

Green Infrastructure

Life support for human habitats

The compelling evidence for incorporating nature into urban environments

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A review of research and literature
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Between 2012 and 2014 Dr. Martin Ely and Sheryn Pitman developed an Evidence Base for Green Infrastructure in South Australia. The full report outlines the findings of the Evidence Base for Green Infrastructure study and includes a wide ranging literature review with emphasis on the most recent peer reviewed research from around the world.

Cover photo: Tony Wong CRC for Water Sensitive Cities.

Executive Summary

Introduction

The value of 'green infrastructure' in urban landscapes is becoming increasingly recognised by health professionals, water managers, planners, policy makers and designers around the world. The rapid expansion of towns and cities contains the real risk of creating unliveable, unhealthy environments. The contention is that human habitats need to be healthy and friendly places that use and recycle resources wisely, are clean, safe and accessible, are protected as far as possible from extreme weather conditions, and where natural systems are not only recognised and valued for the critical functions and services they provide, but are assisted in delivering these services.

Green Infrastructure is the network of green places and water systems that delivers multiple environmental, social and economic values and services to urban communities. This network includes parks and reserves, backyards and gardens, waterways and wetlands, streets and transport corridors, pathways and greenways, farms and orchards, squares and plazas, business and institutional green areas, roof gardens and living walls, sports fields and cemeteries.

Green Infrastructure (GI) is critical to the health, liveability and sustainability of urban environments. It strengthens the resilience of towns and cities to respond to the major current and future challenges of growth, health, climate change and biodiversity loss, as well as water, energy and food security.

Two key features of Green Infrastructure which distinguish Green Infrastructure from its 'grey' counterparts are multifunctionality and connectivity. Importantly, Green Infrastructure can deliver multiple benefits from the valuable urban space it occupies, compared with single purpose engineering infrastructure. Green Infrastructure also 'value adds' by linking and connecting existing green assets, which provides benefits both for people, by enhancing public use opportunities, and for the environment by improving urban ecosystem health and countering habitat fragmentation.

Supporting research

A great deal of research in many parts of the world has firmly established the many and diverse benefits of contact with nature and, inversely, the problems arising from lack of contact with nature. While a wealth of studies focus on human physical and mental health issues, much work has also been done in defining the importance of urban nature in improving temperatures and climatic conditions, water management, economic prosperity, biodiversity and habitat, urban food production and liveability and safety issues.

This study includes a wide ranging literature review with emphasis on the most recent peer reviewed research from around the world. A compelling body of evidence suggests that Green Infrastructure is not only beneficial but essential in the design and development of healthy urban environments.

Ecosystem Services

Green places and water systems form the basis of ecosystems and healthy ecosystems provide goods and services that are essential to human health and well-being, and therefore underpin GI. Ecosystem concepts apply to cities and towns not just to “natural” areas. Ecosystem services include provisioning (food and materials), regulating (moderate environmental conditions and quality), cultural (aesthetic and psychological benefits) and supporting (underlie all ecosystem services) services that apply at a range of scales from the global (such as contributing to the mitigation of climate change) to the local (such as more sustainable management of the local urban water cycle).

Human health and well-being

A large body of research over the last twenty years has investigated the many connections between contact with nature and human health and well-being. Health and well-being are usually defined in the broadest sense to mean not only the absence of disease, but a state of physical, mental and social well-being (World Health Organisation, 1946). Research has focused on the three areas of physical health and well-being, psychological health and well-being, and social interaction and community building.

Clear links have been identified between urban greening, physical activity and health, with widespread recognition that physical activity is promoted by ready access to well-managed green places and ‘walkable streets’.

The psychological benefits of contact with nature are well-documented, including the ‘restorative’ powers of contact with nature in cities and the general positive emotions engendered by natural settings. Many studies, for instance, confirm the therapeutic power of plants and garden environments in speeding up recovery from injury, surgery and other medical or traumatic events. A wide body of evidence also links animals with human health; documented benefits of pet ownership include lower levels of minor health problems, fewer doctor visits, reduced stress and longer life spans than in people without pets. The ‘biophilia hypothesis’ claims that contact with nature is fundamental to human health because we have an innate need to affiliate with living things. This is further supported by studies on self-regulation of mood and on favourite places, indicating that green settings are preferred as places for restorative experiences such as thinking about problems, recovering focus, forgetting worries, emotional release and relaxation.

Also important are the many enhanced opportunities for social interaction, and fostering of community relationships and sense of identity that are facilitated by attractive and welcoming urban green spaces. Such social interaction has been found to be fundamental to human health and well-being.

Green Infrastructure has particular benefits for specific demographic groups, such as older people and children. Access to green places contributes to older people staying active and enhances quality of life through increased physical activity and social interaction. The emerging increase in physical and mental

health issues in Australian children has been partly attributed to a decline in physical activity and outdoor play. Writer Richard Louv has coined the term 'Nature-Deficit Disorder' to describe the effects on children of the alienation from nature increasingly prevalent in cities. An emerging and powerful body of evidence shows that contact with nature during childhood can play a significant role in the prevention and management of physical and mental health problems, and improve lifelong well-being.

Community liveability

Green Infrastructure enhances the general attractiveness and 'liveability' of urban neighbourhoods. The term 'community liveability' covers a range of themes. Some of these are intangible benefits, difficult to quantify, such as cultural or visual and aesthetic values. Research into community liveability is drawn from a wide range of disciplines and looks at a number of issues: cultural and heritage values such as attachments, meanings and symbolism; the visual and aesthetic roles of Green Infrastructure including place making, spatial definition and attractiveness; and enhancements to urban amenity such as comfort and safety. Green Infrastructure also provides more easily quantified benefits such as air quality improvement and noise abatement.

Economic prosperity

The monetary value of a number of services and benefits provided by Green Infrastructure are calculable, including the benefits of ecosystem services, amenity values and perceived attractiveness.

Recently developed methods for quantification of net economic values of the ecosystem services provided by Green Infrastructure have led to the quantification of benefits (such as those provided by urban trees) and include air pollution reduction, storm water runoff reduction, and carbon sequestration and storage. The amenity or replacement value of the green asset can also be calculated.

Evidence shows that well-designed Green Infrastructure enhances the economic attractiveness of commercial precincts, increases residential property values, and creates improved opportunities for tourism and economic regeneration.

Potential and significant savings for health care expenditure through increased human physical, mental and social health as a consequence of well-designed and maintained urban green space have been identified in a number of studies.

Climate modification

The modification of urban climates, especially through temperature reduction, is one of the outstanding benefits of Green Infrastructure. A large body of recent research has shown that vegetation and water can assist in mitigating the 'urban heat island' effect in cities. The urban heat island refers to a metropolitan area that is significantly warmer than surrounding suburbs or rural areas as a result of urban development including the construction of more buildings and paved surfaces that retain heat. The urban heat island is recognised as a significant contributor to health risks in large cities including

increased distress and mortality rates in extreme weather events such as 'heat waves', especially among the aged.

Global climate changes in general and recent droughts in particular have further highlighted the need to make better use of Green Infrastructure in the public realm. Plants and water systems play an important role in both climate change mitigation and adaptation. Green Infrastructure assists in reducing temperatures in cities through shading, evapotranspiration and wind speed modification while also providing protection during extreme weather events, reducing water runoff and flooding, and improving air quality.

Water management

Vegetation plays a critical role in the natural water cycle, modifying rainfall inflows, soil infiltration and groundwater recharge, and patterns of surface runoff. Urbanisation has seen the natural water cycle replaced by an artificial 'urban water cycle', with extensive impervious surfaces and highly efficient drainage systems, which dramatically increase the quantity, while reducing the quality, of urban storm water runoff. This negatively impacts on 'receiving' aquatic ecosystems and also removes a valuable water resource from the city. Green Infrastructure provides efficient and effective contributions, including alternatives, to conventional engineering infrastructure in the process of integrated water cycle management and Water Sensitive Urban Design (WSUD).

Water Sensitive Urban Design now embraces the many ways in which smart and more appropriate water management can contribute to the liveability and resilience of our cities. Along with provision of safe, secure and affordable water supplies, WSUD supports green landscapes that significantly enhance urban amenity, help to cool urban environments, improve the health of waterways and provide opportunities for active and passive recreation.

Urban ecology

In an historical sense, nature and the city have been seen as separate and 'mutually exclusive'. An urban ecology approach, however, sees people, nature and the city as part of the same 'urban ecosystem'. Healthy biodiversity plays a fundamental role in the functioning of ecosystems and their ability to deliver long-term ecosystem services, with biodiversity loss an issue of increasing global concern. Nature and biodiversity in cities contribute to our human sense of place, identity and psychological well-being. Green Infrastructure supports biodiversity by creating or conserving habitat patches linked by corridors, thereby reducing habitat fragmentation. While the 'urban nature' found in cities may be different from 'wild nature', it still contributes to healthy ecosystem function and has both intrinsic and human well-being values.

Food production

The quest for food security along with the health imperative to eat well and be active increasingly brings the subject of 'food' into focus in towns and cities. Green Infrastructure and urban food are intimately

related through the perceived needs to retain productive agricultural land on the urban fringe and to integrate food production into urban areas. Methods of urban food production are many and varied, ranging from private and school kitchen gardens to verge gardens and urban farms, and result in a wide range of health and well-being outcomes.

Community gardens have received particular attention for their multifunctional role in providing access to healthy food options, physical activity, social interaction and the fostering of community relationships.

Green Infrastructure guiding principles

To design, establish and maintain Green Infrastructure necessitates, in many cases, a new way of thinking about urban environments. To achieve the many potential benefits of Green Infrastructure it must be embraced as an integral element of the urban landscape. Government, industry and community sectors require a thorough understanding of the benefits as well as a robust capacity for design, development and maintenance. Planning and investment in Green Infrastructure need to be guided by principles that reflect and ensure a full acceptance of the concept.

We suggest that successful Green Infrastructure is underpinned by the following five principles:

- **Integration:** Green infrastructure is fundamental to urban planning and design frameworks for both new growth areas and redevelopments.
- **Nature-based:** Green Infrastructure utilises natural processes to provide essential services and functions that improve the quality of urban water, air, soil, climate and wildlife habitat.
- **Collaboration:** The design, development and maintenance of Green Infrastructure require open and on-going collaboration between government, industry and communities.
- **Evidence:** Green Infrastructure policy, planning and design are grounded in science and the lessons of experience, and are informed by emerging practices and technologies.
- **Capacity:** Green Infrastructure requires commitment to building motivation, knowledge, skills and access to resources.

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1 Introduction

1.1 Preamble

The Green Infrastructure Project, hosted by the Botanic Gardens of South Australia (Department of Environment, Water and Natural Resources), has developed an *Evidence Base for Green Infrastructure* in South Australia. This report summarizes and provides an overview of the relevant literature in the field, and key findings by specific research topics. The report also identifies areas of research requiring further investigation.

1.2 Study background

The Green Infrastructure Project has a vision of '*South Australians living in healthy, resilient and beautiful landscapes that sustain and connect people with plants and places*'. Green Infrastructure includes the 'green' and 'blue' components of the natural environment that can provide a wide range of social, economic and environmental benefits to cities.

The ultimate success of Green Infrastructure as a new 'paradigm' requires:

- Recognition of its values and benefits by the whole community and at the highest strategic levels
- Capacity building in the institutions and organisations involved in implementing Green Infrastructure in its different forms
- Incorporation of Green Infrastructure as an essential, rather than optional, component in the urban development process.

One of the key strategy areas of the Green Infrastructure Project has been the development of a sound and credible 'evidence base' which 'makes the case' for investment in Green Infrastructure. The 'evidence base' underpins our advocacy and awareness activities, organisational capacity building, resource development, and development of design principles for Green Infrastructure.

1.3 Study scope

Green Infrastructure (also referred to in this report as GI) is by definition a multi-disciplinary topic. GI has its origins in a number of different research fields, and has evolved over time under a number of names. It has also been applied at a range of scales from the global to the local. Owing to its 'multifunctionality', there is no single science or discipline responsible for GI (Benedict and McMahon 2002). According to some authors, the nearest integrative scientific discipline responsible for the evolution of GI is 'landscape planning', which developed as a separate discipline in the 1970s (European Commission 2012). GI is also founded on the theories and practices of a wide range of scientific and land planning professions, such as conservation biology, landscape ecology, urban forestry, urban ecology, urban and regional planning, geographic analysis, information systems and economics (European Commission 2012). Research into GI also occurs at a range of scales, from individual buildings to neighbourhoods, cities and entire regions (Naumann et al. 2011a). A current emphasis is on the role of GI in addressing global issues of climate change, sustainable development, and human

health and well-being, as well as more local issues such as the effects of prolonged drought on Australian cities and the adoption of more sustainable water management practices.

1.4 Report structure

The literature review is presented in the following sections

- Study background, scope and methodology.
- GI concepts and definitions, including concepts of ecosystem services, biodiversity and their links to human health and well-being.
- A literature review of key GI benefits categorized as follows:
 - Human health and well-being.
 - Community liveability.
 - Economic benefits.
 - Climatic modification.
 - Water management.
 - Urban ecology.
 - Food production.
- Study conclusions and recommendations.
- A list of references cited in the text is also provided at the end of each chapter of the report.

1.5 Green Infrastructure research

In the last decade, extensive research has been undertaken documenting the ‘triple bottom line’ (social, economic and environmental) benefits of Green Infrastructure as shown in Figure 1 (McPherson 1995; Staley 2004; McPherson 2005; Nowak and Dwyer 2007; Macdonald and Supawanich 2008; Clark and Matheny 2009). Being a multi-disciplinary topic, this research is spread over a very wide field.

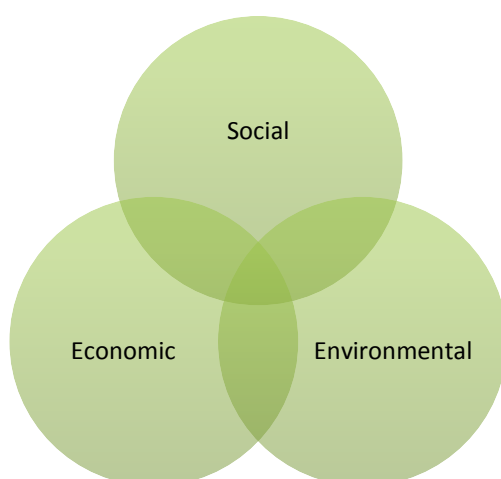


Figure 1: Scope of Green Infrastructure benefits. By author.

Much of the research has taken place in the United States and Europe, however significant recent research and literature reviews have also been undertaken in Australia (Moore 2000; Killicoat et al. 2002; Plant 2006; Tarran 2006; Fam et al. 2008; Tarran 2009; Townend and Weerasuriya 2010). A

significant body of local research has been undertaken recently as part of the City of Melbourne Urban Forest Strategy (City of Melbourne 2011; GHD 2011; Townend and Sick 2011; GHD 2011a). Recent research has also been commissioned by the Nursery and Garden Industry Australia (NGIA) into the benefits of urban trees and green-spaces (Holbrook 2009; NGIA 2011).

The literature review indicates a major current research focus on three key topics, being funded by the Australian government and pursued within local research institutions.

- Recognition of global climate change has led to an emerging body of research into the potential role of Green Infrastructure in climate change mitigation and adaptation (Moore 2006; McPherson et al. 2009; Thom et al. 2009). Important research into mitigating the 'urban heat island' effect is currently taking place in Australia (Coutts et al. 2007; Loughnan et al. 2008; Livesley 2010; Loughnan et al. 2010).
- The related topic of sustainable water management has also become a significant research focus, driven by issues of prolonged drought and water restrictions in Australian cities (Wong 2011).
- Current concerns with the health costs of modern sedentary lifestyles have led to a significant body of research into the human health and well-being benefits of urban nature and Green Infrastructure, including recent Australian based research (Kent et al. 2011; Planet Ark 2011; Planet Ark 2012).

A project at the University of Washington provides access to a green infrastructure knowledge base. The website Green Cities: Good Health represents a collection of more than 2,800 scholarly works, most of which are peer reviewed (University of Washington 2014). The papers are sorted into key themes, each represented by a summary with citations. Support for the Green Cities: Good Health project is provided by the U.S. Department of Agriculture Forest Service, Urban and Community Forestry Program.

USEFUL GREEN INFRASTRUCTURE RESEARCH SITES

Landscape and Human Health Laboratory

A science team at the University of Illinois studies the connection between urban greenery and human health. The research has produced landmark findings concerning people and nearby nature.

Human Dimensions of Urban Greening and Urban Forestry

This web site features research at the University of Washington (Seattle) on people's perceptions and behaviors regarding nature in cities. The site addresses the following topics: nature and consumer environments, trees and transportation, civic ecology, and policy and planning.

American Planning Association, How Cities Use Parks

This web site features a series of briefing papers. Topics include: community revitalization, community engagement, economic development, safer neighbourhoods, green infrastructure, children and learning, improve public health, arts and cultural programs, promoting tourism, smart growth, and climate change management.

The Trust for Public Land, Center for City Park Excellence

The Trust is a national non-profit that conserves built and natural places for people to enjoy, ensuring livable communities for generations to come. TPL shares white papers about why city parks are necessary assets.

Local Government Commission

The web site lists multiple benefits of city trees. A fact sheet about livable communities reports on a range of community benefits, from economic development to public health and safety.

Casey Tree Foundation, The Case for Trees & Growing a Healthier D.C.

The non-profit Foundation works to restore tree canopy in Washington, D.C. A Tree Benefits page highlights why trees are important for green infrastructure and urban livability. A second web page shares documents on the importance of green assets for city life: neighborhoods, streets, parks, schools, business districts, parking lots, residences, and jobs.

Home Depot Foundation, Green Cities Institute

The nonprofit Foundation is dedicated to affordable housing for working families, and to sustainable community development (promoted by Neighborhoods programs and the Green Cities Institute). A Green Infrastructure "classroom" includes information about the role of trees in healthy communities, including economics, community, education, and health.

Sacramento Tree Foundation

This community-based nonprofit works to build the Sacramento's urban forest, and improve regional programs using a collaborative GreenPrint approach. Web page summaries report research on the social, psychological and community benefits of urban greening: girls and greenery, canopy and crime, vegetation and violence, kids and concentration, neighbors and nature, and plants and poverty.

Urban Forestry South Expo

This USDA Forest Service site provides support to urban and community forestry programs in the southeastern U.S., but the materials are relevant to other regions.

Children & Nature Network

The nonprofit Network supports those who work to reconnect children with nature. One web page tracks recent research on the influence of nature on children, including social benefits.

Evergreen, Learning Grounds

This nonprofit organization is working to make Canada's cities more livable by deepening the connection between people and nature. One program, Learning Grounds, is dedicated to transforming the outdoor landscape of Canada's schools. Links share studies about the effects of urban greening on children in Canada.

United Nations Food and Agriculture Organization, Urban Forestry Community

The FAO is a neutral forum for international food security issues. One project is an informational program on Forests and Trees for Healthy Cities, which brings together people from across the globe to promote urban greening. The website tracks international research on the social benefits of trees in cities, and shares files.

UK Forest Research

Forest Research is the science division of the U.K. Forestry Commission, and informs policy on woodlands and forests, from wildland to urban settings. One web page features social science, including decision making. A second page outlines current research (with publications) on the role of trees in human health and well being..

Northwest Public Health, Health and the Built Environment

Links to research studies are provided, along with summaries. Topics include the precautionary principle, the role of the natural environment in healing, daylighting in schools and other settings, building healthy communities, transportation, and urban density, sprawl and land use planning. Many, but not all, of the studies are based in the Pacific Northwest.

Source: University of Washington 2014)
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1.6 Study methodology

This study comprises a comprehensive review of literature on the benefits of Green Infrastructure. Key informants in academic and government organizations in all Australian states were initially contacted to identify the most recent literature in different fields of research. A 'snowball method' of literature review was conducted, starting with the reference lists of key articles and documents (Babbie 2001; Sustainable Development Commission 2008). Where key documents cited other literature, the original source of information was acquired and reviewed.

In deciding which studies to use the following were given preference

- Peer-reviewed, published literature.
- Evidence from other reputable sources (such as reports conducted or commissioned by government bodies or non-government agencies).
- The most recent (post 2000) evidence was preferred, although on occasion older studies have been included which are seminal in nature, or where more recent research is limited.
- Studies from across the world have been referenced; however local Australian studies have been sourced and reviewed where possible to reflect local climatic and other conditions.

1.7 Study limitations

Due to limits on time and resources, and the wide scope of the topic, individual studies have not been assessed on methodology or sample size, although where other research has undertaken this, it has been noted in the text. Areas where evidence is considered weak or in need of further exploration have also been identified.

1.8 Target audience

This evidence base is intended to bring together evidence supporting the concept of Green Infrastructure, to be used as a tool by policy makers, planners, designers and others who are interested in developing and promoting Green Infrastructure in urban environments.

1.9 How to use this document

Users of this document are advised to:

- Read Chapter 1 for an understanding of the study scope and methodology.
- Read Chapter 2 for an overview of the main concepts underlying the study, and definition of key terms.
- Read Chapters 2-9 for a summary and review of GI benefits and ecosystem services relating to specific topics.
- Read Chapter 10 for a summary of key study conclusions and recommendations.

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- Use the Reference list to source the original articles and other documents referenced in each body of the report.

Green Infrastructure is a continually developing field, with a growing body of research, and readers should also refer to additional literature produced since publication of this report.

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2 Green Infrastructure: Concepts and Definitions

2.1 Introduction

The following section comprises a review of the main concepts underlying the study, including the concepts of Green Infrastructure, ecosystem services and biodiversity, and the links between ecosystem services and human health and well-being.

2.2 Definition of key concepts

The following section provides definitions of some of the key terms included in this report. More detailed definitions may also be included in the relevant sections.

Health. The most widely referenced definition of health is that of the WHO which defines health as ‘*a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity*’ (World Health Organization 1946).

Well-being comprises not just the benefits gained from psychological and physical health, but is also related to specific aspects of well-being such as favourable thoughts and feelings, satisfaction with life, ability to be self-sufficient and proactive, possessing a sense of happiness, and a positive evaluation of life in a general sense (Diener et al. 1999).

Nature. Maller et al. (2006) define nature as referring to ‘*any single element of the natural environment (such as plants, animals, soil, water or air), and includes domestic and companion animals as well as cultivated pot plants*’. Researchers also subdivide nature into different categories, for example the Health Council of the Netherlands (Health Council of the Netherlands 2004) nominates the following:

- **Urban nature:** nature in an urban setting (e.g. gardens, parks).
- **Agricultural nature:** primarily agricultural landscape with small, dedicated patches of nature.
- **Natural forests:** nature in ‘woodlands’ where management emphasizes more authentic vegetation.
- **Wild nature:** nature in an environment that develops spontaneously and can be maintained with minimal management (e.g. natural rivers, woodlands etc.).

The concept of ‘nature’ is in one sense a human construct, reflecting societal and individual value systems. Discussing the ‘ethics of sustainability’ Thompson (2000) reviews the different human attitudes to nature and environmental ethics. He identifies the following typologies or positions within environmental ethics:

- **Anthropocentric position**
 - **Ego-centric.** Self-interest.
 - **Homo-centric.** The greatest good for the greatest number. We are responsible for stewardship of nature for human use and enjoyment.

- **Non-anthropocentric position**

- **Bio-centric.** Members of the biotic community have moral standing.
- **Eco-centric.** Ecosystems and/or the biosphere have moral standing. We have a duty of care to the whole environment.

Aldo Leopold's (1948) *Land Ethic* is an early statement of the eco-centric position, as is McHarg's (1979) philosophy of *Design with Nature*, and James Lovelock's (1979) *Gaia* hypothesis. In his book *Man's Responsibility for Nature* Australian philosopher John Passmore (1974) argued that there is urgent need to change our attitudes to the environment, and that humans cannot continue the unconstrained exploitation of the biosphere. However his case for environmental stewardship rested on an anthropocentric viewpoint, of valuing nature in terms of what it contributes to human well-being rather than attributing an intrinsic value to nature, as advocated by the 'deep ecology' movement.

The Urban Forest

The urban forest has been defined as '*the sum of all publicly and privately owned trees within an urban area, including street trees, trees on private property, and remnant stands of native vegetation*' (Nowak et al. 2001; Miller 2007). The urban forest is an integral part of the 'urban ecosystem' in which a wide range of physical and human elements interact to influence the quality of urban life. The concept of urban forestry is widely adopted in the United States and Europe (Konijnendijk 2008), and more locally a number of councils have developed Urban Forest Strategies. Notably the City of Melbourne has recently completed a major strategy for the sustainable management of its urban forest (City of Melbourne 2011). Brisbane's urban forest strategic planning, targets, policies and programs are focused on optimising the multiple benefits of the extensive and diverse public and private tree cover whilst balancing the risks, costs and other priorities of a growing city (Brisbane City 2013a). The City of Sydney's Urban Forest Strategy was adopted in February 2013.

National Urban Forest Alliance

The National Urban Forest Alliance NUFA (2013) has recently been formed to 'promote a thriving, sustainable and diverse Australian Urban Forest that creates a contiguous and healthy ecosystem that is valued and cared for by all Australians as an essential environmental, economic, and community asset'. Its goals are to 'develop, partner trial and implement systems, programmes, communications, guidelines, landscaping and infrastructure to grow the Australian Urban Forest'. Values of the Urban Forest include:

1. Reducing greenhouse emissions by sheltering nearby buildings from sun and wind.
2. Reducing the urban heat island effect in a time of climate change to improve liveability and comfort.
3. Improving air quality for our atmosphere and water quality for our waterways and bays.
4. Sequestering carbon from the atmosphere to help prevent climate change.
5. Increasing habitat to support biodiversity.
6. Providing food such as fruits, nuts, spices.

7. Increasing the life of infrastructure through weather protection.
8. Improving the visual amenity of streetscapes and neighbourhoods.
9. Increasing real estate value of properties with tree lined streets or in close proximity to parks or green landscaped areas
10. Improving the health of residents by encouraging them to walk and be more active.

Current Stakeholders include but are not limited to:

- Arboriculture Australia
- Brisbane City Council
- Nursery & Garden Industry Australia
- Parramatta City Council
- Australian Landscape Industry
- Campbelltown City Council
- Parks & Leisure Australia
- Darwin City Council
- Melbourne City Council
- Launceston City Council
- Sydney City Council
- ENSPEC Pty Ltd

2.3 Green Infrastructure

The following section summarizes the different definitions of GI, the scope of GI practices, and the key GI concepts of multifunctionality and connectivity.

2.3.1 Overview

'Green Infrastructure is a term that is appearing more and more frequently in land conservation and development discussions across the country and around the world. Green infrastructure means different things to different people depending on the context in which it is used. For example, some people refer to trees in urban areas as green infrastructure because of the 'green' benefits they provide, while others use Green Infrastructure to refer to engineered structures (such water treatment facilities or green roofs) that are designed to be environmentally friendly' (Benedict and McMahon 2002) p.5.

Three main perspectives on Green Infrastructure have been identified in the literature review.

- a) **Ecosystem services approach.** In this approach Green Infrastructure emerges from a global perspective in terms of the ecosystem services (ESS) delivered by nature and natural cycles (Costanza et al. 1997; Millennium Ecosystem Assessment 2003). These natural cycles operate globally, but can also be retained, restored and maintained within cities to produce local benefits. Historically this perspective is closely linked to the development of the concepts of sustainable development and urban ecology (Spirn 1984; Hough 2004).

- b) **Linked green spaces approach.** In this approach Green Infrastructure emphasizes the importance of retaining and linking green spaces, nature corridors and drainage networks in cities to enhance ecosystem functioning (Benedict and McMahon 2002). In this sense the network of Green Infrastructure is seen as analogous to the network of conventional engineering infrastructure underlying the functioning of a city. Green Infrastructure networks can provide a 'green' framework for more sustainable urban development.
- c) **Green engineering approach.** In this approach Green Infrastructure is viewed as a specialized form of engineering infrastructure, replacing conventional engineering structures with 'green' elements which can perform ecosystem service functions, such as waste management or building energy efficiency (Margolis and Robinson 2007). For example the City of Sydney labels energy tri-generation and a decentralized water networks as 'Green Infrastructure' responses to climate change (Kinesis 2012; City of Sydney 2012a). This green engineering approach can include the use of green roofs and living walls to cool buildings, or the use of vegetation to purify stormwater runoff in Water Sensitive Urban Design installations.

Green Infrastructure can take a number of forms, and can provide a wide range of what are known as Ecosystem Services (ESS). Some of the ecosystem services that can be provided by Green Infrastructure include the following:

- **Social.**
 - Human health and well-being.
 - Physical.
 - Social and psychological.
 - Community.
 - Cultural.
 - Visual and aesthetic.
- **Economic.**
 - Commercial vitality.
 - Increased property values.
 - Value of ecosystem services.
- **Environmental.**
 - Climatic modification.
 - Temperature reduction
 - Shading.
 - Evapotranspiration.
 - Wind speed modification.
 - Climate change mitigation.
 - Carbon sequestration and storage.
 - Avoided emissions (reduced energy use).
 - Air quality improvement.
 - Pollutant removal.

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- Avoided emissions.
- Water cycle modification.
 - Flow control and flood reduction.
 - Canopy interception.
 - Soil infiltration and storage.
 - Water quality improvement.
- Soil improvements.
 - Soil stabilization.
 - Increased permeability.
 - Waste decomposition and nutrient cycling.
- Biodiversity.
 - Species diversity.
 - Habitat and corridors.
- Food production
 - Productive agricultural land
 - Urban agriculture

2.3.2 Definitions

Grey Infrastructure

Definition of infrastructure

‘the basic physical and organizational structures and facilities (e.g. buildings, roads, power supplies) needed for the operation of a society or enterprise’: *the social and economic infrastructure of a country*.

Source: Oxford Dictionary.

Infrastructure systems are essential to the functioning of the modern high density city. Traditional ‘grey infrastructure’ comprises the engineered network of roads and services, which deliver a range of goods and services to the population of a city. These infrastructure systems require major capital investment to build and maintain, and are generally single use occupiers of large areas of urban land (Wolf 2003).

Green Infrastructure

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'.

Source: (Naumann et al. 2011a).

Green Infrastructure is an emerging concept, based on the realization that natural systems can deliver a range of engineering and human services to the city, known as 'ecosystem services' (Bolund and Hunhammar 1999; Nowak and Dwyer 2007; Pataki et al. 2011). The concept is thought to have originated in the United States in the 1990s, emphasizing the 'life support' functions provided by the natural environment. Green Infrastructure can provide a range of tangible environmental services, including stormwater management, air quality improvement, carbon sequestration, and mitigation of urban heat island effects. However the Green Infrastructure concept also includes the more anthropocentric functions of the natural environment, including those related to human social, recreational and cultural values. For example Green Infrastructure has been described as *'an interconnected network of green space that conserves natural ecosystem values and functions, and provides associated benefits to human populations'* (Benedict and McMahon 2002).

Green Infrastructure

'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.'

Source: Australian Institute of Landscape Architects Green Infrastructure Report (AILA 2012).

Green Infrastructure

'GI is a successfully tested tool for providing ecological, economic and social benefits through natural solutions. It helps us to understand the value of the benefits that nature provides to human society and to mobilise investments to sustain and enhance them. It also helps avoid relying on infrastructure that is expensive to build when nature can often provide cheaper, more durable solutions. Many of these create local job opportunities. Green Infrastructure is based on the principle that protecting and enhancing nature and natural processes, and the many benefits human society gets from nature, are consciously integrated into spatial planning and territorial development. Compared to single-purpose, grey infrastructure, GI has many benefits. It is not a constraint on territorial development but promotes natural solutions if they are the best option. It can sometimes offer an alternative, or be complementary, to standard grey solutions'.

'Many definitions of GI have been developed. It is therefore difficult to cover all aspects in one short paragraph. The following working definition will however be used for the purposes of this Communication'.

'GI: a strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services. It incorporates green spaces (or blue if aquatic ecosystems are concerned) and other physical features in terrestrial (including coastal) and marine areas. On land, GI is present in rural and urban settings'.

Source: European Commission (2013) p.2. *Green Infrastructure (GI): Enhancing Europe's Natural Capital.*

2.3.3 Scope

The following elements can contribute to a city's Green Infrastructure network (Oxigen 2011):

- **Public Parks and Gardens**, including urban parks, open space reserves, cemeteries and formal gardens.
- **Greenways**, including river and creek corridors, cycleways 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 (communal) spaces around apartment buildings, backyards, balconies, roof gardens and community (productive) 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.

2.3.4 Multifunctionality

Green Infrastructure can perform multiple roles in urban areas, for example recreation, biodiversity, cultural identity, environmental quality and biological solutions to technical problems (Sandstrom 2002; see also Figure 2). Green Infrastructure can also be seen as comprising all of the natural, semi-natural and artificial networks of multifunctional ecological systems within, around and between urban areas, at all spatial scales (Sandstrom 2002; Tzoulas et al. 2007). Importantly, Green Infrastructure can deliver multiple benefits from the valuable urban space it occupies, compared with traditional single purpose engineering infrastructure (Wolf 2003). It is this multifunctionality of Green Infrastructure that differentiates it from its 'grey' counterparts, which tend to be designed to perform one function, such as transport or drainage, without contributing to the broader environmental, social and economic context (Naumann, McKenna et al. 2011a).



Figure 2: Victoria Park Sydney, grassed detention basin/community park. By author.

The European Commission's report on *The Multifunctionality of Green Infrastructure* (European Commission 2012) provides a comprehensive list of the Green Infrastructure features that contribute to four types of Green Infrastructure functions or roles:

- Protecting **ecosystem state** and biodiversity.
- Improving **ecosystem functioning** and promoting ecosystem services.
- Promoting societal **well-being and health**.
- Supporting the development of a **green economy** and sustainable land and water management.

The following section lists the Green Infrastructure ‘features’ that can contribute to each of these roles.

Protecting ecosystem state and biodiversity

Green Infrastructure features that contribute to the role of protecting ecosystem state and biodiversity include the following, as adapted from (European Commission 2012):

- **Nature-rich areas**, which function as core areas and hubs for GI.
- **Wildlife and natural areas**, which can be wilderness areas or managed areas.
- **Areas of high value for biodiversity** and ecosystem health outside protected areas, such as floodplain areas and wetlands.
- **Ecological corridors** used by wildlife to allow movement between areas. In general, three types of corridor can be identified:
 - **Linear corridors** comprising long strips of vegetation, such as roadside vegetation, strips of remnant bushland, and the vegetation growing along rivers and streams.
 - **Stepping stone** corridors, which are a series of small, non-connected habitats.
 - **Landscape corridors** of diverse, uninterrupted landscape elements (e.g. riparian zones).
- **Greenways and greenbelts**, where greenways are corridors of undeveloped land and greenbelts are belts of parks or rural land surrounding or within a city.
- **Eco ducts or green bridges**, structures that connect two areas of nature and allow wildlife to travel across significant barriers, such as roads.
- **Fish ladders**, fishways or fish passes are a series of pools at the side of a waterway, enabling freshwater organisms to swim upstream, around a dam or other obstruction.
- **Ecological stepping-stones** are a series of usually small, unconnected habitats that allow wildlife to move from one to another.
- **Ecological buffer areas** comprise zones that surround areas of ecological value, aimed at minimizing the impacts of adjacent land uses or activities.
- **Restored landscapes and ecosystems**. These can be ‘passive’ where the damaging activity has ceased, or ‘active’, involving targeted actions, such as revegetation of brownfield land. Examples of habitats that may be restored include native grasslands, rivers and wetlands.
- **Urban elements**, such as parks, gardens, open spaces, housing allotments, waterways, green roofs and living walls.
- **Agricultural land** that is managed sustainably, in terms of protecting biodiversity and ecosystems.

Improving ecosystem functioning and promoting ecosystem services

Green Infrastructure features that perform the role of improving ecosystem functioning and promoting ecosystem services include the following, adapted from (European Commission 2012), and are additional to those listed in the previous section.

- **Areas of high nature value outside protected areas**, such as floodplain areas, riparian zones, wetlands, natural forests and semi-natural grasslands and sustainably managed agricultural lands, which can deliver ecosystem services such as water regulation, carbon storage and coastal protection.
- **Restored habitats** that have specific functions and/or species in mind, for example, to increase breeding or nesting for those species or to enhance the carbon and water cycles of those areas.
- **Water bodies and wetlands**, including constructed wetlands for water quality improvement.
- **Urban trees, vegetation and soils** which can remove CO₂ from the air and also sequester carbon.
- **Vegetated landscapes to absorb and harvest water** and convey it either to a storage facility for reuse or discharge it into downstream drainage systems. These include:
 - green vegetated roofs or ecoroofs
 - rain/infiltration gardens and trenches
 - vegetated swales which generally consist of a drainage course with gently sloped sides and filled with vegetation
- **Permeable pavements** made from porous materials, such as porous asphalt or eco-paving systems.
- **Water Sensitive Urban Design (WSUD)** also known as Sustainable Urban Drainage Systems (SUDS) in the UK and Low Impact Development in the US which integrates storm water management into the design of urban landscapes. This may include some of the GI features listed above, such as green roofs, permeable pavements, bio-swales and the preservation of natural landscapes and forested areas.

Promoting societal health and wellbeing

Green Infrastructure features that perform the role of promoting societal health and wellbeing include the following, adapted from (European Commission 2012), and are additional to those listed in the previous sections.

- **Public parks**, pathways, playing fields, cycle paths and jogging tracks that encourage outdoor activity and promote physical health.
- **Urban vegetation**, i.e. trees, green roofs and private gardens that regulate air quality and help reduce the 'urban heat island' effect.
- **Wetlands, grassed areas and urban forests** that reduce the risk of flooding and degradation of aquatic ecosystems.
- **Public parks, streets and urban spaces** that enhance community attachment, social cohesion and a sense of environmental responsibility.

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- **Green spaces** that attract tourism and investment and improve employment and income potential.

2.3.5 Green Infrastructure networks

The other distinguishing feature of Green Infrastructure is that of 'connectivity' and 'value adding' by linking existing green assets and resources.

In the US in 1999 the *Green Infrastructure Working Group* developed the following definition of Green Infrastructure.

'Green Infrastructure is our nation's natural life support system - an interconnected network of waterways, wetlands, woodlands, wildlife habitats, and other natural areas; greenways, parks and other conservation lands; working farms, ranches and forests; and wilderness and other open spaces that support native species, maintain natural ecological processes, sustain air and water resources and contribute to the health and quality of life for America's communities and people (Benedict and McMahon 2002).

This 'network' approach to Green Infrastructure comprises a system of 'hubs' (for example parks, reserves and agricultural land) and 'linkages' (for example habitat corridors, greenways and river systems), and is based on the concept that 'green' resources are more effective if linked together rather than fragmented. This concept has its roots in planning and conservation ideas dating back over a century, and includes two important concepts (Benedict and McMahon 2002):

- 1) Linking parks and other green spaces for the benefit of people.
- 2) Preserving and linking natural areas to benefit biodiversity and counter habitat fragmentation.

Linking of open spaces for public benefits

In his work in public parks in the late eighteenth and early nineteenth centuries, United States landscape architect Frederick Law Olmsted believed that *'no single park, no matter how large and how well designed, would provide the citizens with the beneficial influences of nature.'* Instead parks need *'to be linked to one another and to surrounding residential neighbourhoods'* (Little 1989).

Olmsted also believed that *'A connected system of parks and parkways is manifestly far more complete and useful than a series of isolated parks'*. This idea of linking parks for the benefit of people, with a focus on recreation, multi-use trails and public health, subsequently evolved into the modern 'greenways' movement in the United States, and the 'greenbelt' movement in the UK.

Linking to counter habitat fragmentation

Wildlife biologists and ecologists have long recognized that the most effective way to conserve native plants, wildlife and ecosystems is to create interconnected conservation systems which counter the trend towards habitat fragmentation (Benedict and McMahon 2002). Protecting and restoring the connections between parks and other natural assets is now a key concept in both the science of conservation biology and the practice of ecosystem management. Historically the concept was

popularized in the development of the discipline of landscape ecology, which addresses ecological structure and function at the landscape scale, and has since been adopted as a land use planning tool at a range of scales (Forman and Godron 1986). This approach was also incorporated into the practice of landscape architecture and landscape planning by Ian McHarg in the 1970s in his concept of ecological landscape design, which is based on recognizing and mapping natural processes in the landscape and using these as determinants in the design process (McHarg 1979).

The Green Infrastructure network approach envisages a network of 'green' and 'blue' elements providing the framework for more sustainable urban development (analogous to the grey infrastructure networks of pipes and roads that provide the framework of the modern city). Benedict and McMahon (2002) consider that this 'greenprint' approach should be based on the following set of guiding principles:

- 1) Green Infrastructure should be the framework for conservation and development.
- 2) Design and plan Green Infrastructure before development.
- 3) Linkage is key.
- 4) Green Infrastructure functions across multiple jurisdictions and at different scales.
- 5) Green Infrastructure is a critical public investment.
- 6) Green Infrastructure is grounded in sound science and land use planning theories and practices.

2.4 Ecosystem Services (ESS)

The concept of ecosystem services (ESS) is fundamental to an understanding of Green Infrastructure, and is applicable at range of scales from the global to the local.

2.4.1 Global perspective

Ecosystem services are the benefits provided to humans through the transformations of resources (or environmental assets, including land, water, vegetation and atmosphere) into a flow of essential goods and services e.g. clean air, water, and food.

Source: (Costanza, d'Arge et al. 1997)

The concept of ecosystem services has been gradually developing over the last century as a way of recognising the dependence of human societies on nature-based systems. Daily (1997) defines ecosystem services as '*... the conditions and processes by which natural ecosystems, and the species that make them up, sustain and fulfil human life*'. A growing awareness developed in the 1990s that healthy ecosystems provide goods and services that benefit humans and other life. Work by noted scientists such as Ehrlich, Daily, Kennedy, Matson, and Costanza helped to support this groundswell of environmental awareness (Daily 1997).

'Concern has been growing over the last half century as evidence of decline in the world's ecosystems grows and ecologists, economists and other social scientists debate the underlying socio-economic causes. More than ever before in human history, people living in cities have lost their awareness of their reliance on natural ecosystems for food, regulation of the atmosphere and climate, purification of water, provision of building and raw materials for industry, protection from pests, diseases and extreme weather, and for cultural, spiritual and intellectual stimulation and fulfilment'.

Source: (Cork nd).

In response to these concerns the United Nations commissioned a global study called the *Millennium Ecosystem Assessment*, which was conducted by an international consortium of governments, non-profit organisations, universities, and businesses. The group's report, published in 2005, stated that *'ecosystems are critical to human well-being, to our health, our prosperity, our security, and to our social and cultural identity'* (Millennium Ecosystem Assessment 2005). Today the link between environmental well-being, human well-being, and economic prosperity continues to be part of mainstream political conversation (Mainka et al. 2008).

Global value of ecosystem services

In 1997 Costanza and others estimated the global value of ecosystem services expressed in monetary units to be in the range of \$15 - \$47 Trillion/yr, (average \$33 Trillion/yr. in 1995 \$US or \$46 Trillion/yr. in 2007 \$US). This estimate was revisited in 2012 (de Groot et al. 2012). Using the same methods as the 1997 paper, the total global value estimated for 2011 from the new data was \$125 Trillion/yr, assuming both unit values and biome areas changed, \$145 Trillion/yr. assuming only unit values changed and \$41.6 Trillion/yr. assuming only areas changed (all in 2007 \$US). Based on this the loss of ecosystem services from 1997 to 2011 was estimated at \$4.3 Trillion/yr. using 1997 unit values and \$20.2 Trillion/yr using 2011 unit values.

Source: (Costanza, d'Arge et al. 1997).

2.4.2 Scope of Ecosystem Services

‘Ecosystem services are the benefits people obtain from ecosystems. These include provisioning, regulating, and cultural services that directly affect people and supporting services needed to maintain the other services’.

Source: (Millennium Ecosystem Assessment 2003) p.57.

As shown in Figure 3, the Millennium Ecosystem Assessment provided a framework for categorizing the societal benefits of ecosystems into four different groupings (Millennium Ecosystem Assessment 2003):

- **Provisioning services** (which provide food and materials).
- **Cultural services** (which provide aesthetic and psychological benefits).
- **Regulating services** (which moderate environmental conditions and quality).
- **Supporting services** (which underlie all ecosystem services).

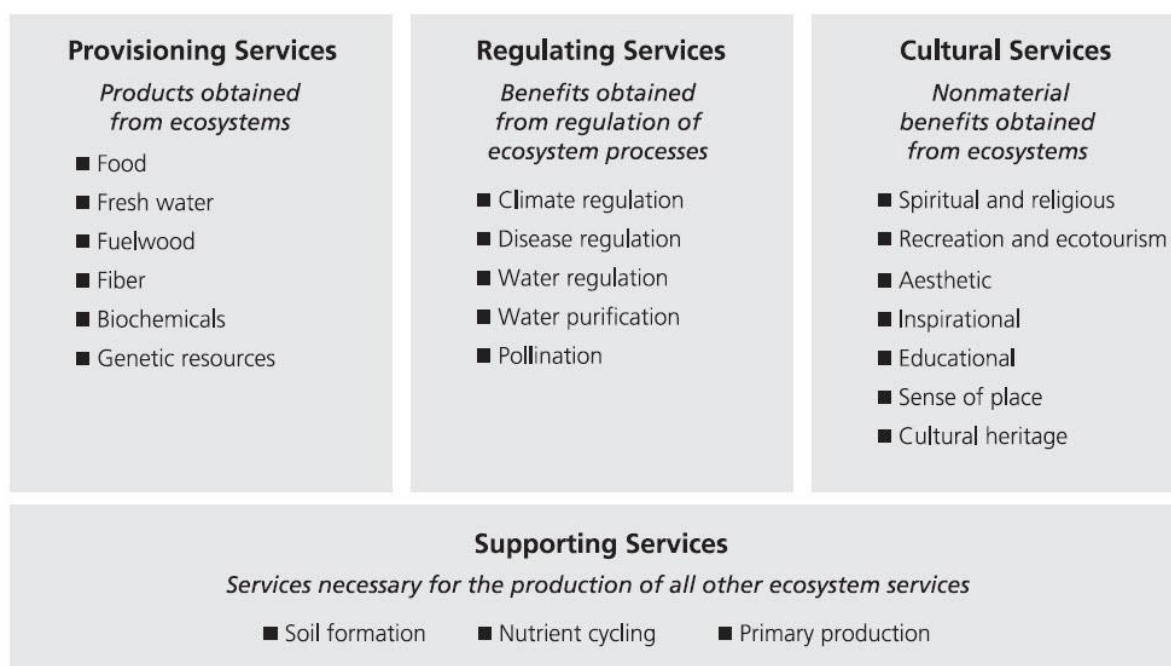


Figure 3: Ecosystem Services. Source: ‘Ecosystems and human well-being: a framework for assessment’ (Millennium Ecosystem Assessment 2003) p.57.

The following section summarizes the scope of these ecosystem services as identified by the Millennium Ecosystem Assessment.

Provisioning Services

Provisioning Services are the products obtained from ecosystems, including:

- **Food and fibre.** This includes the vast range of food products derived from plants, animals, and microbes, as well as materials such as wood, jute, hemp, silk, and many other products derived from ecosystems.
- **Fuel.** Wood, dung, and other biological materials serve as sources of energy.
- **Genetic resources.** This includes the genes and genetic information used for animal and plant breeding and biotechnology.
- **Biochemicals, natural medicines, and pharmaceuticals.** Many medicines, biocides, food additives such as alginates, and biological materials are derived from ecosystems.
- **Ornamental resources.** Animal products, such as skins and shells, and flowers are used as ornaments, although the value of these resources is often culturally determined. This is an example of linkages between the categories of ecosystem services.
- **Fresh water.** Fresh water is another example of linkages between categories, in this case, between provisioning and regulating services.

Regulating Services

These are the benefits obtained from the regulation of ecosystem processes. They are closely linked to many fundamental biogeochemical processes, which are the biological and chemical processes that cycle and transform carbon, nutrients (e.g. nitrogen and phosphorus), water, and other materials in the environment (Pataki, Carreiro et al. 2011). Regulating services include:

- **Air quality maintenance.** Ecosystems both contribute chemicals to and extract chemicals from the atmosphere, influencing many aspects of air quality.
- **Climate regulation.** Ecosystems influence climate both locally and globally. For example, at a local scale, changes in land cover can affect both temperature and precipitation. At the global scale, ecosystems play an important role in climate by either sequestering or emitting greenhouse gases.
- **Water regulation.** The timing and magnitude of runoff, flooding, and aquifer recharge can be strongly influenced by changes in land cover, including, in particular, alterations that change the water storage potential of the system, such as the conversion of wetlands or the replacement of forests with croplands or croplands with urban areas.
- **Erosion control.** Vegetative cover plays an important role in soil retention and the prevention of landslides.
- **Water purification and waste treatment.** Ecosystems can be a source of impurities in fresh water but also can help to filter out and decompose organic wastes introduced into inland waters and coastal and marine ecosystems.
- **Regulation of human diseases.** Changes in ecosystems can directly change the abundance of human pathogens, such as cholera, and can alter the abundance of disease vectors, such as mosquitoes.

- **Biological control.** Ecosystem changes affect the prevalence of crop and livestock pests and diseases.
- **Pollination.** Ecosystem changes affect the distribution, abundance, and effectiveness of pollinators.
- **Storm protection.** The presence of coastal ecosystems such as mangroves and coral reefs can dramatically reduce the damage caused by hurricanes or large waves.

Cultural Services

These are the nonmaterial benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experiences, including:

- **Cultural diversity.** The diversity of ecosystems is one factor influencing the diversity of cultures.
- **Spiritual and religious values.** Many religions attach spiritual and religious values to ecosystems or their components.
- **Knowledge systems** (traditional and formal). Ecosystems influence the types of knowledge systems developed by different cultures.
- **Educational values.** Ecosystems and their components and processes provide the basis for both formal and informal education in many societies.
- **Inspiration.** Ecosystems provide a rich source of inspiration for art, folklore, national symbols, architecture, and advertising.
- **Aesthetic values.** Many people find beauty or aesthetic value in various aspects of ecosystems, as reflected in the support for parks, “scenic drives,” and the selection of housing locations.
- **Social relations.** Ecosystems influence the types of social relations that are established in particular cultures. Fishing societies, for example, differ in many respects in their social relations from nomadic herding or agricultural societies.
- **Sense of place.** Many people value the ‘sense of place’ that is associated with recognized features of their environment, including aspects of the ecosystem.
- **Cultural heritage values.** Many societies place high value on the maintenance of either historically important landscapes (‘cultural landscapes’) or culturally significant species.
- **Recreation and ecotourism.** People often choose where to spend their leisure time based in part on the characteristics of the natural or cultivated landscapes in a particular area.

Cultural services are closely linked to human values and behaviour, as well as to human institutions and patterns of social, economic, and political organization. Therefore perceptions of cultural services are more likely to differ among individuals and communities than, say, perceptions of the importance of provisioning or regulating services such as food production or clean air.

Supporting services

Supporting services are defined as those services that are necessary for the production of all other ecosystem services. They differ from provisioning, regulating, and cultural services in that their impacts on people are either indirect or occur over a very long time, while changes in the other services have more direct and short-term impacts (Millennium Ecosystem Assessment 2003). Some examples of supporting services are:

- Primary production.
- Climate regulation.
- Production of atmospheric oxygen.
- Soil formation and retention.
- Nutrient cycling.
- Water cycling.
- Provisioning of habitat.

2.5 Biodiversity

Maintaining biodiversity and ecosystem health is considered to be essential if ecosystems are to continue to deliver ecosystem services to cities and urban areas. One definition of biodiversity is *'the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems'* (Millennium Ecosystem Assessment 2005) p.18. There are many measures of biodiversity. Species richness (the number of species in a given area) is a single but important metric often used to measure biodiversity, but it must be integrated with other metrics for a full understanding of the biodiversity of a place.

According to the Millennium Ecosystem Assessment (2005a) *'Biodiversity is the foundation of ecosystem services to which human well-being is intimately linked'...breathable air, potable water, fertile soils, productive lands, bountiful seas, the equitable climate of Earth's recent history, and other ecosystem services are manifestations of the workings of life. It follows that large-scale human influences over this biota have tremendous impacts on human well-being'* (Millennium Ecosystem Assessment 2005) p18. Figure 4 summarizes the many links between biodiversity and ecosystem services.

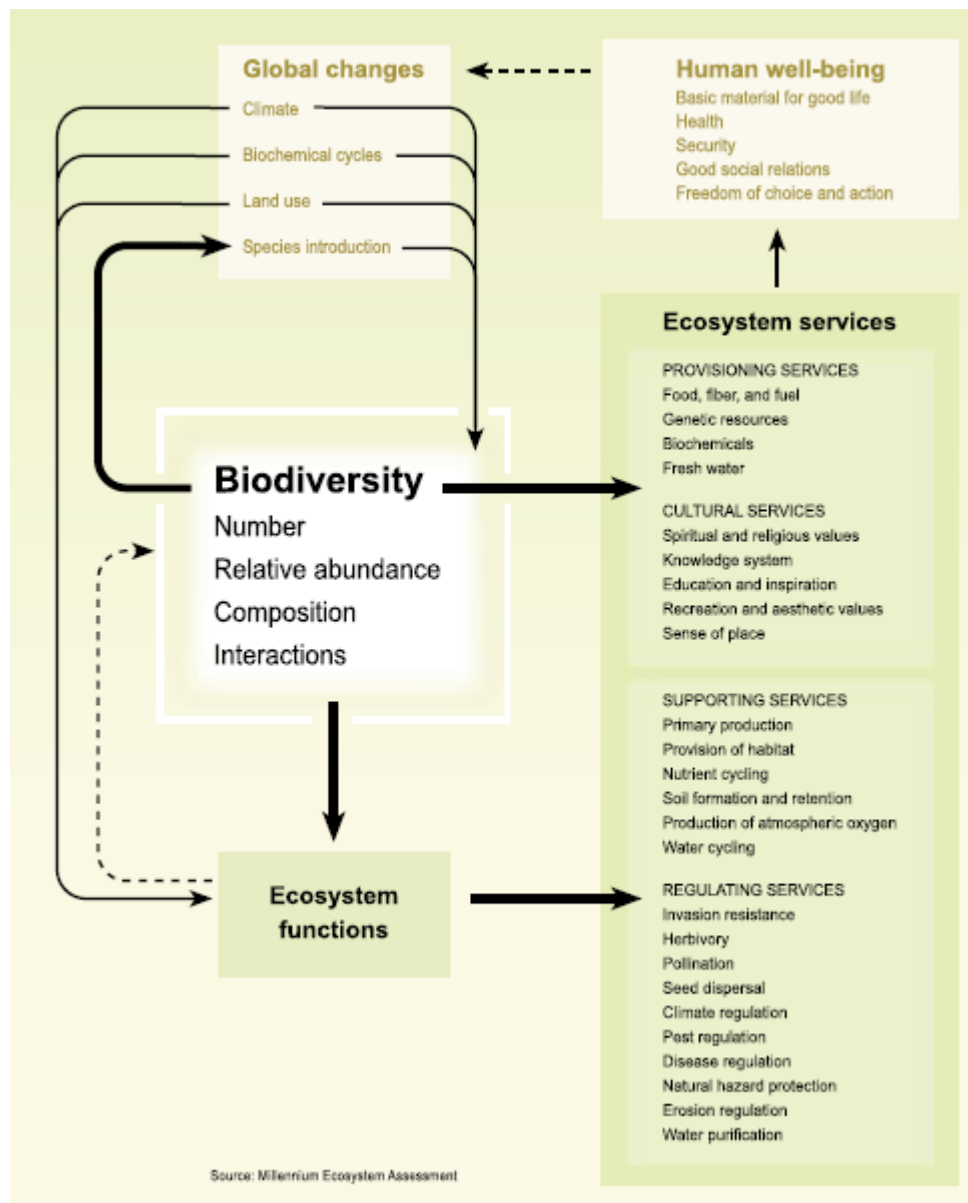


Figure 4: Biodiversity and Ecosystem Services. Source: *Ecosystems and Human Well-being: Biodiversity Synthesis* (Millennium Ecosystem Assessment 2005) p.28.

2.6 Natural Cycles

A number of natural cycles also underlie ecosystem health and the delivery of ecosystem services. Natural cycles process water, carbon, nitrogen and minerals through the living and non-living worlds, and between the land, oceans and atmosphere (Campbell et al. 2006; Cross and Spencer 2009). These natural cycles are part of the supporting services necessary for the production of all other ecosystem services. Urbanization can dramatically modify these natural cycles and their ability to produce ecosystem services. A sustainable approach to design should attempt to integrate these natural cycles into the urban environment (Ely 2010). For example urbanization dramatically modifies the natural water cycle through the use of impervious surfaces and engineered drainage systems. A key objective of WSUD is to restore or replicate the natural water cycle in urban areas.

2.6.1 The Water Cycle

The hydrological cycle recycles and purifies water (see Figure 5). It includes seven main processes: evaporation; transpiration (water lost from plants, having been taken up by their roots); condensation; precipitation; infiltration (water movement into the soil); percolation (water movement through the soil into groundwater); and runoff. The water cycle is driven by energy and gravity, however plants play a crucial role in terms of modifying rainfall inflows, water movement into and through the soil, and water outflows through evapotranspiration, surface runoff and subsurface drainage (Xiao et al. 2006; Cross and Spencer 2009). A key aim of Water Sensitive Urban Design (WSUD) is to better integrate the natural water cycle into the urban environment, at a range of scales (Argue 2004).

