiatives that focus on maintaining, restoring, improving and connecting existing areas and features, as well as creating new areas and features."(Naumann and McKenna, 2011 p1)

> The term 'green infrastructure' describes the network of natural landscape assets which underpin the economic, socio-cultural and environmental functionality of our cities and towns –i.e., the green spaces and water systems which intersperse, connect and provide vital life support for humans and other species within our urban environments. Individual components of this environmental network are sometimes referred to as 'green infrastructure assets', and these occur across a range of landscape scales—from residential gardens to local parks and housing estates, streetscapes and highway verges, services and communications corridors, waterways and regional recreation areas etc.
> (AILA, 2012 p4)

Overall, GI includes features that are multifunctional, networked and natural, having multiple benefits for society and the environment.

3.2. Green infrastructure approaches

Ely and Pitman (2012) identified three main approaches to implementing green infrastructure in the literature as described below.

1) **Ecosystem services approach (ESS)**. This approach emphasises the services that nature and natural cycles provide to society (Costanza et al., 2014, Millennium Ecosystem Assessment, 2003). These services can be found globally (e.g., carbon cycle), or locally where they can be restored and maintained within urban settings to provide benefits in that setting.
2) **Green Spaces Network approach**. This perspective emphasises the importance of conserving and linking green spaces and nature corridors in cities to improve the functioning of ecosystems. This approach is consistent with the more traditional infrastructure approach in which networks are built in order for a city to function (Benedict and McMahon, 2002).
3) **Green engineering approach**. This viewpoint considers GI to be a subset of traditional engineering infrastructure whereby typical practices have green elements added to them which can provide ecosystem services such as cooling through the installation of green roofs and living walls (Margolis and Robinson, 2007).

3.3. Ecosystem assets and services

The different physical forms of GI are very diverse, however, the main categories are described below (European Commission, 2012, Holbrook, 2009, Oxigen, 2011, Sandstrom, 2002, AECOM, 2010):

- Public parks and gardens, including urban parks, open space reserves, cemeteries and formal gardens.
- Greenways, including river and creek corridors, cycle-ways and routes along major transport (road, rail and tram) corridors.
- Residential and other streets, comprising street verges and associated open space pockets.
- Sports and recreational facilities, including ovals, golf courses, school and other institutional playing fields, and other major parks.
- Private/semi private gardens, including shared spaces around apartment buildings, backyards, balconies, roof gardens and community gardens.
- Green roofs and walls, including roof gardens and living walls.
- Squares and plazas, including both public and private courtyards and forecourts.
- Natural green space, including national parks and nature reserves, wetlands and coastal margins.
- Utility areas, including quarries, airports, and large institutional and manufacturing sites. This category also includes unused land reserved for future use.
- Agricultural and other productive land, including vineyards, market gardens, orchards and farms

Whilst the list above demonstrates GI can take many forms, it also provides many different ecosystem services which the literature has grouped into 3 main areas: social, economic and environmental. These are consistent with the well-known triple bottom line approach. While the list is extensive, additional services are likely to be identified as more research is undertaken (Bolund and Hunhammar, 1999, Mainka et al., 2008, Pataki and Carreiro, 2011).

1) Social
    i) Human health and wellbeing
        (a) Physical
        (b) Social and psychological
        (c) Community
    ii) Cultural
    iii) Visual and aesthetic
2) Environmental
    i) Climatic modification
        (a) Temperature reduction
        (b) Shading
        (c) Evapotranspiration
        (d) Wind speed modification
    ii) Climate change mitigation
        (a) Carbon sequestration and storage
        (b) Avoided emissions (reduced energy use)
    iii) Air quality improvement
        (a) Pollutant removal
        (b) Avoided emissions
    iv) Water cycle modification
        (a) Flow control and flood reduction
        (b) Canopy interception
        (c) Soil infiltration and storage
        (d) Water quality improvement
    v) Soil improvements
        (a) Soil stabilization
        (b) Increased permeability
        (c) Waste decomposition and nutrient cycling
    vi) Biodiversity
        (a) Species diversity
        (b) Habitat and corridors
    vii) Food production
        (a) Productive agricultural land
        (b) Urban agriculture
3) Economic
    i) Commercial vitality
    ii) Increased property values
    iii) Value of ecosystem services

As this shows, the GI literature covers a broad range of assets and services which indicates both its high level of complexity and its considerable potential benefits (Ely and Pitman, 2012).

4. Social benefits

The social benefits include human health and cultural and visual aesthetics. The literature surrounding these areas is described below.

4.1. Wellbeing

There is a large body of research supporting the wellbeing benefits of contact with nature in various forms, with a large proportion of these studies undertaken by researchers in the medical and social science areas (BMZ, 2013). This research has focussed on two aspects of wellbeing: the physical and mental health and outlook of individuals, and the role of social interaction and community building. The literature consistently highlights that both older people and children especially benefit from GI and that human health is greatly benefited by green spaces and walkable green linkages. In addition, patient convalescence in medical institutions as well as healthy childhood development are greatly benefited by GI (Bates and Jones, 2012).

The relationship between landscape and health was found to show two main features:

1. Health-promoting landscapes contribute to healthy lifestyles in terms of physical activity and mental and emotional relaxation.
2. Health-promoting landscapes promote the acquisition of resources for health such as social support, concentration and emotional stability (Bates and Jones, 2012).

The impact on human wellbeing has been explored through three main approaches in the literature, including literature reviews of existing research, epidemiological studies, and surveys.

4.1.1. Literature reviews

Several recent literature reviews examine the relationship between human health and wellbeing and green infrastructure. Pretty (2004) examined research linking nature to mental and physical health, finding a strong association between people having contact with nature through either being in or viewing it, and feeling healthier. Grinde and Patil (2009) investigated whether visual contact with nature was sufficient to improve health, finding that a lack of visual contact was associated with negative health effects. In 2010, Abraham et al. reviewed a large number of studies that investigated the health promoting aspects of nature and landscapes and found:

> Landscapes have the potential to promote mental wellbeing through attention restoration, stress reduction, and the evocation of positive emotions; physical wellbeing through the promotion of physical activity in daily life as well as leisure time and through walkable environments; and social wellbeing through social integration, social engagement and participation, and through social support and security (Abraham and Sommerhalder, 2010 p59).

Lee and Maheswaran (2010) examined studies investigating the health effects of green space. In contrast to other reviews, these authors found only 'weak' evidence for the links between physical and mental health and wellbeing, and urban green space. They found that the quality and accessibility of green space are important variables, rather than the space itself. Other factors such as age, gender, ethnicity and the perception of safety are also important in explaining any link. The review also suggested many of the studies examining the link between health and GI were poorly designed and failed to account for bias, reverse causality and weak associations. The review concluded that:

> …most studies reported findings that generally supported the view that green space has a beneficial health effect. Establishing a causal relationship is difficult, as the relationship is complex. Simplistic urban interventions may therefore fail to address the underlying determinants of urban health that are not remediable by landscape redesign. (Lee and Maheswaran, 2010 p212)

On the other hand, after extensively reviewing the literature on the benefits of GI for health, Ely and Pitman (2012) did not have the same concerns regarding research design validity, but rather concluded the evidence was very strong to support the link between GI and improved wellbeing.

4.1.2. Epidemiological studies

Epidemiological studies that have investigated the links between nature and human health and wellbeing include de Vries (2010), Maas et al. (2006) and Conservation Research Institute (2005). These studies found positive links between green space and health, the strongest correlations being with older people, stay at home mothers and lower socioeconomic groups. Although the specific causal mechanism was not investigated, possibilities discussed included less pollution, greater contact with green space and greater physical activity.

> …the percentage of green space in people's living environment has a positive association with the perceived general health of residents. Green space seems to be more than just a luxury and consequently the development of green space should be allocated a more central position in spatial planning policy. (Maas et al., 2006 p587).

4.1.3. Survey research

A UK study examined which aspects of neighbourhood open space are associated with recreational walking and for commuting by older people. It found that agreeable open space and lack of nuisance were associated with recreational walking, while good paths to reach open space and good facilities in open space were conducive to commuting. The study recommended enhancing these characteristics in urban green spaces to encourage more active lifestyles in older people (Sugiyamaa and Ward-Thompson, 2008).

4.2. Physical health and wellbeing

4.2.1. Links between physical activity and health

The design of urban landscape and green spaces is an extremely important influence on the level of physical activity in daily life (Frumkin et al., 2004, Giles-Corti et al., 2005, Humpel et al., 2004, Powell, 2005, McCormack et al., 2004). For example, design can:

- Increase opportunities and reduce barriers to physical activity.
- Influence travel behaviour, including the levels of walking, cycling, public transport and car travel.
- Increase opportunities for recreational activity, by providing useable open spaces, as well as streets conducive to walking and cycling.

A large body of research has identified a wide range of variables with strong evidence to suggest they promote and encourage physical activity, including:

- Design of bicycle and walking paths for better walkability and cycling (Li et al., 2005).

- Land-use-mix, street connectivity, traffic safety (such as pedestrian friendly zones), and aesthetically appealing landscapes (Titze et al., 2005, Leslie et al., 2005).
- Proximity to a park and safety through the absence of traffic which play an essential role in encouraging physical activity (Booth et al., 2000, Neff et al., 2000, Bell et al., 2008) .
- Forests for recreation and exercise play an important role in terms of outdoor physical activity outside cities, especially where people use forests (Pretty et al., 2005, Wolf, 2004).
- Green landscapes need to be aesthetically appealing to their users (Pretty et al., 2005).
- Access to nearby parks, playgrounds and sport fields so people get extra motivation for regular physical activity when they trust their neighbours and perceive them as active and have (Addy et al., 2004).