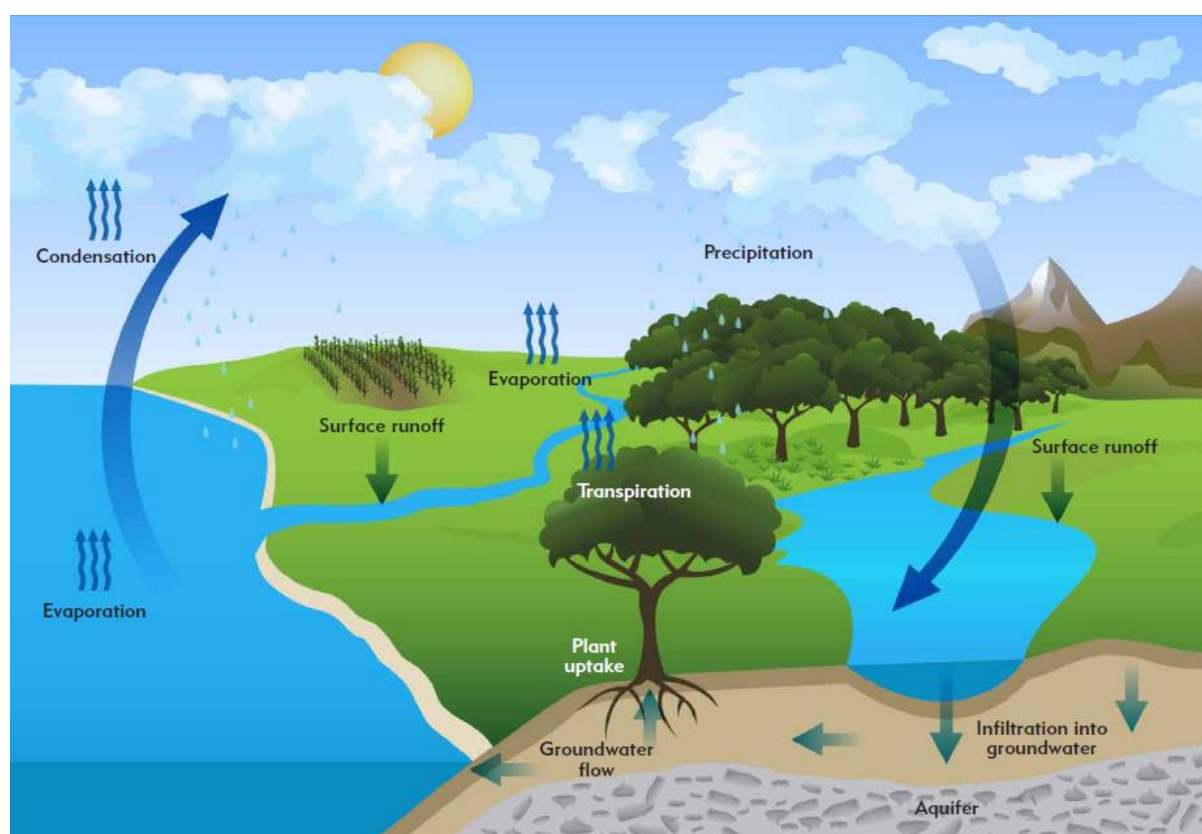


Figure 5: The Natural Hydrologic Cycle. Source: *The Case for Sustainable Landscapes* (Sustainable Sites Initiative 2009) p.29.

2.6.2 The Carbon Cycle

Plants, both terrestrial and aquatic, play a critical role in the carbon cycle, photosynthesizing organic carbon compounds from atmospheric carbon, water and energy from sunlight, and by releasing oxygen during the same process (see Figure 6). Plants are consumed by animals and the organic compounds are re-synthesized in other forms. Plants and animals release carbon dioxide into the atmosphere during respiration by oxidizing these organic compounds. The carbon cycle is completed as plants and animals produce waste products and die, with dead organic matter being decomposed, releasing carbon as carbon dioxide. Carbon is stored in trees and forests and these can act as carbon sinks as long as they are actively growing, and reach a steady state as carbon dioxide uptake is matched by

carbon dioxide released from death and decay (Nowak et al. 2007). Urbanization can significantly modify the carbon cycle, notable in the increased emission of CO₂ and its impacts on global climate change.

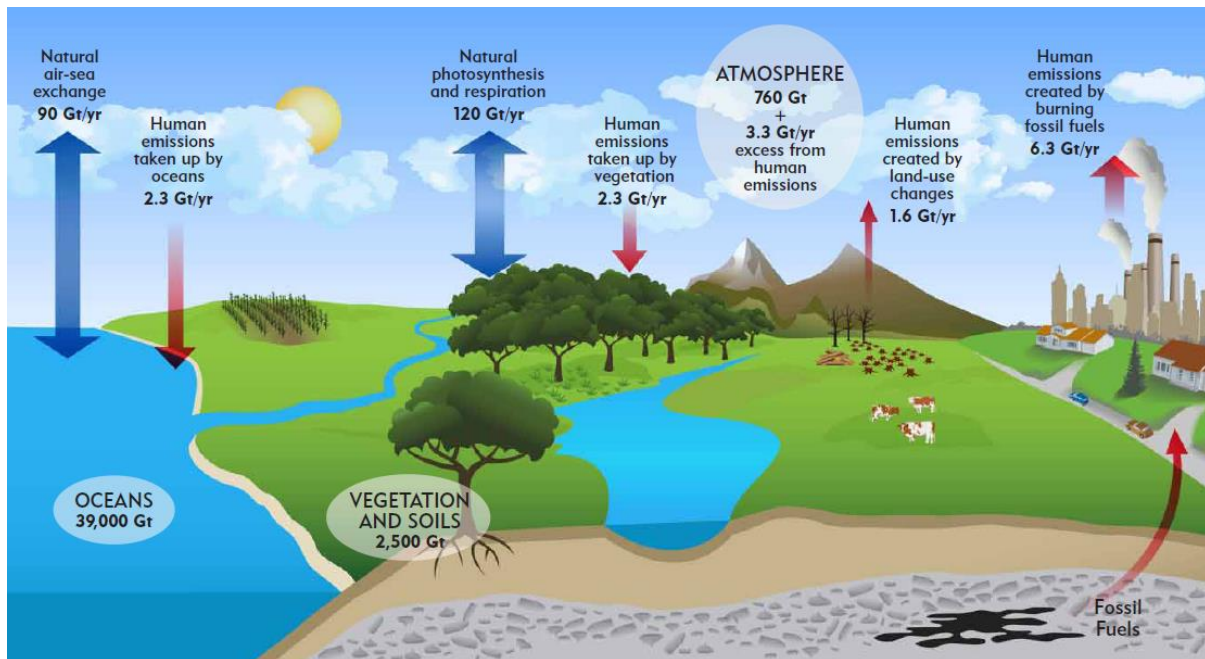


Figure 6: The Carbon Cycle. Source: *The Case for Sustainable Landscapes* (Sustainable Sites Initiative 2009) p.30.

2.6.3 The Nitrogen Cycle

In the nitrogen cycle, (see Figure 7) small amounts of N₂ are converted into forms that can be used by plants, primarily by nitrogen fixing bacteria in the root nodules of some plants (Craul 1992). Decomposition of organic wastes releases nitrogen in the form of ammonia. Under aerobic conditions it is oxidized by nitrifiers to a nitrate. Plants usually take up nitrogen in the form of nitrate in order to synthesize proteins. Humans also add nitrogen to the system through the use of nitrogen fertilizers, and disposal of wastewater into waterways. Urbanisation can impact on the nutrient cycle with impervious surfaces interrupting nutrient exchange with the soil, and with increasingly polluted urban runoff impacting on the health of aquatic ecosystems.

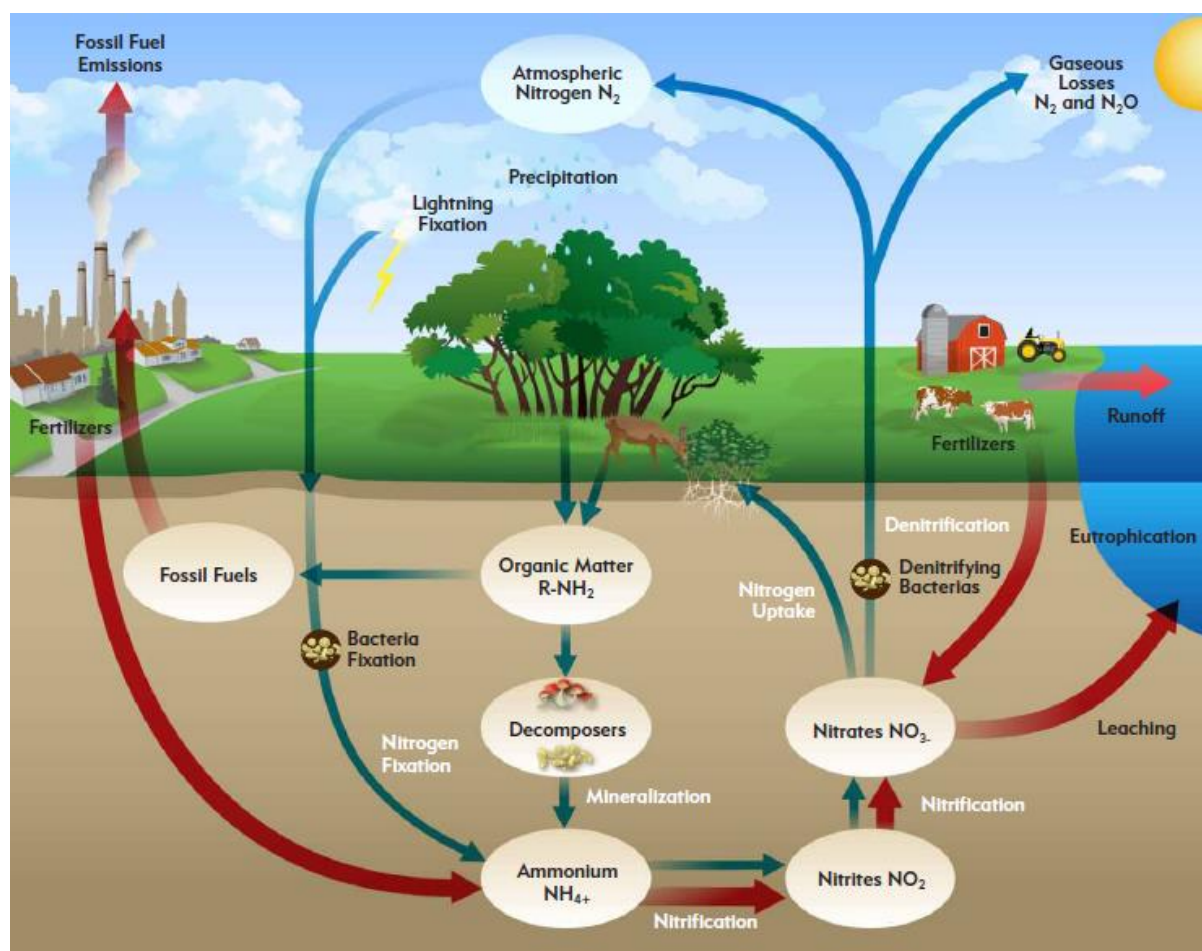


Figure 7: The Nitrogen Cycle. Source: The Case for Sustainable Landscapes (Sustainable Sites Initiative 2009) p.30.

2.7 Human health and well-being

2.7.1 Definitions

From an anthropocentric viewpoint, biodiversity and ecosystem services are fundamental to human health and well-being. There have been many formulations and definitions of human well-being (Alkire 2002). Researchers generally agree that it includes basic material needs for a good life, the experience of freedom, health, personal security, and good social relations. Together, these provide the conditions for physical, social, psychological, and spiritual fulfilment (Millennium Ecosystem Assessment 2003). A research study entitled *Voices of the Poor: Crying Out for Change* identified five key dimensions of human well-being (Narayan et al. 2000):

- The necessary **material** for a good life (including secure and adequate livelihoods, income and assets, enough food at all times, shelter, furniture, clothing, and access to goods).
- **Health** (including being strong, feeling well, and having a healthy physical environment).
- Good **social relations** (including social cohesion, mutual respect, good gender and family relations, and the ability to help others and provide for children).

- **Security** (including secure access to natural and other resources, safety of person and possessions, and living in a predictable and controllable environment with security from natural and human-made disasters).
- **Freedom and choice** (including having control over what happens and being able to achieve what a person values doing or being).

2.7.2 Links between ecosystem services and human well-being

In the 'urban ecosystem' a wide range of physical and human elements interact to influence the quality of urban life (Nowak, Noble et al. 2001; Nowak 2010). People are an integral part of the urban ecosystem, and ecosystem services are indispensable to human health and well-being (see Figure 8).

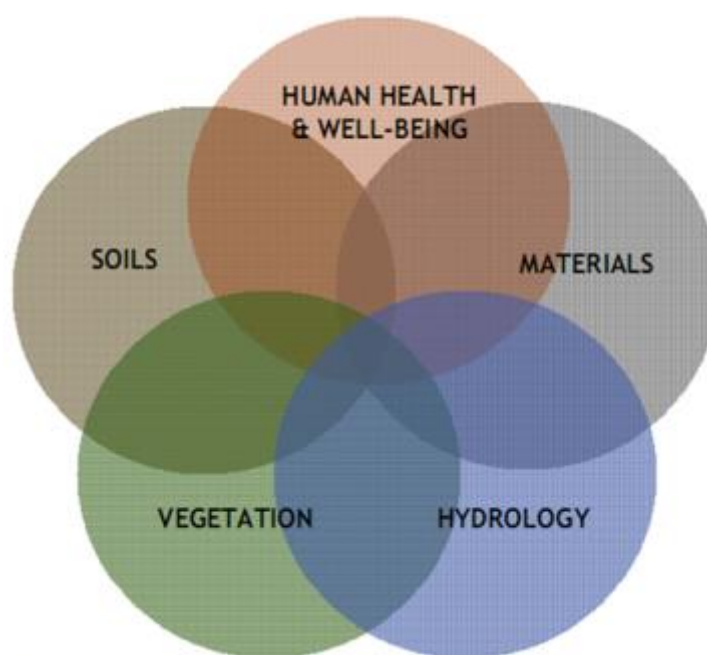


Figure 8: Ecosystems and human health and well-being. Source: (Sustainable Sites Initiative 2009).

Understanding the causal links between the environment and human health and well-being is complex as they are often indirect, displaced in space and time, and dependent on a number of modifying forces. As discussed earlier, the Millennium Assessment identified five main aspects of human well-being: materials, health, social relations, security, and freedom and choice (Millennium Ecosystem Assessment 2005a).

Figure 9 illustrates the ways in which one of these aspects, human health, is affected directly and indirectly by ecosystems, and also by changes to other aspects of well-being. Deficiencies in any one aspect of human well-being (materials, social relations, security, freedom and choice) can have health impacts, and health can also influence these other aspects of human well-being.

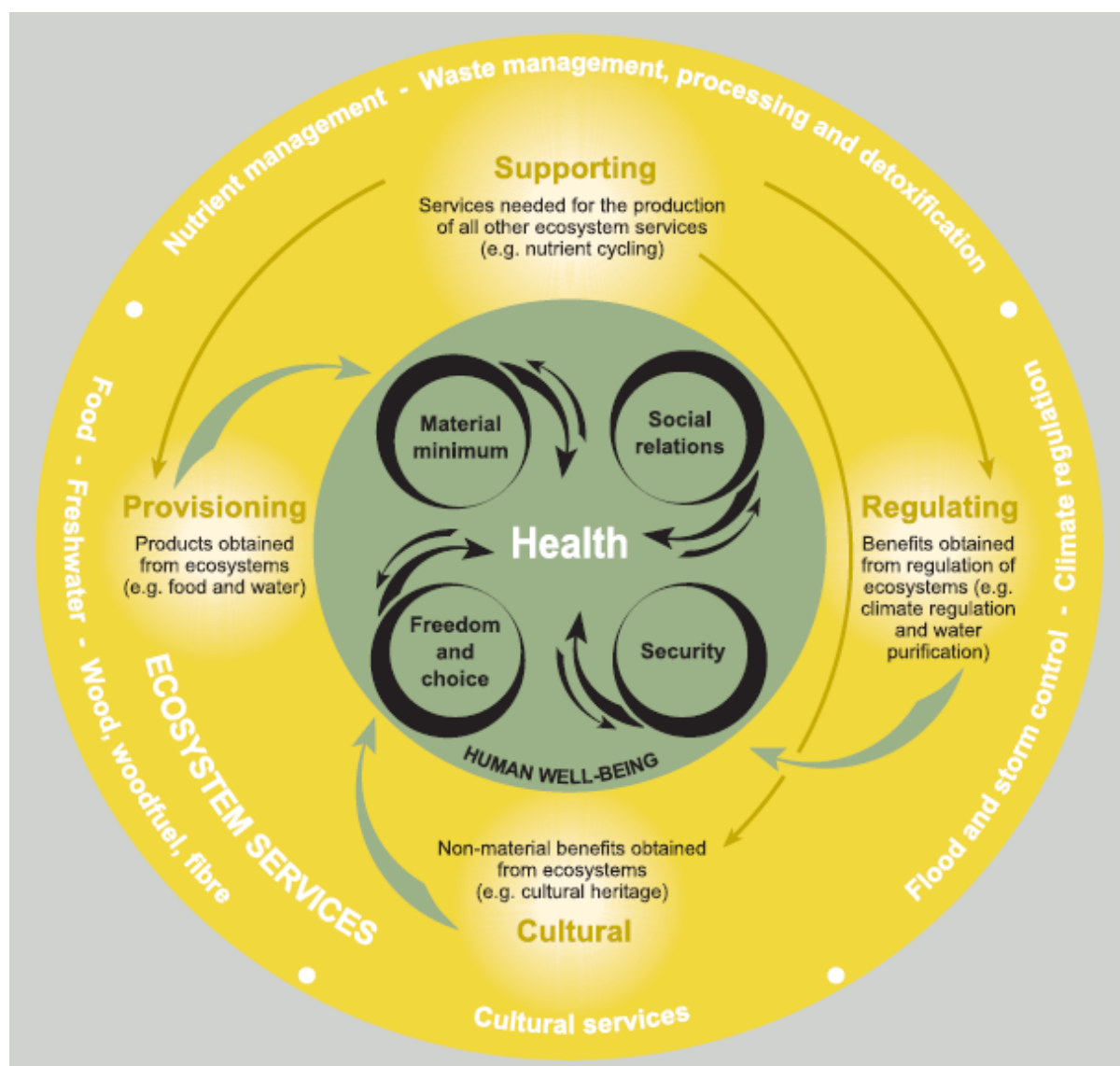


Figure 9: Interrelationship between ecosystem services, aspects of human well-being and human health. Source: Ecosystems and human well-being: health synthesis.(Millennium Ecosystem Assessment 2005a) p.14.

Figure 9 shows how the **provisioning** functions of ecosystems provide goods and services that support human well-being, and shortages of these can impact on health and well-being. The **regulating** functions of ecosystems affect human well-being in a number of ways, including the availability of clean air, fresh water, reduced risk of flooding or drought, stabilization of local and regional climates, and checks and balances on the range and transmission of certain diseases. *'Without these regulatory functions, the varied populations of human and animal life are inconceivable'* (Millennium Ecosystem Assessment 2003). Ecosystems also influence human well-being through the provision of **cultural services**, for example scenic landscapes. These ecosystem attributes influence the aesthetic, recreational, educational, cultural, and spiritual aspects of human life. Changes to ecosystems, through pollution, depletion, and extinction, can therefore have negative impacts on cultural life and human experience. Finally, **supporting services** are essential for sustaining each of the other three ecosystem

service areas. Figure 10 provides a more detailed illustration of the complex interactions between ecosystem services and human well-being.

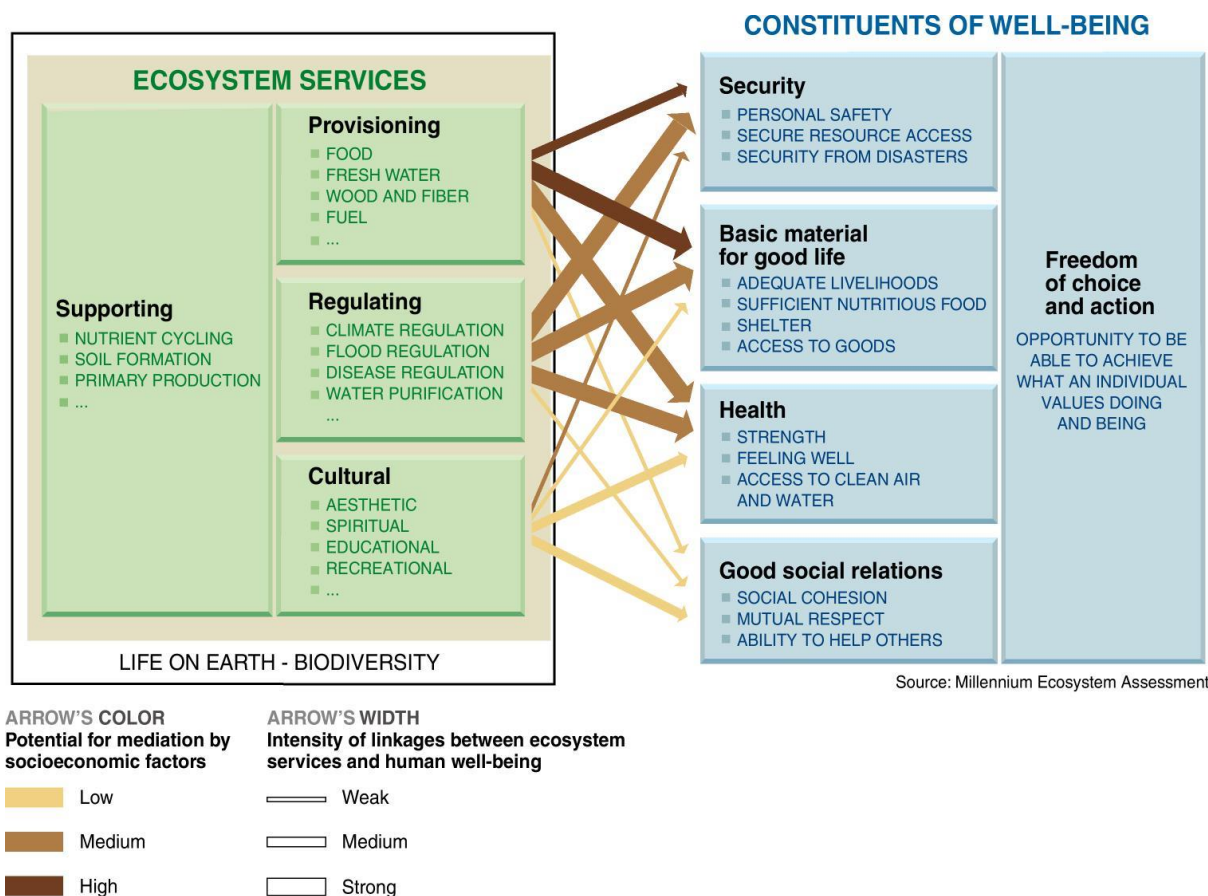


Figure 10: Categories of ecosystem services. Source: *Ecosystems and human well-being: health synthesis (Millennium Ecosystem Assessment 2005a)* p.14.

2.8 Sustainability

Sustainability and the related concepts of 'sustainable development' and 'sustainable design' are closely linked to the concept of Green Infrastructure.

2.8.1 Sustainable design

The term 'sustainability' has emerged in the past decades as a broad set of principles addressing social, economic and environmental development at almost any scale (Watson 2007). However, despite its widespread use, the term does not have an agreed definition, and to some extent has become a 'buzzword' for marketing a range of 'green' products (Thompson and Sorvig 2008). At its core, it refers to the ability to manage a system (social, economic or environmental) so as to perpetuate it indefinitely without compromising the ability to continue to do so in the future (Johnson and Hill 2002). The current widespread use of the term has evolved from the concept of 'sustainable development'. This originated in the Stockholm Conference on the Human Environment in 1972, appeared in the World Conservation Strategy in 1980, and came of age in the 1987 Brundtland Commission Report, *Our Common Future* (Thompson 2000). The often quoted definition used in the latter was development that '...meets the

needs of the present without diminishing the ability of future generations to meet their own needs' (WCED 1990). The scope of the term was later enlarged at the United Nations 1992 Earth Summit in Rio de Janeiro to address global development policies including issues of poverty, resource imbalance and inequalities in global development. The Rio Earth Summit's Agenda 21 produced a well-known set of sustainability principles adopted by many governments, including local government authorities in Australia.

Sustainability as a concept, however, has much earlier roots than the relatively recent concept of sustainable development. Its environmental and ethical basis originates from ecology, as evident in the writings of Aldo Leopold in his 1948 classic *The Land Ethic*, which proposed an ecological approach to land and landscapes (Leopold 1948). The term was also applied to forestry and agriculture in the 1970s to describe management policies which maintain natural resource capacity (Benson and Roe 2000). The concept of 'sustained yield' is used by foresters and others (including fishery and water resource managers) to define a harvestable surplus that can be indefinitely maintained, without reducing the productive capital. However sustainable yield can be difficult to quantify because of the dynamic nature of ecological systems and the role of other non-harvesting factors which affect both the natural capital and its productivity.

A related concept is that of permaculture, an approach to designing human settlements and agricultural systems that mimic natural ecologies. Permaculture was developed by Australians Bill Mollison and David Holmgren in the 1970's and aims to achieve 'permanent', self-sufficient and stable agricultural and cultural systems, through training in a core set of design principles (Mollison 1988). While originating as an agro-ecological design theory, permaculture has grown into a wider value system for sustainable human settlements (Holmgren 2002).

The design professions have also embraced the concept of sustainability, with the roots of 'sustainable design' in the 'ecological design' movement, which emerged in the United Kingdom in the mid-twentieth century in the work of Brenda Colvin, Sylvia Crowe and Simon Hackett, and in the United States in the work of Ian McHarg (Benson and Roe 2000). In 1979 Ian McHarg published his seminal book on ecological design at the regional scale, *Design with Nature* (McHarg 1979), and in 1984 Anne Whiston Spirn applied ecological principles to the city in *The Granite Garden* (Spirn 1984). In the 1980's writers such as John Lyle suggested that sustainability alone was not sufficient, and that designed ecosystems should be 'regenerative' and capable of renewing energy and materials, rather than 'degenerative' (Lyle 1994). Other writers have addressed the relationship between sustainable landscapes, landscape aesthetics and community preferences (Thayer 1989; Thayer 1994).

2.8.2 Sustainable landscapes

The term 'sustainable landscapes' has been adopted more recently by the landscape architecture profession. In their book, *Sustainable Landscape Design and Construction* (first published in 2000 and revised in 2008), Thompson and Sorvig (2000) suggest that sustainable landscapes:

'Contribute to human well-being and at the same time are in harmony with the natural environment. They do not deplete or damage other ecosystems. While human activity will have altered native patterns, a sustainable landscape will work with native conditions in its structure and functions. Valuable resources - water, nutrients, soil etcetera, and energy will be conserved, diversity of species will be maintained or increased.'

Perry (1995) has proposed a number of goals to develop and maintain sustainable landscapes. Similar goals are proposed by Thompson and Sorvig (2008). Such goals and principles typically include: local contextual design; selection of plants suited to local conditions; use of non-invasive plant species; reduced resource inputs of energy and materials; water conservation; enhanced biodiversity and habitat creation; avoidance of harmful chemicals; and productive use of gardens for food production. The *Sustainable Landscapes Project* at the Botanic Gardens of Adelaide in South Australia is a local collaboration between various government agencies, aimed at promoting sustainable landscape design and management (Sustainable Landscapes Project 2012). A sustainable landscape is defined as:

'a healthy and resilient landscape that will endure over the long term without the need for high input of scarce resources such as water. The natural functions and processes of the landscape are able to maintain it into the future'.

The *Sustainable Landscapes Project* defines eight criteria for sustainable landscapes:

1. Design to suit local environmental conditions.
2. Use of low water use plants.
3. Use of non-weedy plants.
4. Water conservation measures.
5. Habitat creation.
6. Minimal chemical use.
7. Low non-renewable energy consumption.
8. Use of local and sustainable products.

In the United States the *Sustainable Sites Initiative* (SITES™) is an interdisciplinary effort by the American Society of Landscape Architects, the Lady Bird Johnson Wildflower Center at The University of Texas at Austin and the United States Botanic Garden to create voluntary national guidelines and performance benchmarks for sustainable landscape design, construction and maintenance practices (Sustainable Sites Initiative 2009).

A common goal is for landscapes' ...*that conserve, recycle, and reuse resources to achieve optimal levels of sustainability*' (Perry 1995). A useful way to consider the sustainable use of resources, such as water, materials, and energy, is to consider designed landscapes as functioning systems with inputs, outputs and internal cycling. Unsustainable systems tend to be 'open' with high resource inputs, minimal internal recycling, and high outputs of waste and energy. More sustainable systems will be more

'closed', with reduced inputs of materials and energy, a high level of internal recycling, and reduced waste outputs (Dunnett and Clayden 2000).

2.8.3 Sustainable urban forestry

Concepts of sustainable forest management can also be applied to the urban forest (Wiersum 1995; Clark et al. 1997; Dwyer et al. 2003). Sustainable urban forests can be defined as:

'The naturally occurring and planted trees in cities which are managed to provide the inhabitants with a continuing level of economic, social, environmental and ecological benefits today and into the future' (Clark, Matheny et al. 1997).

Definitions of sustainable urban forestry emphasize the role of the people who manage and use the urban forest. Sustainable management of the urban forest involves an understanding of its diversity, dynamic nature, and connectedness to a range of human activities (Dwyer, Nowak et al. 2003). Urban forests need to be managed to increase the net benefits they generate, and management systems are required that allow trees to flourish and maximize their benefits, while minimizing their impacts on the urban environment (McPherson 1995). It is generally agreed that a sustainable urban forest will produce long-term net benefits associated with a relatively stable tree population and canopy cover (Miller 2007). A sustainable urban forest, therefore, will exhibit: species and age diversity; a large percentage of healthy trees adapted to local conditions; and native forest as one component of canopy cover. In terms of species diversity, however, it should be noted that stability of tree populations will depend on the extent that the selected species are adapted to local conditions, and not just the number of species planted (Richards 1993).

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3 Human Health and Well-being

Green Infrastructure is the network of green spaces and water systems that delivers multiple environmental, social and economic values and services to urban communities. This network includes parks and reserves, backyards and gardens, waterways and wetlands, streets and transport corridors, pathways and greenways, farms and orchards, squares and plazas, business and institutional green areas, roof gardens and living walls, sports fields and cemeteries. Green Infrastructure is critical to the health, liveability and sustainability of urban environments. It strengthens the resilience of towns and cities to respond to the major current and future challenges of growth, health, climate change and biodiversity loss, as well as water, energy and food security.

3.1 Introduction

Chapter 3 addresses the human health and well-being benefits of Green Infrastructure. A large body of research over the last twenty years has investigated the many connections between urban nature and human health and well-being, with much of the research undertaken by practitioners in the health and social sciences. Recent evidence suggests three principal ways that Green Infrastructure can contribute positively to people's health and quality of life: through support for physical activity such as walking; through support for mental health by offering restorative experiences and engagement with the natural environment; and through opportunities for positive social interaction (de Vries 2010). As illustrated in Figure 11 Green Infrastructure can provide a range of ecosystem services that contribute to human health and well-being.

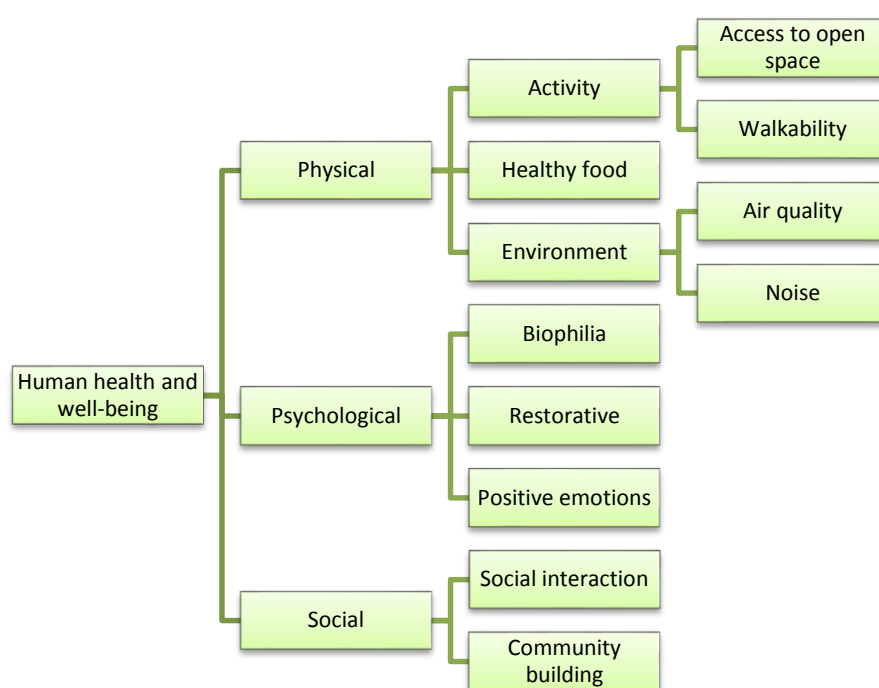


Figure 11: Summary of human health and well-being benefits of Green Infrastructure. By author.

Research shows that physical health and well-being can be enhanced by:

- Environmental factors, such as air quality and climatic variables such as heat extremes and shading, which can be modified by Green Infrastructure.
- Levels of physical activity, associated with a range of positive health outcomes. Green infrastructure can enhance physical activity by providing access to nearby open or green spaces, and by creating more 'walkable' streets and neighbourhoods.
- Access to healthy food options, which can be part of the Green Infrastructure agenda.

Mental, emotional and psychological health and well-being can also be promoted by physical activity, and by contact with nature in various forms. Contact with nature has been shown to contribute to psychological well-being in a number of ways including:

- Satisfying the deep human attachment to nature, termed 'biophilia'.
- Experiencing the therapeutic and restorative effects of nature, including attention restoration and the ability to recover from mental fatigue.
- Generally promoting positive emotions.

Green Infrastructure can also foster social interaction by creating more opportunities for interaction in green outdoor settings. This has been shown to have a number of benefits including community building and the promotion of a sense of belonging with associated health and well-being benefits. The social integration benefits of Green Infrastructure have been found to be especially significant for older people who can gain multiple health and well-being benefits from access to attractive outdoor spaces.

The role of nature in childhood development has become a significant research topic in recent years, with the dramatic increase in childhood physical and mental health problems coinciding with a decline in children's outdoor play in natural environments. Interaction with nature has been found to contribute to a child's physical health, mental health and general cognitive functioning, as well as fostering more responsible environmental attitudes which may persist into adulthood.

3.2 Overview

3.2.1 Definition of terms

The following section summarizes the main terms used by researchers and practitioners, often drawn from different disciplines.

Health. The most widely referenced definition of health is that of the WHO which defines health as '*a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity*' (World Health Organization 1946).

Well-being has been described as not just the benefits gained from good psychological and physical health, but also related to specific aspects such as favourable thoughts and feelings, satisfaction with

life, ability to be self-sufficient and pro-active, possessing a sense of happiness, and a positive evaluation of one's life in a general sense (Diener et al. 1999).

Nature. Maller et al. (2006) define nature as referring to '*any single element of the natural environment (such as plants, animals, soil, water or air), and includes domestic and companion animals as well as cultivated pot plants*'. Researchers also subdivide nature into different categories, for example the Health Council of the Netherlands (2004) nominates the following:

- **Urban nature:** nature in an urban setting (e.g. gardens, parks).
- **Agricultural nature:** primarily agricultural landscape with small, dedicated patches of nature.
- **Natural forests:** nature in 'woodlands' where management emphasizes more authentic vegetation.
- **Wild nature:** nature in an environment that develops spontaneously and can be maintained with minimal management (e.g. natural rivers, woodlands etc.).
-

Planet Ark (2012) summarizes the different interactions between people and 'nature' studied by a range of researchers into human health and well-being:

- **Nature views:** the 'naturalness' of views, refers to people encountering nature by observing it, for example, through a window (a passive type of interaction).
- **Technological nature:** simulations or representations of nature by technological means, such as videos of natural environments (Kahn Jr et al. 2009).
- **Nearby nature:** parks or other natural areas that are conveniently accessible to children and others, from their homes or schools.
- **Wild nature:** more remote wilderness or bush settings. 'Wild nature activities' are those that occur in such settings, such as hiking, camping, playing in nature reserves, or participating in conservation activities.
- **Domesticated nature:** more designed or controlled parks or settings, such as suburban parks, kitchen gardens in schools, and even indoor pot plants. Domesticated nature can also include interaction with animals, such as pets. 'Domesticated nature activities' include planting trees or seeds, and caring for plants, and picking flowers or produce.

Virginia Lohr (2011) of the Department of Horticulture and Landscape Architecture at Washington State University provides a useful overview of the many studies which have documented the wide range of positive effects of plants on people, published by researchers in horticulture, landscape architecture, environmental psychology, medicine, and many other fields. According to Lohr (p.159):

'Plants are essential for our survival, provide food, fibre, building material, fuel, and pharmaceuticals. Plants also produce intangible benefits for people, such as improving our health. These benefits occur with scenes of nature, individual plants indoors, gardens outdoors, parks, and forests. The understanding of the role of trees, in particular, in promoting both human and ecological health is increasing. Plants make our surroundings more pleasant, and they help

us feel calmer. They contribute to cleaner, healthier air, thus improving our well-being and comfort. Plants have been associated with reduced stress, increased pain tolerance, and improved mental functioning in people. Human responses to plants appear to be both learned and innate. Some studies suggest genetic components to the responses. Some primates are known to detect subtle differences in leaf colour, selecting to eat those leaves with the highest nutritive value; people also respond more positively to plants of some colours than to others. Most people in the world now live in urban areas. These areas are typically devoid of plants, resulting in concerns over children being raised in such unnatural areas’.

3.2.2 Existing literature reviews

In recent years researchers have undertaken a number of literature reviews on the linkages between human health and well-being and urban nature or the design of the ‘built environment’ (including landscapes). Pretty (2004) conducted a literature review of the contributions of nature to mental and physical health, and found a strong correlation between people being in or viewing nature, and feeling healthier. A comprehensive review of the relationship between nature and health was undertaken by Grinde and Patil (2009). The review of 50 articles examined the health benefits associated with mere visual contact with nature and concluded that an environment devoid of nature has a negative effect on health and quality of life. In 2010 Abraham et al. carried out a scoping study reviewing over 120 studies examining the health-promoting aspects of natural and designed landscapes (Abraham et al. 2010). The authors concluded that:

‘Landscapes have the potential to promote mental well-being through attention restoration, stress reduction, and the evocation of positive emotions; physical well-being through the promotion of physical activity in daily life as well as leisure time and through walkable environments; and social well-being through social integration, social engagement and participation, and through social support and security’ p.59.

As shown in Figure 12 the study identified three dimensions of human health linked to Green Infrastructure:

- **Mental well-being:** landscape as a restorative environment.
- **Physical well-being:** walkable landscapes.
- **Social well-being:** landscape as a bonding structure.

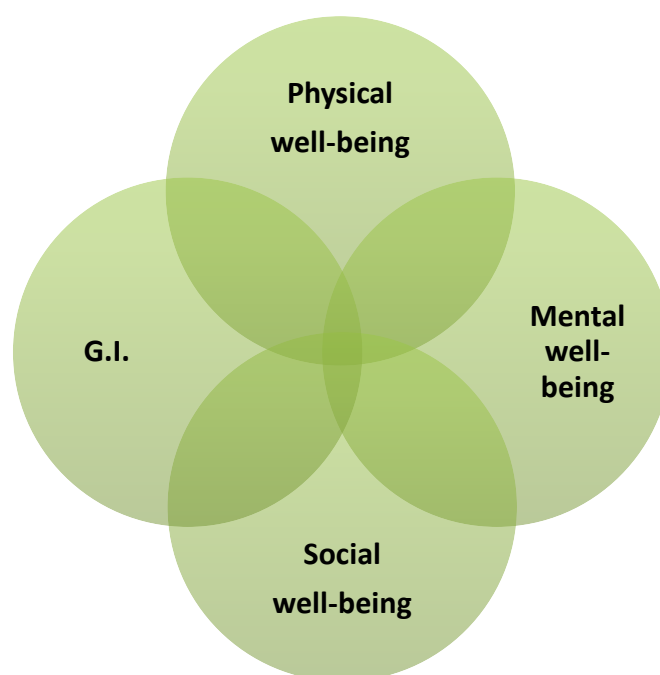


Figure 12: Green Infrastructure and well-being. Adapted from (Abraham, Sommerhalder et al. 2010).

Mental well-being was found to include:

- Attention restoration and recovery from mental fatigue.
- Recovery from stress.
- Positive emotions.

Physical well-being was found to include:

- Physical outdoor activity in cities.
- Physical outdoor activity outside cities.

Social well-being was found to include:

- Social integration.
- Collectively experiencing nature.

The authors concluded that their scoping study showed ‘*strong additional and new support for understanding landscapes as a health resource and health determinant*’ (Frumkin 2003; Maller, Townsend et al. 2006). The relationship between landscape and health was found to show two main features:

- First, health-promoting landscapes contribute to healthy lifestyles in terms of physical activity and mental and emotional relaxation.
- Second, health-promoting landscapes promote the acquisition of resources for health such as social support, concentration and emotional stability.

Table 1 presents the findings of the literature review by Abraham et al.(2010) on the health-promoting influences of landscape on a range of health dimensions.

Table 1: Overview of the literature on the health-promoting influence of landscape

Source: (Abraham, Sommerhalder et al. 2010) p.62-63

Health dimension	Health-promoting landscape effect	Landscape characteristics	Study design	Author(s)
Mental well-being	Attention restoration and recovery from mental fatigue	Natural landscapes such as beaches, waters, forests, parks, mountains Availability of public open spaces used for public entertainment and sports	Conceptual accounts/literature reviews	Health Council of the Netherlands (2004); Frumkin (2003, 2001); Kaplan (1995a, b); Kaplan and Kaplan (1989); Maller et al. (2006)
			Survey-studies (cross-sectional studies, longitudinal studies)	Herzog et al. (1997); Korpela and Hartig (1996); Korpela et al. (2001); Tennesen and Cimprich (1995)
			Experimental studies	Berto (2005); Hartig et al. (1996, 2003); Kuo (2001); Staats and Hartig (2004); Staats et al. (2003)
	Recovery from stress	Landscape perceived as pleasant, i.e. landscape contains visual stimuli such as moderate complexity and richness of natural elements like waters or vegetation Easy access to green areas with lower sound levels from road traffic	Conceptual accounts/literature reviews	Frumkin (2001); Health Council of the Netherlands (2004); Maller et al. (2006)
			Survey-studies (cross-sectional studies, longitudinal studies)	Gidlof-Gunnarsson and O'hrström (2007)
			Experimental studies	Hartig et al. (1996, 1999, 2003); Laumann et al. (2003); Parsons et al. (1998); Ulrich et al. (1991, 2003)
	Positive emotions	Landscape perceived as pleasant Open and accessible forests Perceived amount of open space and vegetation (urban landscapes)	Survey-studies (cross-sectional studies, longitudinal studies)	Herzog and Chernick (2000); Kaplan (2001); Korpela et al. (2002); Kuo and Sullivan (2001b); Kuo et al. (1998)
			Experimental studies	Cackowski and Nasar (2003); Kuo and Sullivan (2001a); Staats et al. (1997)
			Qualitative studies	Milligan and Bingley (2007)
Physical wellbeing	Physical outdoor activity in cities	Daily life: Access to and presence of physical activity-promoting facilities General functionality of urban districts (e.g., sidewalks, traffic regulation, bicycle and walking paths) Leisure time: Land-use-mix Street connectivity Traffic safety (e.g. pedestrian zones) Aesthetically appealing landscapes Trust in neighbours, active neighbours Nearby parks, playgrounds and sport fields Access to places for physical activities	Conceptual accounts/literature reviews	Frank and Engelke (2001); French et al. (2001); Frumkin (2003); Frumkin et al. (2004); Health Council of the Netherlands (2004); Kaspar and Buhler (2006); McCormack et al. (2004); Pikora et al. (2003); Popkin et al. (2005); Powell (2005); Sallis and Glanz (2006)
			Survey-studies (cross-sectional studies, longitudinal studies)	Addy et al. (2004); Ball et al. (2001); Booth et al. (2000); Cervero and Duncan (2003); Craig et al. (2002); Iles-Corti and Donovan (2002); Gordon-Larsen et al. (2006); Humpel et al. (2004a, b); Lee et al. (2001); Leslie et al. (2005); Li et al. (2005); Neff et al. (2000); Ozguner and Kendle (2006); Payne et al. (2002); Pikora et al. (2006); Saelens et al. (2003); Titze et al. (2005); Wendel-Vos et al. (2004)
			Qualitative studies	Coen and Ross (2006); Eyler et al. (1998); Wilbur et al. (2002)
	Physical outdoor activity outside cities	Aesthetically appealing rural green landscapes (e.g. forests)	Conceptual accounts/literature reviews	Gasser and Kaufmann-Hayoz (2004)
			Survey-studies (cross-sectional studies, longitudinal studies)	Baur and Gilgen (1999); Swiss Federal Office for the Environment (1999); Lamprecht and Stamm (2002); Marti et al. (2002); Pretty et al. (2005a)
			Experimental studies	Pretty et al. (2005b)
Social well-being	Social integration	Parks Community gardens	Conceptual accounts/literature reviews	Brown and Jameton (2000); Frumkin (2003); Frumkin et al. (2004); Hancock (2001); Health Council of the

	Sufficient level of safety, attractive, walkable, serve multiple purposes Rich in vegetation		Netherlands (2004); Maller et al. (2006); Twiss et al.(2003);
		Survey-studies (cross-sectional studies, longitudinal studies)	Armstrong (2000); Booth et al. (2000); Kuo et al. (1998); Kweon et al. (1998);Leyden (2003); Seeland and Ballestros (2004);Stigsdotter and Grahn (2004); Sullivan et al. (2004);Waliczek et al. (2005)
		Experimental studies	Doyle and Krasny (2003)
		Qualitative studies	Baum and Palmer (2002); Irvine et al. (1999); Milligan et al. (2004); Rishbeth and Finney (2006); Wakefield et al. (2007)
Collectively experiencing nature	“Wild” nature	Survey-studies (cross-sectional studies, longitudinal studies)	Ewert (1991)
		Experimental studies	Staats and Hartig (2004)
		Qualitative studies	Fredrickson and Anderson (1999); Pohl et al. (2000);Sharpe (2005)

A number of more local literature reviews and scoping studies have been conducted in Australia by Mardie Townsend and others as part of the NiCHE Research Team (Nature in Community, Health and Environment) at the School of Health and Social Development, Deakin University, Melbourne. A study published in 2002 *Healthy Parks Healthy People: The Health Benefits of Contact with Nature in a Park Context* reviewed literature on the multiple health benefits of viewing or interacting with nature in parks (Maller et al. 2002). In a 2006 paper Maller et al. (Maller, Townsend et al. 2006) presented a review of the literature (empirical, theoretical and anecdotal) on the human health benefits of contact with nature, focusing on ‘everyday’ interactions with nature in a park setting by urban populations including: (1) viewing natural scenes; and (2) being in natural environments. Table 2 summarizes the evidence cited by the authors supporting the assertion that contact with nature promotes health and well-being.

Table 2: Summary of evidence supporting the assertion that contact with nature promotes health and well-being. Adapted from (Maller, Townsend et al. 2006) p.50.

What the Research Demonstrates With Certainty	
Assertion	Key References
There are some known beneficial physiological effects that occur when humans encounter, observe or otherwise positively interact with animals, plants, landscapes or wilderness.	(Friedmann et al., 1983a; Friedmann et al., 1983b; Parsons, 1991; Ulrich, et al., 1991b; Rohde and Kendle, 1994; Beck and Katcher, 1996; Frumkin, 2001)
Natural environments foster recovery from mental fatigue and are restorative.	(Furnass, 1979; Kaplan and Kaplan, 1989; Kaplan and Kaplan, 1990; Hartig et al., 1991; Kaplan, 1995)
There are established methods of nature-based therapy (including wilderness, horticultural and animal-assisted therapy among others) that have success healing patients who previously had not responded to treatment.	(Levinson, 1969; Katcher and Beck, 1983; Beck et al., 1986; Lewis, 1996; Crisp and O'Donnell, 1998; Russell et al., 1999; Fawcett and Gullone, 2001; Pryor, 2003)
When given a choice people prefer natural environments (particularly those with water features, large old trees, intact vegetation or minimal human influence) to urban ones, regardless of nationality or culture.	(Parsons, 1991; Newell, 1997; Herzog et al., 2000)
The majority of places that people consider favourite or restorative are natural places, and being in these places is recuperative.	(Kaplan and Kaplan, 1989; Rohde and Kendle, 1994; Korpela and Hartig, 1996; Herzog et al., 1997; Newell, 1997; Herzog et al., 2000)
People have a more positive outlook on life and higher life satisfaction when in proximity to nature (particularly in urban areas).	(Kaplan and Kaplan, 1989; Kaplan, 1992a; Lewis, 1996; Leather et al., 1998; Kuo, 2001; Kuo and Sullivan, 2001)
Exposure to natural environments enhances the ability to cope with and recover from stress, cope with subsequent stress and recover from illness and injury.	(Ulrich, 1984; Parsons, 1991; Ulrich et al., 1991b)
Observing nature can restore concentration and improve productivity.	(Tennessen and Cimprich, 1995; Leather et al., 1998; Taylor et al., 2001)
Having nature in close proximity, or just knowing it exists, is important to people regardless of whether they are regular 'users' of it.	(Kaplan and Kaplan 1989; Cordell et al., 1998)

In a study undertaken for Beyond Blue, Townsend and Weerasuriya (2010) of Deakin University reviewed a large body of literature which demonstrates the many benefits of contact with nature for mental health and well-being. In 2011 Townsend also conducted a *Health Indicators Project*, a review of the benefits of urban forests, as part of the City of Melbourne Urban Forest Project (Townsend and Sick 2011). The study included a review of published literature and research reports providing evidence of urban forest benefits (including urban ecology, biodiversity, community engagement, and human health and wellbeing). The study also identified indicators for measuring the impacts of urban forests on natural processes (including air and water quality, and thermal comfort) and on human health and wellbeing (including physical and mental health, and social connectedness). The study investigated:

- a) Links between urban forest and ecosystem health:
 - a. Urban Heat Island effect.
 - b. Air quality.
 - c. Noise reduction.
 - d. Carbon sequestration.

- e. Biodiversity.
- b) Links between urban forest and human health:
 - a. Air quality and health.
 - b. Noise pollution and health.
 - c. Biodiversity and health.
 - d. Physical activity and health.
 - e. General health and wellbeing.
 - f. Mental wellbeing.
 - g. Social cohesion and health.
 - h. Economic wellbeing.
- c) Strategies for measuring/indicators of impacts of urban forest:
 - a. Measuring impacts on natural processes:
 - i. Temperature.
 - ii. Air pollution.
 - b. Measuring impacts on human health and wellbeing:
 - i. General physical and mental health.
 - ii. Heat related health issues.
 - iii. Air quality related health issues.
 - iv. Noise pollution related health effects.
 - v. Social capital related health issues.

Two recent studies commissioned by Planet Ark have investigated links between nature and children's physical and psychological health. A 2011 study, *Climbing Trees: Getting Aussie Kids Back Outdoors*, investigated childhood interaction with nature and how this interaction is changing between generations (Planet Ark 2011). The study included both a literature review and survey research, and found a significant decline in outdoor interaction with nature in just one generation. A 2012 study *Planet Ark Planting Trees* reviewed literature on 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 revealed an emerging body of evidence 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'. The study also included attitudinal research into how Australians perceive the link between nature and children's health, wellbeing and development.

Another recent literature review was conducted by Australian researchers at the Healthy Built Environments Program, City Futures Research Centre at the University of New South Wales (Kent et al. 2011). The study examined research evidence demonstrating links between the built environment (including landscapes) and human health. The study addressed three of the major risk factors for contemporary chronic disease: physical inactivity, social isolation, and obesity. The focus of the review was on the key built environment interventions that support human health, which were identified as:

- The Built Environment and Getting People Active.
- The Built Environment and Connecting and Strengthening Communities.
- The Built Environment and Providing Healthy Food Options.

In the UK, Lee and Maheswaran (2010) undertook a literature review of studies dealing with the health effects of green space. The authors concluded that there is only 'weak' evidence for the links between physical and mental health and well-being, and urban green space. Environmental factors such as the quality and accessibility of green space are known to affect its use for physical activity. User determinants (such as age, gender, ethnicity and the perception of safety) are also important. However the authors found that many studies were limited by poor study design, failure to exclude confounding factors, bias, reverse causality, and weak statistical associations. The authors 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' p.212.

Other evidence suggests that contact with nature is particularly important in highly urbanised environments (Beer et al. 2003; Nielsen and Hansen 2007; Hartig 2008; Maller et al. 2010) and small scale encounters with nature and people within natural settings appear to be equally as significant to health as access to large areas of natural open space.

In a recent paper Keniger et al. (2013 see Table 3) reviewed research into the 'benefits of interacting with nature'. A qualitative review was undertaken of 57 studies published in peer-reviewed scientific journals. The researchers discovered that evidence for the benefits of interacting with nature is geographically biased towards high latitudes and Western societies, potentially contributing to a focus on certain types of settings and benefits. Social scientists have been the most active researchers in this field. Contributions from ecologists are few in number, perhaps hindering the identification of key ecological features of the natural environment that deliver human benefits. Although many types of benefits have been studied, benefits to physical health, cognitive performance and psychological well-being have received much more attention than the social or spiritual benefits of interacting with nature, despite the potential for important consequences arising from the latter. The evidence for most benefits is correlational, and although there are several experimental studies, little as yet is known about the mechanisms that are important for delivering these benefits. For example, we do not know which characteristics of natural settings (e.g., biodiversity, level of disturbance, proximity, accessibility) are most important for triggering a beneficial interaction, and how these characteristics vary in importance among cultures, geographic regions and socio-economic groups. The authors conclude that these are key directions for future research if we are to design landscapes that promote high quality interactions between people and nature in a rapidly urbanising world.

Table 3: Typology of the benefits of interacting with nature. Source: (Keniger, Gaston et al. 2013).

Benefit	Description	Examples
Psychological well-being	Positive effect on mental processes	Increased self-esteem Improved mood Reduced anger/frustration Psychological well-being Reduced anxiety Improved behaviour
Cognitive	Positive effect on cognitive ability or function	Attentional restoration Reduced mental fatigue Improved academic performance Education/learning opportunities Improved ability to perform tasks Improved cognitive function in children
Physiological	Positive effect on physical function and/or physical health	Stress reduction Reduced blood pressure Reduced cortisol levels Reduced headaches Reduced mortality rates from circulatory disease Faster healing Addiction recovery Perceived health/well-being
Social	Positive social effect at an individual, community or national scale	Facilitated social interaction Enables social empowerment Reduced crime rates Reduced violence Enables interracial interaction Social cohesion Social support
Spiritual	Positive effect on individual religious pursuits or spiritual well being	Increased inspiration Increased spiritual well-being
Tangible	Material goods that an individual can accrue for wealth or possession	Food supply Money

3.2.3 Epidemiological studies

A number of epidemiological studies have been conducted which investigate the links between nature and human health and well-being. Epidemiology can be defined as the study of the patterns of disease or health in well-defined populations, and related causes or influences. Epidemiology is considered to be a cornerstone of public health research and practice, helping inform policy decisions by identifying risk factors for disease and targets for preventive medicine policies. Epidemiological studies are also particularly interesting as they have involved public health and medical researchers in the ecological field.

In one study De Vries et al. (2003) explored the relationship between green areas and health in the Netherlands, by combining data on the self-reported health of over 10 000 people with land-use data on the amount of green space in their living environments. People living in a greener environment were found to be significantly healthier in all three health indicators (number of symptoms experienced, perceived general health and a score indicating propensity to mental health problems). The positive link between green space and health was found to be most apparent among the elderly, 'housewives' and

people from lower socioeconomic groups. The mechanism linking greenness to health was not studied, however suggested possibilities included a less polluted environment, greater contact with green space, or more physical activity. It was also suggested that if green space in living environments actually does make people healthier (rather than just a function of perceived health) then the densification of cities and associated removal of green space may result in unexpected negative health consequences.

A follow up study in the Netherlands investigated the strength of the relation between the amount of green space in people's living environment and their perceived general health for a population of over 250,000 (Maas et al. 2006). The study also analysed the data for different age and socioeconomic groups and level of 'urbanity.' It was found that the percentage of green space inside a one kilometre and a three kilometre radius had a significant relation to perceived general health, and this relationship was generally present at all degrees of urbanity. The overall relation was somewhat stronger for lower socio-economic groups, and the elderly, youth, and secondary educated people in large cities seem to benefit more from the presence of green areas in their living environments than other groups in large cities. The authors concluded that:

'...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' p.587.

Other epidemiological studies on mortality rates found that people with access to green places exhibited greater longevity (Tanaka et al. 1996; Takano et al. 2002). Increased survival of older people was found to be significantly linked to the availability of parks and tree lined streets near their home; and having walkable green streets and spaces nearby was a significant predictor for survival over the following five years.

3.2.4 Survey research

A study in the UK examined which aspects of neighbourhood open space are associated with walking for recreation purposes and for transport purposes by older people (Sugiyama and Ward-Thompson 2008). The study sample consisted of 286 people over 65 years old living in Britain who completed a self-administered questionnaire. It was found that pleasantness of open space and lack of nuisance were associated with walking for recreation, while good paths to reach open space and good facilities in open space were conducive to more walking for transport. The study suggests the possibility that enhancing these aspects of neighbourhood open spaces may contribute to active lifestyles of older adults.

A local study collected survey data from 1,895 residents from 32 neighbourhoods in metropolitan Adelaide, to explore relationships between perceived greenness in the environment and mental and physical health (Sugiyama et al. 2008). The researchers found that perceived neighbourhood greenness was more strongly associated with mental health than it was with physical health.