However, additional research suggest that the success of physical assets in encouraging activity is influenced by the preferences, needs and ability to access places which themselves vary according to gender, age and ethnic background (Eyler et al., 1998, Payne et al., 2002). Despite this, research has focussed on the two main ways in which GI can be used to promote physical activity which includes access to open space and walkability of streets.

4.2.1.1. Access to and design of open space

Some research has found a connection between physical activity levels and the distance to green spaces (Wendel-Vos et al., 2007, Sallis and Glanz, 2009). Bauman and Bull (2007) found associations between access, perceived safety and aesthetic features of parks and physical activity. Kaczynskl and Henderson (2008) reviewed a large number of studies and also found a positive association between provision of recreational spaces and physical activity.

Other literature suggests that the aesthetic quality of recreational areas is also important, for example, Kent et al. (2011) found that:

> Policies to maintain green and open spaces should embrace increased physical activity, social connectivity and improved mental wellbeing as desired outcomes. With continuing growth of urban populations, policies need to target the acquisition of land for green space and improve the quality of existing green space networks beyond their traditional role as recreational areas (Kent and Thompson, 2011 p16).

4.2.1.2. Recreational and transport walking

Saelens and Handy (2008) examined a large number of reviews of built environment with correlates of walking, differentiating between transportation walking and recreational walking. The authors concluded that:

- There are consistent associations between walking for transportation and residential density, distance to non-residential destinations, and land-use mix.
- For children, factors such as walking to school, as well as proximity, density, and the quality of the pedestrian infrastructure and traffic safety appear to play a role.

Some of the key attributes that encourage ‘practical walking’ or ‘transport walking’ identified in the literature include:

- Perceived and actual safety (Spangler-Murphy et al., 2005, Black and Macinko, 2008).
- The provision of networks that are legible, well-maintained and well lit with footpaths, shade and landscaping (Powell et al., 2007, Saelens and Handy, 2008).

- Aesthetics are also a key consideration (Agrawala et al., 2008).

With respect to recreational walking, the provision of special-purpose walking trails has been shown to potentially encourage walking. Some Australian studies demonstrate that people will use walking trails if they are provided; e.g., Merom et al. (2008).

Southworth (2005) concluded the key characteristics of walkable neighbourhoods are:

- connectivity;
- linkage with other transport modes;
- fine grained land use patterns;
- safety;
- quality of path (attention to details such as width, paving, landscaping and lighting); and
- path context (the path context is visually stimulating to the pedestrian).

4.3. Psychological health and wellbeing

A large body of research has been undertaken to examine the social and psychological benefits of urban nature, trees and green spaces; e.g., Tarran (2006) and Elmendorf (2008). This research has focussed on the following areas:

- deeper psychological attachment of people to nature;
- benefits to human health and wellbeing of contact with nature; and
- role of urban greening in community building.

This is consistent with the research undertaken by Kuo (2003), who suggested regular contact with nature could be a prerequisite for good mental and social health. Her paper concluded:

- People should spend time in green, natural settings to relax and recover the ability to concentrate on challenging tasks.
- Trees should be planted and maintained near homes, schools, work sites and other places where concentration and mental energy were needed most.
- Indoors, time should be spent in places where there is a green view to nature from a window, and desks at work and school should be arranged to provide a green view.
- More green spaces should be created, especially in inner city neighbourhoods.

Other psychological benefits of GI have been investigated by Kuo and her associates at the Landscape and Human Health Laboratory, University of Illinois where the following themes have been explored:

- Green Play Settings Reduce ADHD Symptoms: activities in green settings can reduce children's Attention Deficit-Hyperactivity Disorder symptoms (Kuo et al., 1998).
- Views of Greenery Help Girls Succeed: girls who lived in apartments with greener, more natural views scored better on tests of self-discipline than those living in more barren housing (Faber Taylor and Kuo, 2002).
- Adding Trees Makes Life More Manageable: women who lived in apartment buildings with trees and greenery immediately outside reported greater effectiveness and less procrastination in dealing with their major life issues than those living in barren but otherwise identical buildings (Kuo, 2001) .

- Vegetation May Cut Crime in the Inner City: Far less incidences of crime were reported in apartment buildings with trees and greenery around them compared to similar apartment blocks without greenery (Kuo and Sullivan, 2001).
- Where Trees are Planted, Communities Grow: residential common areas with trees and other greenery help build strong neighbourhoods. Residents of buildings with more trees and grass reported that they knew their neighbours better, socialized with them more often, had stronger feelings of community, and felt safer and better adjusted than did residents of more barren, but otherwise identical, buildings (Kuo et al., 1998).

4.4. Community liveability

The term 'community liveability' covers a wide range of factors. Some of these are intangible benefits which are difficult to quantify, such as cultural or visual and aesthetic values. The topic has not been as extensively researched as the other more easily quantifiable benefits of GI, and often involves qualitative rather than quantitative research methods. Much of this research is focussed on urban trees and less on other aspects of GI.

Some research has found built environment design, incorporating GI, can increase the sense of community by facilitating incidental contact with other people and with green spaces. Urban parks and gardens can enhance social integration if they assist factors such as social contacts, exchange, community building, social networks and mutual trust (Armstrong, 2000, Leyden, 2003). For green spaces to do so, important attributes include being safe, multi-purpose and having aesthetical appeal (Baum and Palmer, 2002, Leyden, 2003) as well as containing large amounts of vegetation (Coley et al., 1997).

Community liveability explores the following categories:

- Cultural values, including community heritage and the deeper symbolic and other values of urban nature.
- The visual and aesthetic role of green infrastructure, including place-making, spatial definition and contributions to the attractiveness of urban streets, neighbourhoods and city centres.
- Urban amenity, including the role of green infrastructure in creating more walkable streets and more liveable cities by enhancing human comfort, safety and enjoyment.

4.4.1. Cultural values

Some studies have suggested that urban trees have developed significant cultural and symbolic value (Konijnendijk, 2008). Dwyer and Schroeder (1991) recommended adopting a broader perspective on urban trees, beyond beauty, shade, cooling and also discuss the psychological ties between people and trees.

4.4.2. Visual and aesthetic values

The aesthetic appeal of urban areas has been found to be strongly influenced by the provision of green space (Tibbatts, 2002). Environmental quality has two main components, the physical, and the more subjective perceived quality of the local environment (Macdonald et al., 2008). Visual and aesthetic values have also been considered to form part of a city's urban amenity in the form of neighbourhood attractiveness (Borst et al., 2008).

4.4.3. Urban amenity

In addition to attractiveness, other factors have been found to be a significant influence on the amenity of urban settings with research exploring a range of areas:

- neighbourhood attractiveness;
- 'people friendly' streets and spaces;
- walkability;
- noise abatement.

4.4.3.1. Neighbourhood attractiveness.

Some studies have shown that poor quality green space can negatively affect local activities and business and undermine an area's image and the confidence of the local population and potential investors. The inverse is also true (Land Use Consultants, 2004).

4.4.3.2. 'People friendly' streets and spaces.

Jacobs investigated the factors that contribute to streets being acknowledged as 'great streets' (Jacobs, 1993), as well as multi-lane boulevards. Her conclusions were that trees in such settings are more than decoration, they are important design elements and given a limited budget, the best value for money investment for a great street would be to plant trees (Jacobs et al., 2002).

4.4.3.3. Walkability.

As discussed above, GI can help neighbourhoods become more walkable, which also increases community spirit due to increased community contact and increased social capital (Jacobs, 1993). Street trees, gardens and parks, have been found to be important aspects in making streets appealing for walking (McPherson, 2003).

4.4.3.4. Noise abatement

Noise from traffic and other sources decreases quality of life in urban areas (Zacharias, 2001). Trees and other vegetation can scatter sound and decrease its intensity (Gidlof-Gunnarsson and Ohrstrom, 2007).

4.5. Benefits to children

Planet Ark commissioned research to investigate the "intellectual, psychological, physical and mental health benefits of contact with nature for children" (Planet Ark, 2012). A review of local and international research in this field found a significant amount of literature stating that "contact with nature during childhood could have a significant role to play in both the prevention and management of certain physical and mental health problems, and in forming environmentally responsible attitudes in future adulthood" (Planet Ark, 2012 p2).

4.5.1. Nature-deficit disorder

Campaigner Richard Louv has been a consistent advocate over many years for increasing the amount of contact and experience children have with nature. In his book *Last Child in the Woods*, Louv suggested the expression Nature-deficit disorder (NDD) to describe the effects on children of estrangement from nature. Louv suggests such a separation from nature can lead to a number of behavioural issues, including diminished use of the senses, attention difficulties and higher rates of physical and emotional illness. Louv suggests sensationalist media coverage and paranoid parents have scared children away from nature, while simultaneously promoting a litigious culture of fear that favours 'safe' regimented sports over imaginative play. At the time of writing, NDD has not been recognised as a medical condition, however, the concept provides a framework to view the issue of children's upbringing and their contact with nature, including GI (Louv, 2005, Louv, 2011). A similar phenomenon has been described by other researchers who have used the term 'nature and culture deprivation' (Brook, 2010).