Recreational walking seemed to explain the link between greenness and physical health, whereas the relationship between greenness and mental health was only partly accounted for by recreational walking and social coherence. The researchers hypothesised a link to the restorative effects of natural environments. They also concluded that longitudinal studies were needed to further examine the causal relationship between natural environments and health effects.

In another study a survey of over 11,000 Danes found that the main reason for using green places was to enjoy the weather and fresh air rather than engage in physical activity (**Schipperijna et al. 2010**). Similarly, research in Zurich Switzerland by Frick et al. (2007) showed a preference for low stimulus natural areas to promote relaxation and escape, rather than organised physical activity.

3.2.5 Research critique

A number of recent papers have reviewed methodological issues relating to the design of studies which attempt to relate human health and well-being and urban greening.

A recent paper by Lachowycz and Jones (2011) reported on a systematic review of quantitative research examining the association between objectively measured access to green-space and physical activity, weight status and health conditions related to elevated weight. Sixty studies were assessed for methodological quality and strength of the evidence. The majority (68%) of papers found a positive or weak association between green-space and obesity-related health indicators, but findings were inconsistent and mixed across studies. Several studies found the relationship varied by factors such as age, socio-economic status and green-space measure. The authors recommended developing a theoretical framework which considers the interactions between different types of green-space. Key areas for future research include investigating if and how people actually use green-space and improving understanding of the mechanisms through which green-space can improve health and, in particular, if physical activity is one such mechanism.

In Japan recreation activity and relaxation in a forest environments called 'forest therapy' or 'shinrin-yoku' (forest-air bathing and forest-landscape watching/walking) have become a type of nature therapy popular with urban dwellers experiencing mental stress conditions. The fields of preventive and alternative medicine have also shown an interest in the therapeutic effects of forest therapy. Kamioka et al (2012) summarized the evidence for the curative and health enhancement effects of forest therapy and assessed the quality of studies based on a review of randomized controlled trials (RCTs). The authors concluded that there was insufficient evidence due to poor methodology and reporting and the heterogeneity of RCTs, meaning it was not possible to offer any conclusions about the effects of 'forest therapy' interventions. The authors, however, did propose a strategy for strengthening study quality.

Townshend (2012, p.180) provides a thoughtful critique of research linking human health and well-being and urban greening:

'It is fair to say, however, that research that has tried to unpick the causal pathways between greenness, green space, physical activity and obesity has been inconsistent and many results equivocal. Partly this is because of the complexity of this relatively new arena for research and while a number of studies have been carried out globally, there are many methodological weaknesses and theoretical unknowns'.

Research issues include:

- Most studies are cross-sectional (while longitudinal studies of influences on weight would be more useful).
- There is huge variety and inconsistency in the confounding factors the studies take into consideration.
- More generally there is a lack of consistent methodologies which makes cross comparison of results extremely difficult.
- Green space and/or greenness have been measured in relatively crude ways (using for example, percentage land-use calculations, distance from individual's home and/or relatively simple quality assessment).
- In many studies green space is just one of several environmental factors measured and assessed for their potential influence.
- Research needs to address three dynamics of green space: green space as location for activity; green space as motivation for activity; and additional benefits (physiological and psychological) from activity in green space over and above what might be expected from alternative locations.

Several recent studies have identified a relationship between the natural environment and improved health outcomes. However, for practical reasons, most have been observational, cross-sectional studies. Donovan et al (2013) conducted a 'natural' experiment, (aimed to provide stronger evidence of causality to test whether a major change to the natural environment (the loss of 100 million trees to the emerald ash borer, an invasive forest pest) has influenced mortality related to cardiovascular and lower-respiratory diseases in 15 U.S. states. The researchers found an increase in mortality related to cardiovascular and lower-respiratory-tract illness in counties infested with the emerald ash borer. The magnitude of this effect was greater as infestation progressed and in counties with above-average median household income. The authors suggested that the loss of trees to the emerald ash borer increased mortality related to cardiovascular and lower-respiratory-tract illness. The reliability of these conclusions however has been questioned (Frumkin 2013).

3.3 Physical health and well-being

3.3.1 Links between physical activity and health

Lack of physical activity in daily life is known to have a range of negative health consequences. Recognition of the relationships between physical activity and health has occurred in response to the links between increasing mortality from non-communicable chronic diseases (such as coronary heart disease and diabetes) and sedentary lifestyles (Booth et al. 2001). The role of physical activity as a modifiable risk factor of disease has been well researched and is now firmly established (Kent, Thompson et al. 2011). It is also evident that physical activity is linked to overall community well-being, through increased levels of social interaction and community engagement (Echeverría et al. 2008; Wood et al. 2010).

In addition, a range of other economic and environmental benefits due to physical activity have been identified (Bauman et al. 2008; Shoup and Ewing 2010). In a study commissioned by the US Active Living Research foundation, Shoup and Ewing (2010) synthesized a number of research studies to identify the economic benefits of open space, recreation facilities and walkable community design. They found that open spaces have a positive effect on property values, which in turn can lead to higher tax revenues for governments. They also found that *'people living in walkable neighbourhoods get about 35-45 more minutes of moderate-intensity physical activity per week, and are substantially less likely to be overweight or obese than people of similar socio-economic status living in neighbourhoods that are not walkable.'* Bauman et al (2008) at the School of Public Health at the University of Sydney estimated that commuter cyclists currently save the Australian economy \$72.1 million per year in reduced health costs. Other benefits quantified included reduced congestion (\$63.9 million per annum) and reduced greenhouse gas emissions (\$9.3 million per annum).

According to the National Preventative Health Strategy (2009), obesity-related disease will shortly be Australia's primary preventable health problem. In 2008 obesity was estimated to have financial costs over \$8 billion, and well-being benefits were valued at around \$50 billion (Access Economics 2008). In 2002, the direct health care costs of inactivity alone were estimated at \$1.5 billion (Stevenson et al. 2000). A primary element of the strategy is to encourage activity for recreation and travel (where people choose to walk or ride rather than use a car) through better urban planning and design. A growing body of evidence suggests that green infrastructure such as trees and urban green spaces are critical elements of environmental design to ensure public health. The recent Inquiry into Environmental Design and Public Health in Victoria (Environment and Planning References Committee 2012) found two particular elements of the built environment promote healthy lifestyles: provision of quality green and public open space, and environments that encourage active travel. Many studies suggest that aesthetically pleasing environments, and green spaces in particular, facilitate higher levels of recreational and transportational walking (Turrell 2010). This is reflected in government design guidance for environmental health where provision of trees for shade and amenity is encouraged to

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create walkable environments. An example is *Healthy by Design SA* prepared by the Heart Foundation SA and the South Australian Active Living Coalition (Heart Foundation 2013).

3.3.2 Links between Green Infrastructure and physical activity

Links to physical activity

There is a well-established link between participation in physical activity and the attributes of the physical environment (Booth et al. 2000). Considerable research supports the idea that the presence of green, natural settings can facilitate physical activity (Booth, Carlson et al. 2000; Frank et al. 2004; Ellaway et al. 2005; McNeill et al. 2006; Mobley et al. 2006; Roemmich et al. 2006; Sugiyama and Ward-Thompson 2007; Wendel-Vos et al. 2007; Black and Macinko 2008; Sallis and Glanz 2009; Galvez et al. 2010). Recent epidemiological studies provide evidence of the positive relationship between health, well-being and green places (de Vries et al. 2003). Other studies also emphasize the importance of walkable green spaces for older people (Takano, Nakamura et al. 2002).

It has been shown that the physical environment can be modified in a number of ways to influence physical activity (Kent, Thompson et al. 2011). The scoping study by Abraham et al. (2010), referred to earlier, showed the way the urban landscape and environment is designed and built is crucial for the level of physical activity in daily life, work and leisure time (Frumkin et al. 2004; McCormack et al. 2004; Humpel et al. 2004a; Humpel et al. 2004b; Powell 2005). For example:

- It can be structured in ways that increase **opportunities** for, and reduce barriers to, physical activity.
- It can influence **travel behaviour**, including the levels of walking, cycling, public transport and car travel, as well as the amount of leisure time that is available for other healthy pursuits.
- It can increase opportunities for **recreational** activity, by providing useable open spaces, as well as streets conducive to walking and cycling.

Environmental attributes encouraging physical activity

A wide range of physical environment variables are known to promote and enable physical activity. These include:

- Good access to destinations, the presence of physical activity-promoting facilities, and the general functionality of urban districts (e.g. presence of footpaths, effective traffic regulation) (Pikora et al. 2003; Pikora et al. 2006).
- Design of bicycle and walking paths for better walkability and cycling (Frank and Engelke 2001; Craig et al. 2002; Cervero and Duncan 2003; Li et al. 2005).
- Land-use-mix, street connectivity, traffic safety (such as pedestrian friendly zones), and aesthetically appealing landscapes (French et al. 2001; Saelens et al. 2003; Humpel, Marshall et al. 2004a; Leslie et al. 2005; Titze et al. 2005).
- In terms of physical activity specifically undertaken in leisure time, location and infrastructure, such as presence of a park, safety, and the absence of traffic, have been found to play an essential role (Booth et al. 2000; Neff et al. 2000; Ball et al. 2001).
- Research has found that places for health-promoting physical activities should be made as user friendly as possible (Giles-Corti and Donovan 2002; Wendel-Vos, Droomers et al. 2007).

- In northern Europe forests play an important role in terms of outdoor physical activity outside cities, especially where people use forests for recreation and exercise (Pretty et al. 2005).
- In order to be perceived as an option for physical activity, rural green landscapes need to be aesthetically appealing to their users (Pretty, Peacock et al. 2005).
- Addy et al. (2004) found that people gain additional motivation for regular physical activity when they trust their neighbours, when they perceive their neighbours as active, and when they have the opportunity to use nearby parks, playgrounds and sport fields.
- It has been found that preferences, needs and ability to access places for physical activity vary according to gender, age and ethnic background (Eyler et al. 1998; Lee et al. 2001; Payne et al. 2002).

Research has focussed on the two main ways in which Green Infrastructure can be used to promote physical activity:

- 1) Access to open or green space.
- 2) Walkability of streets and other urban places.

These two topics are explored in the following sections.

3.3.3 Access to open space

According to Kent et al. (2011):

‘People with access to good quality and safe open space are more likely to be physically active for recreation’ and ‘The location and treatment of green and open spaces facilitate contact with nature, as well as contact with community’.

Physical activity and open space

There is evidence of links between levels of physical activity and living in proximity to open space (Wendel-Vos, Droomers et al. 2007; Sallis and Glanz 2009). Bauman and Bull (2007) reviewed 13 studies which in turn reviewed *‘environmental correlates of physical activity and walking in adults and children’*. The study found consistent associations between access, perceived safety and aesthetic features of parks and physical activity. Limitations identified in the review included a lack of standardization of measurement between studies, the wide variety of methods used and reliance on cross-sectional rather than longitudinal study design.

Black and Macinko (2008) cite a number of studies reporting that populations with better access to high quality open space are more likely to walk and undertake physical activity (Frank, Andresen et al. 2004; Ellaway, Macintyre et al. 2005; Giles-Corti et al. 2005; Mobley, Root et al. 2006).

Kaczynski and Henderson (Kaczynski and Henderson 2008) reviewed 50 quantitative studies and identified a positive association between provision of recreational spaces and physical activity. Bauman and Bull (2007) concluded that living near parks, playgrounds, and recreation areas is consistently

related to children's total physical activity. This is supported by a number of other studies (Davison and Lawson 2006; Dunton et al. 2010; Galvez, Pearl et al. 2010; Loukaitou-Sideris 2010).

Several studies show lower levels of obesity in greener neighbourhoods (Tilt et al. 2007; Bell et al. 2008). One study in Europe found that respondents living in greener neighbourhoods were 40% less likely to be overweight or obese (Ellaway, Macintyre et al. 2005). Similarly two studies in the Netherlands and the United States found an inverse relationship between body mass of children and exposure to green places, and that children were more likely to walk or cycle in greener environments (de Vries et al. 2007; Bell, Wilson et al. 2008).

Proximity to green places has also been correlated with longevity of senior citizens in Tokyo Japan (Takano, Nakamura et al. 2002). Another study in England found individuals below retirement age with greater exposure to green space had lower rates of mortality, including specifically from circulatory diseases (Mitchell & Popham 2008).

An Australian study found the presence of trees providing shade in open spaces was positively associated with an increased likelihood of being active (Timperio et al. 2008). While many further studies focus on green infrastructure in parkland settings, findings show streetscape greenery may be equally important (van Dillen et al. 2012).

Recent research published in the American Journal of Health Promotion explored the association between New York City residents' body mass index (BMI) and their access to neighbourhood parks, park quality, and park physical activity resources (Rundle et al. 2013). The results show that higher residential neighbourhoods access to large parks (greater than 6 acres) was associated with lower BMI scores. The researchers concluded that neighbourhood proximity to large park spaces was modestly associated with lower BMI in a diverse urban population.

In a recent study researchers used a simulation model to estimate the potential health benefits and cost-effectiveness of an urban regeneration project in Northern Ireland, the Connswater Community Greenway (Dallat et al. 2013). The researchers found that if 10% of those classified as 'inactive' (performing less than 150 minutes of moderate activity/week) became 'active', 886 incident cases (1.2%) and 75 deaths (0.9%) could be prevented with an incremental cost-effectiveness ratio of £4469/disability-adjusted life year. The researchers concluded that the greenway intervention could be cost-effective at improving physical activity levels. Although the direct health gains are predicted to be small for any individual, summed over an entire population, they are substantial. In addition, the Greenway is likely to have much wider benefits beyond health.

Design of open space

Research suggests that people have specific ideas about their ideal outdoor area for physical activity. Giles-Corti suggests that the conventional concept of open space (such as sporting ovals) should be adapted to include open areas with shade and landscaping and which encourage walking as well as

organised sport (Giles-Corti 2006b). Other literature suggests that the aesthetic quality of recreational areas is also important (Galvez et al. 2010). According to Kent et al. (2011):

'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'.

Levels of open space provision

Despite the strength of this research, a recent study undertaken by Searle (2009) concludes that the provision of local open space in a number of high density developments in Sydney is well below best practice recommendations. Other studies have shown that many city dwellers in socially deprived areas lack access to places for physical activity (Popkin et al. 2005; Coen and Ross 2006; Gordon-Larsen et al. 2006).

3.3.4 Walking and Cycling for Recreation

Recreational versus practical travel

Research suggests that the types of physical environment that encourage 'practical' walking and cycling (for example to work), are not necessarily the same as those that encourage walking and cycling for recreation purposes. Some of the factors relating to 'practical walking' include wider considerations of urban form, the design of pedestrian networks and the design of more 'walkable' neighbourhoods (ITE 2010). Southworth (2005) reviewed a number of pedestrian plans and concluded that walkable neighbourhoods are associated with improved physical and mental health, and increased community vitality. Southworth identified the common characteristics of walkable neighbourhoods, which comprised:

1. Connectivity.
2. Linkage with other modes.
3. Fine grained land use patterns.
4. Safety.
5. Quality of path (attention to details such as width, paving, landscaping and lighting).
6. Path context (the path context is visually stimulating to the pedestrian).

Saelens and Handy (2008) analysed 42 reviews of built environment 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.
- Recent evidence found a less consistent relationship between transportation walking and pedestrian infrastructure, such as sidewalk presence and condition, although pedestrian infrastructure was more consistently related to recreation walking.

- The evidence regarding children primarily relates to factors related to walking to school, and proximity, density, and the quality of the pedestrian infrastructure and traffic safety appear to play a role.

A study by Owen et al.(2007) investigated relationships between neighbourhood walkability and the walking behaviour of adults in Adelaide, South Australia. The study surveyed 2650 adults from different neighbourhoods in the city having either high or low walkability based on an objective walkability index. The researchers found a strong association between weekly frequency of walking for transport and the neighbourhood walkability index. The study confirms associations of neighbourhood walkability with walking for transport in an Australian context.

Some of the key attributes that encourage 'practical 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 be likely to encourage walking. Australian studies demonstrate that people will use walking trails if they are provided (Merom et al. 2008). A review by Kaczynski and Henderson (2008) on associations between parks and physical activity found that provision of open space was more positively correlated with walking for exercise than with recreation itself. According to Lee and Moulden (2004) evidence points to a latent demand for walking, suggesting an opportunity to increase walking through improved environments. Suggested improvements included increased land use intensity and mix along with investments in walking infrastructure, and greater focus by planners on enablers and constraints on walking.

The Green Infrastructure implications of the above research includes enhancing physical activity through:

- a) The provision of accessible **open space**.
- b) The provision of facilities for **recreational walking**, such as linear trails(see Figure13)
- c) Promoting transport walking by enhancing the **walkability** of streets and neighbourhoods with 'greening' improvements.



Figure 13: Windsor Street linear trail, Adelaide. By author.

3.4 Psychological health and well-being

3.4.1 Overview

As discussed in Section 3.2, psychological as well as physical health is an important component of human health and well-being, as is a generally positive sense of mental well-being. Abraham et al. (2010) identified the dimensions of mental well-being in the context of natural environments to include: attention restoration and recovery from mental fatigue; recovery from stress; and promotion of positive emotions. A large body of research emphasizes the social and psychological benefits of urban nature, urban greening and urban trees (Tarran 2006; Elmendorf 2008; Tarran 2009). Research has focused on three main areas:

- 1) The deeper psychological **attachment** of people to nature.
- 2) The benefits to human **health and well-being** of contact with nature.
- 3) The role of urban greening in **community** building.

Much of this research has been carried out by social researchers, particularly in the US. Early research was undertaken by Rachel and Stephen Kaplan, who continue to conduct ongoing research at the University of Michigan School of Natural Resources and Environment (Kaplan et al. 1998). Later research was conducted by Frances Kuo and others at the University of Illinois Landscape and Human Health Laboratory (LHHL) (Kuo et al. 1998). Specific research into the human benefits of the urban

forest has been carried out by urban forest researchers, including the work of the USDA Forest Service (Dwyer et al. 1991; Dwyer et al. 1992; Lewis 1996).

3.4.2 Attachment to nature

In 1929 American biologist E.O. Wilson, known as the ‘father of sociobiology’ coined the term ‘biophilia’ to describe humans’ subconscious attachment to the rest of life, and suggested that this had its origins in human evolution (Wilson 1984). Others consider this ‘biophilia hypothesis’ to be supported by evidence such as: human preferences towards nature (such as the popularity of landscape paintings); psychological well-being from exposure to nature; and even our history of gardening dating back to ancient times (Wilson 1984; Kellert 1997; Gullone 2000). Tarran (2006) emphasizes the fundamental psychological benefits of urban trees. She considers that, while there may be technological alternatives which can provide the same environmental benefits as trees (for example shading):

‘...as regards social and psychological benefits, it may be that our attachment is so deep that urban nature is essential and not easily substituted’ (Tarran 2006) p.59.

Ulrich (1986) conducted a literature review of studies looking at the emotional and psychological responses to different natural environments, and found that humans have a strong preference towards nature, especially when trees are present.

3.4.3 The restorative effects of nature

A number of researchers have investigated the therapeutic and restorative effects of nature, including ‘attention restoration’ theory and ability to recover from mental fatigue.

3.4.3.1 Attention restoration theory

Rachel and Stephen Kaplan have investigated ways in which the natural environment can foster people’s wellbeing and their ability to function effectively (Kaplan and Kaplan 1989; Kaplan 1995). Steven Kaplan’s ‘Attention Restoration Theory’ proposes that contact with nature engages our ‘involuntary attention’ giving our ‘directed attention’ (voluntary attention) the opportunity to rest, therefore helping to overcome the mental fatigue associated with continual directed attention (Kaplan 1995). The Kaplans have established four characteristics of such ‘restorative environments’ (Kaplan and Kaplan 1989; Kaplan 1995; Kaplan 1995b).

- First, restorative environments enable people to get some distance from their daily life.
- Second, they attract people’s attention without being exhausting.
- Third, they enable constant discovery of new things, mostly compatible with already existing information about the environment.
- Fourth, they are in line with the intentions of their users, i.e. the environment enables the users to do what they want to do.

Herzog et al. (1997) consider that these environments contribute to attention restoration through clarifying and ordering thoughts and encouraging reflection on personal goals and vital matters.

3.4.3.2 Stress reduction theory

'Stress reduction' theory is a different proposition from 'attention fatigue'. Stress reduction theory is closely related to the 'biophilia hypothesis' and is sometimes referred to as 'psycho-evolutionary theory'. Stress reduction theory proposes that natural environments promote recovery from stress while urban built environments hinder the same process (Velarde et al. 2007; Konijnendijk 2008). It is suggested that this is because the natural environment, in which humans evolved, does not require the processing of large amounts of information, therefore an individual's level of arousal or stress is reduced by spending time in natural settings (Ulrich 1979; Ulrich et al. 1991). Indicators for the positive effects due to nature have been measured, such as lower physiological excitation in terms of lower pulse rates and lower emotional arousal (Ulrich, Simons et al. 1991; Parsons et al. 1998; Laumann et al. 2003; Ulrich et al. 2003).

Ulrich examined the restorative effects of natural views on hospital patients, finding that those viewing natural scenes experienced a quicker recovery (Ulrich 1981; Ulrich 1984). A recent study by Raanaas et al (2012) also examined the health benefits of a bedroom window view to natural surroundings for patients undergoing a residential rehabilitation programme, using a longitudinal study methodology for studying 278 coronary and pulmonary patients. The subjects self-reported physical and mental health, subjective well-being, emotional states, use of the private bedroom and leisure activities. The research findings indicated that an unobstructed bedroom view to natural surroundings appears to have better supported improvement in self-reported physical and mental health during the residential rehabilitation programme, although the degree of change varied with gender and diagnostic group.

Ulrich et al. (1991) also showed that when people look at a natural landscape, immediate, unconsciously released emotional reactions significantly affect their stress recovery. While looking at a landscape that is perceived as pleasant, negative feelings and thoughts, which had been previously induced by negative stress exposure, were replaced by positive feelings (Hartig et al. 1996). This reaction has been found to occur when the landscape contains particular visual stimuli such as a moderate complexity and richness of natural elements like waters or vegetation. Hartig et al. (2003) pointed out that study participants taking a walk in the woods yielded lower emotional and physical stress levels when compared to those taking an urban walk. Contact with nature has also been shown to help drivers recover more quickly from stress and cope better with further stress (Parsons, Tassinary et al. 1998).

A study by Berman et al (2012) aimed to explore whether walking in nature may be beneficial for individuals with major depressive disorder (MDD). Healthy adults demonstrate significant cognitive gains after nature walks, but it was unclear whether those same benefits would be achieved in a depressed sample as walking alone in nature may induce rumination, thereby worsening memory and mood. Twenty individuals diagnosed with MDD participated in this study. At baseline, mood and short term memory span were assessed autobiographical event to prime rumination, prior to taking a 50-minute walk in either a natural or urban setting. After the walk, mood and short-term memory span were

reassessed. Participants exhibited significant increases in memory span after the nature walk relative to the urban walk, and also showed increases in mood, but the mood effects did not correlate with the memory effects, suggesting separable mechanisms. These findings extend earlier work demonstrating the cognitive and affective benefits of interacting with nature to individuals with MDD, indicate that interacting with nature may be useful clinically as a supplement to existing treatments.

New research at Edinburgh University supports the idea that spending time in green spaces reduces stress and brain fatigue (Aspinall et al. 2013). A body of literature on the restorative effects of nature focuses on the potential benefits to emotional recovery from stress offered by green space and 'soft fascination'. However, access to the cortical correlates of emotional states of a person actively engaged within an environment has not been possible until recently. What makes this study different from earlier research is that it looks at real-time data from the brains of people while they were actually outside, moving through the city and the parks. This study makes use of a recently developed lightweight, portable version of the electroencephalogram (EEG) as a method to record and analyse the emotional experience of a group of walkers in three types of urban environment including a green space setting. Using Emotiv EPOC (a low-cost mobile EEG recorder) participants took part in a 25 minute walk through three different areas of Edinburgh. The areas (of approximately equal length) were labelled zone 1 (urban shopping street), zone 2 (path through green space) and zone 3 (street in a busy commercial district). The equipment provided continuous recordings from five channels, labelled excitement (short-term), frustration, engagement, long-term excitement (or arousal) and meditation. A new form of high-dimensional correlated component logistic regression analysis showed evidence of lower frustration, engagement and arousal, and higher meditation when moving into the green space zone; and higher engagement when moving out of it. The researchers found systematic differences in EEG recordings between three urban areas in line with restoration theory. The researchers concluded that this has implications for promoting urban green space as a mood-enhancing environment for walking or for other forms of physical or reflective activity.

Green settings have also been found to have positive effects on young people with Attention Deficit Hyperactivity Disorder (ADHD) (Faber Taylor and Kuo (2001); Faber Taylor and Kuo 2009; Faber Taylor and Kuo 2011).

3.4.3.3 Studies on the restorative powers of nature

A number of research studies demonstrate the restorative powers of nature, including both the experience of views of nature, or actual interaction with nature itself. The following examples are drawn from a diverse range of studies.

View from a hospital window

One of the best known studies of the restorative powers of nature was by Roger Ulrich who showed that abdominal surgical patients had shorter post-operative hospital stays when in a room looking out

on a stand of trees (Ulrich 1984). Shortening hospital stays by 8.5% as reported would also have annual cost savings of several hundred million dollars (Ulrich 1986).

Views of nature from a prison

Moore (1981) found a significant reduction in the use of health services by prisoners with exterior views to farmland from their cells.

View of nature from the workplace

Rachel and Steven Kaplan found that nearby nature, even viewed from a window, had substantial benefits in work settings including increased job satisfaction and well-being (Kaplan et al. 1988; Kaplan 1993).

Recovery from mental fatigue

A number of studies have found that contact with nature in various forms aids recovery from mental fatigue and promotes enhanced cognitive functioning (Kuo and Sullivan 2001).

Residential settings

Several studies have examined the benefits of contact with nature in residential environments (Faber Taylor et al. 2002). Reported benefits include:

- Increased residential satisfaction (Kaplan 1985).
- Enhanced well-being (Kaplan 2001).
- More effective patterns of coping (Kuo 2001a).
- Greater day-to-day effectiveness (Tennessen and Cimprich 1995).

Children and greener housing

One study found that children moving from poor housing, to housing with improved 'greenness', experienced improved cognitive functioning (in terms of attentional capacity) (Wells 2000).

Access to nearby nature

Research has found that parks provide refuges for privacy, away from the home and the work environment, and that people visiting these areas for privacy nominated 'reflective thought' as the most important reason for visiting (Hammitt 2002).

Restorative effects of natural landscapes

A number of studies emphasize the fact that natural landscapes are more restorative than urban ones. Hartig et al. (2003) showed that walks in natural landscapes have a stronger positive effect on the ability to concentrate than urban walks. This is supported by other studies that suggest people prefer natural landscape (such as beaches, waters, forests, parks, and mountains) for recovery from mental fatigue (Korpela and Hartig 1996; Korpela et al. 2001; Staats et al. 2003; Staats and Hartig 2004). A study by Herzog et al. (1997) in which participants rated the perceived restorative effectiveness of three kinds of

settings (ordinary natural, sports/entertainment, and everyday urban) suggests that natural settings have a high restorative potential, public open spaces used for public entertainment and sports have an intermediate restorative potential, and urban settings have a low restorative potential. The restorative potential of natural landscapes was also demonstrated in an experimental study by Berto (2005) in which exposure to pictures of natural landscapes had a restorative effect on mental fatigue in students. Such results are in line with findings of two earlier studies, which measured the effect of a view of a landscape on concentration (Tennessen and Cimprich 1995; Kuo 2001a).

The scoping study by Abraham et al (2010) also identified the importance of low sound levels for rest and relaxation: people who have easy access to green areas can reduce noise annoyances and thus become more relaxed (Gidlof-Gunnarsson and Ohrstrom 2007). A number of other studies have found that trees and other greenery in urban areas reduce stress and improve physical and psychological health (de Vries, Verheij et al. 2003).

3.4.3.4 The research of Kuo, Sullivan and others

At the University of Landscape and Human Health Laboratory, Kuo, Sullivan and others are currently researching inner-city residents' responses to trees and other vegetation and the ways in which the physical and psychological health of individuals and communities can be improved with enhanced access to nearby nature and natural views (<http://lhhl.illinois.edu/research.htm>). Kuo (2001a) suggests that nature may be an essential component of the human habitat, as evidenced by the apparent effects of nature on health and well-being criteria such as blood pressure, heart rate, mood, day-to-day effectiveness, social behaviour, cognitive functioning and work performance. According to Kuo(2001a, p29), *'Regular contact with nature may be as important to our psychological and social health as the regular consumption of fruit and vegetables is to our physical health'* p.29. She recommends that:

- 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.

Research at the Landscape and Human Health Laboratory is summarised below under the following six themes.

Green Play Settings Reduce ADHD Symptoms

The Landscape and Human Health Lab's research has shown that performing activities in green settings can reduce children's Attention Deficit-Hyperactivity Disorder symptoms. In an initial survey, parents of children with ADHD were more likely to nominate activities that typically occur in green outdoor settings as being best for their child's symptoms, and activities that typically occur in indoor or non-green outdoor settings as worst for symptoms. Also, parents rated their child's symptoms as better,

on average, after activities that occur in green settings than after activities in non-green settings (Faber Taylor, Kuo et al. 2001).

In the subsequent, nation-wide survey, parents again rated leisure activities, such as reading or playing sports, as improving children's symptoms more when performed in green outdoor settings than in non-green settings (Kuo and Faber Taylor 2004). A more recent study tested children with ADHD in a controlled setting after they had walked in one of three environments that differed from one another in the level of greenery: a park, a neighbourhood, and a quiet downtown area. The findings confirmed that the attention of children with ADHD functions better after spending time in more natural settings (Faber Taylor and Kuo 2009). The authors concluded that the research findings suggest adding trees and greenery where children spend a lot of time, such as near homes and schools, and encouraging children with ADHD to play in green spaces may help supplement established treatments to improve their functioning

Views of Greenery Help Girls Succeed

In a study conducted in a Chicago public housing development, girls who lived in apartments with greener, more natural views scored better on tests of self-discipline than those living in more barren but otherwise identical housing. The study tested children on three component abilities of self-discipline: concentration, inhibition of impulsive behaviour, and delay of gratification. Girls with green views scored higher on average than girls with less green views on all three tests. Boys showed no link between test scores and the amount of nature near home. The researchers suggested that this may be because they spend less time playing near home and are then less affected by the environment around it (Faber Taylor et al. 2002).

Adding Trees Makes Life More Manageable

In a study conducted in a Chicago public housing development, 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. In addition, the women in greener surroundings found their problems to be less difficult and of shorter duration. The authors concluded that trees may help poor inner city residents cope better with the demands of living in poverty, feel more hopeful about the future, and manage their most important problems more effectively (Kuo 2001a).

Vegetation May Cut Crime in the Inner City

In a 2001 study in a Chicago public housing development, dramatically fewer occurrences of crime were observed against both people and property in apartment buildings surrounded by trees and greenery than in nearby identical apartments that were surrounded by barren land (Kuo and Sullivan 2001). Compared with buildings that had little or no vegetation, buildings with high levels of greenery had 48 percent fewer property crimes and 56 percent fewer violent crimes, and even modest amounts of greenery were associated with lower crime rates. Kuo suggests that greenery can lower crime through

several mechanisms. First, greenery helps people to relax and renew, reducing aggression. Second, green spaces bring people together outdoors, increasing surveillance and discouraging criminals. Relatedly, the green and groomed appearance of an apartment building is a cue to criminals that owners and residents care about a property and watch over it and each other.

Trees Linked with Less Domestic Violence in the Inner City

In a study conducted in a Chicago public housing development, women who lived in apartment buildings with trees and greenery immediately outside reported committing fewer aggressive and violent acts against their partners in the preceding year than those living in barren but otherwise identical buildings. In addition, the women in greener surroundings reported using a smaller range of aggressive tactics during their lifetime against their partner (Kuo and Sullivan 2001a).

Where Trees are Planted, Communities Grow

It appears that residential common areas with trees and other greenery help build strong neighbourhoods. In a study conducted at a Chicago public housing development, 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, Sullivan et al. 1998).

Kuo explains this link between landscaping and stronger ties between residents and their neighbourhood. When the spaces next to residences are green, they are both more attractive and more comfortable, drawing people to them. Such settings support frequent, friendly interaction among neighbours, the foundation of neighbourhood social ties. These ties are the heart of a neighbourhood's strength, encouraging neighbours to help and protect each other. Sharing resources with and depending upon neighbours may be especially crucial to impoverished inner-city families, so it is especially important to plant and maintain trees in such neighbourhoods.

The Landscape and Human Health Lab also currently has a new project in progress. *The Capacity to Learn* study will examine the effects of schoolyard nature on children's learning and academic achievement as reflected in standardized test scores. The study aims to document whether children learn more in green school settings.

3.4.3.5 Crime reduction

There is longstanding belief that vegetation encourages crime as it can conceal criminal activity. Recent studies, however, have suggested the opposite (Troy et al. 2012) and have shown that urban residential areas with well-maintained vegetation experience lower rates of certain crime types due to increased surveillance in vegetated spaces as well as the therapeutic effects ascribed to vegetated landscapes. Kuo and Sullivan (2001) argue that the presence of vegetation, particularly in public spaces, can deter crime by encouraging greater use of public space, thereby providing greater social supervision which

acts to suppress criminal activity. In addition, Kaplan (1987) suggests that vegetation may have a mentally restorative effect that reduces the psychological precursors to criminal acts, particularly for violent crimes.

A recent research project (Wolfe and Mennis 2012) analysed the association of vegetation with crime in a case study of Philadelphia, Pennsylvania. The researchers examined rates of assaults, robberies, burglaries, and thefts in relation to remotely sensed vegetation abundance. The results indicated that vegetation abundance was significantly associated with lower rates of assault, robbery, and burglary, but not theft. This research has implications for urban planning policy, especially as cities are moving towards 'green' growth plans which must look to incorporate sustainable methods of crime prevention into city planning.

Troy et al (Troy et al. 2012) examined the extent to which urban tree cover influences crime, a subject of debate in the literature. This research took advantage of geocoded crime point data and high resolution tree canopy data in Baltimore City and County, MD, an area that includes a significant urban–rural gradient. The researchers found that there is a strong inverse relationship between tree canopy and their index of robbery, burglary, theft and shooting. The more conservative spatially adjusted model indicated that a 10% increase in tree canopy was associated with a roughly 12% decrease in crime. The relationship continued for both public and private ownership, but the magnitude was 40% greater for public than for private lands. These results do not establish causality, but suggest a strong need for further research to determine the role of vegetation in mediating crime.

3.4.3.6 Proximity to green space

Findings from previous research suggested a correlation between green space and well-being, but those studies were not able to rule out the possibility that people with higher levels of well-being simply move to greener areas. Recent research by White et al (2013) at the European Centre for Environment & Human Health at the University of Exeter Medical School, attempted to advance the field by using by using 'panel' data from a national longitudinal survey of households in the United Kingdom, which collected data annually from over 10,000 people between 1991 and 2008. The data was used to explore the relationship between urban green space and well-being (indexed by ratings of life satisfaction) and between urban green space and mental distress (indexed by General Health Questionnaire scores) for the same people over time. Controlling for individual and regional variation the researchers found that, on average, individuals have both lower mental distress and higher well-being when living in urban areas with more green space. According to the researchers (p.920): *'Living in an urban area with relatively high levels of green space compared to one with relatively low levels of green space was associated with a positive impact on well-being equivalent to roughly a third of the impact of being married vs. unmarried and a tenth of the impact of being employed vs. unemployed'*.

Researchers found that individuals reported less mental distress and higher life satisfaction when they were living in greener areas. This association held even after the researchers accounted for changes in participants' income, employment, marital status, physical health, and housing. Key findings included:

Green Infrastructure Project

- As green space increased within a 2.5-mile radius of where they lived, overall well-being increased proportionally. Specifically, life satisfaction increased by 2% and psychological distress decreased by 4%.
- In relative terms, living in a greener area was associated with mental health gains about 35% as significant as those one gets from being married. It was 12% as beneficial to mental health as being employed.
- In terms of 'life satisfaction', the effect was equal to 28% that of being married and 21% that of being employed.

The research does not prove that moving to a greener area will necessarily cause increased happiness, but it does fit with findings from experimental studies showing that short periods of time spent in a green space can improve people's mood and cognitive functioning. Although effects at the individual level were small, the potential cumulative benefit at the community level highlighted the importance of policies to protect and promote urban green spaces for well-being.

3.4.3.7 *Evoking positive emotions*

Studies suggest that views of a natural landscape enable people to express positive feelings such as joy and satisfaction more easily (Hartig et al. 1999). (Kaplan 2001; Korpela et al. 2002). Open and accessible forests are suggested to enhance positive emotions more than dense and less accessible forests (Staats et al. 1997; Milligan and Bingley 2007). With respect to the general positive impacts on mood, Cackowski and Nasar showed that a pleasant landscape contributes to higher frustration tolerance (Cackowski and Nasar 2003).

3.4.3.8 *Ability to escape*

The ability to 'escape' the urban environment to experience nature is also an important consideration. Guite et al. (2006) measured the impact of physical and social factors in the built environment on the mental health of 2,696 adults in higher density areas in London. The researchers found that the perceived ability to escape to green spaces away from noise and over-crowding was significantly linked to mental well-being. In Sweden Gidlöf-Gunnarsson and Öhrström (2007) used questionnaires to assess the role of nature in providing escape, rest and relaxation for a sample of people living in high density developments that were either noise-affected or noise-unaffected. It was concluded that easy access to nearby green areas can offer relief from long term noise annoyances and reduce the prevalence of stress related psychological symptoms.

3.4.3.9 *Future discounting*

A recent study investigated the relationship to exposure to nature, and the human tendency to 'discount the future', which acts as an important barrier to enduring behavioural change (van der Wal et al. 2013). The study drew on evolutionary theories of life history and biophilia. The results of three studies, two

laboratory experiments and a field study reveal that individual discount rates are systematically lower after people have been exposed to scenes of natural environments as opposed to urban environments. The finding that nature exposure reduces future discounting was considered to have important implications for a range of personal and collective outcomes including healthy lifestyles, sustainable resource use and population growth.

3.4.3.10 Social interaction

As discussed earlier, research by Kuo and others has shown that the presence of nature, including housing areas with trees and greenery, can enhance the physical and social health of individuals and communities, including reducing aggression and crime. It can increase feelings of safety, as well as reducing vandalism and littering (Coley et al. 1997; Kuo et al. 1998a; Herzog and Chernick 2000; Kuo and Sullivan 2001; Kuo and Sullivan 2001a; Kuo 2003). The presence of vegetation, such as greenery and trees, has also been found to increase social interaction in urban neighbourhoods (Kuo, Sullivan et al. 1998). This does not necessarily imply a direct cause and effect between urban nature and human behaviour, but rather a consequence of enhanced social interaction opportunities in urban green spaces (Elmendorf 2008). Trees and greenery increase the attractiveness of places for people, in turn promoting community socialization and passive surveillance, which can reduce crime and increase personal safety (Coley, Kuo et al. 1997; Kuo and Sullivan 2001; Kuo 2003).

3.4.4 Community and identity

3.4.4.1 Sense of community and physical/mental health

The relationships between human health and well-being, and social interaction and sense of belonging to a community, have been well researched and are now widely accepted (Kent, Thompson et al. 2011). It has been shown that people develop a sense of community when they feel part of a group (Butterworth 2000). This sense of community includes feelings of social connection and belonging, which have been identified as influential determinants of mental and physical health (Baum and Ziersch 2003; Ogunseitan 2005; Baum et al. 2006; Poortinga et al. 2007; Cohen et al. 2008; Echeverría, Diez-Roux et al. 2008).

3.4.4.2 Social interaction and the physical environment

The built environment, including the presence of Green Infrastructure, can foster a sense of community through enabling day to day interactions with other people, and with nature. According to a number of authors, urban parks and other public places can enhance social integration if they facilitate factors such as: social contacts, exchange, collective work, community building, empowerment, social networks and mutual trust (Armstrong 2000; Leyden 2003).

Being 'out and about'

As well as being socially connected to others, a sense of belonging has been found to foster perceptions of security, confidence and comfort which can encourage people to be 'out and about', and physically active in their neighbourhood, (Baum, Jolley et al. 2006; McNeill, Kreuter et al. 2006; Michael et al. 2006; Wood, Frank et al. 2010; Kent, Thompson et al. 2011). Being 'out and about' also increases

opportunities for incidental social interactions. Incidental interaction has been shown to have a number of benefits including: augmented connection and caring, increased perceptions of safety and decreased feelings of loneliness and isolation, all of which have well-established links with mental health (Maas et al. 2009a; Maas et al. 2009b; Berry and Welsh 2010; Yang and Matthews 2010).

In the Netherlands, Maas et al. (2009a) explored the hypothesis that green space improves health primarily through fostering of increased social contact. The researchers found an inverse relationship between green space in people's living environment and feelings of loneliness, with less green space being associated with a perceived shortage of social support. Cohen et al. (2008) analysed data from the Los Angeles Family and Neighbourhood Study (LAFANS) to identify the social and environmental features, including the presence of parks, which were associated with personal reports of 'collective efficacy'. The study found that parks were positively associated with 'collective efficacy.' The authors concluded that parks set the scene for neighbourhood social interactions, creating a foundation underlying positive health and well-being.

3.4.4.3 Social capital

In a recent study researchers from the State University of New York identified statistical relationships between green space characteristics, including neighbourhood tree canopy, and an individual's social capital, or the value inherent in neighbourhood social connections (Holtan, Dieterlen et al. 2014). Statistical analysis showed that tree canopy added a 22.72% increase in explanatory power to the model for social capital. The mechanism by which tree canopy facilitates increased levels of social capital is likely through driving increased use of sidewalks and outdoor spaces with trees. The researchers concluded that trees are a relatively inexpensive and easy intervention to enhance the strength of social ties among neighbours.

3.4.4.4 Specific demographic groups

The aged and migrants

The socially integrative functions of landscape have been found in studies of elderly people (Kweon et al. 1998; Booth, Owen et al. 2000; Milligan et al. 2004) and of migrant groups (Rishbeth and Finney 2006). Research by Inclusive Design for Getting Outdoors (IDGO 2012) has found that the design of Britain's gardens, streets, neighbourhoods and open spaces affects older people's ability to age well and live independently by supporting, or preventing, access for all. People who do not find it easy or enjoyable to 'get outdoors' can spiral into poor physical health, have reduced social contact with others and a lower quality of life overall. If older people live in an environment that makes it easy and enjoyable to go outdoors, they are more likely to be physically active and satisfied with life and twice as likely to achieve the recommended levels of healthy walking. The authors conclude that: *'If an older person cannot get out and about locally, they are at risk of becoming 'a prisoner in their own home'.*

According to Catherine Ward Thompson (2011) in the UK, for older people, access to attractive outdoor places in the local neighbourhood is associated with multiple benefits (Sugiyama and Ward-Thompson 2007) including more walking (Li et al. 2005; Sugiyama, Leslie et al. 2008) which is known to enhance health and functioning (Weuve et al. 2004; Simons and Andel 2006) and longevity (Takano, Nakamura et al. 2002). At the same time, a combination of decreasing functional capability and barriers in the environment may act as deterrents to outdoor activity for older adults (Lawton 1986). Sugiyama and Ward-Thompson (2007) found that parks were integral to interaction in an elderly cohort of UK residents. The authors reviewed recent literature in gerontology, public health, environmental psychology, landscape architecture, and urban design, and found that the supportiveness of neighbourhood environments that make outdoor activity such as walking easy and enjoyable, is conducive to a better quality of life for older people. The aesthetic qualities of open space, ease and safety of access, and the opportunities it offers for social interaction, were found to be important predictors of both quality of life and levels of physical activity (especially walking) for older people.

With respect to migrants, Rishbeth and Finney (2006) investigated migrants' perceptions and experiences of 10 urban green-spaces in Sheffield in the UK. The research used innovative participatory and visual (photography) methods. The participants were all asylum seekers and refugees from Asia and Africa. The research examined how and why participants engaged or disengaged with local green-space. The authors concluded that a positive impression of the local environment and meaningful participation in it can assist with integration into a new society. Furthermore, recognition of familiar landscape elements can provide a conceptual link between former and new homes. However, for this specific refugee group many physical and psychological barriers needed to be overcome for the full benefits of urban public open space to be realised

Children

In Melbourne Maller et al. (2010) interviewed informants in 12 primary schools to identify ways to enhance the frequency of chance encounters with nature by children. Learning activities such as tending gardens with vegetables, flowers, and native plants, and practising habitat conservation as well as caring for animals, were all observed by interviewees as benefiting children's health and well-being, particularly their mental health. According to the authors *'In the high-rise developments studied, residents were found to prefer natural scenery such as trees, parks, or bodies of water, rather than images of the built form, noting that the views of nature evoked feelings of relaxation and resulted in self-perceptions of higher well-being'* p.555. Wake (2007) described ways to encourage the involvement of children in natural spaces, including gardens. Johnson (2007) also examined the importance of facilitating children's incidental interaction with nature through environmental learning activities.

3.4.4.5 Desirable attributes of social public space

The literature suggests that urban landscapes should provide a sufficient level of safety, attractiveness and walkability, and should serve multiple purposes (Baum and Palmer 2002; Leyden 2003). They should also be rich in vegetation to promote social integration (Coley, Kuo et al. 1997; Kuo, Bacaicoa et al. 1998a; Sullivan et al. 2004).

3.4.4.6 Community gardening

An important role of community gardens is that of promoting social interaction for a range of demographic groups. According to Kent et al. (2011) '*Community gardens are forums for incidental and organised interaction. They are spaces for people to establish and maintain contact with community and contact with nature*' p.81. The health-promoting impact of community gardening was addressed in a recent article. Among other benefits, community gardening was found to foster the development of community networks and social support and to motivate people towards community engagement (Wakefield et al. 2007). This research complemented findings from earlier studies regarding the health benefits of community and private gardens (Irvine et al. 1999; Armstrong 2000; Brown and Jameton 2000; Hancock 2000; Doyle and Krasny 2003; Twiss et al. 2003; Waliczek et al. 2005). In a comprehensive study of the community garden movement in the UK, Holland (2004) using both quantitative and qualitative methods, concluded that while some gardens played a strategic role in food production, all gardens were '*based in a sense of community, with participation and involvement being particularly strong features*' p.1.

Bartolomei et al. (2003) examined the social and health-promoting roles of a community garden scheme in a high-rise public housing estate in Sydney. The findings confirmed the role of community gardens in strengthening social interaction. The scheme was associated with increased opportunities for local residents to socialise and develop vital cross-cultural ties in a very diverse environment. The authors noted that: '*there were many stories of how participating in the Gardens has helped to diminish cultural boundaries and negative racial stereotypes*' p.5. Thompson et al. (2007) also note that '*Community gardens can play a significant role in enhancing the physical, emotional and spiritual well-being necessary to build healthy and socially sustainable communities*' p. 1034. Kingsley et al. (2009) studied community gardens in Melbourne. The authors described community gardens as places of refuge and social support, where knowledge is shared. These conclusions are generally supported by other studies indicating that the benefits of community gardens extend well beyond physical activity and access to healthy food (Hynes and Howe 2004; Thompson, Corkery et al. 2007; Wakefield et al. 2007; Macias 2008; Teig et al. 2009).

3.5 Benefits to children

3.5.1 Overview

The benefits of nature to children, and the role of nature in childhood development, have become significant research topics in recent years, due to links between the dramatic increase in childhood physical and mental health problems, and the decline in children's interaction with natural environments. Figure 14 summarizes the ways in which children's health and well-being can be influenced by contact with nature.

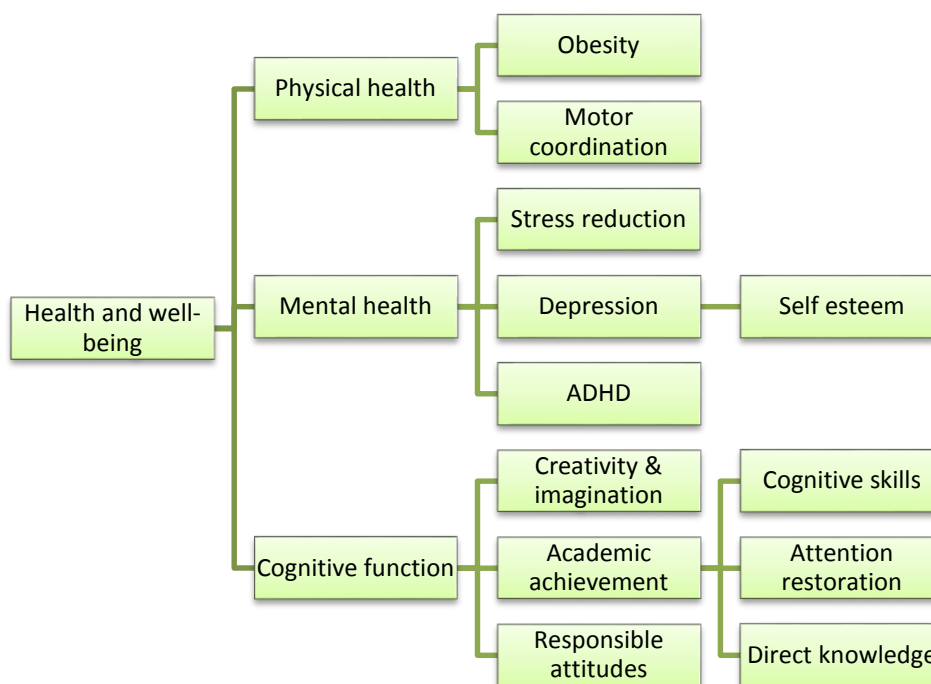


Figure 14: Summary of benefits to children of interaction with nature. By author.

Nature, in the form of Green Infrastructure, has been found to contribute to a child's physical health, mental health and general cognitive functioning.

- **Physical health.** Playing in natural settings can help reduce childhood obesity, and improve motor coordination.
- **Mental health.** Playing in, or exposure to natural settings can improve children's mental health in a number of ways, including relieving stress, combating depression through building self-esteem, and dealing with the symptoms of ADHD.
- **Cognitive function.** It has also been shown that interaction with nature can improve a child's overall cognitive functioning. This includes the fostering of creativity and imagination, and of the cognitive abilities required in the school classroom, such as general cognitive skills, ability to concentrate through 'attention restoration', and the gaining of direct knowledge of the natural world. Lastly engagement with nature while young appears to assist in the development of responsible attitudes to the environment in later adult life.

A study commissioned by Planet Ark in 2012, *Planet Ark Planting Trees*, investigated 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 revealed an emerging body of evidence 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'* p.2. The study also included attitudinal research into how Australians perceive the link between nature and children's health, wellbeing and development.

3.5.2 Children's health issues

Children's health trends

Despite Australia's high standard of living and outdoor climate, emerging physical and mental health epidemics have been observed among Australian children in the last few decades. Nearly a quarter of Australian children have been found to be overweight or obese (Australian Government Department of Health and Ageing 2008). Obesity itself is linked to other health problems and also increases the likelihood of health issues in later adulthood, including type 2 diabetes. Public health authorities have warned that Australia is facing a 'chronic disease time bomb' (Malkin 2011). There are also growing concerns for childhood mental health, and it has been shown that 14% of Australian children have been diagnosed with a mental health disorder. Attention deficit hyperactivity disorder (ADHD) is characterised by inattentiveness, impulsiveness, and hyperactivity. While it is accepted by the medical profession that ADHD does exist, there is still disagreement about the number of people affected. In Australia, the Child and Adolescent Component of the National Survey of Mental Health and Well-being reported ADHD to be present in 11% of children and adolescents, primarily in boys (Sawyer et al. 2000). According to the Australian Guidelines on Attention Deficit Hyperactivity Disorder (ADHD) (Royal Australasian College of Physicians 2009) 5%-10% of the Australian population is diagnosed with ADHD.

Children's lifestyle changes

The rise in childhood obesity and mental health issues in the last 20 years has been linked to dramatic lifestyle changes. Researchers by Planet Ark (2012) has documented these changes including:

- **Indoor rather than outdoor play.** Children now spend significantly more time inside, rather than outside playing and interacting with nature, than in the 1980s (Hofferth and Curtin 2003; Clements 2004; Louv 2005).
- **Structured rather than self-directed play.** Children today engage in different outdoor activities compared with the previous generation. This includes increased time spent in activities which are structured or arranged by adults, and increased time in adult-supervised sport. This coincides with a significant decrease in the time spent by children in self-directed activities such as climbing trees or exploring natural settings (Clements 2004).
- **Changes to housing.** The traditional house and garden on a quarter acre block is now being replaced with a trend towards larger houses on smaller blocks, usually with little garden space, with low maintenance gardens or no gardens at all being favoured by 'time-poor' parents. The emphasis on leisure activities has also shifted from outdoor to indoors and new homes are often equipped with large indoor spaces for the latest technology such as 'home theatres' and computer games (Hamilton and Denniss 2005; Hall 2008; Hall 2010).
- **Urban densification.** Cities are becoming denser due to urban infill of existing suburbs, and denser new housing developments, often promoted for reasons of the supposed increased sustainability of more compact urban developments. However this comes at the expense of private and public green spaces, that once provided the settings for nature based play (Kinner and Wilson 2011).

- **Fear.** Society has seen a heightened fear of 'stranger danger', either real or perceived, which has decreased parents' willingness to allow their children to engage in unsupervised outdoor play. At the same time, changing work patterns have reduced the time that many parents can spend with their children in outdoor activities (Clements 2004).
- **Electronic media.** Children are now spending more time using the various forms of electronic media (Australian Government Department of Health and Ageing 2008). Research suggests that video games can be particularly addictive (Phillips et al. 1995). In addition, television and electronic games have become attractive 'baby sitters' that require little adult supervision.
- **Gadgets.** Research has shown that time spent playing with gadgets can come at the expense of time spent interacting with other family members and participating in creative or outdoor play (Koger and Winter 2010). Researchers have linked this 'nature and culture deprivation' with electronic media use (Brook 2010).
- **Materialism.** Researchers have suggested that increased television watching and sedentary lifestyles can increase 'materialism and consumerism' among children which in turn has a negative influence on their physical health, for example by consuming 'junk food' (Koger and Winter 2010).

3.5.3 Trends in children's play

Research by Planet Ark

The 2012 study by Planet Ark, which explored people's perceptions of the link between nature and children's health, wellbeing and development, included a survey of 1006 Australians aged 18-85 (Planet Ark 2012). In the survey respondents reported on the activities undertaken by the children under their care. (see Figure 15). Playing in the backyard or an urban park was the most recent and common outdoor, nature-based activity reported by carers. Other findings reflect the changes in lifestyles identified above, including:

- 25% of carers said the children in their care have never climbed a tree.
- 26% of carers said the children in their care have never been bushwalking.
- 17% of carers said the children in their care have never visited a national park.
- 11% of carers said the children in their care have never been to the zoo.
- 39% of carers said the children in their care have never been camping.

When did the child(ren) under your supervision most recently do the following? (%)

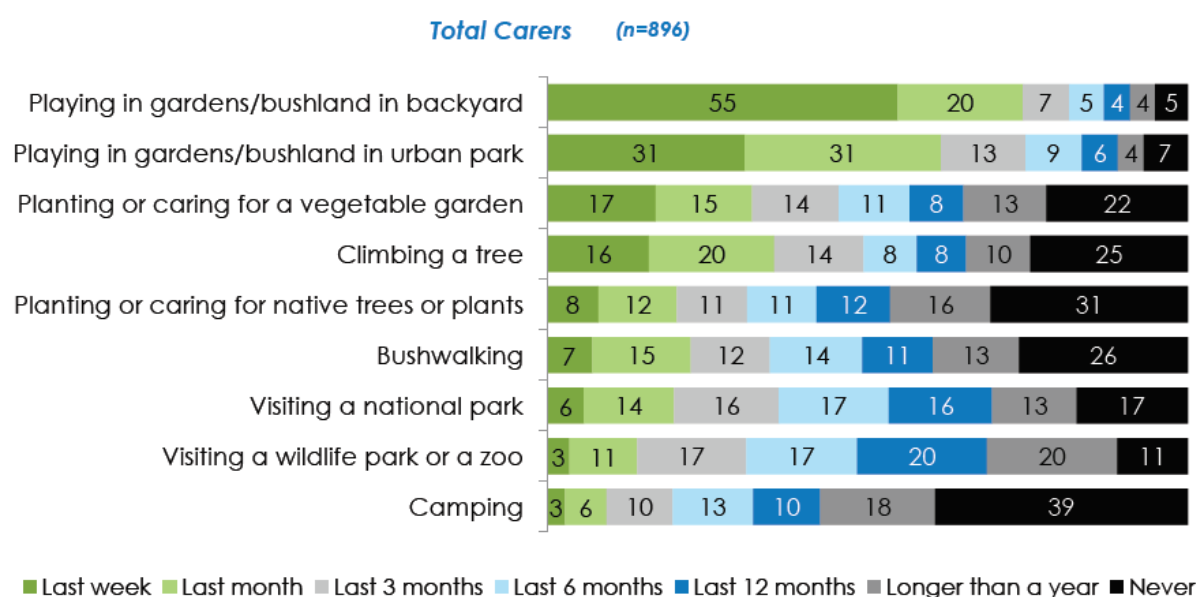


Figure 15: Children's most recent outdoor nature based activity as reported by their carers. Source: (Planet Ark 2012).

A 2004 study in the US, *An Investigation of the Status of Outdoor Play*, looked at the extent to which children in the US 'today' participate in active, outdoor play, compared with the previous generation (Clements 2004). The study surveyed 830 mothers across the US with children between the ages of 3 and 12, and compared the mothers' active outdoor play experiences as a child, with their children's current reported play experiences. The study found that children 'today' spend considerably less time playing outdoors than their mothers did as children. The study identified several fundamental reasons for this decline, including dependence on television and digital media, and concerns about crime and safety.