4.6. Summary

A diverse body of research shows that GI can enhance community liveability of cities and the quality of life in urban areas. This includes factors such as cultural values, aesthetics and urban amenity including the 'walkability' of streets and air quality. Research has focussed on two aspects of wellbeing: the physical and mental health and wellbeing of individuals, and the role of social interaction and community building. In particular, evidence suggests older people and children would especially benefit from additional GI, as well as people recovering from illness.

5. Climatic modification

A large body of research has been undertaken to examine the climatic effect of green infrastructure in urban settings. GI, including trees, green roofs, as well as Water Sensitive Urban Design practices have been found to modify urban climates through:

- urban heat island mitigation;
- reduced energy use and emissions; and
- air pollution interception and mitigation (McPherson et al., 2005).

5.1. Urban heat island mitigation

5.1.1. Temperature reduction

Many studies have established urban microclimates are characterized by significantly higher temperatures, higher wind speeds and lower net rainfall inputs than contiguous rural or natural landscapes (Santamouris, 2013). A significant environmental benefit of GI, especially trees and urban forests is the ameliorating effect on urban microclimates (AILA, 2012). According to Foster et al. (2011) trees improve the climate of cities and planting trees can provide the most cost effective benefit climatically in cities. The climatic benefits provided by trees and urban forests include:

- improving human comfort for street users;
- providing health benefits especially for the aged;
- reducing energy use and carbon emissions; and
- assisting in climate change mitigation and adaptation.

Research indicates that trees and other vegetation can modify urban microclimates and help reduce the Urban Heat Island (UHI) effect through two major natural mechanisms:

1. temperature reduction through shading of urban surfaces from solar radiation, and
2. evapo-transpiration which has a cooling and humidifying effect on the air

Increasing the amount of green space across a city can impact on city temperatures, and estimates have been made of the degree of cooling against different climate scenarios. Modelling in Manchester, UK, suggested that an increase of 10 per cent in green cover could keep maximum surface temperatures in high density residential areas and town centres at or below 1961-1990 levels until the 2080s (Gill et al., 2007). This is illustrated in Figure 2 which shows that with 23 per cent green cover peak surface temperatures are 32°C. Increasing the green cover by 10% for example by increased canopy from street trees reduces peak summer temperatures to 29°C.

Conversely if green cover was reduced by 10%, for example through increased areas of asphalt, the amount of cooling will be reduced and peak surface temperatures rise to 35°C as shown in Figure 2. These estimates were taken in Manchester but are indicative for other cities and urban areas.

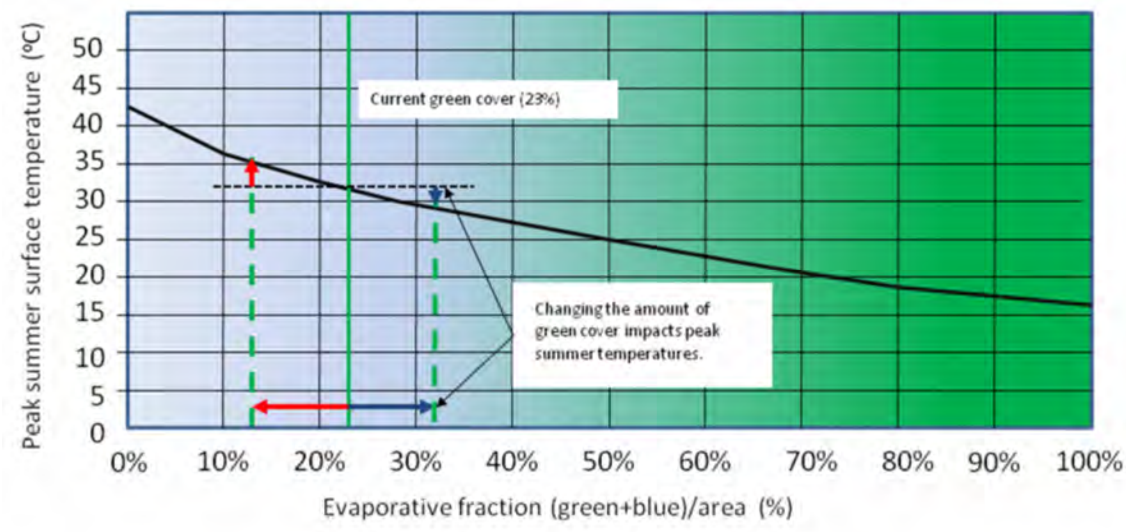

Figure 2: Variation in peak surface temperature as a function of the evaporative fraction (Gill et al., 2007 cited Green Infrastructure Valuation Network, 2010 p22)

Other studies have estimated that trees and other vegetation within building sites reduce temperatures by about 2° when compared to outside non-green space. At larger scales, variation between non-green city centres and vegetated areas has been shown to be as high as 4°C (US EPA, n.d.). Likewise, recent studies done on permeable pavement have found that it reduces or lowers the negative impacts of UHI through its porosity, which serves to insulate the ground better and allow more water evaporation (Kevern et al., 2009). Both of these effects aid in cooling temperatures and mitigating the UHI effect as illustrated in Figure 3

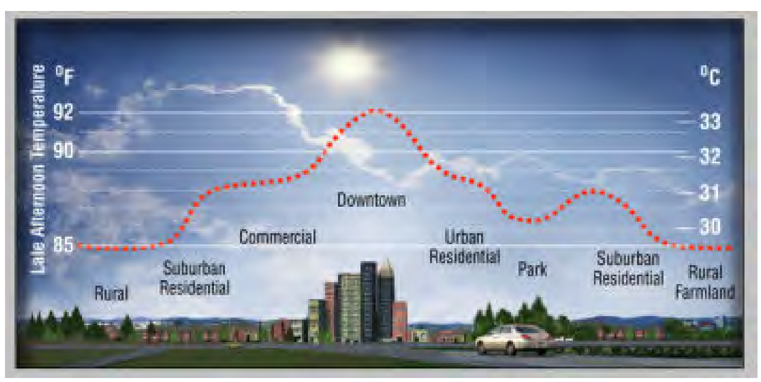

Figure 3: Urban Heat Island Effect (Lawrence Berkeley National Laboratory, 2015b)

This is further demonstrated in Figure 4 with satellite imaging of Atlanta US, using infrared cameras, which demonstrate the link between green cover and temperature.

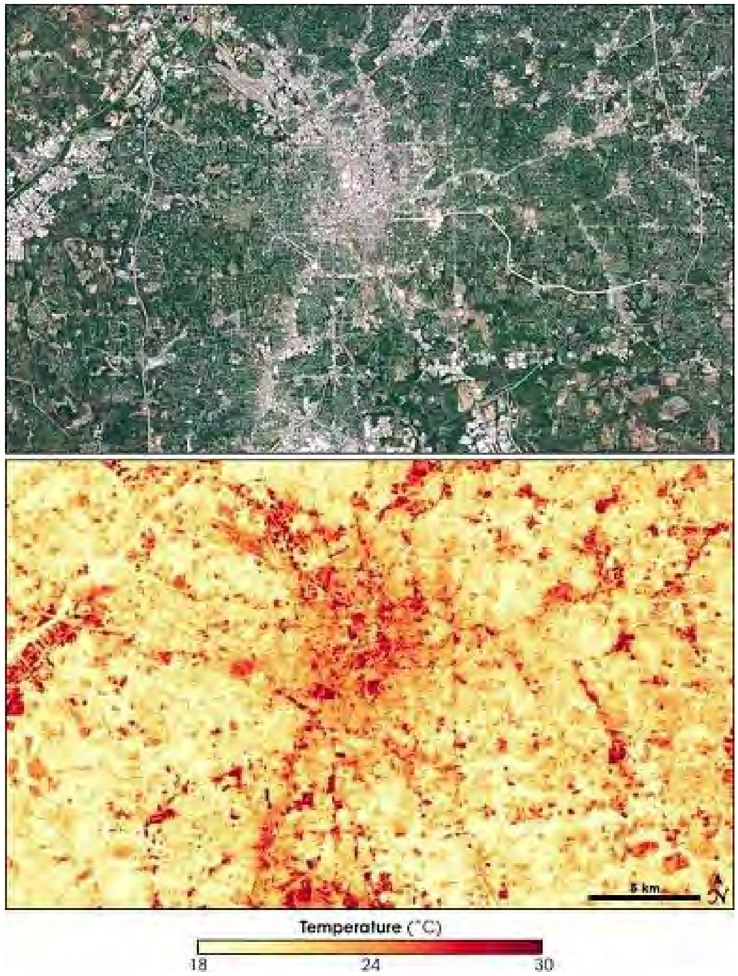

Figure 4: Atlanta Heat Island (Lawrence Berkeley National Laboratory, 2015a)

Research in Melbourne indicates less leafy inner city and western suburbs experience higher temperatures than the more leafy eastern or southern suburbs (Loughnan and Nicholls, 2010). This research suggests that leafy suburbs can be 2–3°C degrees cooler than suburbs with few trees.