In 2011 Planet Ark commissioned an independent study, *Climbing Trees: Getting Aussie Kids Back Outdoors*, to investigate children's interaction with nature, and how this interaction may be changing between generations (Planet Ark 2011). The study was based on an online survey of a representative sample of 1,002 Australians aged 14-65 years, who reported on their children's play behaviour, and their own play behaviour as a child. The research produced similar results to the earlier 2004 US research, and the key findings are discussed below.

The Decline in Outdoor Play in Australia

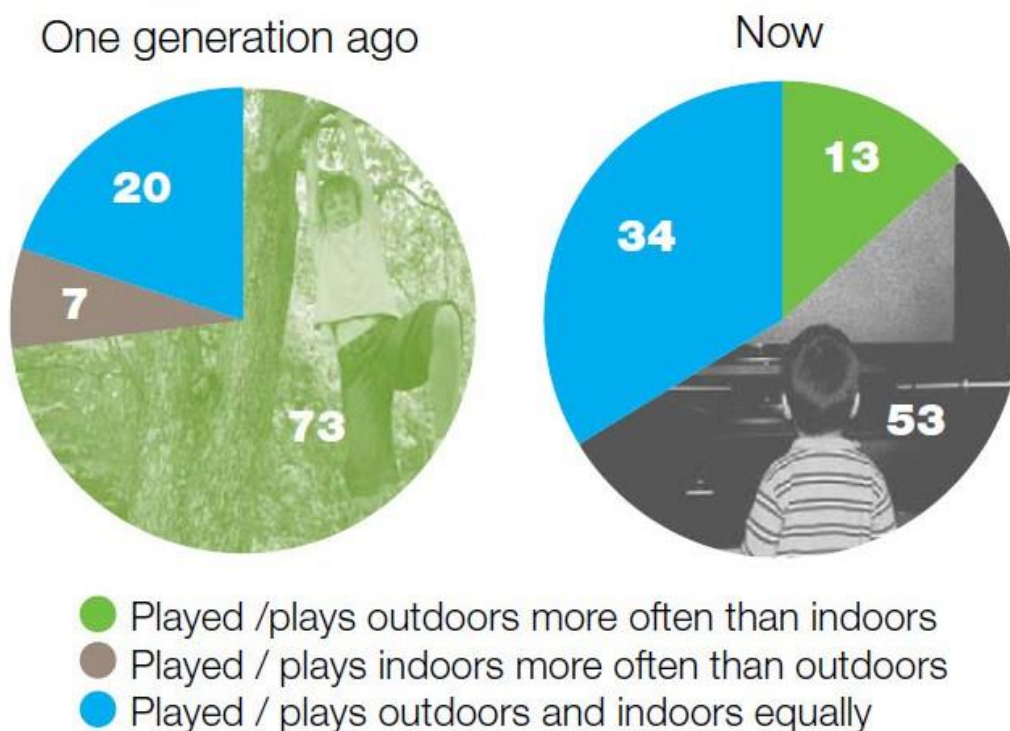
'Australia is a nation defined by its outdoor environments – the red centre, golden beaches, the bush and clear blue seas. However, our research reveals that one in ten Aussie kids plays outside once a week or less. We have become a nation of indoors, not outdoors'.

'The landscape of childhood has changed. In a single generation, we have seen a profound shift from outdoor to indoor play, with 73% of respondents indicating that as children they played outdoors more often than indoors compared to only 13% of their kids. Additionally, 72% of survey respondents indicated that they played outside every day when they were young compared to only 35% of their children'.

Source: (Planet Ark 2011) p.5.

The research shows that there has been 'a dramatic shift in childhood play activity in the space of just one generation' from outdoor play to indoor activities(see Figure 16) For example:

- 73% of respondents played outdoors more often than indoors when they were young compared with only 13% of their children.
- 72% of respondents played outside every day as children compared with only 35% of their children.
- One in 10 children today plays outside once a week or less.



Base is those who have any child currently aged between 3-12 years, n=246

Figure 16: Kids' level of outdoor vs. indoor activity now compared with previous generation. Source: (Planet Ark 2011).

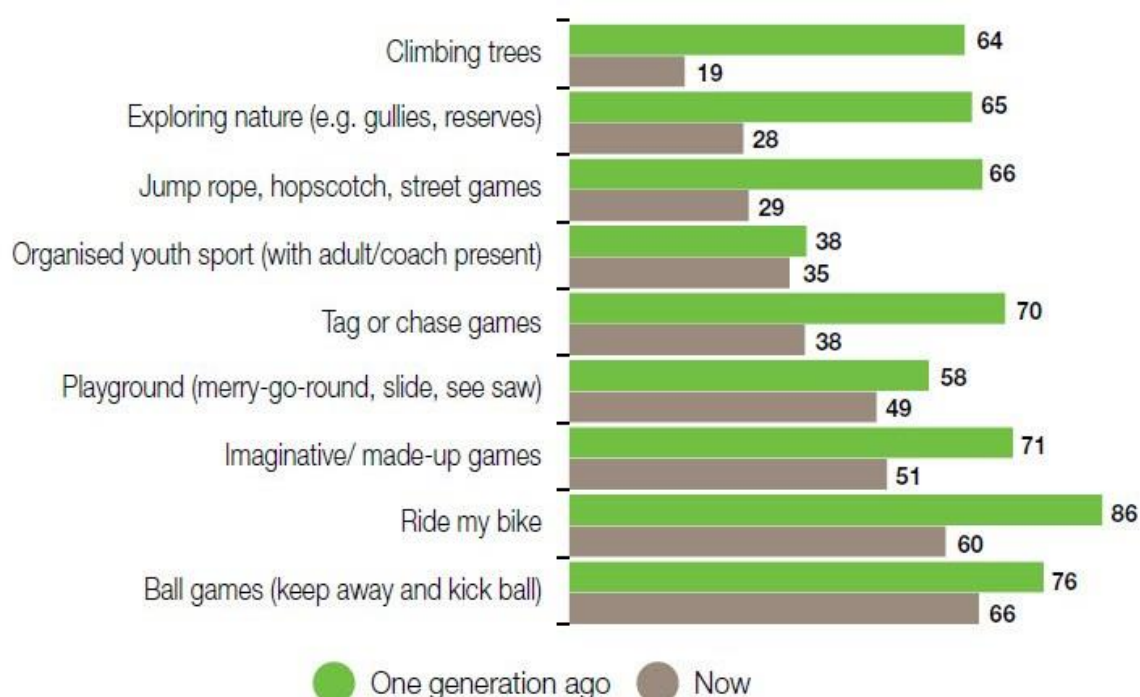
The Nature of Outdoor Play

'Kids don't climb trees anymore, with less than 20% of respondents indicating their kids participate in this iconic outdoor activity. This is a staggering drop from the 65% of parents who were climbing trees during their childhood'.

Source: (Planet Ark 2011) p.5.

As well as playing outdoors less often, the nature of children's outdoor activity also appears to have changed(see Figure 17) for example:

- 73% of respondents said they played on the street when they were young compared with only 24% of their children.
- 64% of respondents said they climbed trees when young compared with only 19% of their children.



Base is those who have any child currently aged between 3-12 years [for PARENT] who played outdoors, n=244 & [for CHILD] whose child plays outdoors, n=243

Figure 17: Outdoor activities participated in by children now compared with previous generation. Source: (Planet Ark 2011).

Benefits of Outdoor Play

Even with these dramatic changes in children's play, respondents still believed in the benefits of active outdoor play.

- 92% of respondents agreed that outdoor play allows children to use their imagination.
- 93% of respondents agreed that outdoor play helps develop physical and motor skills.
- 90% of respondents agreed that outdoor play provides an outlet for reducing everyday stress.

Barriers to Outdoor Play

The research has shown that the 'collapse in outdoor play' can be attributed to a number of barriers, either real or perceived.

- **Crime and safety concerns** showed the most dramatic increase, and 33% of respondents indicated that this is a barrier today compared with 9% who stated that it was a barrier when they were young.

- **Lack of time** parents have to play outside with their children has also become a more significant barrier, with 26% of respondents stating that this is a barrier today, compared with 11% saying it was a barrier when they were young.
- **The amount of homework** children have to do does not appear to be a barrier to outdoor play however, with the reported time spent on homework remaining fairly consistent across the generations.

Conclusions

The Planet Ark researchers concluded that children respond to their parents' fears, which influences the activities that children choose to participate in (Tranter and Malone 2004). While parents understandably prioritise safety issues, many seem to be unaware of the developmental risks of restricting outdoor activities. Not allowing children to play freely and explore their outdoor environment results in the single benefit of safety, however this benefit can be outweighed by multiple risks such as: compromised development; decreased physical exercise; increased obesity; and limited spontaneous play opportunities (Little and Wyver 1998). An alternative view to removing all risk is that minor injuries, like grazes, are a universal part of growing up. Taking moderate risks is essential to healthy development even though it may sometime result in minor injuries (Bundy et al. 2009).

'Children respond to their parents' fears and thus the attitudes of parents and caregivers will help to determine the activities that children choose to participate in, including outdoor play. While parents understandably prioritise safety issues associated with outdoor play, what parents seem to be unaware of is that restricting outdoor activities also involves social and cognitive development risks. There are a wide range of benefits - physical, cognitive and general wellbeing – that come from outdoor play'.

Source: (Planet Ark 2011) p.5.

3.5.4 Nature-Deficit Disorder

Writer Richard Louv in his book *Last child in the Woods* coined the term Nature-Deficit Disorder (NDD) to describe the effects on children of enforced alienation from nature. Alienation from nature leads to a number of behavioural issues, including diminished use of the senses, attention difficulties and higher rates of physical and emotional illness. Louv argues that sensationalist media coverage and paranoid parents have literally '*scared children straight out of the woods and fields*' while promoting a litigious culture of fear that favours 'safe' regimented sports over imaginative play. While not an actual medical diagnosis NDD provides a useful way of thinking about a current problem and of possible means of dealing with it (Louv 2005; Louv 2011). By giving the phenomenon a name that evokes the language of mental health, Louv highlights NDD as something '*that is not normal or healthy, but rather a serious problem that society needs to recognise and address*' (Planet Ark 2012).

Other researchers have described this trend as 'nature and culture deprivation' (Brook 2010). A number of organisations are working to combat the nature deprivation phenomenon, including:

- *Children & Nature Network* (co-founded by Louv).
- *No Child Left Inside Coalition*.

In Australia:

- *Planet Ark's National Tree Day*.
- *Junior Landcare*.
- *Nature Play*(WA, SA and Qld)
- *Victorian Child & Nature Connection*.

In an article entitled '*Rediscovering Nature in Everyday Settings: Or How to Create Healthy Environments and Healthy People*' Maller et al. (2009) suggest there is a need to get nature back into our cities and towns to create healthier environments for people and to foster the connection between humans and nature. This can occur in 'everyday urban places' such as schools, work places and residential housing. (Maller, Henderson-Wilson et al. 2009). The US based Children & Nature Network (C&NN) has reviewed and summarized literature related to outdoor and nature contact and children's health and well-being (Children & Nature Network 2010).

Nature Deficit Disorder

'A recent study from Australia found that of the 1975 children surveyed, 37% of children spent less than half an hour a day playing outdoors after school, and 43% spent more than 2 hours a day on screen time (i.e. watching TV, videos or playing computer games).

The story is similar from most urban places round the world. In the US, between 1997 to 2003, studies have documented a 50% decline in time that 9-12 year olds are spending outdoors. Issues of safety, both working parents, lack of parks and natural surroundings in our bleak urban landscape and the lure of the TV and computer are important reasons why children are spending more time indoors. Richard Louv, in his book "Last child in the Woods," has coined a new term "nature deficit disorder" which includes a range of behavioural problems. He argues that sensationalist media coverage and paranoid parents have literally "scared children straight out of the woods and fields," while promoting a litigious culture of fear that favours "safe" regimented sports over imaginative play.

In the US they have now launched a public service mass advertisement campaign "Leave no child indoors". The campaign is aimed at tweens (8-12 year olds) to foster a lifelong interest in and love of nature. Besides improving their physical and psychological health, it will make them more environmentally conscious'.

Source: (Scientific American, 4 August 2009).

Benefits of outdoor play

It is generally well understood that outdoor activity is beneficial to physical and mental health, in adults as well as children. For example:

- By providing the setting for exercise, sport and other activities that improve fitness and strength (Planet Ark 2012).
- Time spent in nature can provide a simple intervention which addresses a range of paediatric mental and physical health issues such as obesity, ADHD, vitamin D deficiency and mental health problems (McCurdy et al. 2010).
- Exposure to sunshine promotes synthesis of vitamin D, which is important for strong bones, muscles and overall health (Victorian Government 2012).
- Outdoor play can be beneficial for eyesight. The Sydney Myopia Study found that high levels of outdoor activity were associated with low levels of Myopia (short sightedness) as outdoor activity provides a more stimulating setting for a range of eye activities, compared with indoor 'near work', activities such as computers and electronic games (Rose et al. 2008).
- Many of the other benefits of outdoor play are less well understood. Childhood is a period of rapid physical, mental and emotional development, and time spend in nature provides a diversity of experiences important to the human development process. Nature provides high levels of the necessary mental and sensory stimulation, and engaging with diverse and unpredictable natural environments can stimulate exploration, creative play and divergent thinking (Faber Taylor, Kuo et al. 2001; Brook 2010; Koger and Winter 2010).
- Natural environments can also encourage resilience and flexibility, compared with more formal and constructed settings such as urban parks. Unpredictable natural settings create challenges for physical coordination and balance, and provide mental stimulation. Conversely, constructed settings tend to be typically safe and predictable, which may reduce the risk of physical injury while failing to provide the challenges of more natural settings (Planet Ark 2012). One Norwegian study found children who played in the woods near their school performed better on tests of motor coordination than those who played in a traditional playground (Fjortoft 2001).

There is a growing body of research supporting the benefits to children of outdoor play (Planet Ark 2011). Some of the reported benefits include the following:

Physical benefits

- Children who played outside every day were found to have better motor co-ordination and increased ability to concentrate (Grahm et al. 1997).
- Outdoor environments allows children to move freely, by placing fewer constraints on children's gross motor movements and on their range of visual and gross motor exploration (Burdette and Whitaker 2005).

Cognitive benefits

- It has been found that greenery in a child's everyday environment can reduce ADDT symptoms, and while outdoor activities in general are of help, settings with trees and grass were the most beneficial (Faber Taylor, Kuo et al. 2001).
- Children are more likely to encounter opportunities for decision making that stimulate problem solving and creative thinking in the outdoors, as outdoor spaces can be more varied and less structured than indoor spaces (Burdette and Whitaker 2005).
- Children have been found to be more likely to develop a responsible attitude toward risk through actual experience dealing with risky situations (Barker 2004).
- A large part of play is social, and promotes learning about vital social skills including taking turns, sharing, negotiation and leadership (Bundy, Lockett et al. 2009).

Emotional well-being benefits

- Free play has been shown to improve many aspects of a child's emotional wellbeing, such as reducing anxiety, repression, aggression and the incidence of sleep problems (Burdette and Whitaker 2005).
- Mood may be positively affected not only by the physical activity itself but also by exposure to sunlight if outdoors (Wirz-Justice et al. 1996).

The 2012 Planet Ark study reviewed the benefits to children of contact with nature and categorized them as follows (Planet Ark 2012):

- Benefits for mental health:
 - Reducing stress and depression.
 - Increasing self-esteem and confidence.
- Benefits for the mind:
 - Improving creativity and imagination.
 - Improving academic achievement.
 - Reducing the symptoms of ADHD.
- Benefits for the body:
 - Reducing the risk of being overweight or obese.
 - Burning energy: the nature of play.
 - Energy intake: the nature of eating.
- Benefits for the environment:
 - Growing responsible adults.

3.5.5 Benefits for mental health

3.5.5.1 Reducing stress

Researchers have found that contact with nature can help children, and people in general, deal with stress. For example:

- Simply exposing a subject to visual images of nature, especially water, can produce a calming, stress reducing effect (Ulrich 1984).
- Natural outdoor settings have been shown to provide restoration from cognitive effort and stress (Kaplan and Kaplan 1989; Kaplan 1995).
- One study in rural US found that the presence of vegetation near a home helped to moderate the impact of stressful life events on the psychological well-being of children (Wells and Evans 2003).
- A study in Spain found that children who had frequent daily contact with nature showed less stress than those not doing so, in both residential and school environments (Corraliza and Collado 2011).
- It has been suggested that intensive contact with nature can have long-term stress-relieving benefits, and that such experiences during childhood can provide a 'reservoir' of calming memories which can be drawn upon during later periods of stress during adulthood (Chawla 1990).

3.5.5.2 Reducing depression

Research has found indirect associations between increased depression and decreased time spent in nature (associated with increased time spent consuming media); time spent in nature is an important factor in the prevention of mental health issues (Planet Ark 2012). Time spent watching television exposes children to advertising messages leading to the 'commercialization of childhood' and a culture of consumerism and materialism (Kasser 2002). Children who score high on 'materialism' have been found to have a higher incidence of mental health issues, including anxiety, depression and substance abuse (Kasser 2005; Bee-Gates 2007).

Research has found that the psychological well-being of children can be improved by a combination of reducing negative psychological states, while accentuating positive states (Planet Ark 2012). Building confidence and encouraging healthy self-esteem have been found to be vital factors in accentuating these positive states, which can be promoted by outdoors activity and play. For example:

- Time spent in unsupervised nature based activities has been found to provide opportunities for exploration and risk taking, which contribute to the development of confidence and self-sufficiency (Derr 2006).
- A US study into the stress reducing benefits of nearby nature also found that exposure to nature helps strengthen children's self-esteem, making them more resilient during times of stress (Wells and Evans 2003).

3.5.6 Benefits for the mind

3.5.6.1 Improving creativity and imagination

Research has shown that contact with nature plays a role in children's intellectual development, as well as their mental health. For example:

- The experience of nature can help to improve creativity and imagination by providing a diversity of experiences providing sensory and mental stimulation. Literally, '*the diversity of biodiversity stimulates creative and imaginative play, enjoyment, exploration and divergent thinking*' (Kellert 2002).
- Powerful memories of experiences in nature can provide future '*meaning, serenity and creative inspiration*' (Chawla 1990).
- Conversely the characteristics of the built environment and of hard-surfaced play areas can reduce the occurrence of creative play. One study found that children in settings with trees and vegetation showed more creative social play than children in barren, hard-surfaced play areas (Faber Taylor et al. 1998).

3.5.6.2 Improving academic performance

It has been suggested that three measures for improving the academic achievement of children are strongly supported by outdoor nature-based play (Planet Ark 2012):

- 1) Supporting the development of **cognitive and critical thinking skills**.
- 2) Improving **intellectual function** when learning or doing schoolwork.
- 3) Helping children **directly acquire knowledge** and an understanding of the world around them.

Cognitive skills

The research of Stephen Kellert (Kellert 1997; Kellert 2002) and of Koger and Winter (2010) in their book *The Psychology Of Environmental Problems: Psychology for Sustainability* summarises the influence of time spent in nature on intellectual development.

'A significant part of a child's intellectual development involves learning to discriminate, categorize, and name different objects. Due to the wide range of things, features, and behaviors observable within nature, experiences therein provide extensive opportunities for children to acquire these abilities. Observing natural phenomena such as weather patterns and nonhuman animal habitats facilitate children's comprehension of relationships; snow falls and ice forms only when temperatures are in a certain range; ducks are seen near water, and so forth' p.270.

One approach in using nature to enhance intellectual development is the use of natural environments as classrooms. One Florida-based study found links between environment-based education and critical thinking skills in high school students (Ernst and Monroe 2004). Associations have also been found between cognitive function, self-discipline, and access to nearby nature and nature views. One study even found that moving house can make a difference to cognitive functioning. A pre-move and post-move study found that moves that improved the amount of green in nearby settings correlated with

improved cognitive functioning (Wells 2000). Gender differences have also been found in relationships between nature and cognitive function. One study found the naturalness of the view from the home could be used to predict female children's performance on tests of concentration, impulse inhibition, and delay of gratification. However no relationship was found with boys, and the researchers suggested that, for boys more distant green spaces may be important (Faber Taylor, Kuo et al. 2002). According to the authors:

'These findings suggest that, for girls, green space immediately outside the home can help them lead more effective, self-disciplined lives. For boys, perhaps more distant green spaces are equally important' p.49.

Attention restoration

One aspect of cognitive function particularly important to students is that of 'directed attention', the ability to maintain focus on a specific task while managing other distractions. It has been shown that with extended periods of concentration, the brain experiences a form of 'directed attention fatigue' which reduces a person's effectiveness. Sleep provides some restoration but is not considered to be sufficient on its own (Kaplan 1995). Several studies have shown a relationship between information processing effectiveness and 'nature-based' restorative experiences. One US study compared wilderness vacationers with urban vacationers, and also a non-vacationing control group (Hartig et al. 1991). The researchers found that the wilderness group showed significant improvement in a highly demanding directed attention task (proof-reading) while the other two groups showed a decline. In another study participants were given mentally tiring tasks. The researchers then compared the attention restoration benefits of either: a 40-minute walk in a natural setting, a 40-minute walk in an urban setting, or 40 minutes of 'passive relaxation' (listening to soft music and reading magazines). The researchers found that, on average, the resulting restorative benefits were found to be highest for the natural setting group (Hartig, Evans et al. 1991).

Direct knowledge

Contact with nature also allows children to directly observe and acquire knowledge about the natural world. Both structured programs and unstructured free play in natural settings allow children to learn about and connect with local wildlife, and develop a sense of place and connection to their local environment (Watson 2006).

ADHD reduction

Kuo and others at the University of Illinois Landscape and Human Health Laboratory have been investigating the potential of nature based activities in reducing ADHD symptoms in children. Following are some of their key research findings:

- It was found that children function better after activities in green settings and the 'greener' a child's play area, the milder the ADHD symptoms (Faber Taylor, Kuo et al. 2001).
- Green outdoor settings appear to reduce ADHD symptoms across a wide range of individual, and case characteristics (Kuo and Faber Taylor 2004).
- Children were found to concentrate better after a 20-minute walk in a park, than after the same walk in an urban setting. It is suggested that 'doses of nature' could provide a safe, inexpensive and accessible new tool in the suite of options for managing ADHD (Faber Taylor and Kuo 2009).
- The apparent role of green spaces in reducing ADHD symptoms in hyperactive children appears to be true only for relatively open green settings (Faber Taylor and Kuo 2011).

The above research is still in its early years, and the researchers advise against dismissing the benefits of behaviour treatments (Canu et al. 2005). They also conclude that randomised clinical trials are also required, which can measure the effects of regular exposure to green space as a treatment for ADHD.

3.5.7 Benefits for physical health

3.5.7.1 Reducing the risk of being overweight or obese

Childhood obesity trends

It has been estimated that 17% of Australian children are overweight, 6% are obese, and these rates are in fact rising (Australian Government Department of Health and Ageing 2008). Overweight children also face a range of other physical and mental problems including reduced confidence and self-esteem, and increased likelihood of being a victim of bullying. Obese children also face greater health risks as adults, including risks of type 2 diabetes, heart disease, high blood pressure, stroke, joint problems, breathing problems, some forms of cancer and ongoing self-esteem issues (Planet Ark 2012). Central to weight loss and gain is the 'energy balance equation' between energy intake from eating and energy expenditure from physical activity. Planet Ark suggests that 'contact with nature can be of benefit on both sides of this equation' (Planet Ark 2012). A report by the Australian Productivity Commission *Childhood Obesity: An Economic Perspective* identified possible causes of overweight and obesity in children (Crowle and Turner 2010). As shown in Figure 18, the authors summarized potential factors in the rise of childhood overweight and obesity.

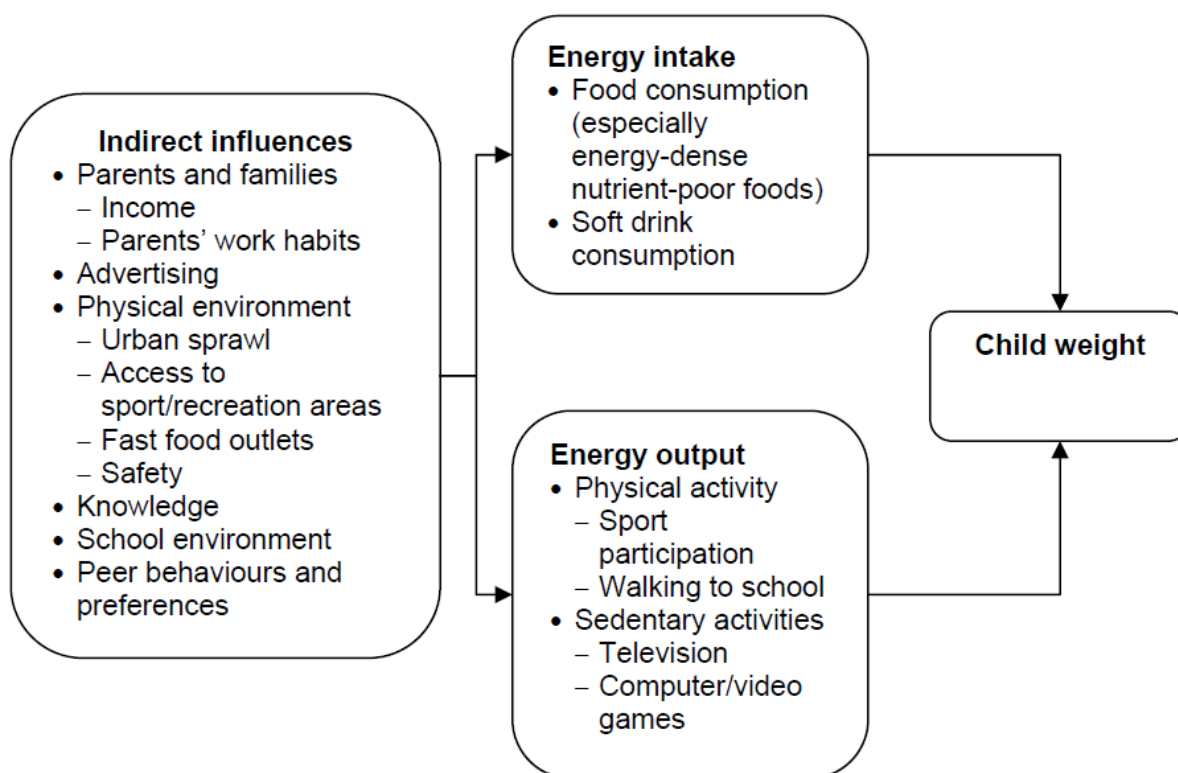


Figure 18: Potential factors in the rise of childhood overweight and obesity. Source: (Crowle and Turner 2010) p.53.

The physical environment is identified as a potential factor affecting childhood obesity through its influence on levels of physical activity. For example, it is argued that areas with parks and bike paths may facilitate physical activity among residents, whereas areas designed for motorised transport or with few facilities for physical activity, would not. The authors note that while ‘... *there is a growing body of research in this area, there are some study limitations*’ p.49. This includes a lack of consensus on how to measure the many environmental variables and the size of the area that influences an individual. In addition, people spend time in multiple geographic areas, making it difficult to identify the environmental factors that influence an individual. There is also a wide array of physical environmental factors that can be studied, and often the choice of variables is based on data available rather than any theoretical underpinning. In addition the direction of the relationships often cannot be determined due to the study design. For example more active people choose to live near parks, rather than living near a park causing people to be more active,

Links between obesity and urban form

Researchers have identified other factors which contribute to childhood obesity, in addition to the shift from outdoor to indoor play. This includes links between the design of cities, levels of outdoor physical activity and obesity. For example:

- A NSW government report ‘*Creating healthy environments: a review of the links between the physical environment, physical activity and obesity*’ highlighted the influence that urban form has on physical activity, particularly the role of transport networks and facilities that encourage ‘active transport’ such as walking and cycling, by both children and adults (Gebel et al. 2005).

- Other researchers however take an opposing stance, asserting that the densification of cities as part of a sustainability agenda has over-emphasized the health benefits of 'walkable neighbourhoods' and ignored other children's issues contributing to obesity. Researchers at the University of South Australia have suggested that studies of 'walkable communities' rarely involve children, and there is stronger correlation with the presence of green space, rather than with residential density. Therefore changes to suburbs that improve walkability at the expense of green open space may not be the best way to prevent childhood obesity (Kinner and Wilson 2011).
- A study of 3-16 year old children in the US tested whether greenness and residential density were independently associated with changes in the BMI (body mass index) of children and youth over a period of two years (Bell, Wilson et al. 2008). The authors found that children living in greener neighbourhoods had lower BMI scores after two years, and that this appeared to be independent of neighbourhood density. They concluded that: *'Greenness may present a target for environmental approaches to preventing child obesity. Children and youth living in greener neighbourhoods had lower BMI scores...presumably due to increased physical activity or time spent outdoors. Conceptualizations of walkability from adult studies, based solely on residential density, may not be relevant to children and youth in urban environments'* p.547, and *'These findings support the exploration of the promotion and preservation of greenspace within neighbourhoods as a means of addressing childhood obesity.'*p.552.

Links between obesity and outdoor play

Research linking childhood obesity and play includes:

- The US organisation, *Children & Nature Network* investigated relationships between play in nature, physical activity and obesity in children. It concluded that natural areas often encourage physical activity, which helps people better maintain their energy balance, and that currently many children do not get the physical activity that they require (Senauer 2007).
- Researchers note that sedentary activities, such as television and electronic games, 'squeeze out' time available for more active pursuits (Anderson and Butcher 2006).
- It has been found that BMI in children is positively associated with time spent watching television, and negatively associated with time spent in outdoor play (Kimbrow et al. 2011).
- Children with better access to public parks and recreation programs were found to be less likely to have significant increases in BMI over time (Wolch et al. 2011).
- A Melbourne study of ten-twelve year olds over a period of three years confirmed the association between lower BMI and time spent outdoors. About 200 five-six year olds and 350 ten-twelve year olds from 19 randomly selected elementary schools in Melbourne participated in this study. The authors concluded that *'The prevalence of overweight among older children at follow-up was 27-41% lower among those spending more time outdoors at baseline.'* The authors recommended further investigation into time spent outdoors as an obesity prevention measure (Cleland et al. 2008).

Links between obesity and eating habits

It has also been found that nature-based activities can influence the 'energy intake' side of the energy balance equation. Findings linking childhood obesity and eating include:

- Bell and Dymont (2008) explored the potential of green school grounds to promote health and well-being and to be an integral element of multifaceted, school-based health promotion strategies. They found that 'domesticated nature' activities can provide opportunities for active learning and improving health literacy. Green school grounds, home vegetable gardens and school kitchen gardens, such as the *Stephanie Alexander Kitchen Garden Program*, can help improve physical health and promote healthy eating habits. The authors highlighted *'the growing body of evidence that green school grounds, as a school setting, can contribute to children's physical, mental, social and spiritual well-being'*.
- In contrast, watching television can encourage unhealthy eating habits, as people tend to snack while watching television, and are also exposed to advertising messages, including those promoting junk food (Koger and Winter 2010).

3.5.8 Promoting environmentally responsible attitudes

Research shows that nature-based experiences can influence a child's attitudes, and that this influence can last a lifetime. One US study found an association between participation in 'wild' nature activities during childhood and future environmental attitudes and behaviours. Childhood participation in 'domesticated' nature activities was associated with pro-environmental attitudes in adulthood, but only marginally with adult environmental behaviour (Wells and Lekies 2006). In contrast, increased time spent indoors watching television can lead to attitudes of materialism and consumerism. It has been suggested that over time excessive materialism can encourage self-centeredness and less concern for the community and the environment (Orr 2002). It has been suggested that through nature based experiences, children form a four dimensional connection to nature (Cheng and Monroe 2012):

- Empathy for creatures.
- Enjoyment of nature.
- Sense of oneness.
- Sense of responsibility.

Direct interaction with nature, including pets, can promote feelings of empathy, making the animal or plant worthy of moral consideration (Gebhard et al. 2003). It is suggested that when children recognise themselves as being part of nature, they develop a sense of 'ecological self', and the stronger this self-perception, the more likely a child is to protect nature (Kals and Ittner 2003). It has also been shown that powerful positive memories of time spent in nature during childhood can provide a 'reservoir of emotional stability' in later life. For some people, these nature-based experiences provide a sense of 'integration' of nature and human life. This perception of being 'part of nature' can calm fears and provide a sense of stability amidst the dramas of life (Chawla 1990). As discussed in the following section, responsibility for nature and pro-environmental attitudes through contact with nature can be incorporated into school and community-based environmental programs (Chawla 2002).

3.5.9 Nature based interventions

Outdoor play and contact with nature can be incorporated into children's health and education programs in a number of ways.

3.5.9.1 Nature and health

Research indicates that nature-based interventions can be used in the treatment of certain physical and mental conditions (Pryor et al. 2006). For instance nature can be integrated into the design of health care facilities, for the benefit of not only the patient but also of families and staff (Planet Ark 2012). One well-known study examined the effects of the view from a window on the recovery rates for adults having undergone gall bladder surgery. The results showed that those patients with a natural view from their hospital rooms recovered faster than those in the control group (as indicated by shorter post-operative hospital stays). In addition the group of patients with a natural view had fewer negative comments in the nurses' notes and reduced use of pain killers (Ulrich 1984). Another intervention involves horticultural therapy programs which use gardening activities for therapeutic purposes (Planet Ark 2012). For example the horticultural therapy program at the Stephen D. Hassenfeld Children's Center for Cancer and Blood Disorders of New York University is designed to complement other treatment options and helps minimise challenges in the quality of life for patients and their families (Fried and Wichrowski 2008).

3.5.9.2 Nature and education

Research findings support the integration of nature based activities into school grounds and into the school curriculum. Benefits could include improved cognitive functioning and fatigue restoration caused by intensive concentration, and also the development of more environmentally responsible attitudes which may persist into adulthood. For example a study in an Australian school suggested that children choose natural green areas for play rather than commercial play equipment or hard surfaced sporting courts (Lucas and Dymont 2010). 'Green' school grounds have been found to encourage greater levels of 'light and moderate' physical activity by increasing '*the range of enjoyable, non-competitive, open-ended forms of play at school*' (Dymont and Bell 2008; Dymont et al. 2009). School kitchen gardens also provide opportunities to connect with nature and learn about healthy eating (Planet Ark 2012).

3.6 Summary

- There is a large body of research supporting the human health and well-being benefits of contact with nature in various form, much of it by researchers in the fields of medical and social science.
- Research has focussed on three aspects of well-being: the physical and mental health and well-being of individuals, and the role of social interaction and community building.
- Two particular groups who would benefit from Green Infrastructure in cities are older people and children.
- Green Infrastructure which can support human health and well-being includes the provision of accessible green spaces, and green linkages and more 'walkable' streets.

Green Infrastructure Project

- Green Infrastructure can also be incorporated into medical institutions for therapeutic purposes, and into schools to foster healthy childhood development.
- Researchers have more recently criticized the methodologies applied to measure the human health and well-being of Green Infrastructure, such as proximity to green space, emphasizing the need for more longitudinal rather than cross-sectional studies.

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4 Community liveability

Green Infrastructure

Green Infrastructure is the network of green spaces and water systems that delivers multiple environmental, social and economic values and services to urban communities. This network includes parks and reserves, backyards and gardens, waterways and wetlands, streets and transport corridors, pathways and greenways, farms and orchards, squares and plazas, roof gardens and living walls, sports fields and cemeteries. Green Infrastructure secures the health, liveability and sustainability of urban environments. It strengthens the resilience of towns and cities to respond to the major current and future challenges of growth, health, climate change and biodiversity loss, as well as water, energy and food security.

4.1 Introduction

Green Infrastructure can enhance the general attractiveness and 'liveability' of urban neighbourhoods, and cities. 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. Other benefits such as human comfort are more easily quantified. The topic has not been as extensively researched as the other more easily quantifiable benefits of Green Infrastructure, and often involves qualitative rather than quantitative research methods. Much of the literature also relates to urban trees which, due to their scale, comprise the most visible component of Green Infrastructure in cities. Figure 19 summarizes the role of Green Infrastructure in enhancing community liveability

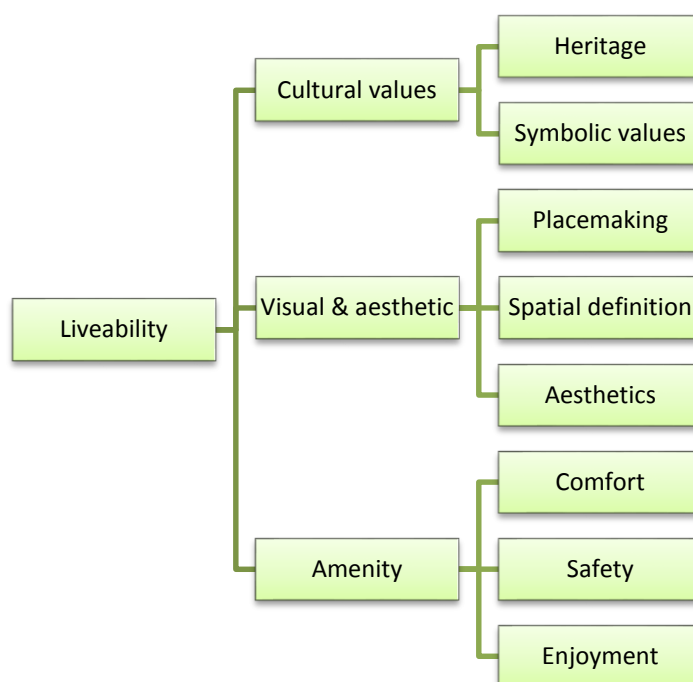


Figure 19: Summary of the role of Green Infrastructure in community liveability (By author).

4.2 Overview

4.2.1 Definitions of liveability

Liveability is a familiar concept which addresses many aspects of urban life. A very broad range of factors contribute to making a place liveable so there is no single definition of liveability. In addition, the factors that contribute to liveability also vary for individuals depending upon their circumstances and life-cycle stage. The Victorian Competition and Efficiency Commission (the Commission) has developed a working definition for liveability (Victorian Competition and Efficiency Commission 2008).

‘Liveability reflects the wellbeing of a community and represents the many characteristics that make a location a place where people want to live’.

This definition encompasses a wide range of characteristics of a liveable place including: community strength; economic strength; built infrastructure; social infrastructure; amenity and place; environment; citizenship; equity and human rights; participation; leadership and good governance; information and communication technology (ICT); transport; government services; and innovation.

Green Infrastructure can help to improve the liveability and quality of life in cities and urban neighbourhoods. In addition to the environmental and economic values described elsewhere in this report, the ecosystem services provided by vegetation, water and other Green Infrastructure provide a range of socio-cultural values that are important to humans because of social norms and cultural traditions. This set of related benefits can be grouped under a broad umbrella category of ‘community liveability’.

Many of the Green Infrastructure ecosystem services which contribute to community liveability are described elsewhere in this report. For example GI can enhance community liveability through

- Promoting general human health and well-being (Chapter 3).
- Facilitating community cohesion and social capital (Chapter 3).
- Promoting the economic vitality of commercial centres (Chapter 5).
- Creating more amenable urban climates and microclimates (Chapter 6).
- Integrating water into urban environments (Chapter 7).
- Enhancing biodiversity in urban areas (Chapter 8).

This section on community liveability focuses more specifically on the following categories:

- Cultural values, including community heritage values 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.
- The specific liveability benefits of air quality improvement and noise abatement in cities.

4.3 Cultural values

4.3.1 Cultural meaning

Significant cultural meaning and symbolic value have become attached to trees and forests, including those of archetypes, myth and religion (Konijnendijk 2008) (Dwyer et al. 1994; Schama 1995). Dwyer et al. (1991) recommended adopting a broader perspective on urban trees:

'Trees and forests play a significant role in the urban environment and have many important meanings to urban residents. However, we find that the effort of many municipal urban forestry programs to expand or sustain trees and forests is justified in terms of a few fairly simple dimensions of their significance to urbanites, such as beauty, shade, cooling, or contribution to global gas balances. Programs based on this narrow spectrum of tree benefits may not fully meet the needs of urbanites or gain their support. We suggest a broader perspective is needed, one that takes into consideration the deep psychological ties between people and urban trees and forests' p.276.

Research at the Morton Arboretum in Lisle, Illinois has identified a number of cultural themes including:

- **The sensory dimension of trees.** The contribution of trees and forests to the beauty of the urban environment is well documented but their influence on people goes deeper than visual aesthetics. Trees and vegetation can have a strong, relaxing effect on people (Ulrich 1981).
- **The symbolic value of trees.** Apart from the sensory experiences they provide, trees are often valued as carriers of symbolic meaning. There are many examples of trees used as symbols of people, as well as in religions.
 - The symbolic value of trees, as **symbols of people**. Appleyard (1980) observes several parallels between our images of people and trees.
 - The symbolic value of trees as **religious symbols**. Chenoweth and Gobster (1990) suggest that urban trees and forests can contribute to experiences that are religious in nature. Schroeder (1988) observes that trees have been used by many cultures to symbolize health, wisdom, and enlightenment.
- **Human roots in the forest.** People's responses to trees and forests are so strong and consistent that some researchers have even suggested that people have evolved instinctive preferences for certain types of treed environments (Appleton 1975; Appleton 1984). Most people seem to appear to prefer groves of widely scattered trees, open at eye level, with overhead canopy and a uniformly textured ground cover. It has been suggested that this environment is attractive because it resembles the African savannah in which the human species evolved.

Dwyer et al. (1991) also suggests a number of emotional ties to the actual act of tree planting(see Figure 20) including:

Green Infrastructure Project

- Tree planting as a demonstration of **commitment to the future**.
- Tree planting as possibly a major **impact on the landscape over time**. Few activities that individuals can undertake have the potential for as large an impact over time as tree planting.
- Tree planting as a means of **improving the environment**. Tree planting is one act an individual can perform that can help them feel they have contributed to solving global environmental problems.



Figure 20: Neighbourhood shadeways tree planting day, Brisbane City Council. Source: Lyndal Plant BCC.

Because of their longevity, tree planting also creates a legacy for future generations, and a link between generations (Moore 2000).

4.3.2 Heritage values

Trees also have cultural and heritage values, as in the creation of 'avenues of honour' (Cockerell 2008). For example the old gum tree at Glenelg in South Australia is significant as a symbol of colonial settlement.

4.3.3 Community values

Communities may place high values on trees compared with other aspects of their urban surroundings, and develop significant attachments to local trees (Hull 1992). This is also reflected in reported preferences by residents for tree lined streets (Getz et al. 1982).

4.3.4 Place making

Historically trees have played a significant 'place making' role in cities, defining a 'sense of place' when configured as an individual shade tree, avenue or grove (Moore et al. 1988). Trees still continue to play a significant place making role in modern cities (Alexander 1977; Arnold 1980).

4.4 Visual and aesthetic values

4.4.1 Introduction

The visual and aesthetic benefits of trees and other forms of Green Infrastructure have received less attention in recent research, compared with the significant body of research on the environmental, economic and human health and well-being benefits of urban greening. In part this is because most research into Green Infrastructure has been quantitative in nature, and has been undertaken within the fields of environmental science, social science and economic modelling (McLean et al. 2007). Much less research has been undertaken by those well-versed in aesthetics and visual design principles (such as landscape architects and urban designers) and few studies have adopted a more appropriate qualitative or mixed-method research methodology.

4.4.2 Environmental quality and aesthetics

The visual appearance and attractiveness of towns and cities have been found to be strongly influenced by the provision of green space (Tibbatts 2002). Environmental quality has two main components, the actual 'physical', and the more subjective 'perceived' quality of the local environment (Khattab 1993). The concept of environmental quality is broad and can encompass many elements including environmental pollution and cleanliness, and visual quality and personal security.

4.4.3 The role of trees

A number of landscape architecture and urban design texts refer to the role of trees in the design of urban spaces, including streets:

- Because of their size and longevity trees have long been a major element in urban landscape design (Dwyer, Schroeder et al. 1994).
- Trees provide structure, connection, presence and scale, amelioration of harsh environments, and a capacity to link diverse landscapes (Moore 2000).
- In her seminal 1961 book, *The Death and Life of Great American Cities*, Jane Jacobs noted the important role of street trees in creating visual unity in the modern city streetscape (Jacobs 1961).
- Alexander (1977) has noted the 'place making' role of trees in urban landscapes, either as a single tree, a grove of trees or a linear avenue (Alexander 1977).
- Arnold (1980) examined the role of trees in urban design in some detail, including street trees (Arnold 1980).
- O'Brien (1993) examined the aesthetic and planning contributions of street trees, comparing the cities of Birmingham and Munich (O'Brien 1993).

- Based on a number of international case studies, Alan Jacobs has examined the qualities that contribute to what are recognized as the worlds 'great streets' and to multi-lane 'boulevards' (Jacobs 1993; Jacobs et al. 2002).

4.4.4 The role of large trees

Larger trees have greater visual presence than smaller stature trees, and are often more highly valued by residents, especially where 'canopy closure' over the street is achieved (Kalmbach and Kielbaso 1979; Schroeder and Cannon 1983; Sommer et al. 1989). In one study the single largest factor in determining the attractiveness of a street scene was the size of the trees and their canopies (Schroeder and Ruffolo 1996).. This was supported by a study in which there was a preference for large canopied trees in a tree replacement program (Heimlich et al. 2008). According to Schroeder et al. (2009) 'big trees' have long been a significant feature in many cities and towns. A canopy of mature trees arching over the street and shading properties has defined the character of many urban and suburban communities. In fact it is the enduring nature of large trees in a rapidly changing urban environment that contributes to their high symbolic value and a sense of permanence in a fast changing society (Dwyer et al. 2003).

4.4.5 Local research

In 2009 Ely administered a national online survey to obtain a 'snapshot' of the attitudes and practices of street tree practitioners throughout Australia (Ely 2010). Responses were obtained from 282 'street tree practitioners' working in tree related fields, mainly in local government. Surprisingly the less tangible visual and aesthetic benefits of trees were rated highest, despite recent emphasis on the quantifiable environmental benefits of trees(see Figure 21).

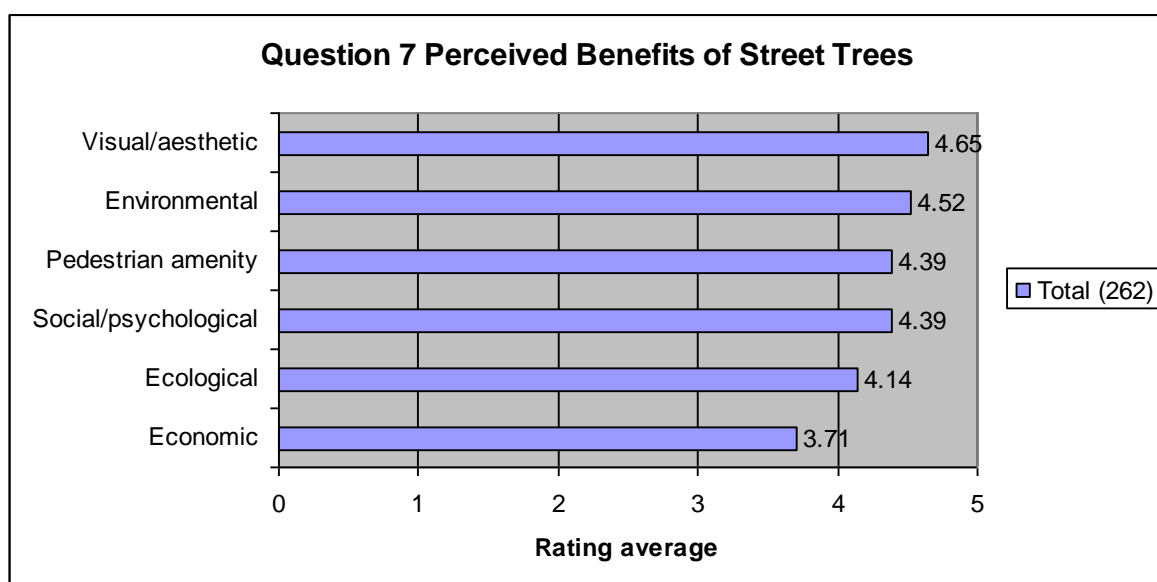


Figure 21: Perceived benefits of street trees. Source (Ely 2010).

Similar annual surveys of residents by the Brisbane City Council also highlight the importance of aesthetics as a reason for tree planting(see Figure 22). In October 2010, the most frequently cited benefits of planting trees were shade (59%), aesthetic appeal (49%) and environmental benefits (45%).

Mentions of shade, the aesthetic appeal and habitat for wildlife increased significantly from October 2009. Since October 2008, the perceived benefits of clean air and greenhouse gas absorption from planting trees have been on the decline.

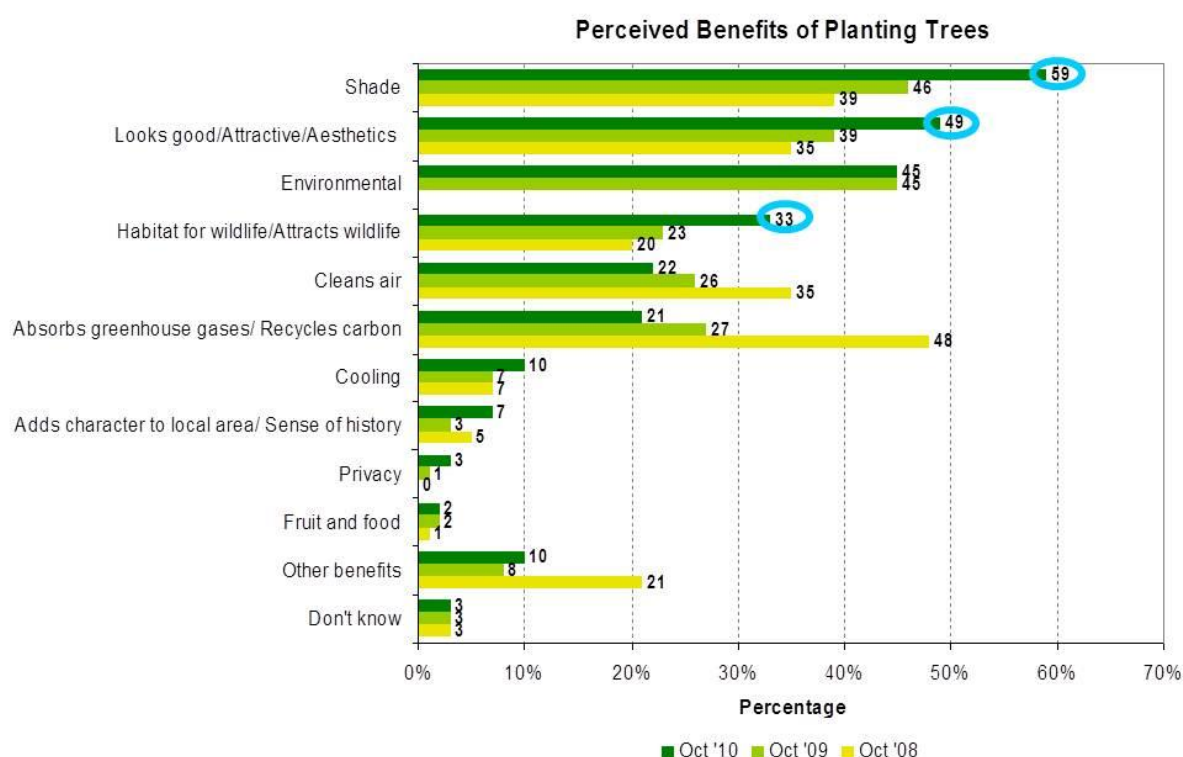


Figure 22: Perceived benefits of planting trees. (Source Brisbane City Council).

In a follow up study, Ely conducted in-depth interviews with street tree managers and related professionals from nineteen local government authorities in the Adelaide metropolitan region (Ely 2009a). Structured in-depth interviews were conducted in the respondent's workplace and the interview transcripts were analysed using qualitative methods to identify emerging themes. Interviewees were asked to identify the main benefits of street trees. There was strong recognition of the visual and aesthetic role of trees in urban neighbourhoods, and the following categories were emphasized:

- Urban amenity.
- Visual character.
- Streetscape appeal.
- Suburb desirability.
- Resident support for trees.
- Identity and legibility.

Verbatim comments also emphasized the many visual and aesthetic values of street trees:

'The usual list of environmental benefits is ok - but more often than not you notice when you drive down a street that has been upgraded. If you get good street trees you get good aesthetic appeal'.

'Tree planting is a relatively cheap way of improving the amenity and character of an area. Trees provide shade. They soften the line of the road and infrastructure, and create light and shade'.

The economic, environmental and human benefits of street trees are well recognised by tree managers, however the benefit most emphasised is their mainly visual role in creating character and amenity in urban streets and suburbs. Street trees provide amenity, visual character and streetscape appeal. In established urban areas, the presence of mature street trees makes certain streets and suburbs more desirable places to live, and their benefits are often reflected in higher real estate values. In such areas there may be strong local resident support for retaining existing trees.

'When a person drives down the street, the biggest impact is the tree. And the leafiest suburbs, that's why the value of the houses are higher than elsewhere, because it's usually the leafy streets, or leafy suburbs'.

In developing outer suburban areas street tree planting also plays a significant role in creating local character and identity. There was also an awareness of the relationship between urban greening and human well-being, however this is less tangible and more difficult to communicate to the public than the more obvious visual benefits. In the words of one participant:

'The most important benefit, they maintain quality of life and community. A lot of people don't see that'.

Marritz (2012) supports the idea that the less easily quantifiable 'visual and aesthetic' benefits of trees are in fact the most powerful.

'I read a lot of news about trees in the urban environment. These stories are usually about how important trees are, and frequently cite statistics like the number of tons of carbon storage and sequestration trees provide, the quantity of pollutants they remove, the amount of money they save us, or their contribution to controlling rising temperatures and flooding. I'm very familiar with statistics like these, because I also use them frequently. But are they really effective? Does data like this really matter to people?'

'Trees do provide an incredible number of environmental and economic benefits. Despite this, it seems that it is often more persuasive to use visuals to communicate their value. Statistics can quickly become tiring and meaningless. Hearing them over and over again eventually

dampens their impact. The average person won't really take in what removing 711,000 metric tons of pollution feels like (that's a \$3.8 billion value, by the way). But we do know how nice it feels to walk on a tree-lined street. Especially in the hot new climate that is no longer an abstract future'.

Ely (2010) also interviewed street tree managers in the Australian capital cities of Sydney, Melbourne, Brisbane and Perth, to identify the strategic 'drivers' behind street tree planting in the most difficult urban environments. Despite local differences, each city has a common agenda in terms of creating urban amenity in the Australian climate, and creating a high quality and inviting public realm. Each city sees trees as part of the image of its State's civic, retail and tourism focus. The public realm of a major city must meet the needs of both residents and daily visitors (workers, shoppers and tourists). Street tree planting in capital city CBD's is therefore considered to be 'mandatory', despite the many constraints on tree planting. These include narrow footpaths, high pedestrian volumes, overshadowing by tall buildings, extensive paved surfaces (often on a concrete slab base), extensive underground services established over the preceding century, and more recent drought and water restrictions. Specific agendas identified for Australian cities include:

- **Melbourne.** Trees are part of a pedestrian friendly city centre (see Figure 23). For the past 20 years Council has been pursuing an innovative program to enhance pedestrian needs over vehicle needs in the central city. The process began in the mid-1980s with the urban design report *Grids and Greenery* (City of Melbourne 1987). In the mid-1990s the Danish urban designer, Jan Gehl measured pedestrian conditions and activity on the ground. He looked at urban amenity from all perspectives, including the role of vegetation. The study was replicated in 2004, showing measurable improvements in public and street life following the implementation of recommended streetscape improvements (City of Melbourne 2004).
- **Sydney.** Trees are fundamental to city projects in providing civic amenity and upgrading the public domain in Australia's largest CBD, despite the constraints imposed by its narrow street network lined with tall buildings.
- **Brisbane.** Creating liveability and responding to the need for year-round shade and 'shade-ways' is a key policy 'driver' in Brisbane's subtropical climate. Trees and greenery are also seen as creating liveability as part of the city's urban densification program (Plant 2006).
- **Perth.** Trees are seen as a fundamental 'given' in a hot dry city and are an integral part of the 'pedestrianization' of the city centre.



Figure 23: Swanston Walk Melbourne. By author.

4.5 Urban amenity

Amenity is a term referring to 'the pleasantness or attractiveness of a place' or to 'the desirable or useful features or facility of a place'. Areas with high levels of amenity are more 'pleasant' or 'attractive' places to live, work or visit. The concept of urban amenity includes not only the visual and aesthetic qualities of a place, but also a range of more functional considerations such as safety, comfort and convenience. Green Infrastructure can contribute significantly to the amenity of urban streets, neighbourhoods and cities. Research has focused on a number areas:

- Neighbourhood attractiveness.
- 'People friendly' streets and spaces.
- Walkability.
- Green Infrastructure and pedestrian/driver safety.

4.5.1 Neighbourhood attractiveness

Increased greenery within urban areas (including street trees and landscaping, water bodies and access to open space) increases the aesthetic value of neighbourhoods. The positive impact of Green Infrastructure practices on aesthetics is reflected in the relationship between urban greening and property values. People appear to be willing to pay more to live in places with more greenery. Several

empirical studies have shown that property values increase with the presence of trees and other greenery, and this is reinforced by research into the preferences of householders (refer to Section 5.3.4).

4.5.2 Improving quality of place

It has been shown that Green infrastructure and green space provision can make positive contributions to improving 'quality of place' (Forest Research 2010). 'Quality of place' has been defined as the physical characteristics of a community that affect the quality of life and life chances of people living and working in it (Cabinet Office Strategy Unit 2009). Research shows that the provision of high quality, well-maintained green space can have a positive effect on local business, and improve an area's image and the confidence of the local population and potential investors (Land Use Consultants 2004). Swanwick (2009) has noted that highly valued green spaces enhance positive qualities of urban life, offer a variety of opportunities and physical settings and encourage sociability and cultural diversity. Another study showed that, conversely, 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 (Land Use Consultants 2004).