A study examining the urban heat island effect in Adelaide measured differences in temperatures across the city. This study indicates a 3–5°C degree difference between the CBD and surrounding Adelaide Park Lands (Ewenz et al., 2012). Another study modelled the potential benefits of vegetation in reducing extreme summer temperatures in the Melbourne CBD under different climate scenarios (Chen, 2012). This study modelled the potential benefits of urban vegetation in mitigating extreme summer temperatures in Melbourne in the mid-21st century relative to 2009. Benefits were calculated using the urban climate model developed by CSIRO (Thatcher and Hurley, 2012). For these calculations, vegetation and building coverage ratios of urban types were based on measurements by Coutts et al. (2007), and building and vegetation ratios were estimated using Google Earth. The average summer daily mean (ASDM) temperature was used as the representative figure and the cooling benefits were predicted to be as follows:

- Suburban areas approximately 0.5°C cooler than the CBD.
- Leafy suburban areas around 0.7°C cooler than the CBD.
- Parklands (such as grassland, shrub-land and sparse forest) or rural area may be around 1.5 to 2°C cooler than the CBD.
- Doubling the CBD vegetation coverage may reduce 0.3°C ASDM temperature.
- 50% green roof coverage of the CBD area may result in a 0.4°C ASDM temperature reduction.
- ASDM temperature reduction of around 0.7°C may be achievable by doubling the CBD vegetation coverage and having 50% green roof coverage in the CBD area.

Bowler et al. (2010) reviewed various studies regarding amelioration of the UHI effect due to green infrastructure and concluded that an urban park would be around 1°C cooler than a surrounding non-green site, while a temperature 2.3°C cooler was reported when compared with a town or city further away. These studies suggest that the cooling benefit of various urban forms and vegetation schemes may be in the range of 0.3°C to 2°C.

5.1.2. Wind speed modification

Trees and other forms of vegetation alter wind patterns by blocking and deflecting or filtering (Miller, 2007). In cities, tall buildings create pathways of high wind velocity (wind tunnels) but the wind tunnel effect can be lessened by trees and other vegetation (Santamouris, 2013). Such reductions can improve human comfort by reducing wind-chill factors in cold weather (Trowbridge and Mundrak, 1988).

5.2. Energy use reduction

Air conditioning is a major consumer of electricity in urban heat islands (Rosenfeld and Akbari, 1998). Numerous studies have found evidence that trees can help reduce energy consumption by reducing the need for air conditioning through reduced air temperatures and by the direct shading of buildings (Akbari et al., 2001, Coutts and J. Beringer, 2007, Donovan and Butry, 2009, Carver et al., 2004). Willraith (2002) found that by applying the effects of tree shade on the eastern and western sides of a Brisbane single storey three-star energy rating home to the Building Energy Rating System model, energy savings of up to 50% per year could be achieved.

5.3. UV radiation

Trees can provide shade from UV radiation and its associated health problems such as skin cancer (Wang et al., 2014, Grant et al., 2002). Shade alone has been shown to reduce overall incidence by significant amounts (Parisi and Turnbull, 2014).

5.4. Climate change

5.4.1. Climate change mitigation

Urban trees can help mitigate climate change by contributing to net reductions in atmospheric CO_2 through:

- Carbon sequestration and storage (sequestering atmospheric carbon from CO_2, and storing it in tree tissues). As approximately 50% of wood by dry weight is comprised of carbon, tree stems and roots act to store up carbon for decades or even centuries. Over the lifetime of a tree, several tons of atmospheric CO_2 can be absorbed (McPherson and Sundquist, 2009).

- Shelter effects, avoided CO_2 emissions due to reduced energy use and the associated reduction in carbon dioxide emissions from fossil-fuel based power plants (Donovan and Butry, 2009). Estimates of tree effects on building energy use have been made, based on field measurements of tree distance and direction to air-conditioned residential buildings (McPherson and Simpson, 2003).

5.4.2. Climate change adaptation

Climate change adaptation strategies include cooling of buildings and houses and cooling of the outdoor surrounds (Santamouris, 2013). The cooling effect of GI and urban trees can help adapt to unavoidable climate change (Thom et al., 2009) and the urban forest can reduce surrounding temperatures (up to 300 m) through shading, evapotranspiration and wind speed modification (Akbari et al., 2001).

5.4.3. Climate change and Water Sensitive Urban Design

Water Sensitive Urban Design (WSUD) can be incorporated into the design of the urban landscape in response to climate change. For example vegetation and water can be incorporated into urban landscapes for their cooling effects (Shaw et al., 2007). The increased use of urban stormwater runoff also has a number of climate change mitigation benefits. For example, urban areas can secure water supply without relying on centralized water systems that can be energy and emission intensive (AILA, 2012, Coutts and J. Beringer, 2007). In Australia, energy use will increase if replacing gravity-fed water (so need to be offset) or by powered by non-fossil fuel energy (Mitchell et al., 2008).

5.5. Summary

Green infrastructure has the potential to ameliorate the effects of climate change in urban environments, thereby increasing resilience and liveability, and reducing energy consumption.

6. Water management

The relationship between urban water management and the health of urban environments has only recently become a focus of researchers; however, this area has developed quickly with numerous issues being investigated (Wong, 2011). Relevant water issues include:

- access to secure and clean water supply;
- clean water environment;
- flood protection;
- urban design strategies; and
- mitigating urban heat.

GI is increasingly being recognised as an alternative to traditional engineering approaches to urban water management through integrated water cycle management and Water Sensitive Urban Design (Water by Design, 2010). The literature has documented the trend away from the traditional engineering approach to urban stormwater with its sole aim being the efficient and quick disposal of stormwater. This approach views stormwater as having no value, being a flood risk and adding nothing to urban amenity (STRATOS, 2009) but has the negative environmental consequences in that local water resources are wasted and receiving waters are polluted, with a commensurate decline in the health of aquatic ecosystems in both local and receiving catchments (Wong, 2011, ECONorthwest, 2007).

The physical form of GI in terms of urban water management includes, but is not limited to, biofiltration systems, stormwater harvesting, passive landscape irrigation, permeable surfaces and green roofs.

6.1. Biofiltration systems

The impact of biofiltration systems is an important component in improving the quality of urban stormwater runoff and protecting aquatic ecosystems (Wong, 2006). Vegetation is the key factor in biofiltration systems because it increases the pollutant-removal function of the soil through a combination of physical, chemical and biological processes (Breen et al., 2004, Somes and Crosby, 2007). Specific tree species can be selected for their relative biofiltration effectiveness in reducing soluble nitrogen and phosphorus in stormwater (Read et al., 2008).

6.2. Stormwater harvesting

Some studies have also investigated stormwater harvesting and its commensurate gradual acceptance as an alternative water source (Wong, 2011). According to Wong, urban stormwater harvesting can increase urban water supply and improve water quality in both riparian environments and receiving waters. Additional benefits from stormwater harvesting include, reduced heat stress, improved balance between high and low flows in water ways and improved amenity of the landscape (Wong, 2011).

6.3. Passive landscape irrigation

Passive irrigation can sustain street trees by capturing stormwater runoff from kerbs and roofs (Stovin et al., 2008). Improved water-sensitive design supports tree growth and survival by increasing stormwater infiltration into the root zone of the tree and recharging the surrounding soil water reservoir and groundwater (Breen et al., 2004).

6.4. Permeable surfaces

Porous surfaces provide benefits by reducing the volume and timing of runoff with a consequential reduction in demand for stormwater infrastructure. Porous paving can also improve the water quality of stormwater runoff by accelerating the biological decomposition of contaminants (Ferguson, 2005). Porous paving can recharge groundwater and help sustain aquifers, cool footpaths and road surfaces, and reduce the urban heat island effect (Thompson and Sorvig, 2008).

6.5. Green roofs

Williams et al. (2010) explored the potential for the increased uptake of green roofs, investigating information gaps and challenges. Green roofs have been categorised into two main types: intensive and extensive. Intensive green roofs can support complex vegetation communities in substrate depths greater than 20 cm. They are often designed as roof gardens for human use and usually require irrigation, maintenance and additional structural reinforcement of the roof (Oberndorfer and Lundholm, 2007). Extensive green roofs have shallow substrate depths less than 20 cm (2–15 cm), require little or no irrigation and are usually planted with slow growing drought-resistant and fire-retardant vegetation (Dunnett and Kingsbury, 2004, Oberndorfer and Lundholm, 2007).

6.5.1. Benefits to building occupants:

Green roofs provide a number of benefits to building occupants, including improved insulation with commensurate reduced need for cooling in summer and heating in winter (Sailor, 2008, Kosareo and Ries, 2007). Green roofs also increase noise abatement (Van Renterghem and Botteldooren, 2009) as well as increase aesthetic values (Maas et al., 2006).

6.5.2. Benefits to the local environment:

Green roofs also provide a wider benefit to the local area through biodiversity and habitat provision (Brenneisen, 2006), reduced stormwater runoff (Carter and Keeler, 2009) and improved roof water runoff quality (Berndtsson et al., 2006).

6.6. Summary

Water management and water sensitive urban design (WSUD) is a key form of green infrastructure, which has many benefits that increase the resilience and network aspect of green infrastructure.

7. Urban ecology

Urban ecology began in the 1950s, but research did not accelerate until the 1990s when it started to be integrated into mainstream urban planning. The concept of urban ecology sees the city as a habitat for people alongside vegetation, wildlife and built form (Niemelä et al., 2011). Biodiversity can be quite high in urban areas, however this may be a form of urban nature comprising species better adapted to life in cities (Alberti, 2008). According to Tarran (2006), the acceleration of urban ecology was due to several reasons including:

- increased levels of urbanism and the need to make urban areas more habitable;
- recognition that disturbed ecosystems are more common than pristine ecosystems and worthy of study;
- increasing concern about human impacts on ecosystems, including biodiversity loss and the impacts of urbanisation on aquatic ecosystems (Kowarik, 2011);
- recognition of an emerging sustainability crisis in cities; and
- recognition that the ecosystem services provided by nature could be applied in urban areas (Gómez-Baggethun and Barton, 2013).

Urban ecology has become a rapidly growing field, (e.g. Platt, 2004, Douglas, 2012, Evans, 2011, Ramalho and Hobbs, 2012, Grimm et al., 2008). Recent books have also been published on urban ecology and green cities (Niemelä et al., 2011, Albino and Dangelico, 2013).

Within the field of urban ecology, the concept of 'biophilic urbanism' or nature-loving cities has been investigated and promoted by several authors (Beatley, 2009, Reeve et al., 2013). According to Beatley (2009) the incorporation of nature into cities has many potential benefits. The following qualities are central to the concept:

- strives to live within its ecological limits;
- is designed to function in ways analogous to nature;
- strives to achieve a circular rather than a linear metabolism;
- strives toward local and regional self-sufficiency;
- facilitates more sustainable lifestyles; and
- emphasises a high quality of neighbourhood and community life (Beatley, 2009).

GI has the potential to address these issues through the provision of a greater number of interconnected green spaces.

7.1. Summary

Natural areas within cities are increasingly being displaced, leading to habitat fragmentation and biodiversity loss. Recent research has shown that urban areas can have quite high levels of biodiversity, increasing the understanding that urban areas and natural areas are not necessarily mutually exclusive. Urban ecology also provides a wide range of benefits to human health and wellbeing.

8. Food production

Urban agriculture and productive agricultural land is a form of green infrastructure that can deliver a wide range of human health and wellbeing benefits that go well beyond providing a secure and healthy food supply (Marsden and Morley, 2014). Urban agriculture commonly takes place on the peri-urban boundary, providing more sustainable food sources for urban areas because of reduced transport to market (Houston, 2005). It also includes community gardens, kitchen gardens and 'edible landscapes'. Community gardens provide significant social and community benefits. Urban agriculture is considered to be part of complementary or alternative food networks that promote more sustainable practices in food production and distribution (Redwood, 2012). These serve as alternatives to current global food production and distribution systems driven by supermarket chains and large-scale primary producers.

8.1. Community food networks

Community Food Networks (CFN) incorporate both commercial and community schemes (Winter, 2003). They also include a diverse range of approaches to food production and distribution. Pearson and Hodgkin (2010) found CFNs provide additional information to consumers including food labelling and food miles. Another aspect of CFNs is an attempt to bring consumers into contact with producers and encouragement of local and seasonal produce (Mason and Knowd, 2010). These networks also include food-sharing schemes in community gardens, as well as giving excess backyard produce to neighbours (Edwards and Mercer, 2010). This phenomenon has not been studied in depth, but could possibly account for up to 5% of food production. In addition, community and kitchen gardens have considerable environmental, social, economic and health benefits (Pearson and Hodgkin, 2010).

8.2. Environmental benefits

8.2.1. Reduced food miles

The distance that food travels from initial production to processing, packaging and finally to consumer has been labelled 'food miles' (Kemp et al., 2010, Schnell, 2013). Due to increasing concern about the environmental impact of food miles, community groups have been formed to encourage the consumption of locally produced food. GI has the potential to contribute to such efforts (Edwards and Mercer, 2010).

8.2.2. Water reuse

Urban agriculture can use waste water from urban development as well as re-using stormwater runoff in the food production process (Barker-Reid et al., 2010). However, such practices require careful consideration to ensure the appropriate crops are grown (Edwards and Mercer, 2010).

8.2.3. Biodiversity

Urban agriculture is made up of a wide range of small producers, which leads to increased biodiversity. This biodiversity includes both spatial diversity and biological diversity (with a variety of ecosystems associated with the different crops grown). Community and private gardens also have a tendency to avoid monocultures and use production methods that are more environmentally sensitive, including heirloom varieties (Goddard et al., 2010).

8.3. Social benefits

The social benefits of growing food close to urban populations include health benefits, education, local economies, stronger producer and consumer links, stronger community networks and maintenance of food security (Pearson and Hodgkin, 2010, Feenstra, 1997).

8.3.1. Health benefits

Urban agriculture has a number of human health benefits including:

- Locally-sourced food can promote a fresher and more seasonal diet as compared with food which has been refrigerated and transported large distance, and can have reduced nutrient content (Feagan, 2007).
- Some studies suggest that if people grow their own food, their diet improves as they reduce consumption of highly processed foods (Dixon et al., 2007).

8.3.2. Food security

Food security has the potential to become a major global issue and some scholars already argue that it is. Urban residents are more susceptible to food security issues than those in rural areas and, while this is more of a concern in developing countries, it may also become an issue in developed countries (Pearson and Hodgkin, 2010). This is especially the case with particular social groups such as the elderly or indigenous populations or where produce is sourced from areas of political instability (Millstone and Lang, 2008).

8.4. Economic benefits

Urban agriculture also has associated economic benefits where personal income may be supplemented from selling produce (Houston, 2005), or reduce food bills (Pearson and Hodgkin, 2010). Some studies suggest that small-scale agriculture is more efficient than large-scale in terms of output per unit of land.

8.5. Summary

Food production in and around cities is considered to be one component of green infrastructure, with different forms including, community gardens, productive street verges, backyards and school vegetable gardens. Urban food production has many benefits including: increased sense of community, improved healthy food options, improved mental and physical wellbeing and reduction in food miles.

9. Green infrastructure economic benefits and valuation tools

Due to the multifunctional nature of the many different forms of green infrastructure, measuring the benefits they provide has proven difficult to quantify as different functions require different forms of measurement (EC, 2012). Nevertheless numerous approaches have been developed in recent decades to place a monetary value on the functions performed by GI, the justification for such an approach being monetary values are easily understood by stakeholders and the community as well as being a unit of measurement that can be used across a range of factors. This overcomes the issue of incommensurability, and hence these value may be simply incorporated into decision making processes (Vandermeulen et al., 2011, USEPA, 2014). However, some of the values provided by ecosystem services remain difficult to quantify in monetary units. This is especially the case with cultural and aesthetic values. It also appears that evidence of the benefits of GI are less easy to quantify, and more variable than costs, and are often expressed in qualitative terms (Naumann and McKenna, 2011).

9.1. Total Economic Value approach

The concept of Total Economic Value (TEV) is a widely used framework for examining the complete value of ecosystems (Pearce and Warford, 2003, BOM, 2013). As illustrated in Figure 5. Total Economic Value (TEV) aims to capture the full value of different natural resources. TEV recognises a range of values, including the following.

1) Use values
    i) Direct use values: direct benefits from the use of primary services such as the provision of food and water.
    ii) Indirect use values: benefits from secondary services such as air and climate regulation.
    iii) Option values: benefits of preserving the option for future use.
2) Non-use values
    i) Existence value: value of the existence of a service without its actual use.

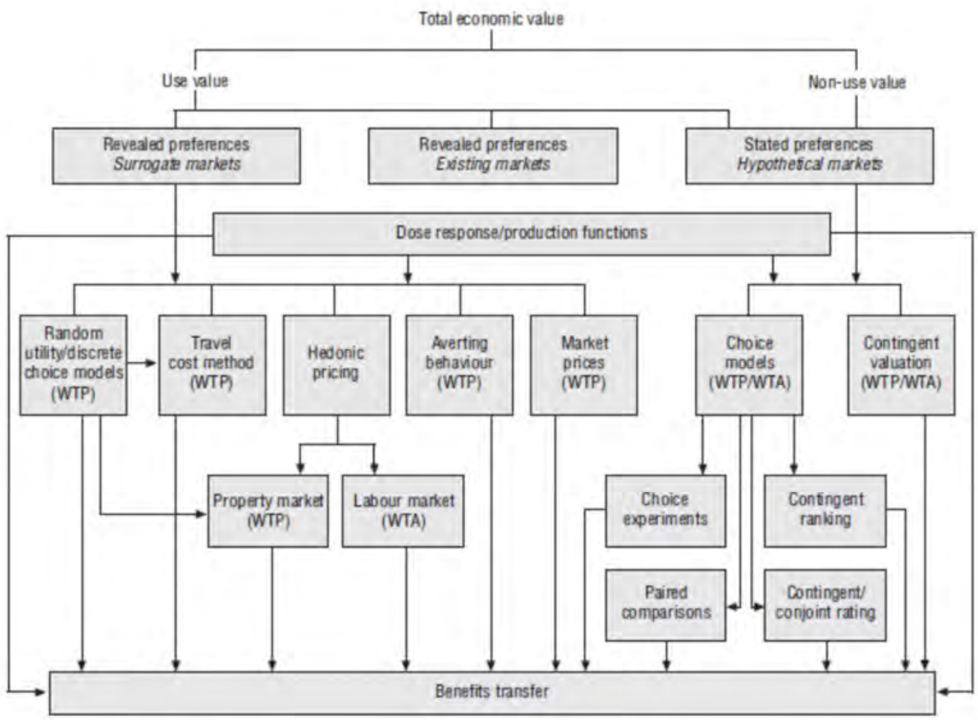

Figure 5: Total Economic Value (Pearce et al., 2006 p88)

9.1. Valuation approach

Ascertaining the economic values of GI is undertaken through primary research or value transfer. Primary research requires qualitative data, quantitative data and economic data while value transfer or benefits transfer relies upon applying an existing research approach to another setting (Vandermeulen et al., 2011).