4.5.3 Principles for liveability

A new report from the Urban Land Institute (2013), using Singapore as a model, offers a top ten list of principles for making high-density cities more liveable. The report '*10 Principles for Liveable High Density Cities: Lessons from Singapore*' draws upon Singapore's successful urbanization experience. Despite its population density, the city-state has consistently ranked favourably in various surveys measuring the liveability and sustainability of cities around the world. The ten principles in the publication were developed during two workshops hosted in 2012 by Singapore's Centre for Liveable Cities and Urban Land Institute Asia Pacific, bringing together 62 leaders, experts and practitioners from different disciplines related to urban planning and development. Each of the ten principles in the publication reflects Singapore's integrated model of planning and development, which weaves together the physical, economic, social and environmental aspects of urban living. The ten principles are:

1. Plan for long-term growth and renewal.
2. Embrace diversity, foster inclusiveness.
3. Draw nature closer to people.
4. Develop affordable, mixed-use neighbourhoods.
5. Make public spaces work harder.
6. Prioritise green transport and building options.
7. Relieve density with variety and add green boundaries.
8. Activate spaces for greater safety.
9. Promote innovative and non-conventional solutions.
10. Forge 3P (people, public, private) partnerships.

Principle 3 (Draw nature closer to people) relates specifically to urban greening. According to the report (p.31):

‘Blending nature into the city helps soften the hard edges of a highly built-up cityscape and provides the residents with pockets of respite from the bustle of urban life.

What started as an aim to build Singapore into “a garden city” has now evolved into Singapore being “a city in a garden”. In addition to the many parks scattered across neighbourhoods, water bodies course through the city and form an important part of the landscape. Nearly half of Singapore is now under green cover, which is not only aesthetically pleasing, but also is good for the air quality and mitigates the harsh heat of the tropical sun.

Another aim of having Singapore residents experience nature as an integral part of their lives is to encourage them to value and, as a result, take better care of the environment and the city’s limited natural resources’.

In creating ‘a city within a garden’, Singapore, due to high density and land scarcity, faced a practical limit on how many parks it could provide. So instead of only making horizontal spaces greener, Singapore adopted a strategy of ‘pervasive greenery’, meaning the city inserted greenery wherever it could, be it a pavement, road median, building façade or a rooftop. The idea was to ‘*cloak spaces with green wherever the eye could see*’.

Singapore also has a *Streetscape Greenery Master Plan*. Tree-lined roads provide shade for motorists and pedestrians while overhead bridges and flyovers are veiled with creepers and other plants to create a softer feel to concrete structures. The city has also introduced various methods to bring greenery to buildings, for instance green roofs, rooftop gardens, greening of vertical walls, and landscaped balconies. The National Parks Board has actively promoted vertical greening through incentive schemes and awards, and has even published extensive guides on ‘skyrise greenery’. Singapore has managed to create many tiers of highly visible greenery from ground level up to the building tops, seeing the high-rise structures that form the cityscape as a means, rather than an impediment, to introducing more greenery.

4.5.4 People friendly streets and spaces

Streets are probably the most important element of the public domain, and are fundamental to the human experience of the city. Traditional streets provided a balance between pedestrians and other uses. However in the twentieth century streets have focussed predominantly on facilitating vehicle movement and accommodating engineering infrastructure. A more balanced concept of street design recognizes the need for pedestrian amenity and public life, as well as fulfilling these engineering functions. Such streets are currently known by a number of names such as ‘walkable streets’, ‘complete streets’, ‘liveable streets’ or ‘context sensitive streets’.

Most recently environmental sustainability has been added as another ‘layer’ to the street design agenda. Streets have a significant potential to provide the city with a wide range of ecological services

in the form of urban greening, climate change adaptation, urban heat island mitigation and sustainable stormwater management (WSUD), as well as encouraging 'active transport' modes which promote community health while minimizing greenhouse gas emissions.

Gehl Architects have developed a set of criteria to assess quality of the public domain, and when all of these criteria have been fulfilled it will result in a place where people 'can use all the human senses and fully enjoy walking as well as staying' (Gehl 2002; Gehl and Gemzoe 2003; Gehl 2008). These quality criteria are divided into three groups: protection, comfort and enjoyment:

- **Protection** focuses on how to minimize unpleasant experiences including crime, traffic accidents and unpleasant climatic conditions.
- **Comfort** deals with the quality of walking and staying in a place, and involves walking, standing and sitting as well as the possibility for seeing, hearing and talking.
- **Enjoyment** covers the human scale, enjoying the positive aspects of the climate and the experience of the qualities of the design of the place, including quality of materials used.

Alan Jacobs has examined the qualities that contribute to streets which are universally recognised as 'great streets' (Jacobs 1993) and to multi-lane urban boulevards (Jacobs, MacDonald et al. 2002). Jacobs has concluded that street trees are more than just 'aesthetic decoration', and are in fact one of the most important elements in the design of the urban streetscape:

'Given a limited budget, the most effective expenditure to improve a street would probably be on trees. Assuming that trees are appropriate in the first place, and that someone will take care of them, trees can transform a street more easily than any other physical improvement. Moreover, for many people trees are the most important single characteristic of a good street'.

Jacobs (1993) considers that street trees can make a significant contribution to each of the following qualities of a street:

- **Places for people to walk with some leisure.** Trees planted along a kerb, especially if closely spaced, define a pedestrian zone separated from vehicular traffic, creating a sense of safety both physically and psychologically. Trees planted in the parking lane may also help to bring it visually into the pedestrian realm.
- **Physical comfort.** Street trees provide physical comfort for pedestrians by providing shelter from wind and rain in winter and cooling shade in summer. Deciduous trees also provide access to warming sun in winter. Closely spaced trees can provide continuous shade and shelter in all seasons.
- **Definition.** Street trees provide physical definition, vertically with 'walls' of tree trunks, and horizontally with 'roofs' of tree canopies. The most satisfactory proportions between street

width and the height of its vertical edges have long been a concern of architects and city designers.

- **Qualities that engage the eye.** Street trees add visual complexity to the streetscape, and have the special attribute of a constant sense of movement of leaves and branches, and changing patterns of shade and light. Green is also perceived as a restful colour in urban settings.
- **Transparency.** Trees provide a semi-transparent edge to the street.
- **Scale.** Trees can also provide a sense of human scale in the streetscape.
- **Design unity.** Trees create a sense of design unity, especially with relatively close spacings and continuity of planting.
- **Maintenance.** In the best streets, trees appear cared for, and adequate funds need to be allocated for their maintenance.

O'Brien (1993), in his book *Street Trees for Cities and Towns*, identifies a similar list of the functional and aesthetic contributions of trees to urban streetscapes. These include:

- Creating or reinforcing **identity** in a street.
- Complementing historic or **culturally** significant buildings or streetscapes.
- Enhancing pedestrian or vehicular orientation, **legibility** and way finding. Street trees can emphasize direction and directional change by accentuating road lines. They can emphasize a sense of movement, and their spacing can be manipulated to create a desired ambience, with closer spacings emphasizing a sense of speed. Trees can also be used to emphasize road junctions and focal points, and to reinforce the hierarchy of streets within the city.
- Playing a **symbolic** or monumental role, for example in major boulevards and city gateways.
- Enhancing **visual amenity** through screening unsightly views, softening the mass of large buildings, and reducing the apparent width of streets (especially if trees are planted adjacent to the kerb).
- Providing **visual interest**, colour and a sense of movement in urban settings.
- Providing awareness of **seasonal** change.
- Providing a sense of **human scale** by creating smaller spaces within the wider streetscape, both vertically (by creating 'walls' of tree trunks), and horizontally (by creating 'roofs' of tree canopies).
- Providing clear **spatial definition** in streets, for example by separating pedestrian and vehicular zones, both physically and psychologically.
- Most significantly, street trees can provide a **unifying** element in an often visually diverse and sometimes chaotic urban streetscape. This design unity, however, does not become 'boring', as it is coupled with a sense of variety, with each tree having its own individual character.

4.6 Walkability

Parks have long been seen as the most important sites for physical activity which can contribute to human health (Maller et al. 2002). More recently there has also been a focus on the role of streets as venues for walking to maintain health, especially for older people. Green elements, such as street trees, gardens and parks, have been found to be important aspects in making streets attractive for walking (Borst et al. 2008). Research in the last decade has broadened the range of public health issues associated with the design of roads and streets. One area of research has investigated the effects of different roadway designs and roadside design elements on 'walkability'. Some researchers have attempted to objectively measure the impacts of street design on the walking behaviour of an area's residents or workers. It has been found that the 'walkability' of a street or neighbourhood depends on a number of factors. For example Southworth (2005) reviewed a number of pedestrian plans and concluded that walkable neighbourhoods are associated with improved physical and mental health, and increased community vitality. Southworth identified the common characteristics of walkable neighbourhoods, which comprise:

1. Connectivity.
2. Linkage with other modes.
3. Fine grained land use patterns.
4. Safety.
5. Quality of path (attention to details such as width, paving, landscaping and lighting).
6. Path context (the path context is visually stimulating to the pedestrian).

Zacharias (2001) reviewed studies of pedestrian behaviour and highlighted the link between the 'legibility' or visual understanding of the pedestrian network and pedestrian travel on that network. His study suggested that both regular forms and spatial differentiation are important in enhancing walkability. He also identified the need for some complexity of space to maintain attention, but avoiding excessive complexity which may be considered dangerous. This reflects the work of Kevin Lynch (1960), an early seminal figure in urban planning, whose study of pedestrians led to the concept that places should be 'imageable' (i.e. the pedestrian should be able to hold the image in their head).

With respect to the role of aesthetics in 'walkability', Saelens and Handy (2008) analysed 42 reviews of built environment correlates of walking. They found that six studies related aesthetic qualities and walking, however the measure of aesthetics varied between studies. Naderi (2003) examined five pedestrian pathways in Texas built in the clear zone of a roadway, to better understand the characteristics of pathways that attract walkers. It was found that walkers tended to associate the ambience or context of a place with its desirability for walking. In addition the edge of the space (defined as either a sense of enclosure, environmental identity or 'genius loci') was the single environmental variable that distinguished 'good' from 'not good' walking sites. It was also found that respondents preferred a 'natural' edge to an 'urban' edge, if walking specifically for health purposes. Naderi did not

define a 'natural' edge but it was concluded that lining a path with trees (as opposed to having no barrier between the pedestrian and traffic) would contribute to a more 'natural' edge.

Lee and Moulden (2006) examined the differences between walking for recreation or for transportation purposes, to better understand how to promote both activities. Based on a survey of 438 participants a model was developed to differentiate between the two activities. The data indicated that the environmental variables associated with walking for recreation differ from those associated with walking for transportation, (including the number of street trees present). Distance was much more important for walking for transportation, as was the presence of street trees. Environmental variables were more strongly associated with frequent rather than moderate walking, suggesting a 'supportive physical environment' may be a key element in promoting recommended levels of walking for health.

The perception of safety is an important component of walkability, and a number of authors have noted the possible pedestrian safety aspects of tree planting in the verge between the footpath and roadway. This includes both an increased perception of safety (by separating pedestrians and moving vehicles) and a real improvement in safety by creating a protective barrier which reduces the risk of being hit by a 'run-off-the-road' vehicle (Jacobs 1993; CTRE 2008).

4.7 Pedestrian safety

Statistics indicate that on average there are 11 pedestrian fatalities and 87 pedestrians seriously injured in metropolitan Adelaide annually. The majority (71%) of these serious casualty crashes occur where a pedestrian is struck at mid- block rather than intersection locations. Research into pedestrian safety has focused on the role of traffic calming measures, which can be similar to the desirable characteristics that make a street more 'walkable'.

There seems to be a self-evident connection between pedestrian safety and traffic calming. Traffic calming has been shown to be particularly important where fewer pedestrians are present, as the presence of large numbers of pedestrians seems to encourage drivers to drive more slowly (Jacobsen 2003). A number of researchers have sought to understand the impacts of different traffic calming measures. Litman (1999) reviewed over 100 research studies into traffic calming, and found that 'comprehensive' traffic calming measures increase safety both directly (by reducing vehicle speeds) and indirectly (by encouraging higher levels of pedestrian activity, leading to increased driver awareness). Reducing vehicle speeds is an important priority as there is an established correlation between higher vehicle speeds and both the occurrence and severity of pedestrian crashes. In 2003 the default urban speed limit in South Australia was reduced from 60km/h to 50km/h, and studies into the effects of this change in speed limit found that the number of hit-pedestrian casualty crashes significantly decreased by 21% in the first 3 years following the change (DPTI 2011).

Research shows that traffic calming techniques (particularly speed humps) are effective in reducing driver speed, and importantly that a combination of techniques is more effective than installing a single

technique (Daniel et al. 2005). It has been shown that traffic calming is best achieved with a combination of roadway (such as road humps) and roadside (such as trees) design elements. Research confirms that a number of such measures can contribute to pedestrian safety, but it is difficult to generalize from the research to quantify the specific impacts that a particular roadside element (such as trees planted in the verge) will have on pedestrian safety in a particular street. One study by Topp (1990) of nine urban streets in Germany found that a reduction in perceived roadway width led to reduced traffic speeds. Street trees were also identified as the most influential element in reducing perceived roadway width. Although there is little existing research on the effects of roadside planting on pedestrian safety, it is widely recognized that narrower roads appear to be associated with lower traffic speeds, and fewer pedestrian/vehicle accidents, and that street trees are one of the most effective means of reducing this perceived roadway width.

4.8 Driver safety

4.8.1 Introduction

One of the major challenges in the design of streets is the apparent conflict between driver safety and the benefits of providing roadside trees. In fact early traffic engineering publications often promoted the use of trees in enhancing roadway design. In 1949 Neale suggested that 'trees have undoubtedly saved many lives and prevented many accidents in intangible ways' and noted that well-spaced trees could improve driver comfort by providing protection from sun and wind, helping keep drivers alert, and reducing cross-glare (Neale 1949). Others such as Ziegler have also noted the benefits of trees and landscaping in terms of providing shade, windbreaks, visual buffers and physical protection for pedestrians from run-off-the-road vehicles (Zeigler 1986).

More recent transportation research and policy making, however, tends to connect roadside trees with an increased probability of road crashes, and an increased accident severity. In many areas traffic authorities have severely restricted roadside tree planting by enforcing 'clear zones' (areas of roadside are to be kept free of rigid objects such as trees above a specified trunk diameter). It is now recognised, however, that street trees can provide a wide range of benefits to street users (including enhanced comfort and walkability) which leads to increased levels of physical activity and psychological well-being. In addition the recent focus on sustainability and climate change has emphasized the Green Infrastructure benefits of trees and roadside landscaping. It is evident that there is a need for a more balanced approach to street design, with consideration of social and environmental responsibility, as well as responsibility for user safety. Recent research has revisited the assumption that roadside trees should be eliminated for safety reasons. Research into the impacts of roadside design elements (such as trees) on driver safety tends to be grouped into two main categories (Macdonald and Supawanich 2008).

- a) Relationships between roadside design elements (such as trees) and driver speed and behaviour. (For example the influences of roadside landscaping on driver stress, and the idea of using trees as 'environmental references' to reinforce desired speed limits).

- b) Associations between roadside design elements (such as trees) and the frequency and severity of vehicle accidents. (For example by correlating accident rates with the presence of roadside design elements such as trees).

4.8.2 Driver behaviour and roadside trees

4.8.2.1 Vehicle speeds

It is well established that higher vehicle speeds are associated with more frequent and more severe crashes (Richter et al. 2006). As well as enforcing legal speed limits road authorities have also sometimes attempted to implement 'environmental reference speeds' using traffic calming devices, especially the visual narrowing of roadways. A number of studies support this concept of using roadside design elements such as trees to reinforce lower vehicle speeds. In Florida Dumbaugh (2005) studied two sections of an arterial highway of the same width but with different cross-section designs. One section comprised 'liveable' street treatments (including wide footpaths, streetscape elements close to the edge of the roadway, a narrow clear-zone, and trees planted between the footpath and roadway). Over the five year study period, the section that was designed as 'liveable' was found to be safer 'in all respects' including fewer collisions and fewer pedestrian and bicyclist injuries and fatalities. Dumbaugh hypothesized that people operate using 'risk homeostasis' (a subconscious evaluation of risk which guides behaviour). Where safety is 'built-in' by engineers, for example by providing wider traffic lanes, the human brain subconsciously interprets the increased provision of space as permission to be less careful and alert. But where the need for lower speed can be communicated through the physical design of the street the driver will tend to be more attentive and careful. Dumbaugh also speculated that this phenomenon may cancel out the desired safety effects of passive safety design measures adopted by traffic engineers.

Successfully planting trees in a narrow road corridor may involve reducing road laneway widths to create additional planting space. This is often assumed to reduce vehicle and bicycle safety. One study investigated the relationships between lane widths and safety on urban and suburban arterials in Minnesota and Michigan. The research found no indication that mid-block lanes narrower than 3.6 metres lead to increased crash frequencies (Potts et al. 2007). This suggests that strategies of narrowing traffic lanes to enhance pedestrian safety can possibly be implemented without impacting on driver safety. In another study Van der Horst and Ridder (2007) conducted a laboratory simulation to investigate the influence of roadside infrastructure (including trees planted at different distances from the roadway) on driver speed and vehicle positioning (in this instance on a multi-lane highway). The findings appear to corroborate the idea of 'environmental reference', as drivers reduced speeds when encountering trees close to the roadway, suggesting that they 'read' their surroundings and react accordingly. Overall this research shows the importance of road design in communicating desired speeds to drivers, including the use of roadside features such as trees.

Influencing driver behaviour by changing the visual characteristics of a road has come to be called the self-explaining-roads (SER) approach (Theeuwes and Godthelp 1995). The SER approach, most well

known in the Netherlands and the UK, and to some extent in New Zealand, focuses on three main principles of functionality, homogeneity and predictability, aimed at eliciting the appropriate driver behaviour for a range of specific road types. One aspect of SER is the development of perceptual cues in the roadside environment that suggest a particular speed or lane position. Consistent use of such cues on a hierarchy of road types allows drivers to correctly categorize a specific road type and automatically respond with the appropriate driving behaviour. The SER approach differs from the application of localized traffic calming measures, which rely on physical obstacles which are often unpopular with both drivers and residents, and lead to the re-emergence of problems at other locations. In New Zealand, Charlton et al. (2010) developed a range of SER designs for different functional road categories, using local design elements. Urban landscaping was used to create restricted forward visibility as a defining feature on the 'local road' category, with a design speed of 30 km/h. The increased landscaping consisted of trees planted in the centre of the road, and landscaped 'community islands' at periodic locations along the kerb sides. Speed data collected three months after implementation showed a significant speed reduction on local and collector roads.

4.8.2.2 Driver stress reduction

Commuting has been shown to be one of the most stressful experiences of modern urban life (Novaco et al. 1990) and stress responses have been documented for all driving experiences, with intensity varying according to traffic and road conditions (Rutley and Mace 1972).

Researchers have suggested that roadside design can actually help to reduce driver stress. This builds on more general research showing that views of nature can have restorative effects and reduce stress (Ulrich et al. 1991; Kaplan 1995). Kaplan (1995) hypothesized that natural settings can provide the variables needed to restore the mind from 'directed attention fatigue' which occurs as a result of over-concentration during tasks which do not seem to be physically demanding, such as driving. This fatigue is a key factor in human error, leading to a reduced ability to comprehensively survey, understand and respond to situations, and choose direction of course. This loss of attention is especially dangerous in tasks where there is a risk of harm, such as driving. Kaplan hypothesized that one way to restore attention is to 'give the mind a break' and let it focus on something that promotes involuntary attention, which he labelled 'fascination'. Kaplan identified three elements necessary for 'fascination': the subject must shift attention to a separate environment, which must be rich and complex enough to create an alternative world, and this environment must be compatible with what the person would like to do. It is evident that natural settings often include all of these variables. This research points to the need for mind 'fascinating' roadside elements, especially natural elements. Kaplan's research also indicates that directed attention fatigue can precipitate stress, and the presence of nature can potentially mitigate both conditions and make driving safer.

Parsons et al. (1998) have examined the effects of a number of different driving environments on stress and found a connection between roadside greenery and stress recovery. 160 participants in a laboratory simulation were exposed to a 'stressor' then to either an urban or natural driving scene. The participants exhibited negative emotional responses and prolonged stress recovery periods after viewing predominantly 'man-made' driving scenes. In contrast, driving scenes through park like settings resulted

in the least effect on blood pressure and the quickest recovery from stress. Cackowski and Nasar (2003) hypothesized that exposure to roadside vegetation may reduce the levels of anger and frustration often associated with driving. In a controlled laboratory experiment, they measured anger levels after subjecting 106 subjects to a stress inducing video. Subjects then watched one of three driving videos: a 'built up' highway with little vegetation, a 'garden highway' with some vegetation, and a 'scenic highway' with intensive vegetation. The researchers then measured anger levels, and frustration tolerance. Although the results did not find any effects on anger levels, they did suggest that roadside vegetation increases a driver's levels of frustration tolerance. The findings also suggested that viewing natural driving scenes contributed to clearer thinking than viewing built-up environments. Although based on laboratory simulations this research does suggest that the presence of more natural roadside elements, such as landscaping, could play a role in reducing levels of driver fatigue, stress and frustration, which can impact on driving safety.

4.8.3 Tree crash studies

A number of researchers have compared accident statistics from similar road sections, but with different roadside treatments. It must be noted that some research into tree crashes does not adequately address the critical question of crash causation, particularly the influences of driver fatigue, speed or alcohol. For example if any of these factors are involved in a crash with a tree, is it appropriate to attribute the cause of the crash, or its severity, to the tree (leading to recommendations for tree removal), or to driver behaviour (leading to recommendations for improved behavioural control)? (Macdonald and Supawanich 2008)

One study reviewed 1999 run-off-the-roadway collision data from fourteen US state transportation authorities and found that 8% of all fatal accidents involved trees, and that 90% of these accidents occurred on two-lane roads (Neuman et al. 2003). Only 24% of crashes with trees occurred in urban areas, and nearly half of those on curved roadway sections. While the study advocated the use of clear zone policies, it has been noted that it failed to consider the role of vehicle speeds in crashes which may have led to erroneous conclusions about crash causation.

Mok and Landphair (2003) compared accident rates on parallel 'freeway' and 'parkway' road sections in different parts of the US. Freeways were characterized by paved shoulders, concrete median barriers and wide vegetation clear zones. Parkways were characterized by grassed shoulders and medians, with roadside trees and other landscaping. Parkway sections exhibited lower fatal accident rates. Fatal accidents involving reflected glare and headlights only occurred on the freeway sections. No fatal collisions with trees were recorded in the survey period, despite the extensive level of landscaping. The difference between urban freeway and urban parkway sections was twice that between rural freeway and rural parkway sections, suggesting that landscaping urban corridors may have greater safety impacts than landscaping in rural corridors.

Dumbaugh (2006) conducted an empirical analysis of the safety of three roadside treatments in Florida: widened paved shoulders, widened fixed object offsets, and liveable street treatments (defined as

including on-street parking, trees, footpaths and buildings located close to the roadway). Crash data were collected for 27 miles of the three different designs. After controlling for other variables, modelling indicated that only the liveable-street treatment was consistently associated with reductions in both roadside and mid-block crashes. To better understand these findings Dumbaugh also examined characteristics of the roadside crash locations for tree and utility pole crashes. His analysis found that the probability of a tree or pole crash declined at greater than 5 metres offset. In addition 65-83% of urban fixed-object collisions did not result from the vehicle errantly leaving the roadway, as is often assumed, but from failing to properly negotiate a turning manoeuvre. Liveable street segments experienced 67% fewer roadside crashes than the other segments, suggesting visible fixed hazards induce behavioural changes which lead to slower driving speeds. Dumbaugh also undertook an informal study gauging the speeds of random cars approaching and passing through a liveable street intersection with 1.2 metre offset trees, which indicated a notable slowing of traffic, which suggests that drivers were adjusting their speeds in response to the surrounding environment.

Lee and Mannering (1999) related two years of accident data and roadside characteristics for a 60 mile length of highway in Washington State. Their analysis indicated differences in the safety characteristics of urban and rural highway sections. For urban highways, wide traffic lanes and wide shoulders were associated with a greater frequency of run-off-the-roadway accidents, but the presence of trees was negatively associated with such accidents. For rural highways, higher speed limits were associated with a greater frequency of run-off-the-roadway accidents.

A California study by Sullivan and Daly (2005) found that large trees in kerbed central medians in major urban and suburban highways were associated with an increased accident frequency, and with more severe left-side collisions, although some associations were not statistically conclusive. It is also possible that if some of these accidents had not involved a collision with a median tree, the vehicle could have crossed the median into on-coming traffic.

A number of researchers have also conducted 'before and after' studies comparing accident statistics on stretches of roadway both before and after landscaping measures have been implemented. In a study of five urban arterial streets in Toronto, Canada, Naderi (2003) found that landscape improvements reduced mid-block accident rates by 5-20% (for the three years before and after the improvements) as well as increasing pedestrian use of urban arterials. Trees themselves could not be directly linked with the results, however it was observed that a well-defined road edge may lead to drivers being more attentive and cautious. Using a 'willingness to pay' formula Naderi also found that the landscape improvements led to a saving in over CD\$1 million in reduced traffic crashes within 3 years of implementation of the CD\$2.5 million improvements. In Texas Mok, Landphair et al.(2006) conducted a before and after study of ten urban arterials in which landscape improvements were implemented (including roadside and median greening, footpath widening and tree planting). The researchers compared accident statistics over a period of 3-5 years both before and after improvements, and found a decrease in crash rates after the improvements. This included decreased

crash rates (from 1% to 71%) at eight out of ten sites. Overall tree collisions were reduced by approximately 71% for all road sections combined, and pedestrian fatalities by approximately 47%. The findings suggest that there may have been a driver response to the increased landscaping resulting in improved traffic safety. It was noted that 'the landscape not only contributes to greater aesthetic compatibility between the urban environment and the highway but may contribute to a safer street.' In Washington State, a before and after study of landscaped medians and other streetscape improvements on two miles of an urban arterial road, concluded that tree variables had little impact on the prediction of crash rates (St. Martin et al. 2007). Data analysis revealed high crash rates before and after improvements, however shifts in crash locations did occur, from mid-block crashes to intersection crashes, due to the installation of medians, kerbs and landscape plantings. The researchers concluded that tree effects were probably masked by other variables. The study highlighted the difficulties of attributing causation in such 'before and after' studies, when a large number of changes are implemented.

It is also of interest to compare the differences between drivers' perceptions of safety in tree lined streets and the assumptions underlying clear zone policies. Naderi et al. (2008) studied how drivers' perceptions of highway safety were affected by the presence of trees. In a virtual simulator study, subjects 'drove through' four digitally created streets (one pair urban and one pair suburban). The two streets in each pair were identical except for the presence of relatively closely spaced mid-sized trees. The subjects were asked to rate their perception of roadway safety, and the sense of spatial definition. The results indicated that suburban streets were perceived as the safest, followed by urban streets with trees. Urban streets without trees were perceived as the least safe. In both urban and suburban streets, the presence of trees was associated with a greater sense of 'spatial edge', which contributed to a greater perceived sense of safety. It was concluded that both city form (urban/suburban) and landscaping (the presence or absence of street trees) influenced the subjects' perception of safety. However the presence of street trees had a greater impact on perceptions of safety than the surrounding land uses. Individual driving speeds were also significantly reduced when street trees were present in the suburban street, and both faster and slower drivers drove more slowly in the presence of trees. (The speed data for urban streets could not be successfully analysed due to the short block lengths.) The authors concluded that drivers' perception of safety had a significant relationship to their perception of the roadway edge, and the addition of kerbside trees significantly increased driver's perception of that spatial edge.

The results of these studies indicate that there may in fact be a positive effect of having a well-defined roadside edge, which may lead to an overall decrease in run-off-the-roadway collisions with roadside objects. Street trees help to define the edge of the road space by providing a diverse visual edge that also is repetitively simple in colour, texture, and form (Naderi, Kweon et al. 2008). Lynch (1960) had earlier theorized that a distinct roadway edge helps contribute to the 'legibility' of the city, fostering a feeling of familiarity and comfort. These findings suggest a different role for trees in urban and suburban streets, one that enhances traffic safety rather than threatening it.

4.8.4 Intersection sight lines

Memorable streets are often tree-lined, with trees at regular spacings, and planted all the way to the intersection corners (Jacobs 1993). However safety concerns have resulted in trees being set back long distances from intersections, to maintain sight lines for drivers (Macdonald 2008). Traffic engineering design manuals by authorities such as the American Association of State Highway and Transportation Officials (AASHTO) recommend designing intersections with clear sight triangles to improve a driver's ability to see potential conflicts with other vehicles before entering the intersection.

In the United States, MacDonald (2008) has queried these restrictions for two reasons. Restricting trees may not solve visibility problems, as other objects can still block sight lines, including parked cars; and streets do not function as well as they should for pedestrians by providing comfort, legibility and shade. MacDonald points out that clear sight diagrams include unrealistic 2-dimensional representations of trees based on a tree canopy circle. This representation is unrealistic as street trees are usually pruned to create a raised canopy on a bare trunk. In reality, the part of the tree which will intrude on the driver's cone of vision is the trunk rather than the canopy, a relatively thin vertical element. In addition, while eliminating trees at intersections, other urban elements such as street furniture and light poles may be allowed near intersections. In addition parked cars may block driver vision to a greater extent than tree trunks. MacDonald has applied three dimensional modelling to simulate sight lines at typical urban intersections, varying the presence of street trees, parked cars and newspaper racks (Macdonald et al. 2006). The models were animated with moving cars and drive through simulations from the driver's viewpoint. It was concluded that street trees, if properly selected, adequately spaced and pruned to branch high, do not create major visibility problems for drivers entering intersections. In fact parked cars, especially large 4WD ones, create substantially more visibility problems. The research suggests that street trees planted close to intersections, spaced as little as 8 metres apart, and pruned to 4.2 metres above the ground, do not constitute a visibility hazard on urban streets. MacDonald concludes that, although further research is required, the AASHTO guidelines need to be re-evaluated.

4.9 Air quality improvement

4.9.1 Introduction

Green Infrastructure can play an important role in improving air quality in cities. Figure 24 summarizes the main atmospheric benefits and air quality related ecosystem services provided by Green Infrastructure.

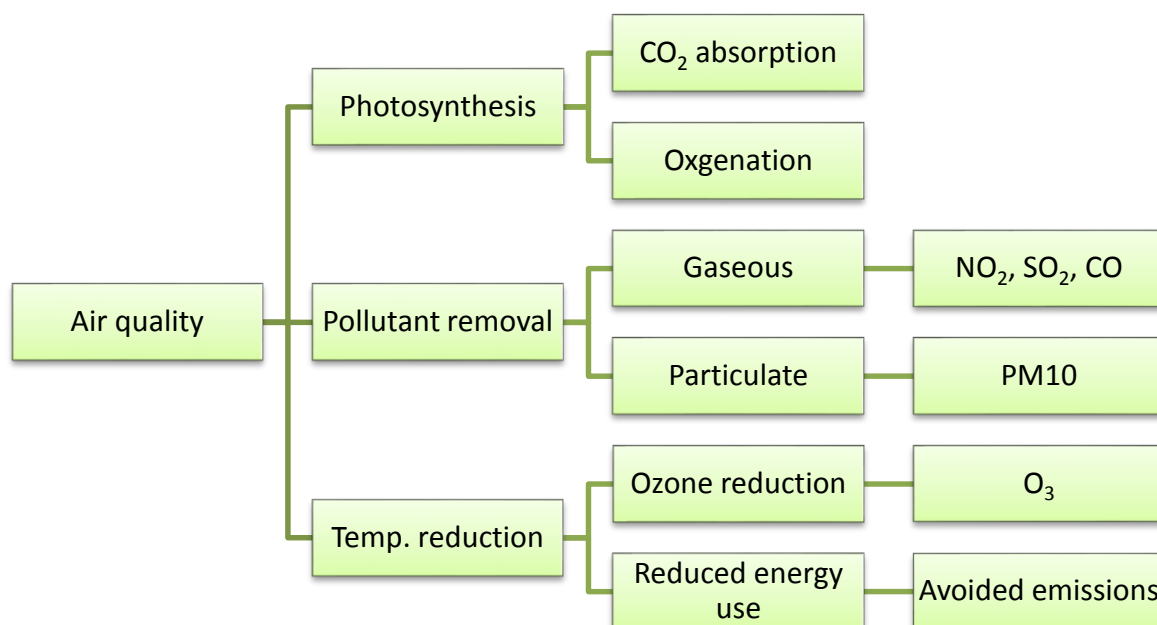


Figure 24: Summary of air quality benefits of Green Infrastructure. By author.

4.9.2 Air quality issues

4.9.2.1 Air pollution

Poor air quality is an issue in many urban areas, due to a combination of population growth and urbanization, and increased pollutant emissions due to industrialization and the use of transport based fossil fuels (Treeconomics 2011). The main pollutants of concern which are monitored by air quality authorities include (EPA nd):

- Nitrogen dioxide (NO₂).
- Fine particles-particulate matter (PM₁₀).
- Carbon monoxide (CO).
- Ozone (O₃).
- Sulfur dioxide (SO₂).
- Lead (Pb).

4.9.2.2 Air quality and urban heat island effects

Urban heat island effects increase overall electricity demand, as well as peak demand generally occurring on hot summer weekday afternoons. During extreme heat events (exacerbated by the urban heat island effect) the resulting demand for cooling can overload supply systems and lead to blackouts, or controlled blackouts to avoid power outages. Research shows that electricity demand for cooling increases by 1.5–2.0% for every 0.6°C increase in air temperatures suggesting that 5–10% of community demand for electricity is to compensate for the urban heat island effect (Akbari 2005). Electricity supply typically relies on fossil fuel power plants, which in turn leads to an increase in air pollutant and greenhouse gas emissions. The primary pollutants from power plants include sulfur dioxide (SO₂), nitrogen oxides (NO₂), particulate matter (PM), carbon monoxide (CO), and mercury (Hg). These are both harmful to human health, and contribute to complex air quality problems including

the formation of ground-level ozone (smog), fine particulate matter, and acid rain. Increased use of fossil fuel by power plants also increases emissions of greenhouse gases, such as carbon dioxide (CO₂) which contribute to global climate change (EPA 2012). In addition to impacts on energy-related emissions, increased temperatures can also directly increase the rate of ground-level ozone formation (formed when NO_x and volatile organic compounds (VOCs) react in the presence of sunlight and hot weather). In general more ground-level ozone will form as the environment becomes sunnier and hotter.

4.9.2.3 Air quality impacts

The problems caused by poor air quality in urban areas are well known and include (i-Tree 2010):

- Impacts on human health.
- Damage to ecosystems and ecosystem processes.
- Damage to buildings.
- Reduced visibility.

In recent years there has been considerable interest in the adverse health effects of exposure to air pollution. A number of epidemiological studies (EPA nd) have shown links between:

- Air pollution and asthma (Jalaludin et al. 2004).
- Air pollution and attendances at emergency departments for cardiovascular disease in the elderly (Jalaludin et al. 2006).

Many of these epidemiological studies have been conducted in the US and Europe. Researchers have observed that in general air quality in Australian cities is much better than that observed in many American and European cities (EPA nd). However studies in Sydney (Morgan et al. 1998a; Morgan et al. 1998b) and Brisbane (Simpson et al. 1997) have indicated that levels of ambient air pollution in those cities have contributed to variations in daily mortality and hospital admissions for cardio-respiratory disease, and that the effects observed overseas do also occur here. The Victorian EPA conducted an epidemiological study to investigate the effects of air pollution on daily mortality in Melbourne from 1991 to 1996 (EPA nd). The results showed that ambient air pollution in Melbourne was associated with increases in daily mortality. Although all of the air pollutants under consideration in this study (ozone, nitrogen dioxide, fine particles and carbon monoxide) were found to be associated with daily mortality, the strongest associations were for ozone and nitrogen dioxide. The main sources of these pollutants in Melbourne were motor vehicles and industrial activity. The report suggests that '*strategies to reduce these pollutants are important to reduce the risk of adverse health effects arising from exposure*' (EPA nd) p.42. The results of the study were also found to be consistent with other studies conducted within Australia and overseas. Another Australian study (Peach 1997) noted that overseas research has linked the levels of particulates, sulphur dioxide and ozone with increased morbidity and mortality.

4.9.3 Pollutant reduction by vegetation

4.9.3.1 Role of vegetation

Studies have found links between urban tree cover and air quality (Escobedo et al. 2008). One study indicated that a higher street tree density was associated with lower childhood asthma prevalence (Lovasi et al. 2008). A study in Santiago, Chile found that urban forestry may be effective in improving air quality, particularly in terms of removing atmospheric particulates (PM10) (Escobedo, Wagner et al. 2008; Escobedo and Nowak 2009). Because the filtering capacity of vegetation is closely linked to leaf area, trees with larger canopies can provide the most benefits (Treeconomics 2011). One Australian study found that vegetation could limit CO₂ fluxes to the atmosphere, caused by urban traffic (Coutts et al. 2007).

4.9.3.2 Pollutant reduction mechanisms

A recognized ecosystem service provided by urban trees and vegetation is that of improving air quality in cities. The natural functions of urban trees are known to remove atmospheric pollutants, oxygenate the air, and absorb carbon dioxide through photosynthesis (Brack 2002; Nowak et al. 2006). The natural functions of vegetation can directly and indirectly improve air quality in the following ways (Nowak 1995; see Figure 25):

- Direct removal of pollutants through either:
 - Absorbing gaseous pollutants through the leaf surface (SO₂, NO₂).
 - Intercepting particulate matter on leaves (PM10).
- Reducing air temperatures through shading and evapotranspiration, and thereby lowering ozone levels (O₃).
- Indirectly, by reducing air-conditioning use and related energy consumption in buildings (through shading of buildings, air temperature reduction and wind modification) leading to lower air pollutant emissions from power plants (known as 'avoided emissions').

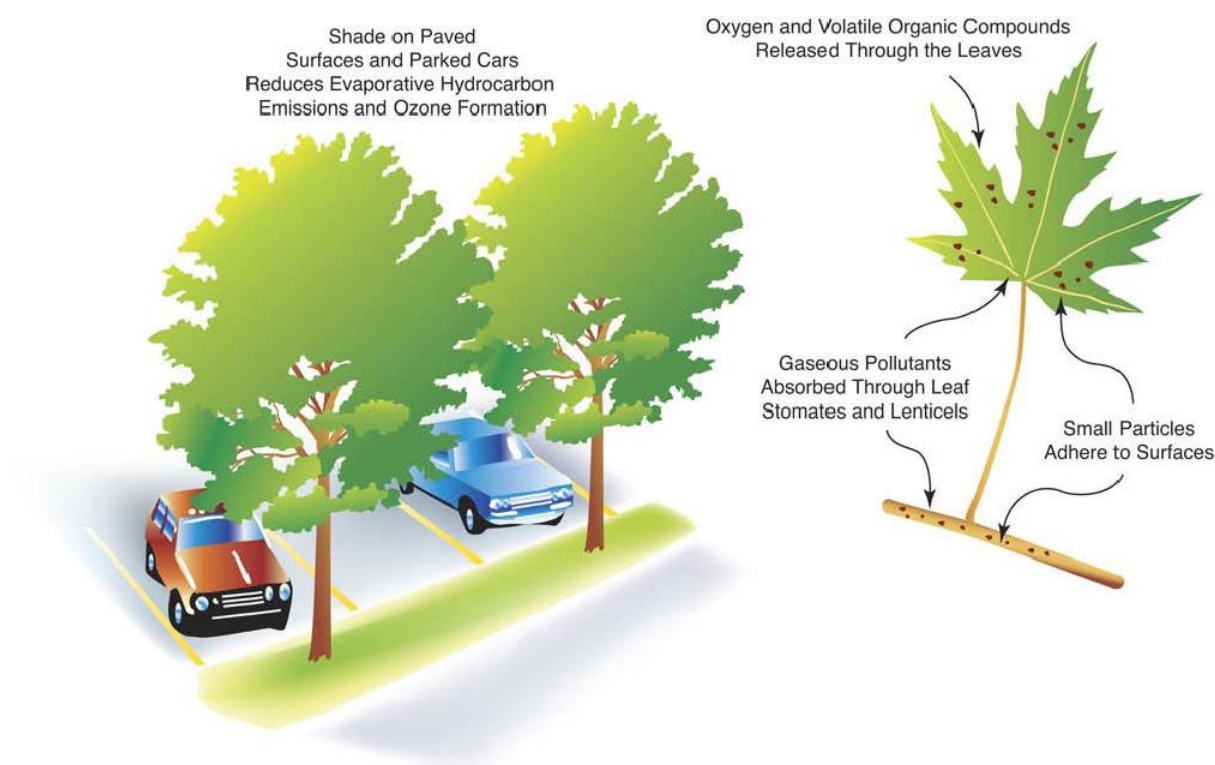


Figure 25: Air quality improvement by trees.Source: (McPherson 2010).

It must be recognised however that trees can also impact negatively on air quality through the emission of volatile organic compounds (VOC) and from emissions resulting from tree management activities. Trees emit volatile organic compounds that can contribute to ozone formation in the atmosphere (Chameides et al. 1988). However cumulative studies involving urban tree impacts on ozone have revealed that increased urban canopy cover, particularly with low VOC emitting species, leads to net reduced ozone concentrations in cities (Cardelino and Chameides 1990; Taha 1996; Nowak et al. 2000; Nowak and Dwyer 2007).

Trees remove gaseous air pollution primarily by uptake via the leaf stomata, although some gases are removed by the plant surface. Once inside the leaf, gases diffuse into the intercellular spaces and may be absorbed by water films to form acids or react with the inner-leaf surfaces (Smith 1990). Studies show that gaseous pollutants are absorbed by leaves and either metabolized or transferred to the soil by decay of leaf litter, which may be particularly important in streets with high traffic volumes (Nowak 1994; Scott et al. 1998).

The leaves of trees also collect and trap airborne particles on their surfaces. Some particles can be absorbed into the tree, although most that are intercepted are retained on the plant surface. The intercepted particles however are often re-suspended to the atmosphere, washed off by rain, or dropped to the ground with leaf and twig fall, therefore vegetation may provide only a temporary retention site for many atmospheric particles (Nowak, Crane et al. 2006). Interestingly oxygenation by urban trees is only of limited value compared with the major global oxygen sources such as the oceans and forests

(Nowak et al. 2007) and the most significant impacts on human health and environmental quality are through indirect reductions in carbon dioxide and atmospheric pollutants (Nowak et al. 2002; Nowak, Crane et al. 2006; Nowak, Hoehn et al. 2007).

4.9.3.3 Quantifying pollutant reduction benefits

The i-Tree tool has been used on a number of occasions to calculate pollutant removal by the urban forest in the US and elsewhere. For example pollution removal by trees in Washington was estimated using field data and recent pollution and weather data (i-Tree 2010; See Figure 26). Pollution removal was greatest for O₃, and it is estimated that trees studied removed 492 tons of air pollution (CO, NO₂, O₃, PM₁₀, SO₂) per year with an associated value of \$2.30 million, based on estimated national median externality costs associated with pollutants (Murray et al. 1994).

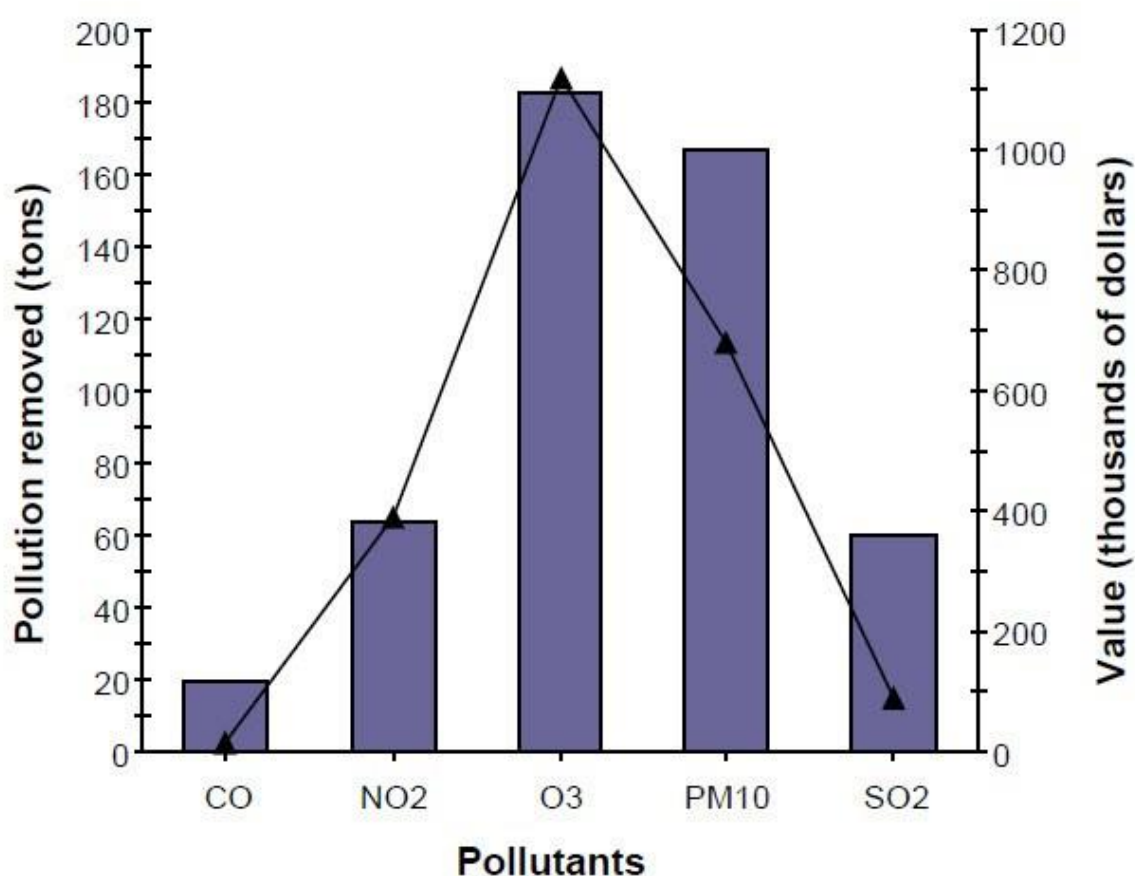


Figure 26: Pollution removal and associated value for trees in Washington (line graph is value). Source: (i-Tree 2010) p.7.

4.9.4 Traffic generated pollutants

4.9.4.1 Health impacts

In recent years increasing numbers of studies have linked proximity to roads with adverse health effects from exposure to traffic-generated pollutants. There is a general consensus that people spending significant amounts of time near major roads face increased risks for several health effects (Health

Effects Institute 2009). These effects can be attributed to particulate matter, gaseous pollutants, and air toxins. For particulate matter the main constituents of concern include ultrafine particles, coarse particles, metal constituents, and organic compounds (Baldauf et al. 2011).

A recent article in the US described how roadway design, including the presence of roadside vegetation, may provide a means of mitigating air pollutant concentrations near roads (Baldauf et al. 2009). In 2010 a multidisciplinary group of researchers and policy-makers in the US met to discuss the state-of-the-science regarding the potential role of vegetation in mitigating air quality impacts from traffic emissions (Baldauf, Jackson et al. 2011). It was found that vegetation near roads can play a number of pollutant mitigating roles outlined in the following sections.

4.9.4.2 Dispersion-only-based impacts

Field and wind tunnel studies have shown that dense vegetation barriers can play a similar role to solid barriers in dispersing near-road pollutant concentrations of inert gases such as carbon monoxide. Wind tunnel and field tracer study have revealed consistent reductions in ground-level concentrations behind barriers relative to situations with no barriers (Heist et al. 2009; Finn et al. 2010). The presence of a barrier was found to lead to an increase in vertical mixing, resulting in lower behind-barrier concentrations at ground level.

4.9.4.3 Enhanced capture of particulate matter

Field and wind tunnel studies have investigated the potential for enhanced capture of particulate matter by vegetation. Generally, these studies have shown decreases in concentrations of ultrafine and coarse particles, with limited reductions measured for PM 2.5 (Baldauf et al. 2008; Fujii et al. 2008). It has been noted, however, that under certain climatic conditions PM concentrations could be higher behind a vegetative barrier than on the roadside (Baldauf, Thoma et al. 2008).

4.9.4.4 Complex flow patterns

Modelling studies indicate that roadside barriers (including vegetated barriers) are associated with complex flow patterns. Two recent modelling studies have simulated the impact of roadside vegetation on near-road air quality (Zhu et al. 2002; Heist, Perry et al. 2009). A 3D model revealed significant reductions in down-wind inert pollutant concentrations in the presence of the barrier due to enhanced turbulence and mixing (Heist, Perry et al. 2009). A 2D model suggested that, under low wind speed conditions, concentrations can be higher on the downwind side of a vegetative or solid barrier, at further distances from the road, than would have occurred without a barrier (Zhu, Hinds et al. 2002). In this situation the traffic emissions were forced up and over the barrier, with the plume remaining mainly intact until returning to ground-level, leading to higher concentrations further downwind

4.9.4.5 Air quality in dense canyons

Modelling vegetation in extremely dense development, such as street canyons, has shown generally lower concentrations on the windward side, but higher concentrations on the leeward side of the street canyon (Gromke and Ruck 2007; Buccolieri et al. 2009). Researchers generally agree that local meteorology and site design are critical factors affecting air quality impacts around roadside vegetative barriers. Pugh et al. (2012) observed that street-level concentrations of nitrogen dioxide (NO₂) and

particulate matter (PM) exceed public health standards in many cities, causing increased mortality and morbidity. These can be reduced in three ways:

- Controlling emissions.
- Increasing dispersion of pollutants.
- Increasing deposition rates of pollutants.

According to Pugh, in the US little attention has been paid to increasing deposition rates as a pollution control method (Pugh, MacKenzie et al. 2012). Both NO_2 and PM are deposited onto surfaces at rates which vary according to the nature of the surface, and deposition rates to vegetation have been found to be much higher than those to hard surfaces. A recent study by Pugh et al. (2012) at Lancaster University has found that adding trees, bushes, green walls, or even ivy or other creeping vines, can reduce street-level nitrogen dioxide (NO_2) and particulate matter (PM) by eight times more than previously thought. Previous city-scale studies have suggested that deposition to vegetation results in only a very minor air quality improvement of around 5%. However few studies have taken full account of the interplay between urban form and vegetation, specifically the enhanced 'residence time' of air in street canyons. The study showed that increasing deposition through the planting of vegetation in street canyons (such as grass, climbing ivy and other plants) can reduce street-level concentrations by as much as 40% for NO_2 and 60% for PM, much more than previously believed (Pugh, MacKenzie et al. 2012). The authors even suggest constructing plant-covered 'green billboards' in such urban canyons to increase the amount of foliage. Trees were also shown to be effective, but only if care is taken to avoid trapping pollutants beneath their crowns. The authors concluded that judicious use of vegetation can create an efficient urban pollutant filter (See Figure 27), yielding rapid and sustained improvements in street-level air quality in dense urban areas.

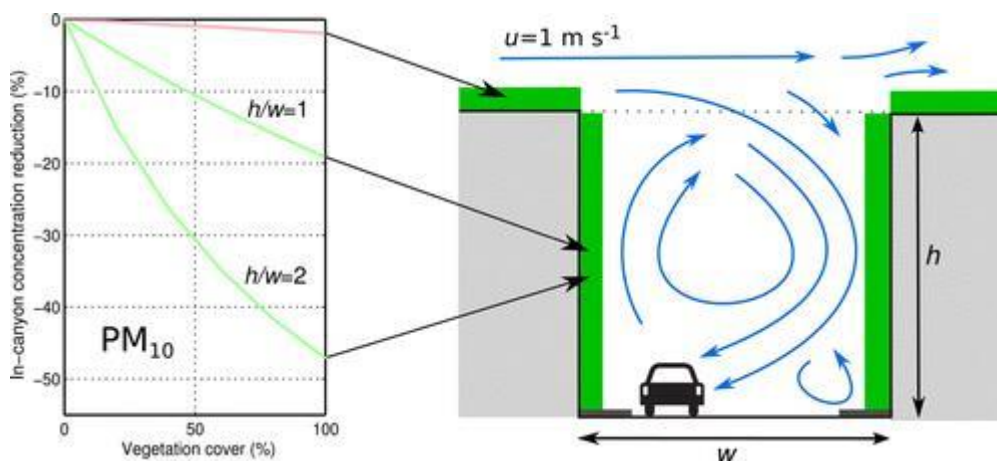


Figure 27: Vegetation cover and pollutant reduction in a street canyon. Source: (Pugh, MacKenzie et al. 2012).

4.9.5 Guidelines for Air Quality Improvement

Table 4 presents a number of urban forest management strategies to help improve air quality as recommended by Nowak (2000).

Table 4: Urban forest management strategies to help improve air quality. Source: (i-Tree 2010).

Strategy	Result
Increase the number of healthy trees	Increase pollution removal
Sustain existing tree cover	Maintain pollution removal levels
Maximize use of low VOC-emitting trees	Reduce ozone and carbon monoxide formation
Sustain large, healthy trees	Large trees have greatest per-tree effects
Use long-lived trees	Reduce long-term pollutant emissions from planting and removal
Use low maintenance trees	Reduce pollutants emissions from maintenance activities
Reduce fossil fuel use in maintaining vegetation	Reduce pollutant emissions
Plant trees in energy conserving locations	Reduce pollutant emissions from power plants
Plant trees to shade parked cars	Reduce vehicular VOC emissions
Supply ample water to vegetation	Enhance pollution removal and temperature reduction
Plant trees in polluted or heavily populated areas	Maximizes tree air quality benefits
Avoid pollutant-sensitive species	Improve tree health
Utilize evergreen trees for particulate matter	Year-round removal of particles

4.10 Noise abatement

4.10.1 Overview

It is known that noise from traffic and other sources can decrease quality of life in cities. Ambient sound has also been shown to affect pedestrian behaviour, and as traffic noise increases pedestrians remember fewer details in the physical environment, walk faster and look around less often (Zacharias 2001). Sound scattering by vegetation is complex and depends on a number of factors (Martens 1981). Recent research has investigated two aspects of noise reduction: the study of vegetative barriers as measurable traffic noise attenuators; and the psychological or perceptual role of vegetation.

4.10.2 Vegetation buffers

In highway situations properly designed plantings of belts of trees and shrubs can reduce traffic noise to adjacent residential areas although not as effectively as solid barriers such as noise walls. However to be an effective noise attenuator or buffer, plantings must be of sufficient width (generally over 10 metres) to achieve reductions in the order of 3-8 decibels (Fang and Ling 2003). Such measures however, are not readily applicable in narrower urban streets. The level of noise reduction will also depend on the type and arrangements of planting, as well as the contribution of soil type to sound absorption (Mulligan et al. 1982; Anderson et al. 1984; Fang and Ling 2003). One study quantified relationships between noise attenuation and the type and height of vegetation. Density, height, length and width of tree belts were found to be the most effective factors, rather than leaf size or branching characteristics ((Hayaashi et al. 1980). Wide plantings of tall dense trees combined with soft ground surfaces have been found to reduce apparent loudness by 50 percent or more (6-10 decibels) (Cook 1978). In many cases the high cost of conventional highway noise abatement measures (such as free-standing walls) has made mitigation of impacted sites economically not feasible, and a solution that may prove more economically acceptable for such sites is the use of strategically planted evergreen vegetation (Harris and Cohn 1985).

Recent research by Van Renterghema et al (2013) entitled '*The Potential of Building Envelope Greening to Achieve Quietness*' shows that urban greening can play a role in quieting urban areas. The study focussed on road traffic noise propagation towards the traffic-free sides of inner-city buildings (i.e. urban courtyards). Preserving quietness at such locations has been shown to be beneficial for the health and well-being of users. The results in the study show that green roofs have the highest potential to enhance quietness in courtyards. Favourable combinations of roof shape and green roofs were also identified. Vegetated façades were most efficient when applied to narrow city canyons with otherwise acoustically hard façade materials. Greening of the upper storeys in the street and (full) façades in the courtyard itself was most efficient to achieve noise reduction. Low-height roof screens were shown to be effective when multiple screens are placed, but only on condition that their faces are absorbing. The combination of different greening measures resulted in a lower combined effect than when the separate effects would have been linearly added. The researchers considered that the combination of green roofs or wall vegetation with roof screens appeared the most useful strategy. According to the researchers, greening

could be used to limit noise from other sources, such as air conditioning units, although the study focused solely on traffic noise.

4.10.3 Psychological roles

It has been shown that trees in urban streets provide only minor noise reduction benefits, unless associated with earth mounding or noise walls. Street trees, however, can also play an important psychological role by 'masking' traffic noise with their rustling leaves (O'Brien 1993). Noise-masking is a useful technique for treating the problem of noise that is simply annoying rather than excessively loud (Heisler 1974). Research has also shown that the visual and acoustic attributes of urban vegetation may interact to alter the perception and evaluation of sound (Mulligan, Goodman et al. 1982). For example, subjects have sometimes reported a noise reduction as a result of thin planting strips, and even hedges that were too sparse to have any physical impact on sound transmission. Other field tests have indicated that the environment in which the sounds are perceived may have an impact on the perception of noise levels. People perceived the same level of noise as higher in green settings than in more typical city settings, which indicates an adaption to certain sounds in different settings (Anderson, Mulligan et al. 1984). In one study researchers found that vegetative barriers created a perceived attenuation of road noise of 3-5 decibels, and concluded that visualization of the noise source directly affected perceived sound levels (Ishii 1994).

4.11 Summary

- A diverse body of research shows that Green Infrastructure can enhance the liveability of cities and the 'quality of life' in urban areas.
- This is a broad topic and includes a range of the less easily measured aspects of liveability including cultural values, aesthetics and other factors that contribute to urban amenity including the 'walkability' of streets and air quality.
- Green Infrastructure including urban greening in various forms can enhance liveability, and urban trees have been identified as making a significant contribution to urban amenity.
- Green infrastructure has been identified as one of the key principles for enhancing liveability in the modern densified city.

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5 Economic benefits

Green Infrastructure

Green Infrastructure is the network of green spaces and water systems that delivers multiple environmental, social and economic values and services to urban communities. This network includes parks and reserves, backyards and gardens, waterways and wetlands, streets and transport corridors, pathways and greenways, farms and orchards, squares and plazas, roof gardens and living walls, sports fields and cemeteries. Green Infrastructure secures the health, liveability and sustainability of urban environments. It strengthens the resilience of towns and cities to respond to the major current and future challenges of growth, health, climate change and biodiversity loss, as well as water, energy and food security.

5.1 Scope

A recent body of research has aimed to quantify the impacts of Green Infrastructure on the economic vitality of commercial centres and on residential property values. Another extensive body of research is attempting to quantify the economic value of the ecological services provided to communities by Green Infrastructure. This section describes the main research findings as well as some of the economic evaluation techniques underlying the research. Figure 28 summarizes the economic benefits provided by Green Infrastructure.

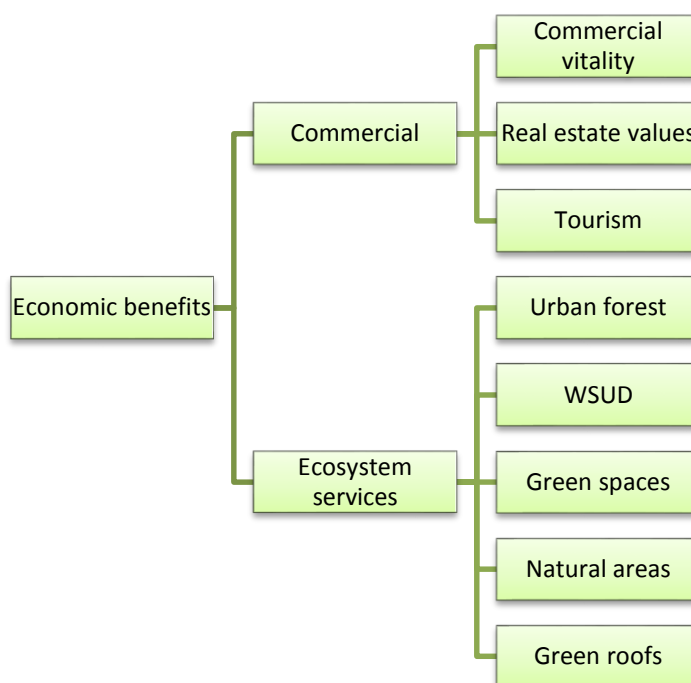


Figure 28: Summary of economic benefits of Green Infrastructure. By author.

5.2 Economic evaluation

5.2.1 Green Infrastructure values

Due to its 'multifunctional' nature the various benefits of Green Infrastructure may be difficult to quantify, as different functions may require a range of different forms of measurement (European Commission 2012). Attempting to place a monetary value on the functions performed by Green Infrastructure, however, is a useful method of deriving a more uniform assessment of the contribution of a range of different ecosystem services. Monetary values can also be easily`

communicated to stakeholders and the community, and can be fed directly into the policy decision making process (Vandermeulen et al. 2011). Some of the values provided by ecosystem services however remain difficult to quantify in financial terms, particularly those associated with cultural and aesthetic values. It also appears that evidence of the **benefits** of Green Infrastructure are less easy to quantify, and more variable than **costs**, and are often expressed in qualitative terms (Naumann et al. 2011a).

Costanza (Costanza 2012) argues that traditional models of the economy, (based on an 'empty world' concept in which natural resources were abundant) including the use of Gross Domestic Product (GDP) as the prime measure of human well-being, are no longer appropriate ways to measure human well-being and quality of life. According to Costanza (2012) p.18:

'We have to first remember that the goal of the economy is to sustainably improve human well-being and quality of life. We have to remember that material consumption and GDP are merely means to that end, not ends in themselves. But in the new full world context, we have to think differently about what the economy is and what it is for if we are to create sustainable prosperity. We have to better understand what really does contribute to sustainable human well-being (SHW), and recognize the substantial contributions of natural and social capital, which are now the limiting factors to improving SHW in many countries'.

In terms of measuring the economic value of ecosystem services, Costanza (2012) suggests that:

- Conventional economic valuation presumes that people have well-formed preferences and enough information about trade-offs that they can adequately judge their 'willingness-to-pay.' However these assumptions do not hold for many ecosystem services.
- The conventional economic approach to 'benefits' is far too narrow and tends to limit benefits only to those that people both perceive and are 'willing to pay' for in some real or contingent sense. But the general population's information about ecosystem services is extremely limited and many ecosystem services go almost unnoticed by the vast majority of people, especially when they are public, non-excludable services that never enter the private, excludable market.
- The benefits one receives from functioning ecosystems do not necessarily depend on one's ability to pay for them in monetary units. For example, indigenous populations with no money economy at all derive most of the essentials for life from ecosystem services but have zero

ability to pay for them in monetary terms. To understand the value of these ecosystem services we need to understand the trade-offs involved, and these may be best expressed in units of time, energy, land or other units, not necessarily money.

- Since many people understand monetary units as an index of value, it is often helpful to express trade-offs in those units. But this does not imply that monetary units are the only or the best way to express the trade-offs.
- It is necessary to not confuse expressing values in monetary units with treating ecosystem services as tradable private commodities. Most ecosystem services are public goods that should not be privatized or traded. This does not mean they should not be valued.

Costanza (2012) also suggests that ecosystem services are, by definition, not ends or goals, but means to the end or goal of sustainable human well-being. To achieve sustainability it is necessary to incorporate natural capital, and the ecosystem goods and services that it provides, into our economic and social accounting and our systems of social choice. In estimating these values we must consider how much of our ecological life support systems we can afford to lose. For example to what extent can we substitute manufactured for natural capital, and how much of our natural capital is irreplaceable? Because natural capital is a public good it is not handled well by existing markets, and special methods must be used to estimate its value.

5.2.2 Total Economic Value approach

As discussed above, it is often useful to convert the costs and benefits of different Green Infrastructure functions into a common measure. The concept of Total Economic Value (TEV) is a widely used framework for examining the utilitarian value of ecosystems (Pearce and Warford 2003; European Commission 2012). As illustrated in

Figure 29 Total Economic Value (TEV) aims to capture the full value of different natural resources. TEV recognises a range of values, including:

- **Use values**
 - **Direct use values.** Direct benefits from the use of primary services such as the provision of food and water.
 - **Indirect use values.** Benefits from secondary services such as air and climate regulation.
 - **Option values.** Benefits of preserving the option for future use.
- **Non-use values,**
 - **Existence value.** Value of the existence of a service without its actual use.

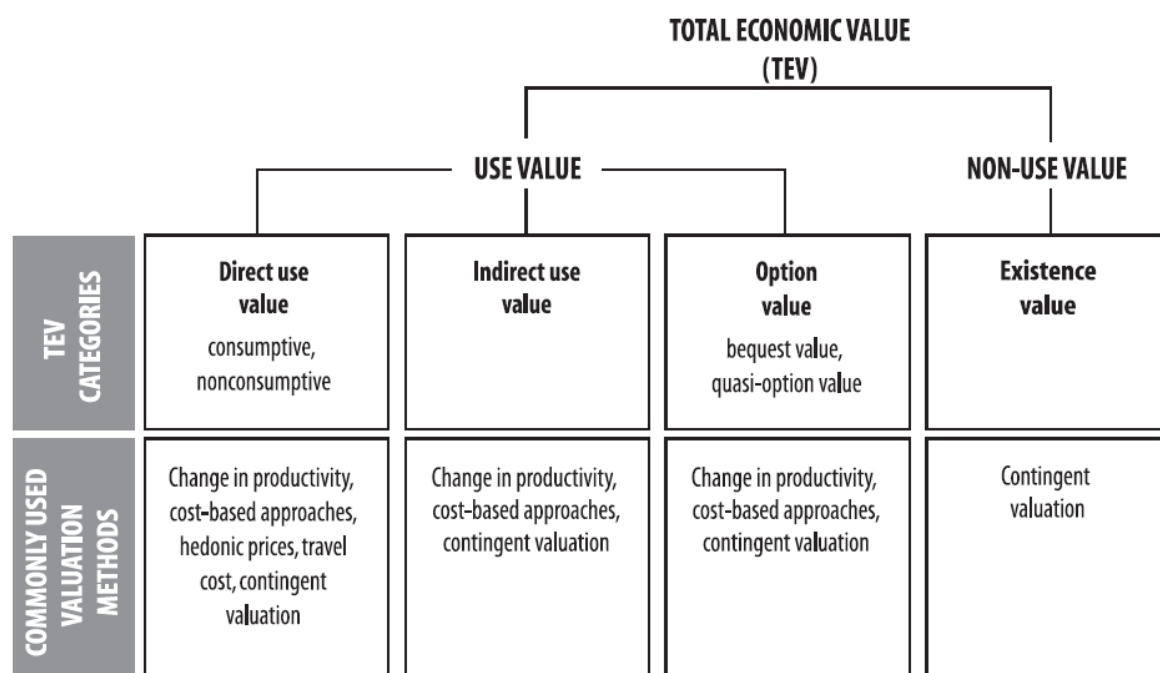


Figure 29: Total Economic Value Framework. Source: (Millennium Ecosystem Assessment 2003) p.132.

Figure 30 further illustrates the use of the TEV framework in the context of evaluating the *European Natura* project.

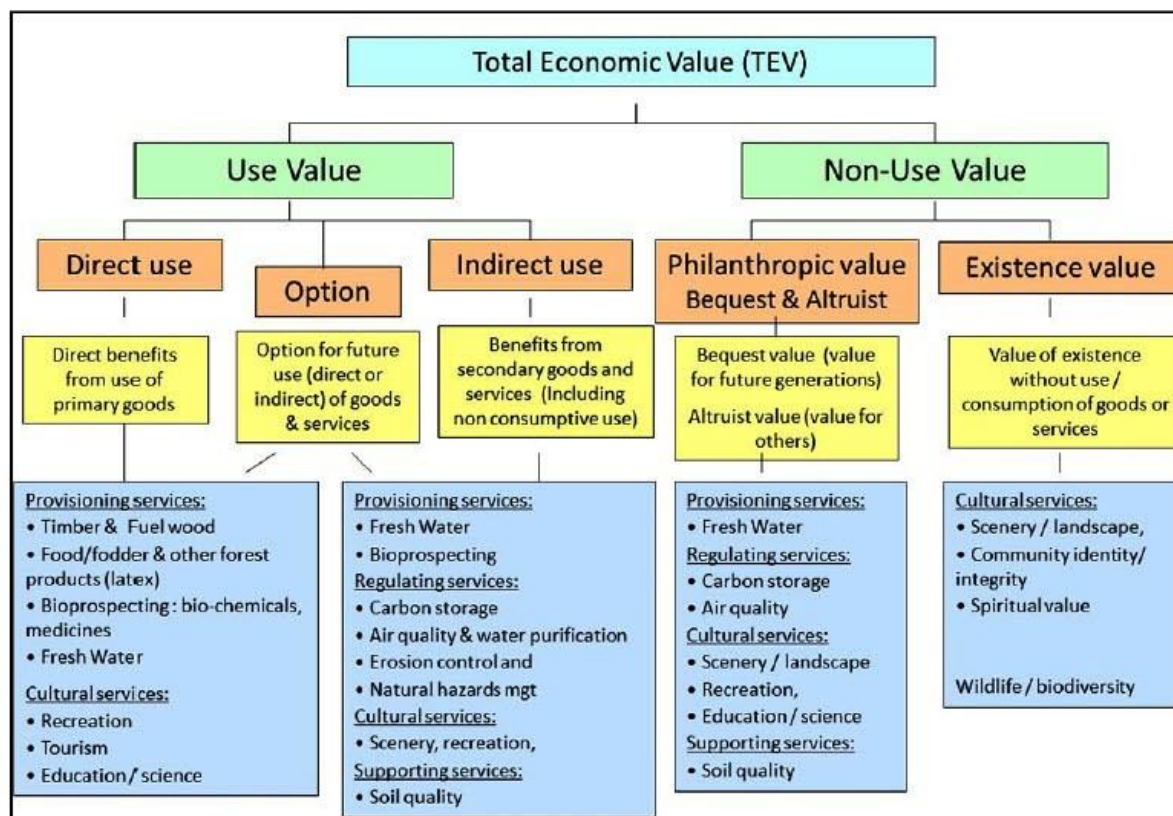


Figure 30: The Total Economic Value framework in the context of Natura 2000. Source: (Ten Brink et al. 2011) p.29.

5.3 Commercial benefits

5.3.1 Attractiveness of cities

Whitehead et al. (2005) examined the impact of general urban quality improvements, such as walkable places, on economic activity in Manchester, England. The researchers measured willingness to shop, do business or work in areas before and after 'walkability' improvements. Previous research had shown a 20-40% increase in foot traffic and a 22% increase in rents in pedestrianized retail areas. They found that adding urban quality improvements that promote pedestrian activity will have a small but significant positive effect on workers and businesses. The urban forest, parks and tree lined boulevards can also play an important role in marketing a city, creating an attractive, welcoming image, and providing settings for a range of events and activities that can boost the local economy (City of Melbourne 2011).

5.3.2 Local economic regeneration

Economic regeneration involves increasing employment, encouraging business growth and investment, and tackling economic disadvantage (Forest Research 2010). It has been suggested that investment in Green Infrastructure can encourage and attract high value industry, entrepreneurs and skilled workers to a region through the creation of high quality, environmentally friendly living and working environments, value adding to local economies (ECOTEC 2008). Local economic regeneration is strongly related to increased quality of place (including visual amenity), recreation and leisure, and tourism. Two UK examples of good local economic regeneration are:

- Developing woodland was shown to enhance property values in the surrounding area, for example in Bold Colliery, St Helens, Lancashire, where property values increased by around £15 million and helped realise a further £75 million for new development (Forestry Commission 2005).
- The Glasgow Green Renewal project stimulated the development of 500-750 new residential properties, enhanced average house prices and the total value of property transactions by a net £3 million–£4.5 million, increased return in council taxes by 47% and increased the value of the land from £100,000 to £300,000 per ha (GEN Consulting 2006).

In 2013 the UK Department for Environment, Food, and Rural Affairs (Defra) released a review of ways green infrastructure contributes to economic growth. The study was conducted by the Economics for The Environment Consultancy and Sheffield Hallam University. Green infrastructure is defined in the report as the 'planned approach to the delivery of nature in the city' (Eftec 2013 p4). The report's definition includes street trees, green roofs, wetlands, and other green spaces, which deliver stormwater management benefits, as well as the cited economic advantages.

The report compiles evidence from several case studies, concluding that green infrastructure increases property values and inward investment, visitor spending, job creation, and health benefits, and it helps prevent environmental costs.

- According to a study by the Urban Land Institute, which is cited in the report, 95% of European real estate developers and consultants think green space adds value to commercial property,

and, on average, developers are willing to pay 3%, and in some cases, as much as 20%, for land near green space.

- In the UK, parks departments, nature reserves, landscape services, and others in the green-space sector, account for 5% of all jobs, according to a CABI (2010) study cited in the report.

A report *The Economic Value of Green Infrastructure* by Natural Economy Northwest (2008) (a partnership between the Northwest Regional Development Agency and Natural England) aims to help practitioners make the case for investment in green infrastructure. The study identified the many benefits of green infrastructure and the way in which it can underpin the success of other economic sectors, offering an improved environment, jobs, sustainable business enterprises, social benefits, economic security and cost savings. These savings include a reduced need for healthcare, better employee productivity and better adaptation for climate change. It also shows how more credible and consistent tests and measures are being developed to assess the value of green infrastructure projects.

Key findings include:

- The Northwest's environment generates an estimated £2.6bn in Gross Value Added (GVA), and supports 109,000 jobs.
- The environment is critical to sustainable economic prosperity by contributing to the conditions for growth and economic security, as well as providing healthy ecosystems.
- Green infrastructure can mitigate and alleviate the effects of climate change and pollution, reduce the impacts of flooding, and improve public health, civic pride and educational opportunities.
- Environmental attractiveness draws in investment and jobs and enhances the value of property.
- Workers with access to green infrastructure are healthier and more productive, and green infrastructure is vital to key Northwest sectors such as tourism and agriculture.
- Assessing the value of green infrastructure is still a work in process. Economic value is complemented by the non-market social and environmental benefits that green infrastructure can offer.

Natural Economy Northwest (2008). *The Economic Value of Green Infrastructure*, Northwest Regional Development Agency and Natural England (see Table 31).

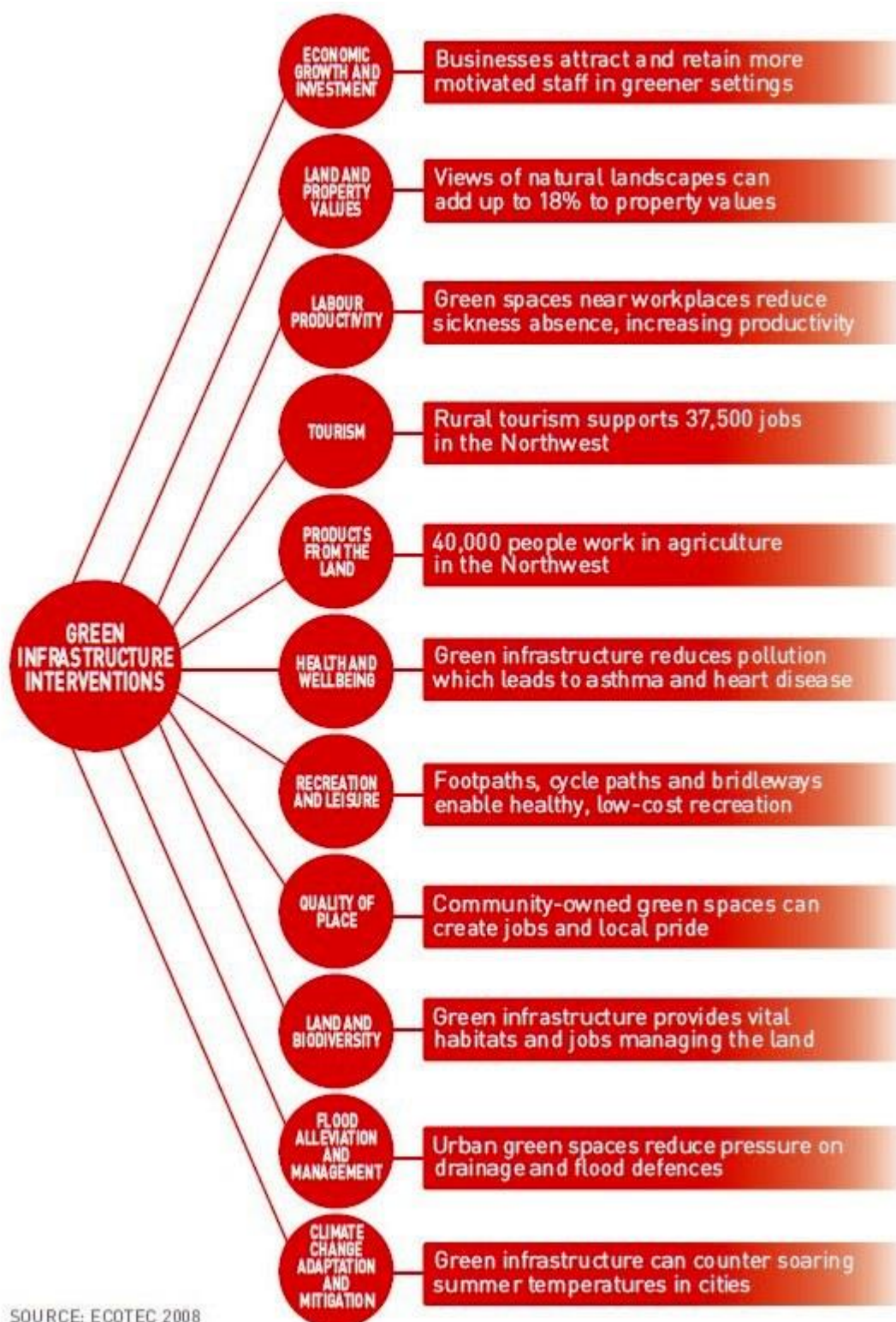


Figure 31: The Economic Benefits of Green Infrastructure (Natural Economy Northwest 2008).

5.3.3 Business resilience

In 2013 experts from The Dow Chemical Company, Shell, Swiss Re, and Unilever, working with The Nature Conservancy and a resiliency expert, evaluated a number of business case studies, and developed a white paper with recommendations that green and hybrid infrastructure solutions should become part of the standard toolkit for modern engineers (The Nature Conservancy 2013). The research team evaluated the assumption that green infrastructure can provide more opportunities than grey infrastructure to increase the resilience of industrial business operations against disruptive events such as mechanical failure, power interruption, raw material price increases, and floods. The evaluation concluded that hybrid approaches, utilizing a combination of green and grey infrastructure, may provide an optimum solution to a variety of shocks and improve the overall business resilience.

The case studies gathered to support this research encompass a wide variety of possible applications of green infrastructure. They range from planting trees that cost-effectively remediate contaminated soil (phytoremediation), to constructing wetlands that naturally treat industrial wastewater, to mitigating air pollution through innovative forest management approaches.

5.3.4 Commercial vitality

A number of studies, mainly in the US, have investigated the role of 'greening' in enhancing the 'commercial vitality' of specific business precincts. One study in 2003, examining the influence of trees and landscaping on rental rates of 85 office buildings in Cleveland, Ohio, found that landscaping with the highest aesthetic values added approximately 7% to average rental rates, while providing building shade by landscaping added another 7% (Laverne and Winson-Geidman 2003). The research appears to indicate an overall net benefit, but further research is also required. Another research study in New York City and New Jersey, using an Image Based Valuation Survey (IVBS) demonstrated a preference for shopping in greener commercial establishments (with trees and landscaping) and a willingness to pay more for their preferences through a payment mechanism of increased travel time (BiscoWerner 1996).

Kathleen Wolf at the University of Washington: College of the Environment has conducted a number of research studies into the relationships between urban trees and commercial vitality in a range of US shopping environments. A study in 2004 investigated the relationships between trees and business district preferences in the downtown business district in Athens Georgia (Wolf 2004). Data was collected via consumer surveys which included preference rating of a number of landscape scenarios. The results indicated that highest ranked photos consistently had a major tree presence, and the highest response values were associated with large trees. The results suggest that landscaping associated with well-maintained buildings positively affected consumer judgement. Wolf also concluded that 'the urban forest

may be the streetscape equivalent of interior store atmospherics and retailers would benefit from greater attention to landscaping’.

In another 2004 study Wolf investigated potential shoppers’ (local residents) and business owners’ preferences and perceptions of trees in several inner-city business districts undergoing revitalization (Wolf 2004a). A mail survey format was used including rating of a range of images of retail settings with different landscaping characteristics. The lowest preference scores went to the ‘sparse vegetation’ category, with the highest score to the ‘formal foliage’ category. Business owners/managers, however, consistently rated the scenes lower than residents.

In 2005 Wolf also looked at the relationship between street trees and main street business districts in a number of large US cities Wolf (2005). In each city mail surveys were administered aimed at measuring perceptions of visual quality, place perceptions, shopper patronage, and product pricing. The findings of mail surveys indicated that image preference ratings increased with the presence of trees, indicating a clear valuing of the trees in terms of their amenity and visual quality. The presence of trees also appeared to influence consumers’ perceptions of the businesses and the quality of their products. Respondents indicated a willingness to travel greater distances, visit more often, and pay more for parking at locations with trees. The survey also revealed a higher estimation of the value of goods sold in business districts with trees (the amenity margin associated with trees ranging from 12% for large cities to 19% for small cities). Wolf acknowledged that the price differentials could also be caused by other factors such as the local economy, however she concluded that the overall results indicated a net benefit for business owners willing to maintain trees near their properties.

In another study Wolf investigated driver perceptions of roadside landscaping in several major urban areas in the US (Wolf 2003). A random sample of residents was surveyed, using images of a variety of freeway landscape treatments and all of the settings with natural vegetation scored higher than non-vegetated settings. The results suggest that drivers pay attention to their surroundings, and the presence of landscaping could influence driver state of mind and even behaviour. Although only a small sample size, the results appear to be consistent with other studies regarding human preferences for green space (Kuo 2003).

5.3.5 Residential property values

A number of studies have attempted to quantify the impacts of tree cover on residential property values. Increased house prices are of value to both property owners and local government (in terms of increased rate revenues). A diverse range of studies has investigated the role of street trees, tree cover on the property itself, and proximity to natural features such as water or green spaces. Some of these are 'hedonic analysis' studies which use the sale prices of comparable properties to isolate increases in market value due to specific variables, such as the presence of street trees.

Hedonic analysis

The hedonic pricing method is used to estimate economic values for ecosystem or environmental services that directly affect market prices. It is most commonly applied to variations in housing prices that reflect the value of local environmental attributes. It can be used to estimate economic benefits or costs associated with:

- Environmental quality, including air pollution, water pollution, or noise.
- Environmental amenities, such as aesthetic views or proximity to recreational sites.

The basic premise of the hedonic pricing method is that the price of a marketed good is related to its characteristics, or the services it provides. For example, the price of a car reflects the characteristics of that car - transportation, comfort, style, luxury, fuel economy, etc. Therefore, we can value the individual characteristics of a car or other good by looking at how the price people are willing to pay for it changes when the characteristics change. The hedonic pricing method is most often used to value environmental amenities that affect the price of residential properties.

Source: (Ecosystems Valuation 2012).

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 7% (Payne 1973). In a study of Philadelphia's revitalized neighbourhoods, houses adjacent to street tree plantings were seen to gain a 9% premium (Wachter and Gillen 2006). In addition, neighbourhood commercial corridors in 'excellent' condition, including a green streetscape, were correlated with a 23% net rise in home values within a quarter mile of the corridor and an 11% rise within a half mile. A survey by the Real Estate Institute of Queensland in 2004 found that the values of homes in leafy streets were up to 30% higher in the same suburb (Plant 2006).

A recent study by Donovan and Butry (2010) used hedonic price modelling to simultaneously estimate the effects of street trees on the sales price and the time-on-market (TOM) of houses in Portland, Oregon. On average, street trees add US\$8870 to sales price and reduce TOM by 1.7 days. In addition, the researchers found that the benefits of street trees spill over to neighbouring houses.

Another recent study by Sander et al. (2010) used hedonic property price modelling to estimate the value of urban tree cover's value in Minnesota, predicting housing value as a function of a number of

environmental variables, including tree cover. The results showed that a 10 percent increase in tree cover within 100 metres increases average home sale price by \$1371 (0.48%) and within 250 metres by \$836 (0.29%). The researchers concluded that the results suggest significant positive effects due to neighbourhood tree cover, for instance the shading and aesthetic quality of tree-lined streets, indicating that tree cover provides positive neighbourhood externalities.

5.4 Value of ecosystem services

5.4.1 Overview

The following section reviews literature related to the economic valuation of the ecosystem services provided by different types of Green Infrastructure. Research aimed at quantifying the value of ecosystem services covers a number of broad areas including:

- Street trees and the urban forest (including the use of the i-Tree tool).
- Water Sensitive Urban Design.
- Urban green space.
- Natural areas.

A 2010 study investigated Green Infrastructure valuation methods, and reviewed the economic benefits of a range of Green Infrastructure practices (CNT 2010). These included:

- Urban Forests:
 - Reduced demand for energy for cooling and heating.
 - Reduced negative health impacts from extreme heat events.
 - Air quality improvements.
 - CO2 Reductions (avoided and sequestered).
- Permeable pavements:
 - Increased stormwater retention.
 - Reducing energy use, air pollution and greenhouse gas emissions.
 - Reduced ground conductivity.
 - Reducing air pollution.
 - Reducing salt use.
 - Reduced noise pollution.
- Water Harvesting:
 - Reduced potable water use.
 - Increasing available water supply.
 - Improving plant life.
 - Public education
- Green Roofs:
 - Storm water retention.
 - Reduced building energy use.
 - Carbon sequestration.
 - Greenhouse gas emissions reductions.

- Urban heat island mitigation.
- Improved air quality.
- Noise reduction.
- Biodiversity and habitat preservation
- Longer roof life.
- Infiltration Practices: rain gardens, bio-swales and constructed wetlands:
 - Rain gardens.
 - Bio-swales.
 - Constructed wetlands.
 - Stormwater retention and pollutant removal.
 - Uncertainties and other considerations.

The authors also reviewed methods of economically valuing ecosystem services including the following:

- Reduced energy use.
- Improved air quality.
- Value of avoided CO₂ emissions and carbon sequestration.
- Property value.
- Recreation value.
- Avoided grey infrastructure costs.
- Avoided construction costs.
- Reduced treatment costs.
- Reduced flood risk/damage.
- Groundwater recharge.
- Noise reduction.
- Mitigation of urban heat island effect.

5.4.2 Trees and the urban forest

The value of trees

'The aesthetic value of trees in the avenues, boulevards, parks and gardens of Australian cities is often widely appreciated, but their economic value is often under-valued. Trees provide services and fulfil functional roles in cities. They are significant components of urban infrastructure and have a real and calculable economic value. An urban forest of 100,000 trees can save \$1million per annum because their shade reduces electricity consumption. Shade can prolong the life of tarmac, and carbon is sequestered as the trees grow. A single large tree growing in a school may provide the equivalent shade of four shade sails, returning a value of about \$2000 per annum, while five trees can stabilise a steep suburban block which would otherwise require about \$50 000 of engineered piling to secure building insurance. Calculation of the economic contributions of trees can change the economic algorithms upon which decisions are made in cities'.

Source: Moore (2012) p.167. *'The importance and value of urban forests as climate changes'.*

5.4.2.1 Amenity valuation

The amenity or replacement value of an individual tree can be expressed in monetary terms using a number of established formulas, with the Thyer and the Burnley methods being most commonly used in Australia (Moore 2000a). 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), which is recommended by Arboriculture Australia. The CTLA formula is as follows: Tree Value = Base Value × Cross Section Area × Species Class × Condition Class × Location Class.

5.4.2.2 Structural and functional values

Urban forests can be seen to have a structural value based on the trees themselves (e.g., the cost of having to replace a tree with a similar tree); they also have functional values (either positive or negative) based on the functions the tree performs (i-Tree 2010). The structural value of an urban forest tends to increase with a rise in the number and size of healthy trees (Nowak, Crane et al. 2002). Annual functional values also tend to increase with increased number and size of healthy trees, and are usually of the order of several million dollars per year. Through proper management, urban forest values can be increased; however, the values and benefits also can decrease as the amount of healthy tree cover declines. For instance the following structural and functional values were calculated for the urban forest in Washington:

- Structural values:
 - Structural value: \$3.99 billion.
 - Carbon storage: \$12.3 million.
- Annual functional values:
 - Carbon sequestration: \$393 thousand.
 - Pollution removal: \$2.30 million.
 - Lower energy costs and carbon emission reductions: \$3.58 million.

Replacement Value of Seattle's Urban Forest

Infrastructure systems are essential for supporting human health and well-being in cities. While grey infrastructure is made up of drains, pipes, and wires that deliver water and energy and carry away waste, trees and vegetation make up a green infrastructure. This report demonstrates that the urban forest in Seattle is part of a green infrastructure system that works to provide a wide array of services and benefits. To get a sense of the costs to re-establish Seattle's urban forest, i-Tree Eco estimates the replacement value. This equates to the cost of physically replanting trees and nurturing them to the size and extent of Seattle's current forest. The replacement value of Seattle's current urban forest is estimated to be **\$4.99 billion dollars**. This value is estimated using methods established by the Council of Tree and Landscape Appraisers. Much as houses can be appraised, the replacement value of trees can be assessed. Field-collected size, species, condition, and location data, as well

as literature-based replacement costs, transplantable size information, and local species factors are used in this estimate.

Source:(Green Cities Research Alliance 2012).

5.4.2.3 Value of ecosystem services

A number of 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). These benefits 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 1996 study of stormwater management costs, showed that the urban forest provided stormwater management benefits valued at US\$15.4 million in Milwaukee, Wisconsin, and US\$122 million in Austin, Texas, by reducing the need for constructing additional retention, detention and treatment capacity (MacDonald 1996).

Other environmental services provided by trees, which can be given a monetary market value, include carbon sequestration and air pollution mitigation. Results of the 3-year Chicago Urban Forest Climate Project indicate that there are about 50.8 million trees in the Chicago area Counties; 66% of these trees are in good or excellent condition. It was estimated that the trees removed 6145 tons of air pollutants (valued at \$9.2 million), and sequestered 155 000 tons of carbon per year, in addition to providing energy savings for residential heating and cooling that, in turn, reduce carbon emissions from power stations. The projected net present value of investment in planting and care of trees in Chicago indicates that the long-term benefits of trees are more than twice their costs (Nowak 1994).

Another study in Davis, California, showed that the city's 24,000 public street trees provided US\$1.2 million annually in net environmental and property value benefits (Maco and McPherson 2003). It was also shown that the benefit cost ratio was US\$3.81 for every US\$1.00 spent on tree planting and management in Davis. Another study showed cooling cost reductions of 20-50%, and heating cost reductions of 10-15% for residential allotments with trees (Heisler 1986).

A recent study at the Australian National University estimated that the trees in Canberra have an annual economic value of more than \$23 million through energy reduction, pollution mitigation and stormwater reductions (Killy et al. 2008). A study at the University of Adelaide attempted to estimate the gross annual benefits from a typical medium sized street tree in Adelaide (Killicoat et al. 2002). As shown in Table 5, a four year old tree was estimated to generate a gross annual benefit of 'roughly' \$171 per tree, consisting of energy savings due to reduced air conditioning costs, air quality improvements, stormwater management, aesthetics and other benefits.

Table 5 Gross Annual Benefits of an Adelaide Street Tree (2002).

BENEFIT CATEGORY	VALUE
Energy Savings	\$64.00
Air quality	
CO ₂ (reduced power output)	\$1.00
Air Pollution	\$34.50
Storm Water	\$6.50
Aesthetics/others	\$65.00
Repaving Savings	Not known
ESTIMATED GROSS BENEFITS	\$171.00
Source: Compiled from data in Killicoat, Puzio et al.(2002)	

Stringer revisited this estimate in a 2007 paper and concluded that, with more adequate data and computer simulations, the gross benefits would actually be significantly higher (Stringer 2007). In a follow up paper in 2009 the annual benefits for a typical Adelaide street tree were re-calculated at approximately \$424 per tree, as shown in

Table 6: Gross Annual Benefits of an Adelaide Street Tree (2009) (Brindal and Stringer 2009).

Table 6: Gross Annual Benefits of an Adelaide Street Tree (2009)

Benefit Category	Value	Notes
Household benefits		
Energy savings	\$64	
Aesthetics/others	\$65	
Capital appreciation	\$72	Based on a median house value of \$360,000 and assuming 2% pa appreciation
Local Government Benefits		
Storm water	\$6.50	
Repaving Savings	\$180	
Community Value		
Air Quality (reduced pollution)	\$34.50	
Reduced CO ₂ Emissions	\$1.00	
CO ₂ sequestration	\$1.40	Based on absorption figures for a mature deciduous tree with a CO ₂ trading price of \$20.00 per tonne
ESTIMATED GROSS BENEFIT	\$424.40 pa	
Source: Compiled from data in Brindal and Stringer (2009).		

5.4.2.4 The big tree argument

Geiger advocates the case for growing large trees in cities (Geiger et al. 2004). Large, mature trees are considered to deliver more significant benefits than smaller stature trees. Therefore large tree species should be planted, and trees should be allowed to grow to maturity to maximize their benefits. For example, large trees provide greater benefits of improved shade, water quality and air quality than smaller trees (McPherson 2005). Large trees out-perform small trees in moderating air temperatures, blocking UV radiation, conserving energy, sequestering carbon and reducing air pollution, in a manner directly related to the size of the tree canopy (Nowak 2004). McPherson estimates that a large tree with a height of 14 metres provides three times the annual environmental benefits of a similarly aged 7 metre

high tree, and that the value of benefits increases faster than the costs of managing a larger tree (McPherson 2005).

Larger trees also have greater visual presence, and are often more highly valued by residents, especially where 'canopy closure' over the street is achieved (Kalmbach and Kielbaso 1979; Schroeder and Cannon 1983; Sommer et al. 1989). In one study the single largest factor in determining the attractiveness of a street scene was the size of the trees and their canopies (Schroeder and Ruffolo 1996). This was supported by a study in which there was a preference for large canopied trees in a tree replacement program (Heimlich et al. 2008). According to Schroeder et al. (2009) big trees have long been a significant feature in many cities and towns. A canopy of mature trees arching over the street and shading properties has defined the character of many urban and suburban communities. In fact it is the enduring nature of large trees in a rapidly changing urban environment that contributes to their high symbolic value and a sense of permanence in our fast changing society (Dwyer et al. 2003).

5.4.2.4 The i-Tree tool

Economic modelling is now commonly being used in the United States to quantify the economic benefits generated by urban forests (USDA Forest Service 2005). The United States Department of Agriculture (USDA) Forest Service provides online tools allowing communities to estimate the net economic benefits generated by their urban forest. i-Tree STRATUM (Street Tree Resource Analysis Tool for Urban Forest Managers) is a user-friendly online model which allows communities to quantify the environmental benefits of their urban forest, in comparison with its management costs (McPherson et al. 2005). The model can quantify benefits such as energy conservation, air quality improvement, CO₂ reduction, stormwater control, and property value increases. Such economic modelling has been applied in a number of United States cities including Davis California, Milwaukee, Minneapolis, Pittsburgh, Houston and New York (Maco and McPherson 2003). Importantly, these analyses are helping cities like New York, Los Angeles, Portland, Sacramento and Baltimore to justify investments in major urban greening projects that address declining urban tree cover, increasing population and urban climate change.

i-Tree Eco was developed to help managers and researchers quantify urban forest structure and functions based on standard inputs of field, meteorological, and pollution data. The model currently calculates the following parameters based on local measurements:

- Urban forest structure, including species composition, tree cover, tree density, tree health (crown dieback, tree damage), leaf area, leaf biomass, and information on shrubs and ground cover types.
- Hourly pollution removal by the urban forest for ozone, sulphur dioxide, nitrogen dioxide, carbon monoxide, and particulate matter (PM₁₀). The model accounts for potential negative effects of trees on air quality due to BVOC emissions.
- Effect of trees on building energy use and related reductions in carbon dioxide emissions.
- Total carbon stored and net carbon sequestered annually by trees.
- Rainfall interception and value.

- Susceptibility to significant pest and diseases.
- Exotic species composition.

i-Tree Eco makes use of user-collected field data. For large-scale areas (entire cities, councils or regions), a random sample of fixed area plot can be analysed. For smaller-scale sites, a complete inventory option is available that will provide information on urban forest structure, pollution removal, carbon sequestration and storage, and resource value. Model outputs are given for the entire population and, for smaller scale projects making use of complete inventories, results are also provided for individual trees. i-Tree is based on a number of key peer reviewed research papers into the 'functional' values of the urban forest by Nowak et al. (2006) on pollutant removal and carbon sequestration and storage (Nowak and Crane 2002) and by James McPherson on passive energy benefits (McPherson 1992). i-Tree also includes the amenity or 'compensatory' values of the urban forest based on the CTLA (Council of Tree and Landscape Appraisers) methodology (Nowak, Crane et al. 2002).

i-Tree Tools

i-Tree is a state-of-the-art, peer-reviewed software suite from the USDA Forest Service that provides urban and community forestry analysis and benefits assessment tools. The i-Tree tools help communities of all sizes to strengthen their urban forest management and advocacy efforts by quantifying the environmental services that trees provide. Developed by USDA Forest Service and numerous co-operators, i-Tree is in the public domain and available by request through the i-Tree website www.itreetools.org. The i-Tree suite v4.0 includes the following urban forest analysis tools and utility programs.

- **i-Tree Eco** provides a broad picture of the entire urban forest. It is designed to use field data from complete inventories or randomly located plots throughout a community along with local hourly air pollution and meteorological data to quantify urban forest structure, environmental effects, and value to communities.
- **i-Tree Streets** focuses on the benefits provided by a municipality's street trees. It makes use of a sample or complete inventory to quantify and put a dollar value on the street trees' annual environmental and aesthetic benefits. Streets also describes urban forest structure and management needs to help managers plan for the future.
- **i-Tree Hydro** (beta) is a new application designed to simulate the effects of changes in tree and impervious cover characteristics within a watershed on stream flow and water quality.
- **i-Tree Vue** allows you to make use of freely available national land cover data maps to assess your community's land cover, including tree canopy, and some of the ecosystem services provided by your current urban forest. The effects of planting scenarios on future benefits can also be modelled.
- **i-Tree Design** (beta) is a simple online tool that provides a platform for assessments of individual trees at the parcel level. This tool links to Google Maps and allows you to see how tree selection, tree size,

and placement around your home affects energy use and other benefits. This beta tool is the first stage in development of more sophisticated options that will be available in future versions.

- **i-Tree Canopy** offers a quick and easy way to produce a statistically valid estimate of land cover types (e.g., tree cover) using aerial images available in Google Maps. The data can be used by urban forest managers to estimate tree canopy cover, set canopy goals, and track success; and to estimate inputs for use in i-Tree Hydro and elsewhere where land cover data are needed.

As an example the STRATUM model was applied in Pittsburgh in April 2008 to evaluate the resource structure, function and value of the city's street tree population, as shown in Table 7 (Davey Resource Group 2008).

Table 7: Pittsburgh Municipal Forest Resource Analysis.

Item	Annual value (total) (US\$)	Annual value (per street tree)
Energy savings (shading and climate effects)	\$1.2 million	\$40.66
Atmospheric carbon dioxide removal	\$35,424 (5,303 tons)	\$1.20
Air pollutant removal/avoidance	\$252,935	\$8.53
Stormwater interception	\$334,601 (158 million litres)	\$11.00 (14,113 litres)
Property value increases, aesthetics, other less tangible improvements	\$572,882	\$19.33
Cumulative gross annual benefits	\$2.4 million	\$81.00
Annual tree related expenses	\$816,400	
NET ANNUAL BENEFIT	\$1.6 million	\$53.00
Benefit/cost ratio	\$2.94 for every \$1.00 (2.94:1)	
Source: Compiled from data in Davey Resource Group (Davey Resource Group 2008).		

A recent i-Tree analysis of street trees and canopy cover completed by the Wisconsin Department of Natural Resources showed that public trees provide \$6.14 million in annual benefits. As shown in Figure 32 the study highlighted the significant benefits that community trees provide Green Bay area residents including the following:

- \$1.81 million per year in summer cooling and winter heating energy savings.
- \$1.78 million per year in storm water management savings by intercepting approximately 65 million gallons of storm water annually.
- \$2.02 million per year increase in local property values.
- \$296,206 per year in air quality improvement by mitigating harmful air pollutants.
- \$233,998 per year in atmospheric carbon dioxide reduction.



Figure 32: Green Bay Metro Area Street Tree Benefits. Source: http://www.itreetools.org/resources/reports/WDNR_GreenBay_Metro.pdf

i-Tree in Australia

i-Tree was developed in the US primarily for use there and had limitations when applied elsewhere. Since i-Tree was first introduced in 2006, there has been interest in applying the tools outside the United States, including Australia. As the i-Tree tools were developed for use in the United States, they require regional adaptation for Australian conditions. 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 newer outer suburban City of Hume. The study, funded by Nursery and Garden Industry Australia, was intended as a 'proof of concept' for adapting i-Tree tools to an Australian setting (NGIA 2011). The model showed that for the environmental benefits estimated (carbon sequestration, water retention, energy saving, aesthetics and air pollution removal) the population of 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. On an individual scale, the 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. Australian users in New South Wales, Australian Capital Territory and Victoria now have the same access and automated processing as Eco users in the U.S. and can refer to an *i-Tree ECO Australia Users Manual* produced by ENSPEC and Arboriculture Australia (ENSPEC 2012).

In 2013 a representative sample of Brisbane City Councils street tree population was run through version 5 of Australian i-Tree ECO to estimate the value of three of the annual environmental benefits provided by street trees (Brisbane City 2013). The 3% sample comprised a stratified random sample of 16,600 street trees across 80 sample areas, considered to be representative of Brisbane's street tree population. The results were extrapolated to provide an estimate of these three environmental benefits of the city's street tree population (see Figure 8). Brisbane's estimated 575,000 street trees and their 2,000 hectares of canopy coverage were estimated to provide an annual estimated \$1.65m worth of carbon sequestration, air quality improvement and rainfall interception. That comprises a return of a little over 10% of the annual planting and maintenance costs. Stratified random sample surveys were found to offer representative, rapid assessment of street tree population, stocking level, species diversity, condition, maintenance needs, risk profile, and i-Tree ECO extrapolation opportunities

Table 8: Estimates of 3 types of annual benefits of Brisbane street tree population, based on Australian V5 i-Tree ECO. Source (Brisbane City 2013).

i-Tree ECO benefit type	Quantity/year	\$ value/year
Carbon dioxide sequestration	7,300 tonnes	\$168,300/yr.
Air Pollution Removal	87,200 kg	\$44,200/yr.
Rainfall Interception	635,733 cubic metres	\$1,444,533/yr.
TOTAL		\$1.657m/yr.

The Victoria Business Improvement District (BID) in Greater London considers trees to be a core component of the local infrastructure and commissioned a research study to provide a clearer understanding of the financial benefits of its trees (Rogers et al. 2013). This report presents a baseline quantitative assessment of the air pollution, amenity, carbon storage and sequestration benefits of trees as well as the storm water and surface temperature benefits of existing green infrastructure in the Victoria BID, using i-Tree Eco. The Green Infrastructure Valuation Toolkit (GIVAT) (<http://www.greeninfrastructurenw.co.uk>) was also used as a companion to the i-Tree Eco assessment, to quantify the water management and temperature moderation benefits associated with green infrastructure. Similarly, the Capital Asset Valuation for Amenity Trees (CAVAT) was also applied to the field data.

The study found that existing trees, green spaces and other green infrastructure assets in Victoria divert up to 112,400 cubic meters of storm water runoffs away from the local sewer systems every year. This is worth between an estimated £20,638 and £29,006 in carbon and energy savings every year. The trees in Victoria also remove a total of 1.2 tonnes of pollutants each year and store 847.08 tonnes of CO₂. The total structural value of all trees in Victoria (which does not constitute a benefit provided by

the trees, but rather a replacement cost) currently stands at £2,103,276. When implemented, the green infrastructure opportunities identified by Victoria BID have the potential to:

- Divert up to 67,600 additional cubic meters of storm water runoff every year, representing an estimated extra £6,300 and £17,500 in yearly carbon and energy savings respectively. Future design choices (particularly in relation to green roofs) will have a determining impact on the scale of water management benefits realised.
- Reduce peak summer surface temperatures by up to 5.1°C in the area surveyed. This will moderate local air temperatures, helping to ensure that the BID remains an attractive and comfortable environment for residents, visitors and workers alike. It will also reduce the need for air conditioning in office buildings, lowering energy costs and carbon emissions.

5.4.3 Open Space

A number of studies have examined the economic benefits to householders and communities of open space. Findings from some of the key studies are summarized below.

5.4.3.1 City Parks Forum

The City Parks Forum of the American Planning Association produces briefing papers on how cities can use parks to address urban challenges. A 2002 briefing paper addressed the ways in which 'cities use parks for economic development' (City Parks Forum 2002). The researchers concluded that

'Parks provide intrinsic environmental, aesthetic, and recreation benefits to our cities. They are also a source of positive economic benefits. They enhance property values, increase municipal revenue, bring in homebuyers and workers, and attract retirees. At the bottom line, parks are a good financial investment for a community. Understanding the economic impacts of parks can help decision makers better evaluate the creation and maintenance of urban parks' (p.1).

The study made the following 'key points':

1. Real property values are positively affected.
2. Municipal revenues are increased.
3. Affluent retirees are attracted and retained.
4. Knowledge workers and talent are attracted to live and work.
5. Homebuyers are attracted to purchase homes.

Real property values

Over 100 years ago US landscape architect Frederick Law Olmsted conducted a study of how parks influence property values. From 1856 to 1873 he followed the value of property immediately adjacent to Central Park to justify the \$13 million spent on its creation, and found that over the 17-year period there was a \$209 million increase in the value of the property affected by the park. More recent studies in the US also show how proximity to a park setting is related to property values.

In the early 1980s the city of Chattanooga, Tennessee faced rising unemployment and crime, polluted air, and a deteriorating quality of life. To attract middle-class residents back it was decided to improve the quality of life by cleaning the air, acquiring open space, and creating new parks and trails. As a result, property values increased by 127.5 percent (Lerner and Poole 1999). In Atlanta, Georgia, after the Centennial Olympic Park was built, adjacent condominium prices rose from \$115 to \$250 a square foot. In Amherst, Massachusetts, cluster housing with dedicated open space was found to appreciate at 22 percent annually compared with the comparable conventional subdivision rate of 19.5 percent.

Municipal revenues

Another component of Olmsted's Central Park 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. As shown with Central Park, parks can actually pay for themselves and even generate extra revenue. In addition, tax revenues from increased retail activity and tourism-related expenditures can further increase municipal income.

In terms of property tax benefits, the improvements in Chattanooga discussed above resulted in a 99 percent increase in annual combined city and county property tax revenues (Lerner and Poole 1999). In Boulder the presence of a greenbelt in a Boulder neighbourhood was found to annually add approximately \$500,000 in property tax revenue. In terms of sales tax benefits the East Bay Regional Park District in Oakland, California is estimated to stimulate about \$254 million annually in park-related purchases, of which \$74 million is spent in the local East Bay economy. In terms of tourism-related benefits, the Atlanta Centennial Olympic Park has about 1.5 million visitors each year, attending public events. In San Antonio, Texas, the Riverwalk Park, created for \$425,000, is lined with outdoor cafes and shops and has become the most popular attraction for the city's \$3.5 billion tourism industry.

Attracting affluent retirees

According to Longino (1995) p.7 'There is a new, clean growth industry in America today - the industry is retirement migration'. According to the U.S. Census Bureau, by the year 2050 1 in every 4 Americans will be 65 years or older, creating an affluent group of retirees with financial benefits and with an average life expectancy of 75 to 83 years. They are also mobile, moving to various locations across the country. Members of this mobile retiree cohort have been termed 'GRAMPIES' (growing number of retired active moneyed people in excellent shape). And GRAMPIES are attracted to communities with leisure and recreation amenities. In a study by Miller et al.(1994) retirees were asked to review 14 features and identify their importance in the decision to move. The first three chosen were scenic beauty, recreational opportunities, and mild climate. Retirees also bring expendable income to their communities. One study found that if 100 retired households come to a community in a year, each having an annual retirement income of \$40,000, the impact is similar to that of a new business spending \$4 million annually in the community (Crompton 2001).

Attracting knowledge workers

In the US industry today is composed of smokeless industries, high technology, and service-sector businesses, collectively referred to as the 'New Economy.' Workers in this New Economy are now selling their knowledge rather than their physical labour, and are referred to in studies as 'knowledge workers' who work in a 'footloose' sector. Companies are not tied to a particular location in order to achieve a competitive advantage (Florida 2000). Several studies have been undertaken to determine what factors are important to these people when making employment decisions. A 1998 KPMG survey of 1,200 high technology workers found that quality of life in a community increases the attractiveness of a job by 33 percent. Knowledge workers apparently prefer places with a diverse range of outdoor recreational activities, from walking trails to rock climbing. Portland, Seattle, Austin, Denver, and San Francisco are among the top cycling cities and are also leaders in attracting knowledge workers.

Attracting homebuyers

A survey in 2001 by the National Association of Realtors (NAR) found that 57 percent of voters would choose to live close to parks and open space. In addition 50 percent of voters would be willing to pay 10 percent more for a house located near a park or open space. The National Association of Home Builders found that 65 percent of home shoppers surveyed felt that the presence of parks would realistically influence them to move to a community. A 1991 Economics Research Associates (ERA) survey in Denver found that 48 percent of residents would pay more to live in a neighbourhood near a park or greenway (Phillips nd.).

5.4.3.2 Active Living Research program

In a study for US Active Living Research program of the Robert Wood Johnson Foundation entitled '*The Economic Benefits of Open Space, Recreation Facilities and Walkable Community Design. A Research Synthesis*' Shoup and Ewing (2010) reviewed a large body of peer-reviewed and independent reports on the economic value of outdoor recreation facilities, open spaces and walkable community design. Their study focused on the 'private' benefits that accrue to nearby homeowners and to other users of open space. While it was noted that parks may also generate a range of 'public' benefits to the whole community not reviewed in the study (including alleviating traffic congestion, reducing air pollution, flood control, wildlife habitat, improved water quality and facilitating healthy lifestyles), the literature estimating the economic value of these types of benefits is not reviewed. Key research findings were classified as follows.

1. Open spaces such as parks and recreation areas can have a positive effect on nearby residential property values, and can lead to proportionately higher property tax revenues for local governments.
2. The level of economic impact recreational areas have on home prices depends on how far the home is located from a park, the size of the recreational area and the characteristics of the surrounding neighbourhood.

3. Open space in urban areas provides a greater economic benefit to surrounding property owners than open space in rural areas.
4. Open space land, recreation areas and compact developments may provide fiscal benefits to municipal governments.
5. Compact, walkable developments can provide economic benefits to real estate developers through higher home sale prices, enhanced marketability and faster sales or leases than conventional development.

Effects on nearby residential property values

Two studies conducted in 2000 and 2001 analysed the same group of more than 16,400 home sales in Portland, Oregon, using two different methods. The first found that the 193 public parks analysed had a significant, positive impact on nearby property values. The existence of a park within 1,500 feet of a home was found to increase its sale price by between \$845 and \$2,262 (USD\$ in 2000). In addition, as parks increased in size, their impact on property value increased significantly (Bolitzer and Netusil 2000). The second study found that large natural forest areas had a greater impact on nearby property values than smaller urban parks, playgrounds and golf courses. Houses located within 1,500 feet of natural forest areas enjoyed significant property premiums, averaging \$10,648, compared with \$1,214 for urban parks, \$5,657 for specialty parks and \$8,849 for golf courses (USD\$ in 1990) (Lutzenhiser and Netusil 2001).

Studies in a number of US municipalities have used data from residential sales, the population census and Geographic Information Systems (GIS) to investigate the marginal values of different types of parks. These studies confirmed that different types of open space have different effects on property (Geoghegan 2002; Song and Knaap 2004; Nicholls and Crompton 2005; Anderson and West 2006; Payton et al. 2008). In general, urban parks, natural areas and preserved open spaces showed positive effects on property values (Nicholls 2004).

The effects of natural open space on nearby property values can result in higher valuations and therefore higher property tax revenues for local governments. In one Boulder, Colorado neighbourhood, the overall value of a greenbelt was approximately \$5.4 million, which contributed potentially \$500,000 annually to property tax revenue. The purchase price of this greenbelt for the city was approximately \$1.5 million and it was concluded that the potential property tax revenue alone would allow a recovery of the initial costs in only three years (Correll et al. 1978). Another study conducted in three Maryland counties calculated the economic benefits of preserved agricultural land to homeowners, and estimated the property tax revenues generated from an increase in permanent open space. It was found that with a 1 percent (148 acre) increase in preserved agricultural land in Calvert County the increase in housing values within a one-mile radius generated \$251,67, which was enough tax revenue to purchase an additional 88 acres of parkland in one year (Geoghegan et al. 2003).

It has also been suggested that the impact parks can have on property values may actually underestimate the value of open space, by excluding the nonmarket values associated with passive

uses, such as simply knowing that the open space exists. Stated preference surveys (similar to hedonic pricing methods) attempt to value such 'nonmarket benefits' by asking respondents their willingness to pay for such an amenity. Residents in one Boulder, Colo., neighbourhood were willing to pay \$234 per household (USD\$ in 1995) to keep a 5.5 acre parcel of undeveloped land preserved forever. Extrapolating this to the whole neighbourhood within a mile of the parcel gave a total value of \$774,000, more than the \$600,000 cost of the land (Brefle et al. 1998). Another method for calculating the economic benefits of parks and open space is to estimate the travel costs associated with visiting a park. A study of the Monon Trail in Indianapolis found that the average property price premiums for 1999 home sales could total \$140.2 million, with an additional net present recreational benefit of \$7.6 million (Lindsey et al. 2004).

Effects of distance from park

A review of over 60 studies on the impact open spaces have on residential property values showed a general increase in property values but with the magnitude depending on the size of the open space, its proximity to housing, the type of open space and the method of analysis. The review found increases in property values 500–600 feet from the park (McConnell and Walls 2005). As shown on Figure 33 for community-sized parks over 30 acres, the effect was measurable out to 1,500 feet, but 75 percent of the premium value generally occurred within 500–600 feet (Miller 2001; see Figure 32; Crompton 2004). One study estimated that an average household living half a mile from open space would be willing to pay \$4,104 more for a home (USD\$ in 1992) to live a quarter mile closer to the open space (Walsh 2007).