9.1.1. Primary research

Qualitative evidence such as expert judgment, anecdotal evidence or qualitative social research is used to demonstrate the benefits provided by ecosystem services. Quantitative evidence such as changes in air quality, ambient temperature, noise levels, bird counts, numbers of visitors to a new park, number of businesses relocating to an area and number of people they employ can be used to establish the economic value of ecosystem services. Economic evidence such as visitor spending, reduction in medical expenditure due to improved health, income from new businesses, individual's willingness to pay or accept compensation for the changes in ecosystem services (Wise et al., 2010).

9.1.2. Benefit transfer

Where primary research is not possible or feasible, 'benefit transfer' can be employed, which is a process for selecting value evidence from existing literature and adapting it to the characteristics of ecosystems and services of interest. The benefits transfer method adapts information from valuation studies undertaken elsewhere and applies them to a new scenario (Natural England, 2013). A more sophisticated approach is called the transfer function approach where the results from one study are adapted and modified to make it more suitable to another situation – for example making adjustments for location or socio-economic factors. However, the validity of the benefit transfer approach depends upon the rigour of the original study upon which it is based (ECOTEC, 2008) and the suitability of the target area for the transfer.

Values can be calculated for individual services or services of the ecosystem as a whole (McConnell and Walls, 2005).

9.1.3. Individual services value

Individual services can be valued separately and the values totalled. This is an appropriate approach if services can be identified individually and change differently. As ecosystems produce a complex and inter-related set of services, separate analysis of each service needs to be undertaken carefully to avoid double counting or indeed underestimating the synergies between services (Natural England, 2009b).

9.1.4. Whole ecosystem value

The whole-of-ecosystem value approach involves Identifying and quantifying all the services provided by an ecosystem and valuing them as a whole. This is useful when, say, a new green infrastructure asset is likely to provide all the services associated with it, or when an improvement in an existing asset will improve the quality of all the services it provides. This whole 'bundle' approach to valuing ecosystems cannot necessarily capture all the services provided at different levels; however, it is able to generate indicative values (Ten Brink et al., 2011).

9.2. Double counting and displacement

Double-counting involves valuing benefits twice (or more) in a single valuation. For example, if recreational benefits of a park are valued, it may be double-counting if the landscape is also valued. Nevertheless, there is an argument that the landscape may be valued for visual amenity by onlookers, as well as for recreation by visitors and the effect on neighbouring property prices. The difficulty in establishing an economic value is illustrated by the necessity to often employ multiple tools to value different benefits of a green infrastructure feature and incorporate any displacement into the valuation process (DEFRA, 2007). Displacement is the extent to which any increase in activity is not additional, but has simply moved from one area to another (DEFRA, 2007). Double-counting and displacement are two common errors in economic valuation and consequently, a considerable amount of literature explores the issue (Natural England, 2009b).

9.3. Valuation tools

The main methods for establishing intangible values within Total Economic Value are described below:

9.3.1. Contingent valuation

Contingent valuation (CV) is a survey method which aims to capture individual preferences for a change in the provision of a good or service through assessing their willingness to pay (WTP) or willingness to accept (WTA) compensation. The changes in provision of the good or service are hypothetical and consequently such surveys must be carefully constructed to minimise potential problems of bias (Whittington and Pagiola, 2012). CV has been used to establish option and existence values in areas such as protecting biodiversity. CV is a stated preference technique; i.e., the preferences of the individual are explicitly stated. A large number of studies have utilised the CV approach in order to ascertain green infrastructure value (Breffle et al., 1998, Carson, 2012)

9.3.2. Hedonic pricing

Hedonic pricing has been developed in the literature whereby the price of a marketed good is related to a non-marketed good with the most common application being property and labour (Brander and Koetse, 2011). The property value (PV) approach has been often used to calculate the effect trees and green spaces have on property prices (e.g., Tyrvainen, 2000). This approach involves observing differences in the values of property between locations, and isolating the effect of the particular environmental quality being studied on those values (Donovan and Butry, 2011). Hedonic pricing is a revealed preference approach as opposed to stated preference where individual preferences are not explicitly stated but rather revealed through other behaviours. Studies that have utilised this approach include Ecosystems Valuation (2012) and Waltert and Schläpfer (2010).

9.3.3. Travel cost method

Another revealed preference method developed in the literature is the travel cost method. This method utilises the cost of getting to a site as the value attributed to the good or service. Consequently, the value people place on an environmental space is inferred from the time and cost they incur in travelling to it. This approach is often applied to national or state parks with free or minimal admission charges where it is argued that the cost of travel is a good proxy for the entry price (Veisten et al., 2012). The travel cost method is also a revealed preference approach. Numerous studies have used the travel cost method to ascertain values such as (SFFA, 2006, Lindsey et al., 2004)

9.3.4. Effect on production

Effect on production measures the effect a particular project may have on the output, cost or profitability of producers through its effect on their environment and the welfare of consumers. For example the effect may be reservoirs creating new fisheries, or bee keepers benefiting neighbouring gardens. This approach is often used to examine the negative effects of a potential investment. The effect on production approach is not employed in as many studies as the previous methods, nevertheless, studies such as Mallawaarachchi et al. (2006) utilise this approach.

9.3.5. Preventative expenditure

The preventative expenditure method is commonly used to compare the benefits of taking a green infrastructure approach as opposed to traditional engineering solutions such as flood risk from stormwater. Preventative expenditure is commonly employed informally in industry but has not had as much attention from researchers. However, one study showed that when water saving benefits and cost prevention were included, green infrastructure initiatives are better value (Vesely et al., 2005).

9.3.6. Specific values

Specific values refer to monetary values being allocated to particular goods or services, usually to account for an external cost. A commonly used specific value is the 'shadow price of carbon'. This value is a shadow price set by government and is to be applied when conducting public sector cost benefit analyses (DEFRA, 2007). Shadow prices for carbon in the UK, USA and World Bank are based on estimates of the social cost of carbon, the marginal damage per tonne of CO_2 emitted (Interagency Working Group on Social Cost of Carbon, 2013, ESMAP, 1999, DEFRA, 2007). Shadow prices are used in practice on Melbourne's waterways for nutrient removal and stormwater interception.

9.4. Commercial and property values

Research based upon surveys by Wolf (2005) showed a preference for shopping areas with trees, which also influenced customer perceptions of businesses and their products. Survey respondents indicated they would travel further, visit more often and spend more (BiscoWerner, 1996).

Trees have also been shown to affect property prices. In a variety of studies the presence of trees has been found to increase the selling price of a residential unit from 1.9% (Dombrow et al., 2000) to 3–5% (Anderson and Cordell, 1988) to 9% in a study examining Philadelphia's rejuvenated suburbs (Wachter and Gillen, 2006). In addition, commercial areas with green spaces and trees in excellent condition, were correlated with significant increases in home values (Plant, 2006). Donovan and Butry (2010) used hedonic price modelling to estimate the effects of street trees on the sales price and the time-on-market (TOM) of houses in Portland, Oregon. They found on average, street trees add US$8870 to sales price and reduce TOM by 1.7 days. Sander et al. (2010) used hedonic property price modelling to estimate the value of urban tree cover, concluding that neighbourhood tree cover provides significant positive effects.

The proximity of open green space is also correlated with property prices. A review of over 60 studies on the impact open spaces have on residential property values showed an increase in sale prices; the size of the increase depended upon the area of open space, its proximity to housing, the type of open space and the method of analysis. The review found increases in property values approximately 200 metres from the park (McConnell and Walls, 2005, Miller, 2001). The size of parks is also a factor, with larger parks having a larger impact on prices (Bolitzer and Netusil, 2000) and large natural forest areas have an even larger effect on nearby property values than smaller urban parks, playgrounds and golf courses (Lutzenhiser and Netusil, 2001).

Another study attempted to place a value on non-marketable land by developing a model using proximity to factors such as urban areas as well as proximity to the sea and the socio-economic state (Lavee and Baniad, 2013).Results suggested such land value was much higher than traditional valuing techniques would suggest.

Research into this field dates back to the 1850s where landscape architect Frederick Law Olmsted conducted a study of how parks influence property values. From 1856 to 1873 Olmsted documented the value of property immediately adjacent to Central Park in order to justify the $13 million spent on its creation. Olmsted found that over the 17-year period there was a $209 million increase in the value of the property affected by the park (Anderson and West, 2006). Another component of Olmstead's study was increased tax revenue as a result of the park. The annual excess of tax increase from the property value was $4 million more than the increase in annual debt payments for the land and improvement. It was concluded that New York City actually made a profit from building Central Park.

9.5. Ecosystem services

Green infrastructure valuation methods and economic benefits of a range of green infrastructure assets are summarised in Wise et al. (2010) and (Millennium Ecosystem Assessment, 2003). The global economic value of ecosystem services has been increasing over time with greater understanding of its benefits (de Groot et al., 2012). The economic benefits of GI are listed below.