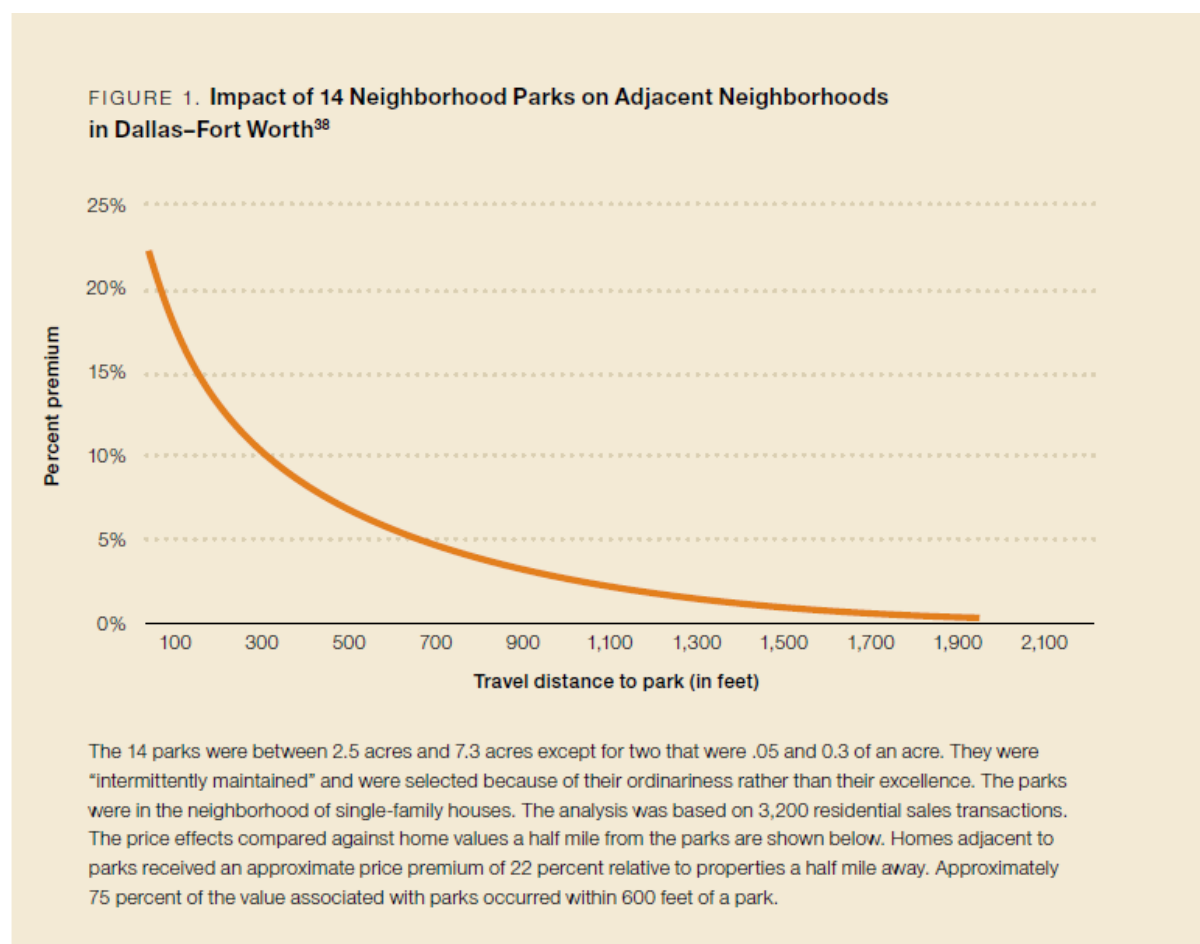


Figure 33 Impact of 14 Neighbourhood Parks on Adjacent Neighbourhoods in Dallas-Fort Worth. Source: (Miller 2001).

5.4.3.3 Center for City Park Excellence

In 2003, the US Trust for Public Land's Center for City Park Excellence gathered two dozen park experts and economists in Philadelphia for a colloquium to analyse how park systems economically benefit cities. Based on this and subsequent consultation with other leading economists and academics, the centre identified seven attributes of city park systems that provide measurable economic value. These were:

- 1) Property value.
- 2) Tourism.
- 3) Direct use.
- 4) Health.
- 5) Community cohesion.
- 6) Clean water.
- 7) Clean air.

Five test cases were also undertaken as part of this program: the cities of Washington, D.C., San Diego, Boston, Sacramento, and Philadelphia. In 2009 a report was issued entitled *'Measuring the Economic*

Value of a City Park System’ which identified a methodology for assessing economic benefits (Harnik and Welle 2009). Two of the factors identified provide a city with direct income. The first factor is increased property tax from the increase in property value because of proximity to parks. (Also known as ‘hedonic value’ by economists.) The second is increased sales tax on spending by tourists who visit an area primarily because of the parks. Beyond tax revenue, these factors can also enhance the collective wealth of the community through increased property values and increased tourism revenue.

Three other factors provide a city with direct savings. The largest value accrues from residents’ free use of a city’s parkland and other free or low-cost recreation opportunities (rather than having to purchase these in the marketplace). Health is the second direct benefit, with savings in medical costs due to the benefits of increased physical activity in parks. The third is the community cohesion benefit of communities ‘coming together’ to save or improve local parks. This is referred to as ‘know-your-neighbour’ social capital which helps reduce antisocial problems that may otherwise cost the city more in policing and rehabilitation.

The last two factors provide environmental savings, including water pollution reduction through stormwater retention via the park system’s trees, vegetation and soil, reducing treating stormwater control and treatment costs. The other benefit considered is air pollution reduction by a park’s trees and vegetation.

In 2010, the City of Virginia Beach requested that The Trust for Public Land carry out a study of its park and recreation system based upon these seven factors. The following section provides a description and estimate of the economic value of each park attribute in Virginia Beach, using the formulas which can be obtained from the Center for City Park Excellence.(The Trust for Public Land 2011). Table 9 summarizes the annual value of the Virginia Beach park and recreation system as estimated by the study.

Table 9: The Estimated Annual Value of the Virginia Beach Park and Recreation System.
Source: (The Trust for Public Land 2011) p.2.

Revenue-Producing Factors for City Government	
Tax receipts from increased property value	\$2,218,740
Tax receipts from increased tourism value	\$8,428,688
Total	\$10,647,428
Wealth-Increasing Factors for Citizens	
Property value from park proximity	\$10,249,256
Net profit from tourism	\$295,004,064
TOTAL	\$305,253,320

Property Value

Studies consistently show that parks and open space have a positive impact on nearby residential property values, with people willing to pay more for a home close to an attractive park. A park’s effect on property values has been shown to be determined by two main factors: distance from the home, and the quality of the park. While the value of park proximity has been documented up to 2,000 feet from a

large park, most of the value has been shown to be within the first 500 feet. In this study the researchers identified all residential properties within 500 feet of a Virginia Beach, comprising 25,598 residential properties with a combined assessed value of \$7.6 billion. A regression analysis was conducted of residential property sales from 2006 to 2010 to identify the 'hedonic value' of location near a park, which showed a 3.26 percent 'park effect' (an additional \$9,246 in average sale price per park-proximate dwelling). As shown in Table 10 this was multiplied by the total number of park-proximate dwelling units in Virginia Beach giving a collective gain in personal wealth to homeowners of just over \$249 million. The researchers also determined the tax revenue generated from the additional property value attributable to parks, using the same 3.26 percent park-proximate factor, multiplied it by the property tax rate which determined the value of additional tax received by the city in 2010 to be more than \$2.2 million. In addition the researchers considered the additional value to the sellers of dwelling units. The value of park-proximate residential properties sold in 2010 was \$314,396,427; therefore the 3.2 percent of that value attributable to parks yielded more than \$10.2 million in personal wealth to the sellers.

Table 10: Effect of Virginia Beach Parks on Residential Property Values. Source: (The Trust for Public Land 2011) p.4.

Value of residential properties within 500 feet of parks	\$7,647,187,931
Value attributable to parks (3.26%)	\$249,296,681
Property tax revenue from properties within 500 feet of parks	\$68,059,973
Tax revenue attributable to parks (3.26%)	\$2,218,740
Value of properties sold in 2009 within 500 feet of parks	\$314,396,427
Value attributable to parks (3.26%)	\$10,249,256

Tourism value

Statistics indicate that approximately 3.15 million tourists visited Virginia Beach in 2010, some of them (700,000) staying for just the day but most of them (2.45 million) staying at least one night. The typical overnight visitor was found to spend over \$100 per day and stayed an average of 4.6 days, while the typical day visitor spent just over \$50. The researchers applied these to the estimated number of tourists who visit Virginia Beach because of its parks, which comprised the 65 percent of total tourists who report travelling to Virginia Beach for its beach parks, another 3 percent estimated to travel to the area for adventure tourism, and nearly 100,000 tourists who visit to attend sporting events each year. Combined, these groups of tourists spent nearly \$843 million in Virginia Beach in 2010(see Table 11). City-managed athletic facilities generated roughly \$30 million in tourist spending, while natural areas generated \$36 million from adventure tourists. Of this total tourist spending, one percent was retained by the city as sales tax (with the majority of sales tax being taken by the state). The researchers concluded that the total tax revenue to the city of Virginia Beach from park-based tourism was \$8,428,688 in 2010. In addition, as 35 percent of every tourist dollar is considered profit to the city economy, the community's collective increase in wealth from park and beach based tourism was estimated to be \$295,004,064.

Table 11: Tourism Value of Virginia Beach Parks. Source: (The Trust for Public Land 2011) p.6.

Types of park tourists	
Tourists who come to Virginia Beach for beach parks	2,047,500
Spending by beach park tourists	\$777, 959,000
Tourists who come to Virginia Beach for adventure tourism	94,500
Spending by adventure tourists	\$35,905,800
Total city tax receipts attributable to tourism	\$8,428,688
Total profit to local businesses	\$295,004,064

Direct Use Value

Virginia Beach's public parks provide services to residents that are known to economists as 'direct uses' (see table 12). Most of these direct uses of public parks are free of charge, but their value can still be determined in terms of a consumer's 'willingness to pay' for the recreational experience in the private marketplace i.e. if parks were not available how much would the resident pay for a similar experience at a commercial facility? The method used in the study for quantifying direct use benefits was based on the 'unit day value' method documented by the U.S. Army Corps of Engineers Water Resources Council recreation valuation procedure. The unit day value method categorizes park visits by activity, and then assigns each activity a dollar value, for example playing in a playground is worth \$3.50 each time to each user. A random telephone survey of 600 Virginia Beach residents was also conducted to provide data on typical patterns of park usage.

Table 12: Direct Use of Virginia Beach Parks. Source: (The Trust for Public Land 2011) p.8.

Facility/Activity	Person-visits	Average value per visit	Total value
Common activities (picnicking, walking on trails, visiting playgrounds, watching sports, etc.)	62,988,218	\$2.25	\$141,704,055
High-intensity activities (fitness training, running, bicycling, swimming, team sports, etc.)	41,218,463	\$3.84	\$158,412,661
Special activities (camping, fishing, golf, boating, before- and after-school programs, summer camp, etc.)	6,463,998	\$5.78	\$37,337,158
Total value of direct use of parks		\$337,453,874	

Health Value

A recent report by the United States based Centers for Disease Control and Prevention (CDC) estimated that in 2008, \$147 billion in health care costs could be attributed to obesity. Research suggests that nearby parks and walkable urban environments can help increase levels of physical activity and reduce medical expenses. A Health Benefits Calculator was used to measure Virginia Beach residents' collective health care savings attributable to parks. The calculator was created by identifying common medical problems associated with lack of physical activity, such as heart disease and diabetes. Based on other studies, a value of \$351 was assigned as the annual difference in health care costs between people who exercise regularly and those who do not. An increased value of \$702 was assigned to people over the age of 65, as seniors typically incur two or more times the medical

care costs of other adults. Unfortunately no established metric was available for calculating the dollar value of exercise to children. The key data input used in the study to determine health care cost savings was the number of park users participating in a sufficient amount of physical activity to make a difference in their health. (The Centers for Disease Control and Prevention defines this as at least 150 minutes of moderate activity or at least 75 minutes of vigorous activity per week). The researchers found that 94,991 residents (82,206 aged younger than 65 and 12,785 aged 65 or older) exercised actively enough in parks to result in a reduction to their health care costs. Virginia Beach residents' combined health care savings attributable to park use in 2010 was estimated to be \$38,472,475 (see Table 13)

Table 13: Health Value of Virginia Beach Parks. Source: (The Trust for Public Land 2011) p.9.

Adults Younger Than 65 Years of Age	
Average annual medical care cost difference between active and inactive persons	\$351
Number physically active in parks*	82,206
Medical care cost savings subtotal	\$28,854,306
Adults 65 Years of Age and Older	
Average annual medical care cost difference between active and inactive persons	\$702
Number physically active in parks*	12,785
Medical care cost savings subtotal	\$8,975,070
Subtotals combined	\$37,829,376
Regional multiplier for health costs	1.017
Total annual value of medical care cost savings attributable to parks	\$38,472,475

Community Cohesion Value

Like other social gathering places parks can promote a sense of community. Studies show that institutions that foster the web of human relationships can make communities stronger and safer. Urban anthropologist Jane Jacobs coined the term 'social capital' for this human web. The economic values of social capital are not easy to quantify. In this study a proxy measure was adopted, i.e. the amount of time and money that residents donate to their parks. The researchers combined this information with a dollar value assigned to volunteerism by the Points of Light Foundation, \$20.85 in 2010. In addition the researchers added the value of cash donations, corporate sponsorship, and in-kind donations to parks. The Social Capital Calculator for parks in Virginia Beach calculated value just under \$4 million (see Table 14).

Table 14: Community Cohesion Value of Virginia Beach Parks. Source: (The Trust for Public Land 2011) p.11.

Total value of donations	\$85,433
Volunteer hours	185,560
Value per hour	\$20.85
Total value of volunteer hours	\$3,868,926
Total community cohesion value	\$3,954,359

Air Pollution Removal Value

Vegetation in Virginia Beach's parks absorbs air pollutants such as nitrogen dioxide, sulphur dioxide, carbon monoxide, and ozone, and improves air quality through particulate matter adhering to plant surfaces. The vegetation in city parks therefore represents a 'free green infrastructure' that helps urban residents avoid costs associated with air pollution. The Northeast Research Station of the U.S. Forest Service in Syracuse, New York, has designed a calculator to estimate the pollution removal value of trees in urban areas, which was applied in this study. Analysis determined that 51.8 percent of the city's 33,640 acres of parkland is covered with trees. Total pollutant flux (pollutant flow within a given time period) was multiplied by tree-canopy coverage to estimate total pollutant removal by trees in the study area. The monetary value of pollution removal by trees was estimated using the median U.S. externality values for each pollutant, which is the amount it would otherwise cost to prevent a unit of that pollutant from entering the atmosphere. The result of applying the Air Quality Calculator for the park system of Virginia Beach in 2010 was a saving of \$4,516,704 (see Table 15).

Table 15: Air Pollution Removal Value of Virginia Beach Parks. Source: (The Trust for Public Land 2011) p.12.

Pollutant	Tons removed	Savings per ton removed	Pollutant removal value
Carbon dioxide	19.4	\$870	\$16,863
Nitrogen dioxide	116.5	\$6,127	\$713,871
Ozone	451.5	\$6,127	\$2,766,475
Particulate matter	216.3	\$4,091	\$884,851
Sulphur dioxide	89.8	\$1,500	\$134,643
Total savings	\$4,516,704		

Stormwater Management Value

Virginia Beach's parks can reduce stormwater management costs by capturing rainfall and slowing runoff. The large pervious surface areas of parks allow rainfall to infiltrate and recharge groundwater. Vegetation also intercepts and stores some rainwater. The authors conclude that 'in effect, urban green spaces function like mini-storage reservoirs-green infrastructure'. The study used a model developed by the Western Research Station of the U.S. Forest Service in Davis, California, which estimates the value of retained stormwater runoff from public green space, and which gives a preliminary indication of the stormwater management value of the Virginia Beach park system. The researchers compared actual runoff against the theoretical runoff that would occur if the city had no parks. They then calculated the costs of managing stormwater using 'hard' infrastructure such as concrete pipes and sewers. By considering rainfall, patterns of land cover, and cost factors, the researchers obtained a total stormwater management value of just over \$1.5 million for the park system of Virginia Beach in 2010 (see Table 16).

Table 16: Stormwater Retention Value of Virginia Beach Parks. Source: (The Trust for Public Land 2011) p.14.

Rainfall	5,169,051,756 cu. ft. (42.33 in.)
Runoff from parks	523,982, 657 cu. ft.
Runoff from same acreage if there were no parks (theoretical)	636,296,686 cu. ft.
Runoff reduction due to parks	112,314,029 cu. ft.
Runoff reduction rate	18%
Average cost of treating stormwater (\$ per cubic foot)	\$0.0135
Total savings due to park runoff reduction	\$1,516,239

5.4.3.4 Cooperative Research Centre for Irrigation Futures

In Australia, a study by Fam and Mosely (2008), at the Cooperative Research Centre for Irrigation Futures, reviewed the environmental, social and economic benefits to the community of irrigated green spaces. In terms of economic benefits the researchers examined increases in economic activity related to urban green spaces, and the values of greenery in increasing property value and tax revenue.

Increased Economic activity related to urban green spaces

The researchers found that in Australia there were 52,164 separate recreational parks and gardens at the end of June 1997, covering 3,386,354ha including national parks, which employed 16,646 people at a cost of AU\$470.2 million in wages. Open urban spaces were also seen as having the ability to enhance the image and identity of a city, for example Central Park in New York, Royal Parks in London, Red Square in Moscow and the Royal Botanical Gardens in Sydney (Tajima 2003). These urban amenities will become even more important as cities compete for skilled workers, and more cities are beginning to recognize the importance of urban green spaces in attracting skilled workers and companies (Glaeser et al. 2001).

The authors refer to a survey conducted in Melbourne which found that 90% of human resource managers felt that city parks and gardens improved staff morale in their businesses, and 55% of respondents used parks and city gardens for employee events. Economic benefits may relate to reduced work related stress, reduced absenteeism and increased productivity. The importance of vegetation and greenery has been recognised by the City of Melbourne which has valued its green spaces, which include 55,000 mature trees, at AU\$500 million dollars. The tourism sector can also be positively affected by attractive public parks and gardens. A 1998 study found that Melbourne's gardens and parks were a valuable economic and social asset, which contributed \$15 million in export sales to the metropolitan economy, \$1.25 million from organized bus tours, \$2.4 million from the Melbourne International Flower Show and \$11.6 million from parks related to the Moomba festival (Maller et al. 2002). The tourism benefits of Melbourne's public parks and gardens were reflected in a survey of related businesses which found that:

- 92% felt the parks & gardens were important in attracting visitors.
- 83% felt that tourism would be affected by a decline in city parks.
- 41% felt that businesses would be affected by a decline in city parks.

Increasing Property Value and Tax Revenue

Research shows that people are willing to pay more for a property located close to parks, open space and greenery. One US survey found that 50% of respondents would be willing to pay 10% more for a house near a park, with 57% stating they would select neighbourhoods close to parks and open space if in the market for a home (Crompton 2000). Homebush Bay, site of the 2000 Olympics, was a former ammunitions dump, abattoir, and ground for a toxic chemical dump. The 'green' transformation of the site for the Olympics has been shown to have helped improve property values in the area immediately around the park (Dann 2004). Residential properties with well-maintained gardens and properties in close proximity to green public spaces have also been found to be valued approximately 10% higher than comparable properties (Real Estate Industry Australia 2007).

Increased property values near parks can also benefit local government through increased property taxes, which in certain cases may even be sufficient to finance the development of the park (Crompton 2000). Australian local governments were found to have collected \$8,920 million in property taxes in 2005/06, therefore it may be to their economic advantage to maintain public parks and urban green spaces (Dann 2004). The authors conclude that maintaining public parks, private gardens and green sporting fields benefits the community socially, economically and environmentally; it provides an advantage to property owners in increasing value of homes and is of economic benefit to local governments as increased tax revenue (Real Estate Industry Australia 2007).

5.4.4 Land and water conservation

Researchers have also investigated the economic benefits of conserving natural areas, such as forests and water ways. For example the Land and Water Conservation Fund (LWCF) uses a portion of receipts from offshore oil and gas leases for land conservation and recreation, including creating and maintaining the US system of state, local and national Parks. In a study entitled '*Return On The Investment From The Land & Water Conservation Fund the Trust for Public Land*' the Trust for Public Lands (TPL) conducted an analysis of the return on the investment by LWCF for 16 federal land 'units' acquired between 1998 and 2009 (The Trust for Public Land 2010). A total of 131,000 acres were acquired with \$357 million in funding (see Figure 33). The study found that every \$1 invested returned \$4 in economic value, over this time period, from natural resource goods and services alone. In addition it found that approximately 10.6 million people visit these federal parks each year and spend \$511 million in the surrounding communities.

Natural Goods & Services

Natural goods and services provided by these protected lands were reviewed in terms of 12 distinct ecosystems, as shown in Figure 34.

Exhibit 2. Acreage Acquired by Land Cover Type		
Land Cover	Acres	Percentage
Open Water	3,050	2%
Developed	3,474	3%
Barren Land	6,490	5%
Deciduous Forest	41,600	32%
Evergreen Forest	20,700	16%
Mixed Forest	26,700	20%
Shrub/Scrub	15,100	11%
Grasslands/ Herbaceous	3,260	2%
Pasture/ Hay	1,130	1%
Cultivated Crops	1,910	1%
Woody Wetlands	2,090	2%
Emergent Herbaceous Wetlands	6,050	5%
Total	131,000	100%

Figure 34: Acreage acquired by land cover type. Source: (The Trust for Public Land 2010) p.9.

Natural goods and services provided, and their monetary values, were determined using a benefits transfer methodology. This comprised a literature review of the types of goods and services provided by the 12 ecosystem types identified, and an estimate was made of per acre economic value of these goods and services. The benefits transfer method is used to estimate economic values for ecosystem services by transferring available information from published studies in another location and/or context. The basic goal of benefit transfer is to estimate benefits for one context by adapting an estimate of benefits from some other context. Benefit transfer is often used when it is too expensive and/or there is too little time available to conduct an original valuation study, yet some measure of benefits is needed. It is important to note that benefit transfers can only be as accurate as the initial study. (The Trust for Public Land 2010) p.10.

The researchers estimated the per acre value of the following natural goods and services:

- Protecting water quality and supply.
- Flood protection.
- Fish production.
- Habitat provision.
- Storm protection.

- Carbon sequestration.
- Grazing.
- Aesthetics.
- Pollination.
- Dilution of wastewater.
- Erosion control.

Based upon these per acre values, the researchers concluded that the 131,000 acres of conserved land would provide \$2 billion in total economic value from date of purchase to 2019 (10 years from 'today') in natural goods and services. They then estimated the return on the present value (the value of past investments in today's dollars) of \$537 million invested in the 131,000 acres of land conservation from 1998 to 2009, by comparing this investment with the \$2 billion of natural goods and services generated by these lands in the past (from 1998 to 2009) and into the future (over the next ten years). It was found that every \$1 invested returned \$4 in economic value. These goods and services would also continue to be provided well beyond the next ten years, increasing the total return on investment beyond that calculated in the analysis.

Additional Economic Benefits

In addition to providing natural goods and services, the federal lands studied were found to play a significant role in the local recreation and tourism industries, as follows:

- **National Forests.** Visits to US national forest lands are an important contribution to the economic vitality of rural communities, with about 174 million recreation visits to national forests per year. Regional spending by these recreation visitors is estimated to be nearly \$13 billion annually. Visitor spending also 'ripples' through the economy sustaining over 224,000 full and part time jobs.
- **National Parks.** Outdoor recreation at National Parks also provides an economic boost to surrounding communities. The national park system received 275 million recreation visits in 2008, with these visitors spending about \$11.6 billion in regional economies, supporting 205,000 jobs and \$4.4 billion in employment income.
- **National Wildlife Refuges.** Wildlife based recreation at national wildlife refuges also contributes to regional economies. In year 2006, 34.8 million people visited national wildlife refuges in the 'lower 48' US states for recreation, and their spending generated sales of \$1.7 billion in regional economies, which supported 27,000 jobs and \$543 million in employment income.
- **Bureau of Land Management Managed Lands.** Recreational use on the public lands managed by the Bureau of Land Management (BLM) also helps support the economies of Western US communities and states. More than 55 million people live within 25 miles of BLM managed lands, and two-thirds of these lands are within 50 miles of an urban area. Visits to

recreation sites on BLM managed lands have significantly increased from 51 million in 2001 to 57 million in 2008.

- **Increased Tourism, Recreation & Spending.** The relatively 'modest' investment in protection of land by LWCF has been found to support an 'impressive' level of tourism visits to federal lands. About 10.6 million tourists visit the 16 federal units studied each year, spending \$511 million annually in these local economies. For example, over the past 10 years LWCF has invested \$3.85 million dollars in land acquisition in the Acadia National Park. Over that same time period it is estimated that 22.0 million visitors recreated in the park and spent \$1.40 billion in the local economy.
- **State & Local Parks Benefits.** While the focus of the Trust for Public Land study is on the economic benefits of federal LWCF investments, several other studies have documented the economic benefits from state and local parks and recreation, which are supported through the LWCF state grants program. For example, the National Association of State Park Directors reports that America's state park system contributes \$20 billion to local and state economies. According to the National Recreation and Park Association, studies have shown that for every \$1 million invested in parks and recreation infrastructure, at least 20 jobs are created.

5.4.5 Water Sensitive Urban Design

5.4.5.1 Overview

Research is being undertaken in a number of Australian cities to develop a 'business case' for the implementation and institutionalization of Water Sensitive Urban Design (WSUD) practices. Water Sensitive Urban Design benefits commonly cited in literature and studies include (Taylor 2005):

- Avoided waterway rehabilitation costs.
- Prolonged 'useful life' of stormwater conveyance assets. Stormwater drains will be less clogged with gross pollutants and sediment, natural creeks will be in better condition to handle major storm flows without eroding, posing risks to infrastructure, property and public safety.
- Increased land value, locality 'branding' and marketability.
- Improved amenity, for example, urban areas taking advantage of waterway corridors; 'greener' streets and reduced 'urban heat island' effects.
- Improved active and passive recreation, health and lifestyle, and social well-being through improved open spaces.
- Biodiversity and ecological benefits.
- Improved sustainability of primary industries, tourism and other businesses that rely on healthy waterways.

On the other hand, Water Sensitive Urban Design 'lifecycle costs' can include:

- Land acquisition costs for stormwater measures.
- Design, construction and establishment costs.
- On-going maintenance costs.
- Possible negative impacts on nearby residents.

5.4.5.2 *Lynbrook Estate development*

Lynbrook Estate 35kms south east of Melbourne was the first broad scale application of Water Sensitive Urban Design in Melbourne, with the implementation of a 'treatment train' to detain and treat stormwater and has been used as a case study to demonstrate the benefits of a Water Sensitive Urban Design approach to stormwater management (Farrelly and Davis 2009). Monitoring the performance of the treatment train technology indicated that hydraulic performance of the Water Sensitive Urban Design drainage system was exceptionally good. The treatment train was considered to have 'performed hydraulically better than the other conventional drainage systems in the estate' (Brown and Clarke 2007). Monitoring of pollutant loads demonstrated that the WSUD approach significantly improved the quality of stormwater runoff in comparison to conventional drainage (a reduction of 60% of total nitrogen, 80% reduction in total phosphorus and 90% reduction of total suspended solids) (Wong 2006a). In addition, stormwater was found to be draining efficiently through the system, remnant red river gums were reviving and water was being filtered and cleaned before being discharged to Dandenong Creek (Melbourne Water 2003).

Early concerns regarding consumer acceptance by developers were quickly overcome following the strong land sales (Lloyd 2004). Sale prices for subdivisions that incorporated WSUD reported increases in the order of 20%-30%. Stakeholders involved in the project attributed this strong market acceptance to the improved aesthetics of the development, relative to others at that time. Melbourne Water however believe that there were also other reasons relating to market changes that contributed to the development's success (Brown and Clarke 2007). VicUrban now applies WSUD in all new greenfield, urban developments where appropriate.

Capital costs are often cited as a barrier to the introduction of any new technology. A cost comparison between the conventional and WSUD stormwater drainage systems demonstrated only a 5% difference in costs for applying Water Sensitive Urban Design (Lloyd 2001; Wong 2001).

Other social research showed that the local community found the development more aesthetically attractive than earlier traditional developments (Lloyd 2004). Researchers also assumed that the inclusion of water features, preservation of remnant vegetation and an emphasis on environmental issues made the development more desirable and marketable (Wong 2001).

5.4.5.3 Living Victoria Living Melbourne Road Map

The Victorian Government's *Living Melbourne, Living Victoria* policy aims to:

- Establish Victoria as a world leader in liveable cities and integrated water cycle management.
- Drive generational change in how Melbourne uses rainwater, stormwater and recycled water to provide better water services and reduce Victoria's footprint with regard to energy and water use.
- Drive integrated projects and developments in Melbourne and regional cities to use stormwater, rainwater and recycled water to postpone Victoria's next major water augmentation.

One of the reform priorities of the recent *Living Victoria Living Melbourne Roadmap* (Living Victoria Ministerial Advisory Council 2011) is to 'establish a common approach to economic evaluation'. Integrated water cycle management is seen as providing multiple benefits to the community (including improvements to downstream water quality, reduced urban heat, reduced risk of flooding and improved urban amenity). These benefits accrue to the general public, rather than water providers and users, and are often not considered in investment decision-making. The negative impacts of some projects, however, are not borne by the project owner, but are felt more broadly, for example, stormwater pollution leading to degraded urban waterways.

At the moment decision-making does not account for the full costs and benefits of different options. Risks of climate variability and the availability of more diverse water supply options highlight the need for a more holistic economic assessment of water projects including real option and insurance values associated with different investment choices (Farrier Swier Consulting 2011). Option value captures the benefits of deploying a diversified portfolio of water sources, including the value of deferring large supply augmentations. Figure 35 illustrates what such a holistic assessment framework might look like.

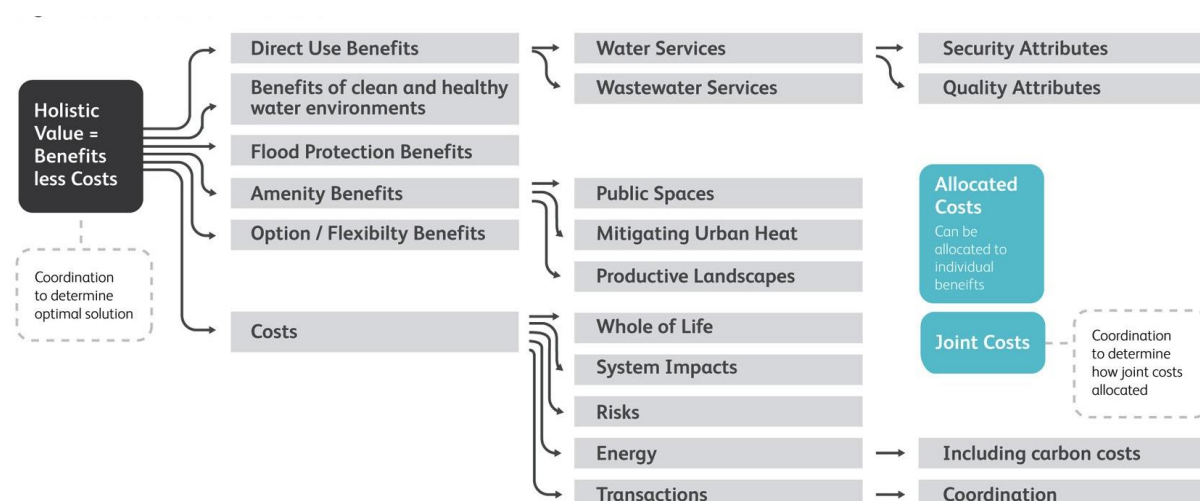


Figure 35: Holistic value assessment. Source (Living Victoria Ministerial Advisory Council 2011).

5.4.5.4 South East Queensland Business Case

In 2010 Water by Design prepared a *Business Case for Best Practice Urban Stormwater* in South East Queensland (Water by Design 2010). Both ‘tangible’ (market) and ‘intangible’ (non-market) costs and benefits were estimated from six case study assessments of a range of WSUD developments across Queensland. Whilst the policy scenarios modelled are specific to Queensland, the detailed methodology adopted in the study is relevant to the development of a ‘business case’ for the other aspects of Green Infrastructure. The study outlines a useful framework for analysing the costs and benefits of WSUD including both market factors (such as property values) and non-market factors (such as improved water quality). Quantitative data is provided in the study where it was available and the reference section lists a range of relevant resources, both Queensland specific and generic to WSUD.

The study authors concluded that the benefits of implementing Water Sensitive Urban Design practices to achieve the government’s stormwater management objectives ‘*are likely to outweigh the costs for typical development types*’. The study made the following observations with regard to the valuation of Water Sensitive Urban Design benefits.

- Best practice urban stormwater management via WSUD potentially provides a range of benefits, however the majority of benefits are non-market benefits and estimations of their economic worth are difficult.
- More easily quantifiable benefits include the value of annual reduction in pollutant loads discharged to water ways.
- Most benefits occur over a long time scale (albeit with some immediate benefits such as improved amenity of developments).
- Many of the benefits may be returned to the wider community or region rather than to local householders or developers.
- Costs associated with WSUD can often be indirectly borne by households, particularly by land costs and local government rates.
- The majority of benefits will then accrue to a wider section of the current and future community, via lower costs, an enhanced environment, and benefits such as improved recreational activities and stronger tourism industries

A summary of the value of benefits identified in the study is presented in Table 17.

Table 17: Typical benefits of WSUD practices to achieve stormwater management objectives. Source: (Water by Design 2010) p.14.

Item	Potential benefit	Distribution	Value estimates	Data source
Indirect Financial				
Avoided water way rehabilitation costs*	Implementing WSUD practices will enhance waterway stability by reducing the volume and velocity of runoff during rainfall events. This will reduce in-stream erosion, the disturbance of in-stream ecosystems, and the risk to ecosystem function within waterways (Walsh et al. 2009). There is therefore the potential to avoid stream rehabilitation costs if WSUD is applied to developments.	Local governments, community	Capital cost rates range from \$200-800/m for a number of Gold Coast City Council projects to \$2,500-3,000/m for BCC projects. Rates vary according to the extent and scope of works. Maintenance costs rates are approximately \$25/m of stream per year.	DesignFlow estimates, BCC, Australian Wetlands Pty Ltd.
Premium on land values (linked to a range of social values)*	Some WSUD practices (e.g. constructed wetlands) that are included in or are additional to a developments green space may create a premium market for adjacent land.	Developers and households	The premium on land close to urban green space (e.g. in Ipswich) is around 10% for properties within 500 m of open space. Premium on land adjacent to water, particularly open water, can be as high as 100%.	(Marsden Jacob Associates 2007a)
		Developers and households	Research in WA indicated property values increase by 7% when located adjacent to natural wetlands that are preserved, or newly created stormwater treatment wetlands.	(Tapsuwan et al. 2007)
	Marketability of sustainable developments	Developers and households	Positive perceptions of WSUD were noted by market research, which showed over 85% of homebuyers drawn from Melbourne's growth corridors support the introduction of biofiltration systems, wetlands and water reuse schemes into their neighbourhoods.	(Lloyd 2002)
	Protection of water quality in in receiving waters improves land prices.	Households	A review of six studies that attempted to measure the effect of water quality on the value of nearby properties in Washington found a premium associated with improvements in water quality typically ranged from 1%-20%.	(Washington State Department of Ecology 2003)
		Households	There was a drop in property values for water frontage lots around Lake Boga (Victoria) after major algal blooms in the summers of 1993-94 and 1994-95. Property valuations in late 1995 indicated on average, lakeside properties	(Read Sturgess and Associates 2001)

			were worth 20%-25% less than before the blooms.	
Avoided development costs on flat sites	Infrastructure costs such as conventional pits, pipes and earthworks can be reduced through alternative stormwater conveyance and management approaches.	Developers	The avoided capital cost on flat sites is estimated to be at least \$36,000 per hectare on flat sites	DesignFlow estimates
Estuarine and marine ecosystem management costs avoided	Potential to reduce management costs associated with changes in Moreton Bay, the Great Barrier Reef and other similar ecosystems.	State and federal government, local governments, community	Some evidence is available, but it is insufficient to develop quantitative estimates.	
Tourism reliant on waterway health.	The tourism sector, particularly in the Great Barrier Reef, is reliant on the quality of experience that is partially reliant on waterway health.	Tourism and associated industries	The economic contribution to the national economy of the recreational dive and snorkelling industry in the Great Barrier Reef catchment is between \$690 million and \$1.09 billion per annum.	(Marsden Jacobs Associates 2009b)
			The value of the freshwater recreational fishing industry in South East Queensland is estimated to be approximately \$3 million per annum (\$2002)	(Taylor 2002)
			The estimated direct expenditure by local residents on recreational fishing in the Maroochy River is \$19 million per annum	(CSIRO 2008)
			The estimated annual expenditure of South East Queensland resident anglers is \$193 per angler (\$2001)	(Marsden Jacob Associates 2006)
Seafood industry reliant on waterway health.	Commercial fishing is partially reliant on waterway health.	Industry	The value of commercial fishing in the Moreton Region is estimated at \$33 million per annum (\$1998)	(Taylor and Fletcher 2006)
Non-market				
Waterway health*	Non-market values associated with waterway health	Community	Queensland-1% change in the proportion of waterways in good health is worth \$6.35 per householder per annum (\$2009)	(Windle and Rolfe 2006)
			SE Queensland-1% improvement or preservation worth \$3.74 per householder per annum (\$2009)	Windle and Rolfe 2006)
			Mackay-1% improvement or preservation worth \$8.65 per householder per annum (\$2009)	Windle and Rolfe 2006)
			The value of the Maroochy River to the local council through direct investment (funded by an environmental levy) in the 'Improving our waterways program' was \$1.4 million in 2006/07.	(CSIRO 2008)

			The global average value of estuaries has been estimated at \$22,382/ha/year, seagrass as \$19,004/ha/year and wetlands as \$14,785/ha/year (in US1994).	(Costanza et al. 1997)
			Blackwell estimated the value of lakes and rivers in Australia to be \$1,528,078 (\$2005) per km ²	(Blackwell 2005)
Reduced pollutant loads*	Lower loads of pollutants discharging to downstream waterways and ultimately receiving wetlands	Utilities and ultimately households	Levelized annual treatment costs to remove nutrients from wastewater in urban areas range from \$180,000-\$850,000 per tonne of TN removal and from \$80,000-\$600,000 per tonne of TP removal (national estimates).	(BDA Group 2006)
Wetlands	Non-market value of wetlands in South East Queensland	Community	One off value of wetland protection estimated at \$11-19 per household	(Clouston 2002)
Urban cooling	Shading and cooling offered by vegetated WSUD treatment systems.	Community	Where urban cooling does occur, benefits of avoided energy consumption for air conditioners and reduced CO ₂ emissions could be significant, albeit unquantified	(Cleugh et al. 2005)
		Community	Shading offered by trees in car parks in the United States resulted in a local air temperature reduction Of 1-2 degrees Celsius	(McPerson et al. 2002)
Area's general liveability and amenity	WSUD potentially enhances amenity (e.g. wetlands and the marginal benefit of well-designed, vegetated bioretention systems (compared to lawn or turf)).	Community	A survey of 300 property owners and prospective buyers from four greenfield development areas in Melbourne found that 85-90% of respondents supported the integration of grassed and landscaped bio-filtration systems into local streetscapes to manage stormwater.	(Lloyd 2002)
Recreation	WSUD has the potential to enhance open space.	Community	Previous analysis of the economic benefits of outdoor recreation in South-East Queensland found that a 1% enhancement in outdoor recreation opportunities is worth around \$12 per household per annum, while the same increase in recreational fishing opportunities is worth around \$2 per household per annum.	(Marsden Jacob Associates 2008)
Education	Provision of a research or educational asset	Community	Data is unavailable	
Ecological 'existence' values	The impact on the ecological health of affected local or regional ecosystems ('existence' values).	Community	It is estimated that residents of the (former) Maroochy Shire were willing to pay up to \$2 million per annum for	(Taylor 2005b)

			non-use values associated with Moreton Bay and its environs.	
Ecological 'option' values	The impact of the value of providing healthy aquatic and riparian ecosystems for potential use in the future (i.e. 'option' values).	Community	A New Zealand study found that the 'option price' (i.e. the sum of use, preservation and option values) is \$17.05 (NZ\$2004) expressed as a mean willingness to pay per household per year for users and non-users of the River.	(Taylor 2005b)
Ecological 'bequest' values	The impact of the value of providing healthy aquatic and riparian ecosystems for future generations (i.e. 'bequest' values).	Community	The Rakia River study by Kerr et al. (2004) found the present value of preservation values of the river to be approximately \$19 million (NZ\$2004).	(Taylor 2005b)
*Major benefits that should dominate the assessment of the likely net benefit of applying WSUD to new developments in Queensland.				

5.4.5.5 US EPA

In 2013 the US EPA prepared a report to help utilities, state and municipal agencies, and other stormwater professionals understand the potential benefits of low impact development and green infrastructure (LID/GI) programs. The US EPA (2013) uses the term "green infrastructure" to generally refer to systems and practices that use or mimic natural processes to infiltrate, evapotranspire (the return of water to the atmosphere either through evaporation or by plants), or reuse stormwater or runoff on the site where it is generated. Green infrastructure can be used at a wide range of landscape scales in place of, or in addition to, more traditional stormwater control elements to support the principles of LID. LID is an approach to land development (or re-development) that works with nature to manage stormwater as close to its source as possible

The report highlights different evaluation methods that have been successfully applied in 13 case studies, and also demonstrates cases where LID/GI have been shown to be economically beneficial (See Figure 36).

Although many entities have begun to implement LID and GI approaches for stormwater anagement, research shows that a relatively small percentage of jurisdictions have conducted economic analyses of their existing or proposed programs. This lack of program analysis is due to many factors including uncertainties surrounding costs, operation and maintenance requirements, budgetary constraints, and difficulties associated with quantifying the benefits provided by LID/GI.

Entity	Charlotte-Mecklenburg Storm Water Services, North Carolina	Bureau of Environmental Services Portland, Oregon	Philadelphia Water Department, Pennsylvania
Program	Stream restoration and BMPs are used to reduce impacts of rapid development on drinking water quality	Ecoroofs program: The City of Portland encourages the construction of green roofs by providing incentives to developers and by requiring green roofs on new city-owned facilities and roof replacement projects.	The Green City Clean Waters Program aims to reduce combined sewer overflows (CSOs) and improve water quality.
Role of economic analysis	BMP project prioritization through evaluation of alternatives	<ul style="list-style-type: none"> • Determine if benefits exceed cost • If so, use results to increase implementation of ecoroofs in the city 	Demonstrate full range of societal benefits of LID/GI to regulators and the public
Type of analysis	Cost-effectiveness	Benefit-cost analysis (BCA; including TBL elements) of hypothetical new commercial building with 40,000-square-foot roof	Benefit-cost analysis (referred to as a TBL analysis by PWD)
Key metrics	Capital cost per pound of sediment prevented from entering stream	<ul style="list-style-type: none"> • Present value (PV) life-cycle costs • Avoided costs • Environmental and social benefits • Net present value (NPV) of program to the public (e.g., public stormwater system and the environment) • NPV of the program to developers and building owners • NPV to public and private stakeholders combined 	<ul style="list-style-type: none"> • NPV life-cycle costs and benefits of GI and grey approaches • Quantified and monetized social and environmental benefits
Results	<ul style="list-style-type: none"> • For urban retrofits, stream restoration is the most cost-effective means of controlling sediment deposition into the reservoir. • Prioritization allows the county to implement need-based, rather than opportunity-based, projects 	Construction of ecoroofs has: <ul style="list-style-type: none"> • Immediate and long-term benefits to the public • Positive net benefits accrue to building owners starting in year 20 for the assumed conditions 	<ul style="list-style-type: none"> • LID/GI-based approaches provide important environmental and social benefits that are generally not provided by grey infrastructure • A LID/GI-based approach, coupled with targeted grey infrastructure, is the city's preferred approach to optimize net benefits

Figure 36: Summary of analytical approaches used by three LID/GI case study agencies (US EPA 2013).

5.4.6 Green Roofs

A recent study commissioned by *Green Roofs for Healthy Cities* in Toronto, Ontario (Peck 2012) aimed to provide guidance in attributing economic values to selected 'hard' and 'soft' public benefits of green roofs at the community level, in order to provide a basic understanding of the public return on investment associated with green roof policies. Green roofs can offer tangible solutions to many challenges faced by urban communities. Articulating the value of those benefits in monetary terms provides an estimate of their contribution to local and regional economies and permits governments, land developers and building owners to assess short- and long-term public and private gains. While some benefits are directly measurable and have 'hard' values (such as the energy savings due to the insulation provided by the growing media and vegetation of a green roof), many benefits are 'soft' (not readily measurable) and their values are difficult to estimate (such as the health benefits of a green roof).

Benefits may be attributed directly to the owners/occupants of the facility on which they are installed (e.g. reduction in cost of energy used for cooling). However the nature of green roofs is such that there are many public benefits that will accrue to the larger community (e.g. improvement in air quality). Some benefits, such as increase in property values, may accrue to the owners but will also benefit the larger community in the form of long term changes to the tax base. In addition, many public/private benefits such as the reduction in urban heat island effect, or the incidence and severity of flooding, will only be felt when a certain minimum scale of green roof implementation is achieved.

The researchers reviewed and consolidated work on the economic benefits of green roofs reported elsewhere, primarily in North America, and attempted to provide, in one location, a range of methods that can be employed by policy makers and others to determine the potential economic impact of green roof policies. This approach requires a trade-off between ease of use and the level of detail and precision. A more accurate evaluation of the hard and soft public economic benefits would require a much greater investment in biophysical studies of impacts (e.g. reduction in the urban heat island), and socio-economic studies (e.g. avoided costs of stormwater infrastructure investment) of the resulting benefits.

The public benefits of 'living architectural systems' were broadly categorized as follows (Peck 2012):

- Urban heat island mitigation.
- Improvements in on-site stormwater management.
- Aesthetic improvements.
- Urban food production.
- Carbon sequestration.
- Employment from manufacture, design, installation, and maintenance.
- Increase in property values and corresponding increase in municipal tax base.
- Noise attenuation.
- Shading.
- Increase in life of building envelope components.
- Improved biodiversity.
- Incorporation of green products and systems.
- Reduced flooding.

The following method was proposed for determining an estimate of the benefits (see Table 18) of investing in a green roof program that utilizes incentives to help overcome the higher initial costs.

- Step 1: Determine the Scope (What is the Area of Green Roofs That Will Result?)
- Step 2: Estimate the costs and applicable benefits.
- Step 3: Normalize Values to local conditions.
- Step 4: Calculate the Potential Benefits.

Table 18: Public economic values of green roofs. Source:(Doshi and Peck 2013).

Benefit	Value ranges \$/m ²	Studies cited
Stormwater infrastructure cost reduction due to volume reduction – Capital	\$0.3 to \$45.9	(EcoNorthwest 2008; Tomalty and Komorowski 2010; Garrison and Lunghino 2012; Toronto City 2013)
Stormwater infrastructure cost reduction due to volume reduction – Operating and Maintenance	\$0.358	(EcoNorthwest 2008)
Combined sewer overflow reduction in storage – Capital	\$0.9	(Toronto City 2013)
CSO – environmental impact – annual	\$0.015	(Toronto City 2013)
Reduction of pollutants through capture by vegetation – annual	\$0.052 to \$1.695	(EcoNorthwest 2008; Tomalty and Komorowski 2010; Toronto City 2013)
Air Quality (Nitrous Oxide compounds)(EPA Study)	\$0.000074 to \$0.055	(GSA 2011)
Air Quality (Particulate Matter PM10)	\$0.000106	(GSA 2011)
Air Quality (Sulfur-oxygen compounds)	\$0.000000185	(GSA 2011)
Building Energy – Reduction in energy infrastructure – Capital	\$1.378	(Toronto City 2013)
UHI – reduction in energy demand and infrastructure – Capital	\$1.601	(Toronto City 2013)
Reduction in GHG due to reduction in energy demand – annual	\$0.002 to \$0.215	(EcoNorthwest 2008; Tomalty and Komorowski 2010; Garrison and Lunghino 2012; Toronto City 2013)
Creation of habitat – Capital	\$6.808	(EcoNorthwest 2008)
Habitat Creation (Australia's BushBroker Scheme which replaces vegetation on denuded land for habitat) - Capital	0.039 - 0.1356	(GSA 2011)
Habitat Creation (US Biodiversity Banking System) - Capital	\$0.0381	(GSA 2011)
Job creation – job creation estimates are provided as jobs/ m2 of green roof	0.6 to 1.1 person years of jobs per 1000 m2 of roofing (Toronto) or 4.2 jobs per 1000 m2 of installed roofing (Washington DC)	(American Rivers 2012; Toronto City 2013)
Maintenance (Extensive)	0.124 person hours/square meter/visit (2 per year)	(GSA 2011)
Maintenance (Intensive)	139 person hours/square meter/visit (4 per year)	(GSA 2011)
Flooding Avoided Costs (Figures are very site specific)	\$9000 per 4,046 square meters of floodplain for the 100 year event to \$21,000 per 4046 square meters for the 2 year storm event.	(American Rivers 2012)

This tool provides a basic approach to estimating the costs and benefits of investment and regulatory initiatives that concern green roof installation. Although far from perfect, the tool does provide policy makers with approximation of public costs and benefits that can be applied before conducting a more detailed assessment.

A 2013 study by the US EPA documented the economic benefits of 'ecorooft' in Portland Oregon by the Portland Bureau of Environmental Services (BES). BES calculated the net present value (NPV) of its ecoroof program to the public, i.e., the public stormwater system and the environment to private property owners, e.g., developers and building owners, and to a combination of both public and private

stakeholders. Based on this analysis, BES concluded that the construction of ecoroofs provides both an immediate and a long-term benefit to the public. At year five the net present benefit is US\$101,660, and at year 40 the net present benefit is US\$191,421. For building owners, the benefits of ecoroofs do not exceed the costs until year 20, when conventional roofs require replacement. In the long term (over the 40-year life of an ecoroof), the net present benefit of ecoroofs to private stakeholders is more than US\$400,000.

Focus area	Costs		Benefits		Summary	
	One-time	Annual	One-time	Annual	5 year NPV (2008)	40 year NPV (2008)
Public costs and benefits						
Stormwater management						
Reduced system improvements			\$60,700		\$60,700	\$60,700
Climate				–	–	–
Carbon reduction				\$29	\$145	\$845
Carbon sequestration				–	–	–
Improved urban heat island ^a				–	–	–
Improved air quality				\$3,025	\$15,515	\$104,576
Habitat				–	–	–
Habitat creation			\$25,300		\$25,300	\$25,300
Total public costs and benefits	\$0	\$0	\$86,000	\$3,053	\$101,660	\$191,421
Private costs and benefits						
Stormwater management						
Volume reduction				\$1,330	\$6,822	\$45,866
Peak flow reduction ^a				–	–	–
Energy						
Cooling demand reduction				\$680	\$3,424	\$19,983
Heating demand reduction				\$800	\$4,028	\$23,509
Amenity value						
Amenity value ^a				–	–	–
Building						
Ecoroof construction cost	\$230,000				(\$230,000)	(\$230,000)
Avoided stormwater facility cost			\$69,000		\$69,000	\$69,000
Increased ecoroof O&M cost		\$600			(\$3,077)	(\$20,677)
Roof longevity (40-year period)			\$600,000		–	\$474,951
HVAC equipment sizing			\$21,000		\$21,000	\$21,000
Total private costs and benefits	\$230,000	\$600	\$690,000	\$2,810	(\$128,803)	\$403,632
Total costs and benefits					(\$27,143)	\$595,053

a. The economic literature reports that an ecoroof can provide these economic benefits; however, data that would allow the calculation of a dollar amount for these benefits for an ecoroof in Portland are unavailable at this time.

Source: City of Portland, Bureau of Environmental Services. 2008. *Cost Benefit Evaluation of Ecoroofs*.

Figure 37: Summary of ecoroof costs and benefits (US EPA 2013).

5.5 Summary

- A number of researchers have attempted to measure the economic benefits of Green Infrastructure, which provides a useful metric for policy makers.
- One approach is the Total Economic Value method of measuring ecosystem services, however some benefits are difficult to quantify.

- Hedonic analysis attempts to systematically measure the impacts of different variables, such as tree cover, on residential property values.
- A major research focus has been on quantifying the economic benefits of the urban forest, using the US based i-Tree tool now being adapted to Australian conditions.
- Recent research has also attempted to build a 'business case' for Water Sensitive Urban Design in Australian cities.
- Other researchers have developed tools for measuring the economic benefits of green roofs.
- Research generally supports the economic benefits of Green Infrastructure and can be used to help develop a business case for Green Infrastructure.
- It must be noted, however, that some benefits remain difficult to quantify, and that the existing body of research draws upon a wide range of methodologies.
- Some researchers have criticized the use of economic values to measure ecosystem services provided by Green Infrastructure, where other measures may be more appropriate.

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6 Climatic modification

Green Infrastructure

The Green Infrastructure Project has a vision of South Australians ‘living in healthy, resilient and beautiful landscapes that sustain and connect people with plants and places’. Green Infrastructure (GI) is a systems based approach to the design and function of our towns and cities which aims to secure the health, liveability and sustainability of urban environments. Green Infrastructure strengthens the resilience of towns and cities to respond to the major current and future challenges of growth, health, climate change and biodiversity loss, as well as water, energy and food security. Green Infrastructure is effectively described as the network of green spaces and water systems that deliver multiple environmental, social and economic values and services to urban communities.

6.1 Introduction

Considerable research is being undertaken into the climatic modification benefits of Green Infrastructure in urban areas. Urban trees, other forms of greening, as well as Water Sensitive Urban Design practices have been found to contribute to:

- Urban heat island mitigation.
- Reduced energy use and emission.
- Air pollution interception and mitigation.

Issues of global climate change have further highlighted the need to address a range of environmental issues, including making better use of Green Infrastructure in the public realm. Figure 38 summarizes the climate modification roles of Green Infrastructure.

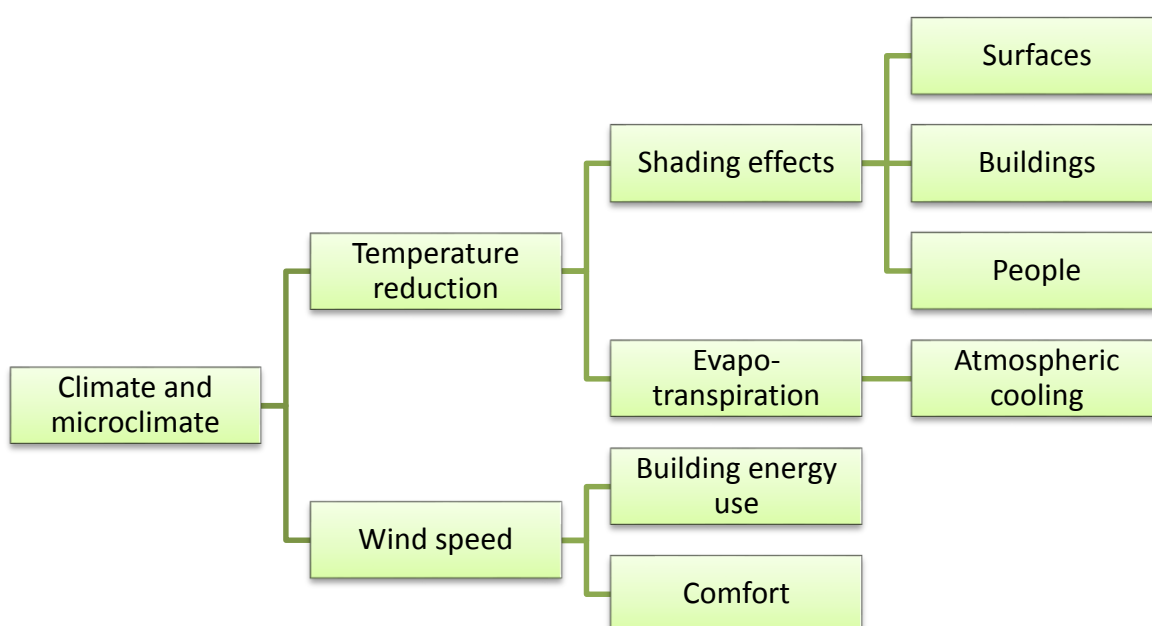


Figure 38: Summary of climatic benefits of Green Infrastructure. By author.

6.2 Temperature reduction

6.2.1 Overview

Urban microclimates are characterized by significantly higher temperatures, higher wind speeds and lower net rainfall inputs than rural or natural landscapes (Miller 1980). The most significant environmental benefit of Green Infrastructure, and trees in particular, is probably their ameliorating effect on urban climate and microclimate (McPherson and Rowntree 1993; McPherson 1994). According to O'Brien (1993).

'Trees improve cities climatically, indeed this is probably the greatest benefit of tree planting in a built up area'. p.14.

A large body of research over the past twenty or so years has shown that trees and vegetation can improve local microclimate and help reduce the 'urban heat island effect'. The climatic benefits provided by trees and vegetation include:

- Improving human comfort for street users.
- Modifying local microclimates.
- Reducing the urban heat island effect.
- Providing health benefits especially for the aged.
- Reducing energy use and carbon emissions.
- Assisting in climate change mitigation and adaptation.

6.2.2 The Urban Heat Island Effect

6.2.2.1 Description

The 'urban heat island effect' (UHI) refers to the phenomenon where the air and surface temperatures of cities are typically much higher than surrounding rural or forest areas, especially at night (Bornstein 1968; McPherson 1994; Rosenfeld et al. 1998). Temperatures in cities have been found to be as much as 12°C warmer than surrounding rural areas, on cloudless days (Oke 1987). In Melbourne researchers have reported an urban heat island effect of a mean of around 2 to 4°C and as high as 7°C depending on the location, time of the year and day (Morris and Simmonds 2000; Coutts et al. 2010). Akbari (2001) modelled the effects of the urban heat island on elevated summertime temperatures and corresponding increased energy use in ten large US cities, including trends over the last 100 years. The analysis concluded that temperatures in urban areas had increased by about 0.5-3.1°C since 1940. The researchers also estimated increases in cooling energy demand to compensate for temperature increases. It was also noted that urban trees and high-albedo (light-reflecting) surfaces can help ameliorate the urban heat island effect.

The urban heat island has also been described as an 'unintended consequence of urbanization' (GHD 2011). The urban heat island effect results from the storage and re-radiation of heat by building

materials and paved surfaces, and from urban heat sources such as the burning of fuel for heating and transportation. The predominance of artificial surfaces is known to substantially modify surface energy budgets (Quattrochi and Ridd 1994). Lack of vegetation in cities also contributes to the urban heat island effect. Reduced tree cover leads to a reduction in both shading of surfaces and in transpiration cooling by tree canopies, compared with rural areas (Federer 1976). In cities natural ground surfaces are usually replaced with asphalt and concrete surfaces which create higher surface temperatures and reduce soil evaporation that may normally cool the surface (Miller 1980). Humidity tends to be low in cities due to increased heat loads and the removal of rainfall as stormwater. Vegetative evapotranspiration increases humidity levels and levels of human physical comfort.