1) Urban forests:
    i) Reduced demand for energy for cooling and heating
    ii) Reduced negative health impacts from extreme heat events

iii) Air quality improvements
iv) CO_2 reductions (avoided and sequestered)

2) Permeable pavements:
   i) increased stormwater retention
   ii) reducing energy use, air pollution and greenhouse gas emissions
   iii) reduced ground conductivity
   iv) reducing air pollution
   v) reducing salt use
   vi) reduced noise pollution
3) Water harvesting:
   i) reduced potable water use
   ii) increasing available water supply
   iii) improving plant life
   iv) public education
4) Green roofs:
   i) stormwater retention
   ii) reduced building energy use
   iii) carbon sequestration
   iv) greenhouse gas emissions reductions
   v) urban heat island mitigation
   vi) improved air quality
   vii) noise reduction
   viii) biodiversity and habitat
   ix) longer roof life
5) Infiltration practices: rain gardens, bio-swales and constructed wetlands:
   i) rain gardens
   ii) bio-swales
   iii) constructed wetlands
   iv) stormwater retention and pollutant removal
   v) uncertainties and other considerations

Some of these are described in more detail below.

9.6. Urban forest value

The monetary value of trees has been explored by many authors (e.g., McPherson et al., 1997, McPherson, 2005, BiscoWerner, 1996, Clark and Matheney, 2009, Nowak et al., 2002, Sander et al., 2010). Such methods have developed formulas which have become widely accepted, with the Thyer and the Burnley methods being most commonly used in Australia (Moore, 2000). i-Tree Eco also includes the amenity or compensatory values of the urban forest based on the CTLA (Council of Tree and Landscape Appraisers) methodology (Nowak et al., 2002). The CTLA formula is summarised below:

Tree value = base value × cross section area × species class × condition class × location class

- Urban forests and trees have structural and functional values (i.e. replacement cost and values of the functional service they provide) (i-Tree, 2010). The structural value of an urban forest will usually increase with a rise in the quantity and size of healthy trees (Nowak et al., 2002).

Functional values also increase with increased number and size of healthy trees and are often valued in millions of dollars per annum on a municipal wide scale. For example the following structural and functional values were calculated for the urban forest in Washington:

- Structural values:
  - Structural value: $399 billion
  - Carbon storage: $123 million
- Annual functional values:
  - Carbon sequestration: $393 thousand
  - Pollution removal: $230 million
  - Lower energy costs and carbon emission reductions: $358 million (Nowak et al., 2002)

Numerous studies have attempted to quantify the economic benefits generated by an individual tree, or the collective value of the ecosystem services delivered by an urban forest (Coder, 1996, MacDonald, 1996, Hewett, 2002). The benefits they have attempted to capture include air pollution reduction, storm water runoff reduction, direct carbon capture, indirect emission reduction from the cooling effects of tree shade, and higher sales prices of houses in leafy streets. For example, a study of stormwater management costs showed that urban forest provided stormwater management benefits valued at US$15.4 million in Milwaukee, Wisconsin, and US$122 million in Austin, Texas, valued through avoided additional retention, detention and treatment capacity (MacDonald, 1996).

Research in Canberra suggests the trees there have an annual economic value of more than $23 million through energy reduction, pollution and stormwater reductions (Killy et al., 2008). Another study attempted to calculate the gross annual benefits of individual trees in Adelaide (Killicoat et al., 2002) with a typical four year-old tree estimated to generate a gross annual benefit of approximately $171 per tree. This was comprised of energy savings due to reduced air conditioning costs, air quality improvements, stormwater management, and other benefits.

Large, mature trees are considered to deliver more significant benefits than smaller trees due to the greater shade, water and air quality, cooling effects and sequestering carbon (Livesley, 2010). Consequently, some research suggests large tree species should be planted, and trees should be allowed to grow to maturity to maximize their benefits (Geiger et al., 2004, McPherson, 2005). In addition, when compared to a shade provided by cloth, the shade provided by trees combined with grass is significantly more effective at lowering temperatures (Shashua-Bar et al., 2009).

9.6.1. The i-Tree tool

Modelling to calculate the value of trees and urban forests has become increasingly common in the last decade. The United States Department of Agriculture (USDA) Forest Service developed online tools which allow the estimation of economic benefits generated by their urban forests (USDA Forest Service, 2005). i-Tree STRATUM (Street Tree Resource Analysis Tool for Urban Forest Managers) is an online tree valuation model designed to quantify the environmental benefits of their urban forest and compare these with management costs (McPherson et al., 2005). The model enables the quantification of energy conservation, air quality improvement, CO_2 reduction, stormwater control, and property value increases. Cities such as New York, Los Angeles, Portland, Sacramento and Baltimore have used this model to justify investments in major urban greening projects (Maco and McPherson, 2003).

9.6.1.1. i-Tree in Australia

As the i-Tree model was developed for use in the United States, it was subsequently adapted for Australian conditions and flora. i-Tree STRATUM was trialled by the University of Melbourne in a study of two Melbourne city councils: the central City of Melbourne, and the City of Hume (NGIA, 2011). The study found the environmental benefits (including carbon sequestration, water retention, energy saving, aesthetics and air pollution removal) of the street trees in two suburbs of the City of Melbourne provides ecosystem services equivalent to approximately $1 million dollars, and approximately $1.5 million dollars in the City of Hume. Individually, trees in the City of Melbourne provide ecosystem services valued at $163 per tree, and in Hume at $89 per tree. An Australia-compatible version of the i-Tree Eco application was introduced at the 2011 ISA Conference in Parramatta, Australia (ENSPEC, 2012).

9.7. Green infrastructure and regional economics

Vandermeulen et al. (2011) developed a model to illustrate the regional benefits of investing in green infrastructure. They utilised the Total Economic Value (TEV) concept. In addition, to use and non-use values they incorporate investment value which is the value generated by the production of the goods, in this case the creation of green infrastructure. This may include the costs of purchasing land, the costs of designing and constructing the green infrastructure or the income generated through the implementation and use of the green infrastructure. Vandermeulen et al. (2011) suggest that economic evaluation of green infrastructure should occur at two levels: the project level and the indirect value for the development of the region. This is shown diagrammatically in Figure 6.

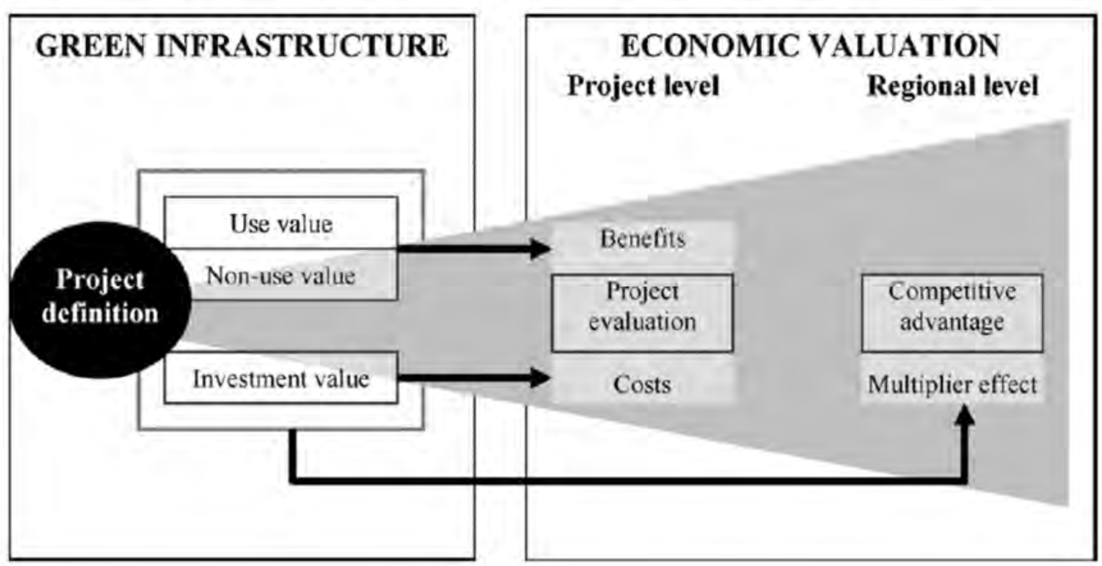

Figure 6: Project and Regional Value Framework (Vandermeulen et al., 2011 p199)

While the value of a green infrastructure project is done at a project level using the techniques discussed above, such as contingent valuation, hedonic pricing, and travel cost method, the regional effect is examined using multiplier analysis. Multiplier analysis incorporates input-output relationships with one industry needing inputs from another and estimates the wider benefits of project spending within the regional economy.

The case study used by Vandermeulen et al. (2011) centred on a separated bicycle road in Bruges, Belgium with costs and benefits including project investment costs, regional investment benefit, project maintenance costs, regional labour benefits, regional costs of land use change, avoiding costs by not commuting by car, project and regional recreational benefits, health effects from cycling, environmental effects and improved traffic safety. They found that up to a discount rate of 6.2% the project remained profitable. However, they caution that not all values were captured, such as stress reduction, emotional benefits or adverse impacts on the automobile industry.

The impact of GI on employment can also be significant. Edwards et al. (2013) found evidence that job creation per million US$ spent on nature conservation and restoration is considerably higher than for traditional industries including coal, gas, and nuclear energy generation.

9.8. Summary

A substantial body of literature has been developed to establish economic values for goods and services that fall outside conventional economic frameworks. One such approach is the Total Economic Value method of measuring capture of all ecosystem services; however, the benefits still remain difficult to quantify. Various tools have been developed to quantify these benefits including contingent valuation, hedonic pricing and travel cost methods. Such methods have been used to establish the impact GI has on commercial and property values. An important advance in the past decade has been the development of the i-Tree modelling tool to quantify the benefits of trees and urban forests.

10. Green infrastructure, sustainable development and Gross Domestic Product

Since the development of national accounts, GDP per capita has been widely adopted as a comprehensive and objective measure of economic wellbeing. The first system of national accounts, initially devised by Kuznets and formalised in 1953 (United Nations, 1953) provided a measure of gross national product (GNP) as the sum of all consumption, investment, and government spending by a country's economy, whether within the national territory or not (Stanton, 2007). Subsequently, the measure of economic production was modified to include trade transactions, exports less imports and was known as gross domestic product (GDP), the now common measure of economic growth.

However, subsequent criticisms, including those by economists, have reflected on the narrowness and inadequacies of this measure. In proposing the development of a broader-based human development index (HDI) in 1990 the UNDP observed that:

> People often value achievements that do not show up at all, or not immediately, in higher measured income or growth figures: better nutrition and health services, greater access to knowledge, more secure livelihoods, better working conditions, security against crime and physical violence, satisfying leisure hours, and a sense of participating in the economic, cultural and political activities of their communities. (UNDP, 1990 p9)

In addition, GDP measures have failed to deal with issues of sustainability. The Club of Rome's report, *The Limits to Growth* (Meadows et al., 1972), presented a Malthusian conflict between continued economic growth and limited resources. Despite many criticisms, a recent analysis suggests the world remains on this path (Turner and CSIRO Sustainable Ecosystems., 2008).

In 1987, the UN World Commission on Environment and Development, published *Our Common Future* (Brundtland, 1987), which defined sustainable development as one that "meets the needs of the present without compromising the ability of future generations to meet their needs" and broadened the scope of sustainability to include fundamental needs such as nutrition, education and health. The 1992 UN Summit in Rio de Janeiro brought the notion of Sustainable Development into the policy debate (Agenda 21), with positive consequences for the promotion of sustainable development indicators. The more recent developments have attempted to address these problems (Afsa et al., 2009).

The Commission on the Measurement of Economic Performance and Social Progress (CMEPSP) consisting of Joseph Stiglitz, Amartya Sen and Jean Paul Fitoussi, was commissioned by the French President to identify the limits of GDP as an indicator of economic performance and social progress including measurement problems and what additional information might be required to develop more meaningful indicators (Stiglitz et al., 2009). The report expands the set of indicators used to measure economic performance and social progress.

The shortcomings of GDP as a measure are noted, including many that have been previously identified (Easterlin, 2010). These include:

- the technical difficulties of measuring the value of services, such as health and education, which tend to be measured by the value of their inputs rather than outputs, leading to underestimating quality and therefore productivity improvements;
- the exclusion of many household activities that are productive in an economic sense;

- the problems concerning the measurement of non-market output, such as some government services, and its aggregation with market production;
- the fact that GDP is an aggregate and excludes income distribution effects; and
- the fact that it is only a measure of flows and does not take into account changes in stocks.

Of particular relevance to this review is the focus in the report on broader quality of life measures and attempts to measure sustainability.

The report addresses the question as to whether wellbeing can be sustained across generations. It adopts a wealth or ‘stock’ based approach to environmental sustainability and explores whether current consumption levels will so diminish the stock of resources (in the broadest sense) to cause a decline in future consumption levels. While the concept of resources are broadly defined, they relate largely to the natural environment, land, forests, CO_2 emissions, etc., and the indicators selected designed to measure their depletion and degradation.

The UNECE/OECD/Eurostat working group on sustainability measurement (UNECE, 2014) further advances this work by distinguishing between a conceptual and thematic categorization. The conceptual categorisation proposes a set of indicators that differentiates between the ‘here and now’, ‘later’ and ‘elsewhere’. The first captures current human wellbeing, the ‘later’ the stock of comprehensive capital (economic, natural, human and social) on which future wellbeing is based, and the ‘elsewhere’ deals with the trans-boundary issues in which the distribution of development, in particular the impact of countries on one another, is taken in account.

The framework develops indicators across twenty themes, including economic issues, such as income and employment, health, education and a range of environmental quality measures. While the framework is comprehensive, devising the indicators remains work in progress in some of the most difficult areas. The eco system accounts are being prepared for a subsequent volume with concepts such as ecosystem services still regarded as experimental.

The report also cautions against attempting to monetize all capital measures due in part to the arbitrary nature of many of the assumptions necessary, such as using market prices when these are not appropriate, the level of substitutability between various forms of capital, the value of future discounted income flows when the appropriate discount rate is so uncertain and the unknown profile of continuing technical progress. Nonetheless, this report prepared by a task force of leading statisticians drawn from around the world, indicates progress in the transition of sustainability measures from the academic domain to their inclusion in official statistics.

These developments are important with respect to green infrastructure as the benefits associated with investing in GI improve wellbeing and the stock of comprehensive capital, namely economic, natural, human and social. As a consequence, it would appear GI has a role to play in facilitating sustainable development and the inclusion of indicators in official statistics may be a further driver in the uptake of GI due to the prominence of such statistics in the public domain.

11. Green infrastructure and resilience

Building resilience is a growing aspect of climate change policy and planning, featuring in both the state Adaptation Plan (Department of Sustainability and Environment, 2013) and State Emergency White Paper (Department of Premier and Cabinet, 2012). Resilience has also become a key focus of organisations such as Economic Development Australia, who see it as a core need for future industry and business (Young and Jones, 2013).

Understanding when and where changing risks may lead to critical thresholds being exceeded is an essential requirement for managing and maintaining resilience. Exceeding a critical threshold such as a loss of operations, prohibitive input costs or specified level of accrued financial, can result in a loss of resilience. It is particularly important to be able to identify the signals that precede these thresholds and take action before the threshold is reached (Hunt, 2013).

Resilience means different things to different people, having no commonly accepted definition, and making it a difficult concept to put into operation. A recent definition adopted by the Arctic Council is "The capacity of a social-ecological system (or organisation) to cope with a hazardous event or disturbance, responding or reorganizing in ways that maintain its essential function, identity, and structure, while also maintaining the capacity for adaptation, learning, and transformation" (Arctic Council, 2013).

Further definitions suggest resilience is the capacity to change in order to maintain the same identity (Tyler and Moench, 2012). Resilience has also been examined as an outcome of social contracts that underpin governance by O'Brien et al. (2009). They explore use examples from Norway, New Zealand, and Canada to suggest the concept of resilience does fall within existing social contract structures. This leads to the conclusion that new arrangements may be required to underpin resilience goals with respect to climate change.

For urban areas, Leichenko (2011) identified four types of urban resilience studies: (1) urban ecological resilience, (2) urban hazards and disaster risk reduction, (3) resilience of urban and regional economies, and (4) urban governance and institutions. The first two types are directly relevant to green infrastructure. Leichenko suggests that while there is not a consensus within the literature as how to define and measure resilience there is general agreement that: (1) it is necessary for cities to become resilient to a wide range of shocks and stresses arising from climate change; and (2) efforts to increase climate change resilience must go hand in hand with attempts to encourage urban development and sustainability.

The urban ecological resilience literature relates to the concept of green infrastructure and draws and extends upon traditional notions of ecosystems resilience (Andersson, 2006, Folke, 2006, Berkes, 2007). Literature focussing on from an early focus on urban-based ecosystems (Alberti et al., 2003) to the analysis of urban coupled human–environment systems (Liu et al., 2007) to examination of cities and urban networks as complex adaptive systems (Resilience Alliance, 2007). All of which examine the role of green infrastructure in these urban settings.

The urban hazards and disaster risk reduction literature concentrates on increasing the adaptive capacity of cities, infrastructure systems, and communities to quickly and effectively recover from both natural and human-made hazards. Climate change is regarded as one of many threats, including terrorism, for which urban areas must build resilience (Coaffee, 2008, Coaffee and Rogers, 2008). Recent work in this area includes efforts to: quantify economic resilience to hazards (Rose, 2007); evaluate resilience of infrastructure systems and urban built environments (McDaniels et al., 2008, Allenby and Fink, 2005).

During the 21st century, much of the infrastructure of the developed world will need to be replaced or rebuilt, and even more infrastructure will be needed to service the rapidly expanding cities of the developing world (Ahern, 2011). This represents an opportunity to reshape the process of urbanization towards a more sustainable and resilient form. Ahern (2011) suggests green infrastructure is a key concept in order to build resilience capacity. He identifies a need to know how the knowledge of nature-society interactions within both science and society can be used to build resilience capacity and to provide a pathway for society to follow are more sustainable course (Kates et al., 2001). As such, solutions for sustainability and resilience are more likely to evolve from inter- and trans-disciplinary research and project-based collaborations involving an increasing number of overlapping and complimentary disciplines.

Boyd et al. (2008) promote resilience as a way of guiding future urbanization that would be better 'climatized'. The Asian Cities Climate Change Resilience Network is applying a resilience planning framework, with attention given to the role of agents and institutions (Tyler and Moench, 2012).

12. Conclusions and next steps

While the literature reviewed in this paper comes from many different fields and has been developed in many different ways, both primary and secondary, it provides compelling evidence for the many benefits of green infrastructure including physical and mental health, community, economic, climate modification, water management, urban ecology and food production benefits.

While many tools have been developed to evaluate these benefits in the literature, further research and application is justified in order for these economic values to become accepted within conventional economic analysis.

This paper provides the information required to support the development of an economic framework, which is discussed in a companion paper on the economics of green infrastructure. The framework itself will be developed in the first half of 2015.

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