While the general urban heat island effect is well documented, micro-energy exchanges between trees and adjacent built surfaces are less easily categorized (Miller 1980). At a local level heat is reflected and re-radiated from adjacent surfaces, with daily variations. Metallic structures such as cars heat and cool quickly, while concrete and masonry surfaces and structures continue to re-radiate heat into the evening.

6.2.2.2 Health implications of the urban heat island

Increases in average and peak temperatures due to urban heat island effects have a number of implications for cities including detrimental effects on human comfort in the public realm, increased costs of energy use in buildings (with associated greenhouse gas emissions) and increased health stress and related mortality rates (GHD 2011).

The relationship between heat and mortality has long been recognised (Haines et al. 2006). Several researchers have attempted to quantify this relationship for the city of Melbourne. The urban heat island is recognized as contributing to health risks in large cities such as Melbourne (Loughnan 2009). Urban heat island effects can contribute to increased morbidity/mortality rates in 'heat wave' events, especially among the aged (Loughnan et al. 2008; Loughnan et al. 2010; Tapper 2010). In Melbourne on days over 30 degrees C the risk of heat related morbidity and mortality of people over 64 years of age increases significantly. Evidence suggests that buildings with little or no surrounding vegetation are at a higher risk of heat related morbidity (Loughnan, Nicholls et al. 2010). Chen and Wang (2012) also observed a triggering mean daily temperature of around 30°C for Melbourne based on analysis of historical mortality data from 1988 to 2009 for people over 75. Increasingly the focus has been on health prevention rather than alerts, trying to mitigate heat stress in the first place, for example through improvements to urban vegetation coverage and the use of cool roofs. Shade provided by large canopied trees during hot summer days can help reduce localized day time temperatures up to two degrees C. Reports from the USA and Australia indicate that, for the last century, excessive heat exposure has contributed to more deaths than that from natural disasters such as hurricanes, lightning, tornadoes, floods, and earthquakes combined (McKeon 2011; U.S. EPA 2011). Victoria's Chief Health Officer found that the heatwave preceding the Black Saturday bushfires in 2009 contributed to an increase of 374 excess deaths over what would normally be expected for that period for inner Melbourne, more than double the number who died in the fires. This also represented a 62% increase

in total all-cause mortality and an eight fold increase in direct heat-related presentations in the emergency departments (DHS, 2009). The situation of urban summer heat accumulation is likely to be further exacerbated with global warming. Climate change projections for Australia suggest an increase in the number of warm nights and heat waves which can pose significant threats to human health (Alexander and Arbalster 2008; see also Figure 39).

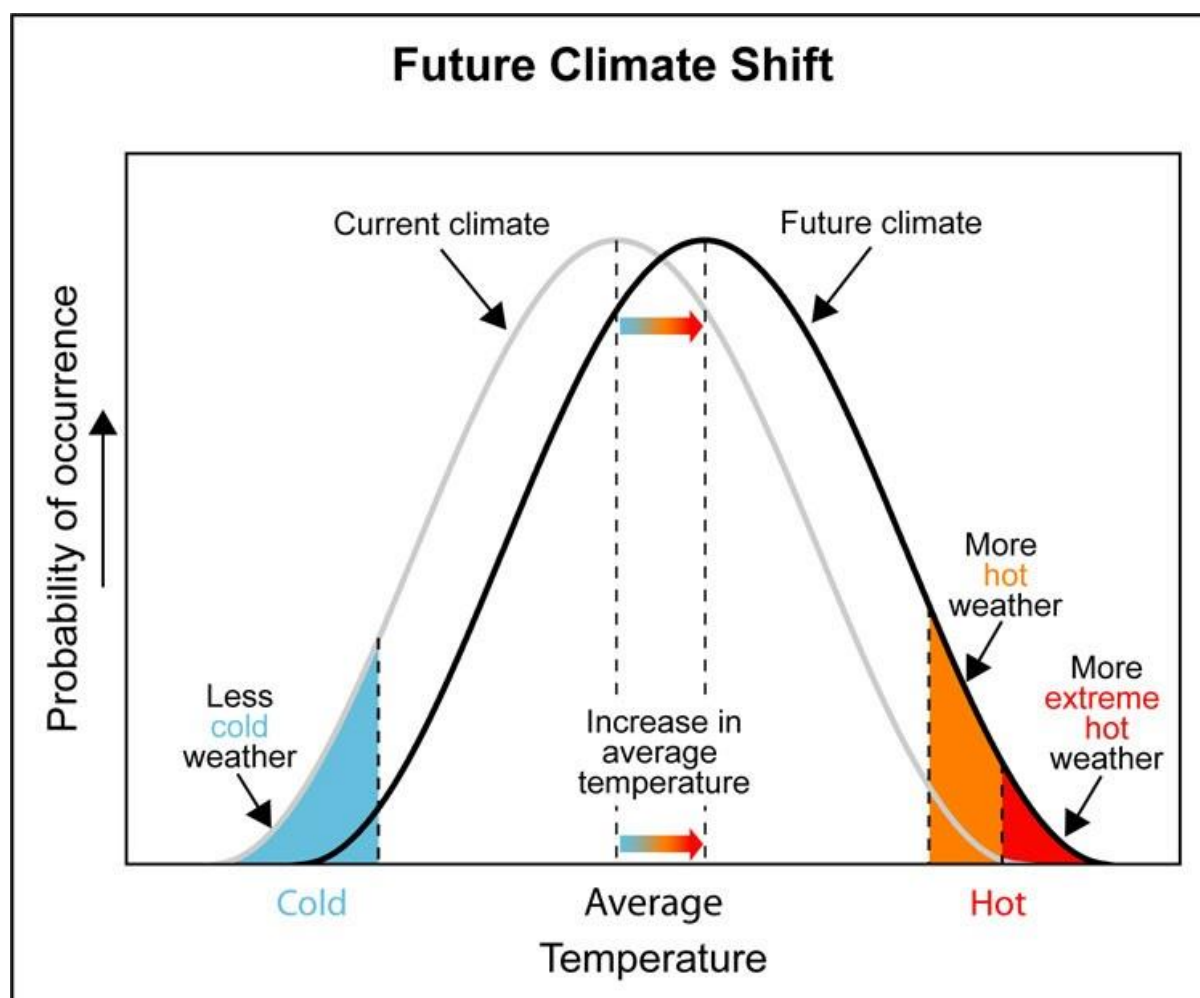


Figure 39: Graphical representation showing the relationship between increased mean temperatures and the effect on hot weather based on a normal temperature distribution. Source: (South West Climate Change Network 2012) modified from IPCC 2007.

6.2.3 Reducing the urban heat island with trees and vegetation

One initiative to mitigate extreme summer temperatures in the urban areas is the 'cool cities' strategy (Luber 2008). A 'cool cities' strategy aims to reduce the urban heat island effect by (a) promoting tree planting to shade buildings and to cool the ambient environment by evapotranspiration of vegetation and (b) using reflective roof and paving surfaces to reduce heat accumulation due to solar radiation. Research shows that trees and other vegetation can modify urban microclimates and help reduce the UHI effect through two major natural mechanisms: (a) temperature reduction through shading of urban surfaces from solar radiation, and (b) evapo-transpiration which has a cooling and humidifying effect on the air (McPherson et al. 1988; McPherson 1994; Akbari, Pomerantz et al. 2001; Pokorny 2001; Georgi

and Zafiiridiadis 2006). In fact it has been suggested that trees can operate as natural 'air conditioners' which require only natural energy inputs to operate (Pokorny 2001).

6.2.3.1 *Shading Effects*

The surfaces of pavements and buildings can reach very high temperatures unless shaded (Kjelgren and Montague 1998). By shading ground surfaces, trees can reduce the amount of radiation reaching, being absorbed by, and then being re-radiated from paved surfaces (Roberts et al. 2006). Trees can intercept the majority of the sun's energy, and while some of it is reflected, most is absorbed and used in photosynthesis. Research shows that tree canopies can reduce the temperatures of the surfaces they shade by as much as 10-25°C (Akbari et al. 1997; Livesley 2010). Shading effects of different tree species vary according to their Leaf Area Index (LAI) a ratio of leaf area per unit of ground surface area. It is also known that shading by trees is more effective than shading by non-natural materials (Georgi and Dimitriou 2010). Research in the USA showed that increasing the amount of leaf area in urban or suburban areas can have a substantial effect on surface temperatures (Hardin and Jensen 2007). Recent research in Melbourne supports these findings, with inner city areas and the western suburbs experiencing higher temperatures than the more leafy eastern or southern suburbs (Loughnan, Nicholls et al. 2010). It appears that leafy suburbs can be 2-3°C degrees cooler than new tree-less suburbs. A study by Taha et al. (Taha 1996) found that the addition of a large number of trees to the public realm should result in an air temperature reduction of 1-3°C in the hottest areas.

6.2.3.2 *Evapotranspiration effects*

Transpiration is the process by which water is taken up from the soil by tree roots, and lost to the atmosphere through the stomata in its leaves. Most of the water taken up by a tree is used for transpiration, which has the important function of cooling the leaf during evaporation (Kopinga 1998). The conversion of water from a liquid to a gas during evaporation requires energy, which removes heat from the leaf, cooling the leaf and the surrounding air. (Evapo-transpiration is a term that refers to the combined effects of transpiration from plant leaves, and evaporation from exposed soil surfaces).

Plants, however, need water for transpiration, highlighting the need to maintain soil moisture in cities to maximize the temperature reduction effects of evapotranspiration (Tapper 2010). However in cities rain falls on extensive impermeable surfaces, resulting in increased runoff and reduced soil infiltration and soil water recharge. Urban runoff is also directed away from the areas where soil moisture recharge is most needed, below the tree canopy, via engineered systems of gutters and stormwater drains (Bernatzky 1983). Drought and prolonged water restrictions can also impact on soil water levels resulting in premature tree deaths and loss of a valuable community resource (Connellan 2008). Mature trees however should be viewed as a valuable resource which can deliver significant benefits including amelioration of the UHI effect both through shading of urban surfaces and atmospheric cooling through evapotranspiration (McPherson 1994).

In 2012 the Kestrel Design Group developed a formula for the Minnesota Pollution Control Agency to estimate evapotranspiration benefits from trees to include in their stormwater crediting system. The

formula, included in the Minnesota Stormwater Manual is possibly the first in the US to formally quantify this benefit (Minnesota Pollution Control Authority 2014). To maximize the incentive to plant trees for stormwater, the Kestrel Design Group recommended giving credits based on the projected mature canopy size for trees that are planted and maintained correctly and provided with adequate rootable soil volume.

6.2.3.3 Australian urban heat island research

Studies have been conducted in a number of Australian capital cities using thermal imaging to evaluate urban heat island effects and potential mitigation strategies. UHI effects in Melbourne City were investigated using aerial and ground thermal imaging, in the development of the Melbourne Urban Forest Strategy (City of Melbourne 2011; GHD 2011; GHD 2011a). Thermal mapping was related to site conditions such as pervious area, vegetation area or leaf area index, bitumen area, urban canyon dimensions, anthropogenic heat sources, thermal mass and retention of heat and albedo levels. A set of UHI mitigation strategies was then developed which includes:

- Increasing vegetation cover to shade ground surfaces and increase evapotranspiration. Research shows that *'trees and planting in the urban canyon layer provides, perhaps, the greatest benefits in terms of mitigating the UHI effect'* due to increased evapotranspiration rates, and shading thermally massive ground surfaces from solar radiation (GHD 2011).
- Trees should have a Leaf Area Index of 5.3 (the same as a deciduous temperate forest) to achieve greater than 30% canopy cover over ground level (Hardin and Jensen 2007). Deciduous trees are favoured as they provide summer shade while allowing winter sun penetration.
- Water management systems need to be matched to planted vegetation to maximize evapotranspiration effects. Research has shown that, without an adequately matched water supply, the evapotranspiration benefits of vegetation will be minimal. The most desirable means of achieving this is through natural water infiltration and retention, rather than irrigation with potable water.
- Increasing permeable surfaces to encourage water infiltration and subsequent evapotranspiration. Pervious ground areas should be as large as possible but no less than 30% of available site area.
- Use of stormwater harvesting ('low flow stormwater management') for the passive irrigation of street trees.
- Encouraging appropriate micro level wind movement.
- Utilising active adiabatic cooling systems like water features and pools.
- Replacing dark asphalt surfaces with surfaces of albedo greater than 0.4, with pavements having albedo values greater than 0.5.

In Sydney in 2010 a pilot research program examined the degree to which different components of the urban environment, and associated landscapes, contribute waste heat to the urban climate and to the UHI effect (City Futures Research Centre 2010). A study was made of the thermal emissivity of different elements in the designed urban environment at the Victoria Park medium density housing development,

and their transience to the surrounding urban air. Thermal imagery was used to measure radiant emissivity at micro-urban-climatic scale. The findings were used to develop a Thermal Performance Index representing the transience contribution of elements, ranked from hottest to coolest (radiators to coolers). The thermal imagery indicated that: albedo reflects heat and cool coloured elements apparently contribute less heat; and water stores heat as expected. However, unless the thermal energy is transformed by living vegetation, the problem of excess heat in the urban environment still persists. Trees providing shade in a grassed park had a 3-4°C transient contribution over the diurnal cycle and a 7-8°C transience shading light coloured paving. Unshaded grass in a park had a 12°C transience, and vegetated swales had a 6-9°C transience. Swales located along dark asphalt roads were less effective coolers (9°C transience) than along a light coloured/non-porous concrete path at a park edge (6°C transience).

In South Australia, the *Adelaide Urban Heat Island Project* is currently being undertaken by Flinders University and the City of Adelaide, measuring spatial differences in temperatures across the city. Preliminary findings indicate a 3-5°C degree difference between the CBD and surrounding Adelaide Park Lands (Vinodkumar et al. 2011; Ewenz 2012).

In a study for Nursery and Garden Industry Australia (NGIA), Dr. Dong Chen of the CSIRO modelled the potential benefits of vegetation in reducing extreme summer temperatures in the Melbourne CBD under different climate scenarios (NGIA 2012). The potential benefits of urban vegetation in mitigating extreme summer temperatures in Melbourne for 2009 (referred to as the present day) and for future climate in 2047, 2050 and 2090 were investigated using an urban climate model TAPM UCM developed by CSIRO (Thatcher and Hurley 2012). Vegetation and building coverage ratios of the generic urban types were based on measurements by Coutts et al (Coutts et al. 2007), while the vegetation and building coverage ratios of Melbourne CBD areas were estimated from Google Earth images. Considering the average summer daily mean (ASDM) temperature, the following predictions were made:

- 1) Suburban areas are predicted to be around 0.5°C cooler than the CBD.
- 2) A relatively leafy suburban area may be around 0.7°C cooler than the CBD.
- 3) A parkland (such as grassland, shrub-land and sparse forest) or rural area may be around 1.5 to 2°C cooler than the CBD.
- 4) Doubling the CBD vegetation coverage may reduce 0.3°C ASDM temperature.
- 5) 50% green roof coverage of the CBD area may result in 0.4°C ASDM temperature reduction.
- 6) 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.

Morris et al (2001) reported UHI observations of around 1.3°C for Melbourne summers between 1972 and 1991. Simulation studies by Coutts et al (2008) also showed that day time UHI is in the range

between 1 and 2°C. By reviewing a number of observation studies, Bowler et al (2010) concluded that, on average, an urban park would be around 1°C cooler than a surrounding non-green site, while 2.3°C cooler was reported when compared with a town or city further away. Chen concludes that the predicted 0.5 to 2°C temperature differences in the ASDM temperatures between Melbourne CBD, suburbs, rural areas are reasonable. In summary, the results showed that the cooling benefit of various urban forms and vegetation schemes may be in the range of 0.3°C to 2°C and that although Melbourne is projected to be warmer in 2050 and 2090, the relative benefit of urban vegetation will not change significantly.

In 2013 Chen was again commissioned by the NGIA to investigate the impacts of urban vegetation on heat related mortality (Chen 2013). This research represents one of the first attempts to develop quantitative estimates of the potential benefit of urban vegetation in reducing heat related mortality. The study involved modelling of vegetation and mortality relationships for the summer of 2009 and projected future climates for the city of Melbourne. Simulations of indoor thermal environment were carried out using the AccuRate software to quantify the potential benefit of urban vegetation in reducing heat related mortality. This was done for the 2009 summer and also for projected 2030 and 2050 future climates in Melbourne. The results show that urban vegetation can potentially reduce excess heat related mortality(see Figure 40). Different urban vegetation scenarios were tested, with the forest scheme predicted to achieve 60-100% reduction in excess mortality rate in comparison with the CBD vegetation scheme. From these results it was recommended that urban vegetation be a key component in heat wave mitigation and for preventative health. The model established as part of the study is currently undergoing further testing, verification and development.

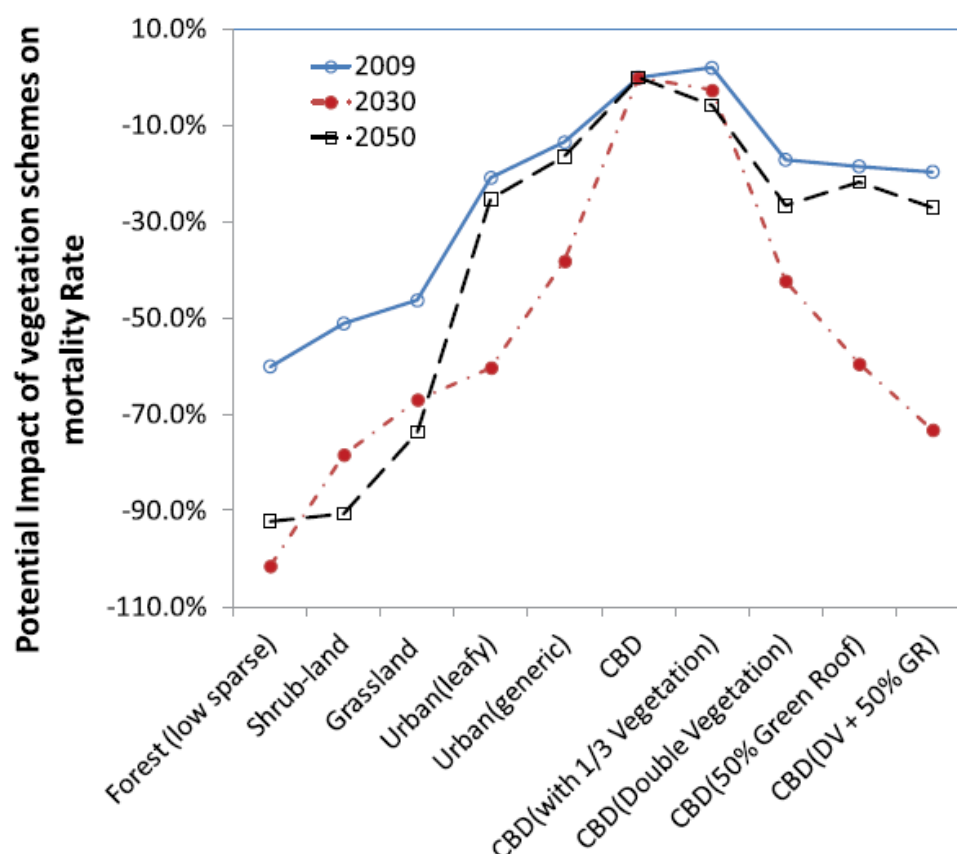


Figure 40: The potential impact on excess mortality rate with different urban vegetation schemes relatively to the CBD vegetation scheme. Source: (Chen 2013).

Brisbane's urban forest strategic planning, targets, policies and programs are focused on optimising the multiple benefits of the extensive and diverse public and private tree cover whilst balancing the risks, costs and other priorities of a growing city (Brisbane City 2013a). Targets are therefore relative to recognised values of the urban forest and not just tree canopy cover, or tree planting numbers and include:

- Restoring 40% of Brisbane to natural habitat by 2026.
- Reconnecting ecological corridors.
- Providing 50% tree shade cover for residential footpaths and off-road bikeways by 2026.

In 2012, Brisbane's natural habitat cover was assessed at 34.9%, greatly assisted by the Two Million Trees project which restored almost 500 hectares of available waterway and ecological corridors, including bushland acquisition program sites. This intensive four year project was completed in 2012. In 2010, there was an estimated 575,000 street trees of over 200 species, mostly of maturing age (72% estimated less than 15 years of age). This provided an average of 35% tree shade cover to footpaths supporting walking and cycling in residential suburbs. Ongoing progress is focusing on partnerships with community and other Council programs and policies.

Brisbane's shade cover target recognises the importance of shade in a subtropical city and increasingly so with climate change studies predicting an increasing number of extreme hot summer days. A direct relationship between areas of Brisbane with high levels of tree cover, and cooler surface temperatures was confirmed more than ten years ago in a University of Queensland research project. Current measures of tree cover use a combination of high resolution satellite imagery and aircraft acquired LiDar (www.lidar.com.au) to help identify the city's most shade hungry hot spots. This information is then used to target Council's tree planting policies.

Some of the suburbs with the most shade hungry footpaths are those already targeted for increased dwelling density because of their proximity to public transport and employment centres. Within these suburbs and many others, Neighbourhood Shadeways projects target the most shade-hungry pathways used to walk or cycle to shops, school, bus and train stations for footpath and bikeway shade tree planting. Neighbourhood Shadeways projects have added 50,000 new shade trees since the program commenced in 2006. Almost half of those trees have been planted with local residents at community planting events on Saturday mornings. These partnerships are encouraging stewardship of the newly planted trees and engaging residents on the many values of street trees and urban greening.

6.2.4 Reducing the Urban Heat Island with Water Sensitive Urban Design

As mentioned earlier, maximizing the temperature reduction effects of vegetation with shading, and especially evapo-transpiration, requires the maintenance of adequate soil moisture levels (Tapper 2010). It has been demonstrated that Water Sensitive Urban Design practices can also be used to maintain soil moisture levels and help in reducing the UHI effect. According to Wong (2011):

'Green Infrastructure supported by stormwater can provide microclimate benefits by reducing excess urban heating (through shading and cooling by evapotranspiration). Use of harvested stormwater and vegetated stormwater management systems has the potential to limit exposure to extreme heat'.

Mitigation of the UHI effect is one of the research focuses of the Water Sensitive Cities project at Monash University (Wong 2011). Researchers consider that UHI mitigating responses should place particular emphasis on the implementation of WSUD technologies and Green Infrastructure including (in order of priority):

- 1) **Trees**, which have a particularly important place in the urban landscape, providing shade and supporting evapotranspiration (cooling).
- 2) **Irrigated landscapes** using harvested stormwater to encourage cooling through evapotranspiration, and support healthy and productive vegetation. Irrigation of trees provides greater cooling efficiency than irrigation of grassed areas.
- 3) **Vegetated stormwater treatment** measures that retain water in the urban landscape and return moisture to urban soils. Trees should be incorporated into these systems to provide additional benefits from shading.

- 4) **Green roofs and green walls**, with green walls providing more outdoor cooling benefit at street level than green roofs. The outdoor street level benefit of green roofs reduces with building height.
- 5) **Parks and water bodies.**

Importantly, the different types of Green Infrastructure to be implemented in the urban landscape should be linked to stormwater harvesting practices, to use the large volumes of unutilized stormwater runoff. They also recommend that microclimatic improvement should be included under WSUD and stormwater harvesting policy objectives. A good example of this is the City of Melbourne which has recently developed an Urban Forest Strategy aimed at *'building a resilient, healthy urban forest that can thrive in the future'* (City of Melbourne 2011). Council anticipates that with *'increases in urban temperatures and density we can expect that Melbourne's Urban Heat Island (UHI) effect will intensify'*. A key principle of the Strategy, therefore, is to reduce the urban heat island effect.

'Established research and ongoing studies by the City of Melbourne confirm that the addition of trees and vegetation in the built environment provides the greatest benefit in terms of mitigating the Urban Heat Island effect. Through the natural process of transpiration trees help reduce day and night-time temperatures in cities, especially during summer. Trees provide shade for streets and footpaths and their leaves reflect and absorb sunlight, minimising the heat absorbed by the built environment during the day' (City of Melbourne 2011) p.7.

Council also recognizes that maintaining healthy vegetation that delivers both shading and evapotranspiration benefits, requires maintaining adequate soil moisture levels.

'Mitigating the urban heat island effect may mean increased water usage during periods of low rainfall 'to maintain the health of urban forests' (City of Melbourne 2011) p. 27.

The higher the level of moisture in the soil, the more trees are able to transpire at maximum efficiency, allowing for cooling of the urban environment and combating the urban heat island effect' (City of Melbourne 2011) p.40.

Council also has a related strategy to 'improve soil moisture and water quality', with a target that 'soil moisture levels will be maintained at levels to provide healthy growth of vegetation'.

6.3 Wind speed modification

Vegetation modifies wind patterns by obstructing, guiding, deflecting or filtering (Miller 2007). Trees decrease wind speed by either deflecting it or allowing a portion of it to pass through them. Studies on the effect of trees on wind speed in residential areas found that trees in a dense arrangement may reduce the mean wind speed by 90% compared with bare land (Heisler and DeWalle 1988, Heisler 1990). McGinn (1983) found that trees in residential areas to reduce wind speed by 65 and 70% in winter and summer respectively. A more recent study in Bahrain found that wind speed under trees was

always below wind speed in bare land, and the mean reduction in wind speed under trees compared to bare land ranged from 60 to 90% at all sites (Tahir and Tawhida 2013).

Tree planting to reduce wind speeds has long been practised around the world, especially the planting of semi-porous windbreaks in rural settings. A barrier of approximately 35 percent transparent material can create a long calm zone that can extend up to 30 times the windbreak height (Caborn 1965). In cities tall buildings create pathways of high wind velocity (wind tunnels) and vegetated buffers can help disrupt these straight pathways. Reduced wind speeds can improve human comfort by reducing wind chill factors and improving human mobility, including walking or cycling in places subject to 'wind tunnel' effects (Trowbridge and Mundrak 1988). Reduced wind speeds lead to microclimate modification within the protected zone by reducing air temperature and evaporation, and increasing humidity levels. Air flow modification by trees depends on the area, surface roughness and type of vegetation (Wilmers 1991).

Evergreen tree species are generally preferred as windbreaks as deciduous species are only about 60 percent as effective in winter compared with summer when they are in leaf (Heisler 1991). Movement of air along trees depends on tree spacing, crown spread and vertical distribution of leaf area within height. Therefore, extensive tree cover in urban areas can trap air below their crowns (**Grant 1991**). The more compact is the foliage on the tree or a group of trees, the greater is the influence of these trees on wind speed. Therefore, many city designers use trees for wind reduction in many urban situations. However, for sites to be used during both warm and cold weather, trees should not form an extremely tight enclosure as a thicket that would essentially reduce wind speeds to zero (**Herrington, Bertolin et al. 1972**).

Studies on the effect of trees on wind speed in residential areas found that trees in a dense arrangement may reduce the mean wind speed by 90% compared with bare land (**Heisler and DeWalle 1988, Heisler 1990**). **McGinn (1983)** found that trees in residential areas to reduce wind speed by 65 and 70% in winter and summer respectively. A more recent study in Bahrain found that wind speed under trees was always below wind speed in bare land, and the mean reduction in wind speed under trees compared to bare land ranged from 60 to 90% at all sites.

Heisler (1990) describes wind reductions due to buildings and trees in residential neighbourhoods. Modification of wind speed and direction can also affect cooling and heating costs in buildings. Decreasing wind speeds can reduce heating costs in winter, but reduce cooling effects in summer (Akbari and Taha 1992). One study investigated the combined effects of increased shade and reduced wind speeds on residential air conditioning costs, giving an annual savings of 2-23% (Heisler 1989).

6.4 Other climatic benefits

6.4.1 Energy use reduction

Air conditioning is a major consumer of electricity in 'urban heat islands' (with associated increases in carbon emissions by power stations) (Rosenfeld, Akbari et al. 1998). Research has shown that appropriately planted trees can play a role in reducing energy consumption especially in 'urban heat islands'. Trees can help reduce energy consumption, by reducing air temperatures, and by the direct shading of buildings (Heisler 1986; Simpson and McPherson 1996; Akbari, Pomerantz et al. 2001; Coutts, Beringer et al. 2007; Donovan and Butry 2009; Laband and Sophocleus 2009). Wilraith (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.

Trees can also redirect winds or reduce wind speeds, reducing winter heat loss (Heisler 1986). However such energy savings can only occur with appropriately located trees, and inappropriate placement may actually increase energy use (Dwyer et al. 1992). Researchers have quantified these energy saving costs of the urban forest in a number of US cities (McPherson, Herrington et al. 1988; McPherson and Rowntree 1993; McPherson and Simpson 2003).

Recent research at Ryerson University in Toronto assessed the energy conservation merits of a residential Toronto tree planting program (Sawka et al. 2013). Researchers adapted the Sacramento Municipal Utility District's (SMUD) Tree Benefits Estimator for application in Toronto, Canada and used it to model the air conditioning energy conservation savings delivered by 577 trees planted in Toronto backyards between 1997 and 2000. The researchers found that the study trees contributed 77,140kWh (167kWh/tree) of electricity savings as of 2009, 54.4% of which was due to shading of neighbouring houses. The researchers also found an average tree conserves 435-483 kWh of electricity over 25 years post planting. The research findings also indicate that densely settled urban neighbourhoods should prioritize tree survival over shading potential, as the energy conservation benefits of a mature tree often outweigh the benefits of a strategically planted one.

6.4.2 Pedestrian and human comfort

Heisler (1974) reviewed literature on the role of trees in regulating urban microclimate. Shading was found to only minimally reduce air temperature, but provided significant solar radiation shielding, the component of the sun which humans actually feel. Depending on crown density, various trees allow only 2-40% solar penetration. Shade-tolerant species (such as maples) have denser canopies and provide more shade than shade-intolerant species (such as honeylocusts). He concluded that streets are an ideal place for trees due to evaporative cooling and shading benefits, as well as shielding of people from long-wave radiation from nearby buildings. These findings reinforce the importance of providing shade in streets for two main reasons:

- The need to shade pedestrians from the direct sun.

- Urban surfaces (buildings and pavements) consistently absorb and re-radiate heat, and shading by trees can reduce the amount of absorption and protect pedestrians from re-radiation.

6.4.3 UV Radiation

Trees can provide shade from UV radiation and its associated health problems such as skin cancer (Heisler et al. 1995; Parisi et al. 2000; Grant et al. 2002). It has been shown that shade alone can reduce overall exposure to UV radiation by up to 77% (Parsons et al. 1998). Shading by urban trees reduces ultraviolet irradiance when they obscure both the sun and the sky, (i.e. when there is dense shade). When only the sun is obscured, leaving much of the sky in view, UV irradiance is greater than suggested by the visible shade. A recent study developed a methodology to estimate the amount of protection tree canopies can provide (Grant, Heisler et al. 2002). The paper recommended a number of improvements to the urban environment including increased tree canopy coverage.

6.4.4 Shading of cars and car parking spaces

Scott et al. (1999) studied the effects of tree cover on parking lot microclimate and vehicle emissions in Davis, California. An analysis was made of the temperatures of pavements and parked vehicles in different parts of the car park with different levels of shading (1-25 %, 25-75%, or 75-100% shaded). The findings indicate a clear connection between shade and the temperatures of both:

- The parking lot pavement and above-ground air, and,
- The interior cabin temperatures of the automobile.

Although the shaded area of the car park was warmer than the air temperature of a control site (a nearby area of irrigated turf) the unshaded area was warmer for nearly the entire duration of the experiment. The air temperature of the shaded site was approximately 1.3°C cooler than the unshaded site during the hottest period of the warmer days, while the pavement temperatures were nearly 20°C cooler during the same period. Emissions modelling also showed the shaded areas released 3% less emissions than unshaded areas. Although these findings relate to parking lots, they would also be applicable to car parking spaces in urban streets.

6.4.5 Extended Materials Life

McPherson and Muchnick (2005) examined the effects of street tree shade on asphalt pavement performance in Modesto, California. The researchers studied 48 street segments divided into 24 low shade/high shade matching pairs. The streets were controlled for age, use, tree history and maintenance history and traffic volumes. A Pavement Condition Index (PCI) and Tree Shade Index (TSI) were calculated for each street segment. Three hypothetical scenarios were developed to demonstrate how the amount of tree shade can influence preventative maintenance expenditure over a 30-year period: an unshaded segment; a segment with small trees (crepe myrtle) with close spacings; and large trees (hackberry) at wider spacings. Analysis indicated a positive association between better pavement condition and higher levels of tree shade. Although further research is required into different road types, the results indicate that tree shading can contribute to extended pavement life.

6.5 Climate change

6.5.1 Introduction

It is now widely accepted that human activities are contributing to global climate change due to increased levels of greenhouse gases in the atmosphere (Thom et al. 2009). Figure 41 summarizes Green Infrastructure roles in climate change mitigation and adaptation.

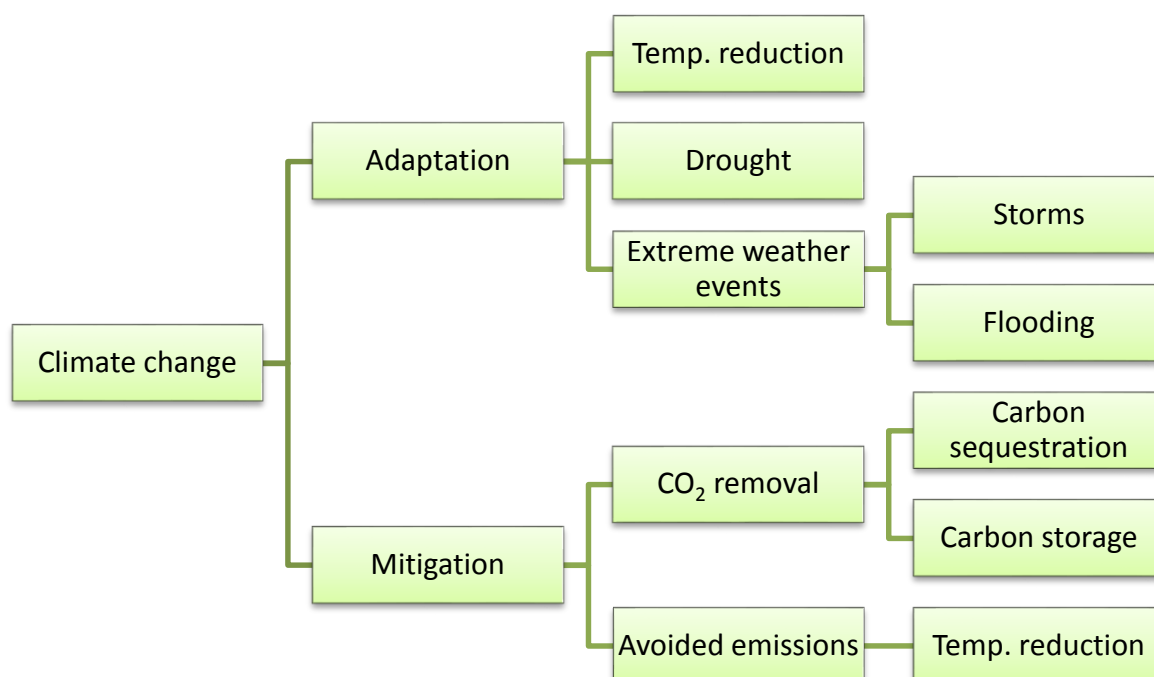


Figure 41: Climate change roles of Green Infrastructure. Source: By author.

6.5.2 Climate change impacts

The impacts of climate change are difficult to predict and vary from region to region, however the likely impacts in Australia include: increased temperatures; reduced rainfall and extended periods of drought; increased bushfire risks; and more extreme weather events such as storms and flooding (Suppiah et al. 2006). Table 19 summarizes potential climate change impacts on the 'built environment' in Australia.

Table 19: Climate change impacts on the built environment. Source: Adapted from NCCARP: Settlement and Infrastructure. Sept 2009.

Climate change variable	Impacts on built environment
More extreme hot days	Dwelling habitability Increased energy demand Human health impacts
Warmer, drier summers	Increased outdoor recreation demand
Longer more intense droughts	Water shortages Increased irrigation demand
More extreme weather events-storms, flood, fire	Damage, disruption
Drier summers, wetter winters	Damage, disruption
Sea level rise	Damage, disruption

Climate projections prepared by CSIRO and the Bureau of Meteorology in 2007 suggest that the future climate of South Australia will generally be characterised by:

- Lower average rainfall.
- More intense extreme rainfall events.
- Higher storm surge events.
- Higher average sea levels.
- Higher average temperatures.
- More frequent occurrence of extreme temperatures.
- More frequent very high and extreme fire danger days.

Small changes in average annual and seasonal temperatures and precipitation can reflect large changes in individual extreme weather events, such as heat waves, storms, strong winds and higher intensity rainfall. According to AECOM (2009) changes in extreme weather events projected for South Australia include :

- An increase in the frequency of hot days (days over 35°C)
- An increase in both peak precipitation intensity (measured in millimetres per hour) and the number of dry days (days with less than 1mm of precipitation) leading to longer dry spells interrupted by heavier rainfall events
- An increase in storm surge events characterised by high–intensity storms intersecting with a high tide and amplified by increases in mean sea level can be expected in coastal areas.

These changes in average climatic conditions and extreme weather events will increase the risks of damage to the state's natural and man–made assets (caused by floods, bushfires and storms) if appropriate adaptive measures are not implemented.

Changing climatic regimes may also impact detrimentally upon the health, structure and management of the urban forest (Moore 2006). Urban trees, however, can play an important role in the two main responses to climate change: mitigation and adaptation.

6.5.3 Climate change mitigation

Climate change mitigation strategies include reduction of CO₂ emissions through increased use of public transport and energy efficiency (ClimateWorks 2010). Urban trees can help mitigate climate change by contributing to net reductions in atmospheric CO₂ through (see Figure 42):

- Carbon sequestration and storage (sequestering atmospheric carbon from carbon dioxide, and storing it in tree tissues).
- Avoided CO₂ emissions due to reductions in building energy use, consequently reducing carbon dioxide emissions from fossil-fuel based power plants (Abdollahi et al. 2000).



Figure 42: Role of trees in climate change mitigation. Source: (McPherson 2010).

6.5.4 Carbon sequestration and storage

Urban trees can help reduce the amount of carbon in the atmosphere by sequestering carbon in new growth every year, as part of the carbon cycle. The amount of carbon annually sequestered increases

with the size and health of the trees. Since about 50% of wood by dry weight is comprised of carbon, tree stems and roots act to store up carbon for decades or even centuries (Kuhns 2008). Over the lifetime of a tree, several tons of atmospheric carbon dioxide can be absorbed (McPherson and Sundquist 2009).

Definitions

Carbon sequestration is the annual removal of CO₂ through photosynthesis by plants. Photosynthesis is the process where plants use sunlight to convert CO₂ to plant tissues.

Carbon storage refers to the carbon bound in above and below ground plant tissues, including roots, stems, and branches. Once plants die and begin decomposing, carbon is slowly released back to the system. For example, stored carbon can be released into the atmosphere as CO₂ or stored as organic matter in the soil.

Source: (Green Cities Research Alliance 2012) p.15.

In Australia Moore (2006) has estimated that the 100,000 public trees in Melbourne would sequester about one million tonnes of carbon. Plant (2006) estimated that in 2000, Brisbane's residential tree cover was estimated to be absorbing the equivalent amount of CO₂ emitted by 30,000 cars per year, and cooling surface temperatures in the relatively mild month of October 1999 by up to 5 degrees Celsius. These reductions must be balanced against CO₂ released by the decomposition of dead trees and vegetable matter, and emissions produced in the management of the urban forest (McPherson and Sundquist 2009). Unfortunately, however, urban vegetation is not currently included in calculations of greenhouse gas emissions for the purposes of creating carbon sinks to store carbon and reduce atmospheric CO₂ levels (Moore 2006).

6.5.4.1 Quantifying carbon sequestration

The i-Tree tool has been used to calculate carbon sequestration by an urban forest. For example the gross sequestration of Washington trees is estimated to be about 19,000 tons of carbon per year with an associated value of US\$393,000. Net carbon sequestration in the Washington urban forest is estimated to be about 13,600 tons (i-Tree 2010 and see Figure 43).

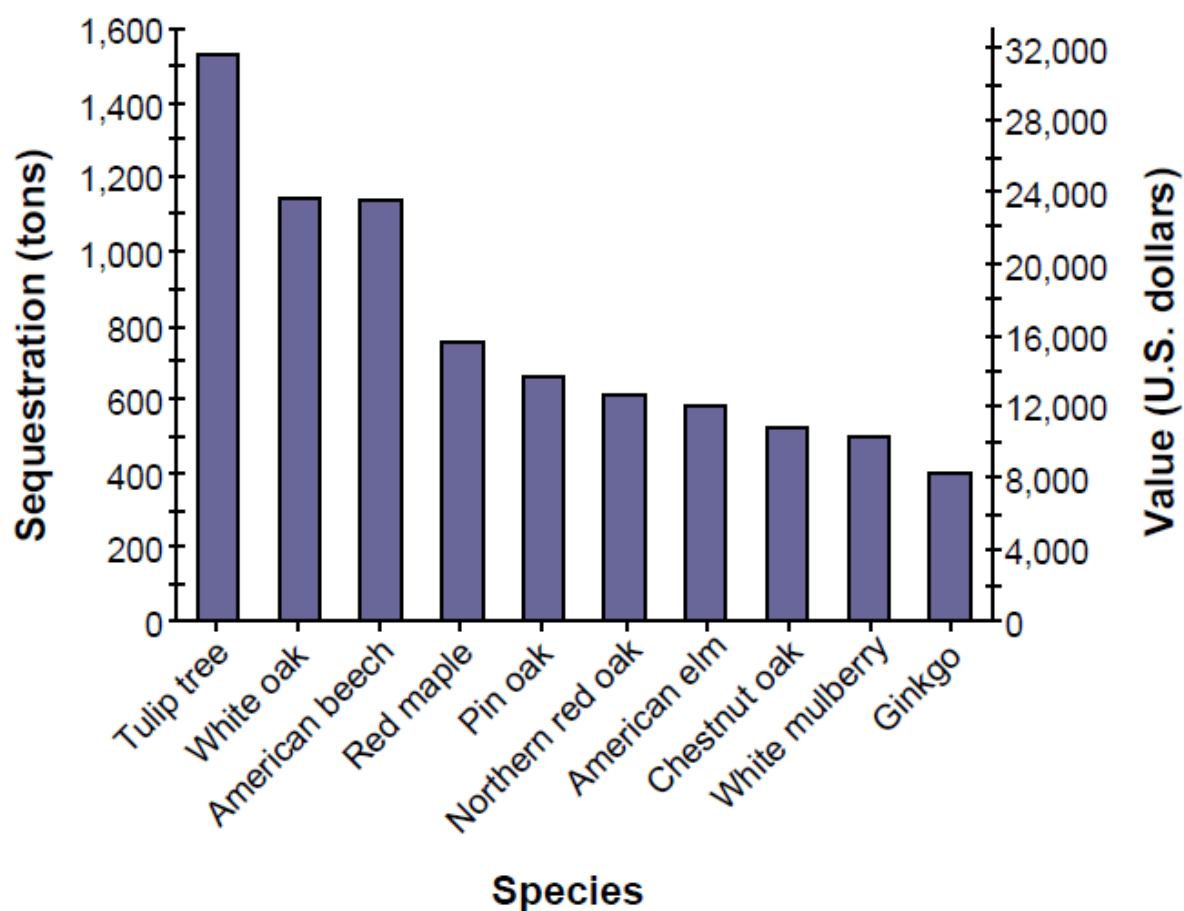


Figure 43: Carbon sequestration and value for species with greatest overall carbon sequestration in Washington. Source: (i-Tree 2010) p.8.

6.5.5 Quantifying carbon storage

Carbon storage by trees, including urban trees, is another way that Green Infrastructure can influence global climate change. As trees grow they store more carbon as wood, and as trees die and decompose they release this carbon back into the atmosphere. Therefore the carbon storage of the urban forest is an indication of the amount of carbon that could be released if trees are allowed to die and decompose. Maintaining a healthy tree population will ensure that more carbon is stored than released. Utilizing the wood in long term wood products or to help heat buildings or produce energy will also help to reduce carbon emissions from other sources, such as power plants.

Trees in Washington have been estimated to store 596,000 tons of carbon (\$12.3 million). Of all the species sampled the Tulip tree was found to store and sequester the most carbon, approximately 15.4% of the total carbon stored and 11.2% of all sequestered carbon (i-Tree 2010). Seattle's urban forest stores approximately 36 metric tons of CO₂ equivalent (or 9.9 metric tons of carbon) per acre and sequesters approximately 2.6 metric tons of CO₂ equivalent (or 0.7 metric tons of carbon) per acre. Across Seattle, carbon storage in urban forest biomass amounts to almost 2 million metric tons of CO₂ equivalent, with an additional 141,000 metric tons of CO₂ equivalent sequestered in 2011. This equates to a city-wide savings of \$10.9 million from carbon storage and an annual savings of \$768,000 from carbon sequestration. The urban forest CO₂ removal rate per year is 2% (or 7 days) of the city's total

annual emissions (Green Cities Research Alliance 2012). These reductions must be balanced against CO₂ released by the decomposition of dead trees and vegetable matter, and emissions produced in the management of the urban forest (McPherson et al. 2009).

It must be recognized however that the potential of urban trees for carbon storage should not be overstated, as street trees are often short lived and small in stature (Nowak and Crane 2002; McPherson 2008). The direct impacts of urban trees on carbon reduction therefore may seem to be negligible at first glance. However, the potential for the urban forest to reduce CO₂ emissions through energy reduction, and its role in climate adaptation, lowering urban temperatures through evaporative cooling and protecting soil carbon should not be overlooked. For example it has been shown that increasing green cover by 10% within the urban area of Manchester could reduce surface temperatures by 2.2 - 2.5 % (Gill et al. 2007). Trees also play an important role in protecting soils, which is one of the largest terrestrial sinks of carbon. Soils are an extremely important reservoir in the carbon cycle because they contain more carbon than the atmosphere and plants combined.

6.5.6 Avoided emissions

Trees affect energy consumption by shading buildings, by evaporative cooling, and by blocking cold winter winds. Trees tend to reduce building energy consumption in the summer months and can either increase or decrease building energy use in the winter months, depending on the location of trees around the building (see Tables 20 and 21). Estimates of tree effects on energy use can be made, based on field measurements of tree distance and direction to air conditioned residential buildings (McPherson and Simpson 1999). Reduced energy demand from reduced air-conditioning can also lead to a reduction in carbon emissions from power stations (McPherson and Simpson 2001). Based on 2002 prices, trees in Washington are estimated to reduce energy-related costs from residential buildings by US\$3.45 million annually. Trees also provide an additional US\$129,006 in value (Nowak and Crane 2000) by reducing the amount of carbon released by fossil-fuel based power plants (a reduction of 6,240 tons of carbon emissions) (i-Tree 2010).

Table 20: Annual energy savings in Washington due to trees near residential buildings. Note: negative numbers indicate an increased energy use or carbon emission. Source: (i-Tree 2010) p.9.

	<i>Heating</i>	<i>Cooling</i>	<i>Total</i>
MBTU ¹	31,628	n/a	31,628
MWH ²	557	30,312	30,869
Carbon avoided (t)	625	5,612	6,237

¹One million British Thermal Units

²Megawatt-hour

Table 21: Annual savings (US \$) in residential energy expenditure in Washington during heating and cooling seasons. Note: negative numbers indicate a cost due to increased energy use or carbon emission. Source: (i-Tree 2010) p.9.

	<i>Heating</i>	<i>Cooling</i>	<i>Total</i>
MBTU ²	267,534	n/a	267,534
MWH ³	57,376	3,122,407	3,179,783
Carbon avoided (t)	12,928	116,079	129,006

¹Based on state-wide energy costs for Maryland.

²One million British Thermal Units

³Megawatt-hour

6.5.7 Carbon storage protocols

In the United States the State of California has developed the *Urban Forest Greenhouse Gas Reporting Protocol*, an accounting and reporting tool that allows communities to obtain carbon credits for urban forest schemes (CCAR 2008a). To be eligible, schemes must meet a number of criteria such as a stable tree population and long term ownership. The protocol includes a registry and annual online reporting of Net CRT (carbon stored minus carbon emitted). A Centre For Urban Forest Research (CUFR) Tree Carbon Calculator has also been developed as part of the reporting protocol. This comprises a standardized Excel based carbon calculation tool, optimized for California's climatic zones (CCAR 2008b). The tool calculates carbon sequestered, carbon stored in dry biomass, and carbon emissions avoided by energy conservation. However urban forest projects have not yet been successful at registering under this protocol to serve as offset projects. Some of the main challenges are the protocol's requirement of a 100-year, lifetime guarantee of project, the high costs of planting and maintaining urban trees and of monitoring/reporting costs, and the limited eligibility for applicants (e.g. non-governmental organizations and developers are not allowed to apply). Without being able to register under this protocol, urban forest projects cannot be credited as carbon offsets to be used in the California cap-and-trade market. Currently, the urban forestry project closest to registering under the Urban Forest Protocol for carbon offset credits is a Greenhouse Gas Tree-Planting Project in Santa Monica that is designed to plant 1,000 new trees in parkways along boulevards (Housholder 2012).

6.5.8 Climate change adaptation

The other climate change role of Green Infrastructure is in adaptation to unavoidable climate change (Thom, Cane et al. 2009). Climate change adaptation strategies include cooling of buildings and houses and cooling of the outdoor surrounds (Nice 2012). As discussed earlier the urban forest can assist in reducing temperatures in cities through shading, evapotranspiration and wind speed modification (Akbari, Pomerantz et al. 2001). Urban trees can also play a role in relation to future climate change impacts such as shelter from extreme weather events, and flood reduction (McPherson et al. 2006). The recent City of Melbourne Urban Forest Strategy specifically addresses issues of climate change adaptation (City of Melbourne 2011) According to the strategy:

‘As we anticipate increases in urban temperatures and density we can expect that Melbourne’s Urban Heat Island (UHI) effect will intensify. An increased canopy cover throughout the municipality will minimise the impact of the UHI effect’.

City of Melbourne Urban Forest Strategy

To achieve our vision of a healthy and resilient urban forest that contributes to the health and wellbeing of our communities and to a liveable city, we need to create better urban environments for everyone. Our guiding principles defined above highlight the importance of a well-designed city, and the following strategies list how we go about creating these ‘living spaces’.

Strategy 1: Increase canopy cover

Target: Increase public realm canopy cover from 22 per cent to 40 per cent by 2040.

Strategy 2: Increase urban forest diversity

Target: The urban forest will be composed of no more than 5 per cent of any tree species, no more than 10 per cent of any genus and no more than 20 per cent of any one family.

Strategy 3: Improve vegetation health

Target: 90 per cent of the City of Melbourne’s tree population will be healthy by 2040.

Strategy 4: Improve soil moisture and water quality

Target: Soil moisture levels will be maintained at levels to provide healthy growth of vegetation.

Strategy 5: Improve biodiversity

Target: Melbourne’s green spaces will protect and enhance a level of biodiversity which contributes to the delivery of ecosystem services.

Strategy 6: Inform and consult the community

Target: The community will have a broader understanding of the importance of our urban forest, increase their connection to it and engage with its process of evolution.

Source: (City of Melbourne 2011).

According to the US based Sustainable Sites Initiative (2009) climate change adaptation can be addressed through a range of landscape or Green Infrastructure strategies including:

- Increased temperatures:
 - Use vegetation to reduce building cooling requirements.
 - Reduce urban heat island effects.
- Extreme weather events:
 - Protect and restore riparian, shoreline buffers.
 - Manage stormwater on site.
 - Reduce risk of catastrophic wildfire.
- Reduced rainfall, drought:
 - Reduce water use for landscape irrigation.
 - Design rainwater/ stormwater features to provide landscape amenity.

- Maintain water features to conserve water.
- Subsidence:
 - Create a soil management plan.
- Human health impacts:
 - Provide views of vegetation and quiet outdoor spaces for mental restoration.
 - Provide outdoor spaces for social interaction.
- Outdoor recreation demand:
 - Provide opportunities for outdoor physical activity.
- Sea level rise:
 - Protect and restore shoreline buffers.

6.5.9 Climate change and Water Sensitive Urban Design

It has been suggested that Water Sensitive Urban Design and Water Sensitive City principles and practices 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). Urban developments designed to encourage evapotranspiration such as trees and green-spaces, can also act as carbon sinks (Coutts, Beringer et al. 2010). Cooling through increased albedo of urban surfaces and passive cooling techniques can decrease the amount of anthropogenic heat released through air conditioners, as well as savings in CO₂ emissions from reduced mechanical cooling requirements (Coutts, Beringer et al. 2010). 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 (Coutts, Beringer et al. 2010).

6.6 Summary

- The literature review shows that climatic modification is one of the main ecosystem services provided by Green Infrastructure, especially in terms of mitigating ‘urban heat island’ effects in Australian cities.
- The urban heat island has also been linked to increased mortality of older people in extreme heat events in Australian cities.
- Research shows that vegetation, especially large canopied trees, can provide significant climatic benefits through shading and evapo-transpiration effects.
- Research also highlights the need to retain water in urban areas to maximize tree canopy cover and evapo-transpiration.
- Green Infrastructure can also play a role in climate change mitigation, and more importantly in adaptation to unavoidable climate change.

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7 Water management

Green Infrastructure

Green Infrastructure is the network of green spaces and water systems that delivers multiple environmental, social and economic values and services to urban communities. This network includes parks and reserves, backyards and gardens, waterways and wetlands, streets and transport corridors, pathways and greenways, farms and orchards, squares and plazas, roof gardens and living walls, sports fields and cemeteries. Green Infrastructure secures the health, liveability and sustainability of urban environments. It strengthens the resilience of towns and cities to respond to the major current and future challenges of growth, health, climate change and biodiversity loss, as well as water, energy and food security.

7.1 Introduction

‘The way we manage urban water, particularly urban stormwater, influences almost every aspect of our urban environment and quality of life. Water is an essential element of place making, both in maintaining/enhancing the environmental values of surrounding waterways and in the amenity and cultural connection of the place’ (Wong 2011).

The ‘nexus’ between sustainable urban water management and the vitality and prosperity of urban environments is only beginning to be recognised and include (Wong 2011):

- Access to secure and clean water supply.
- A clean water environment.
- Flood protection.
- Efficient and low energy systems.
- Urban design strategies.
- Mitigating urban heat.
- Creating productive landscapes.
- Quality of public spaces.

Trees and other vegetation can act as Green Infrastructure, providing alternatives to conventional engineering infrastructure in the process of integrated water cycle management and Water Sensitive Urban Design (WSUD). Figure 44 summarizes the water related benefits provided by Green Infrastructure.

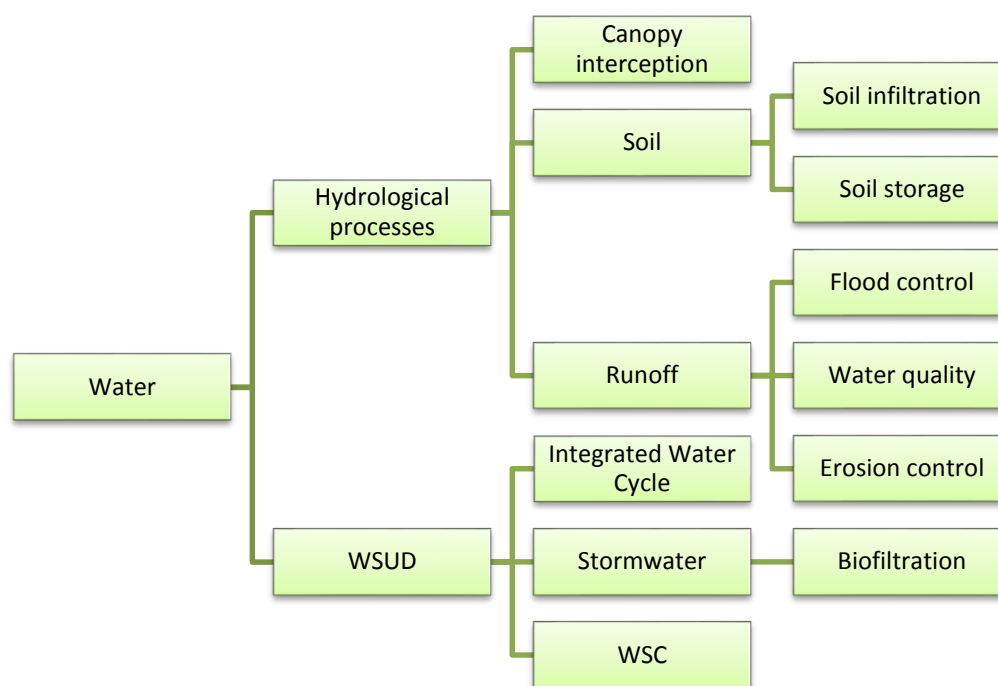


Figure 44: Summary of water related benefits of Green Infrastructure

7.2 Hydrological processes

7.2.1 The natural water cycle

Trees and other vegetation play an important role in the natural water cycle (Bernatzky 1983; MacDonald 1996; Stovin et al. 2008). According to Day & Dickson (Bartens et al. 2008):

'Natural forests with their complete canopy cover, large leaf areas, and permeable soils, handle rainwater effectively through interception and infiltration, returning water to groundwater and the atmosphere and protecting water quality in surface waterways'.

Vegetation performs a number of hydrologic functions in the natural water cycle, and has become an important component of Water Sensitive Urban Design strategies which aims to better replicate the natural water cycle in urban areas.

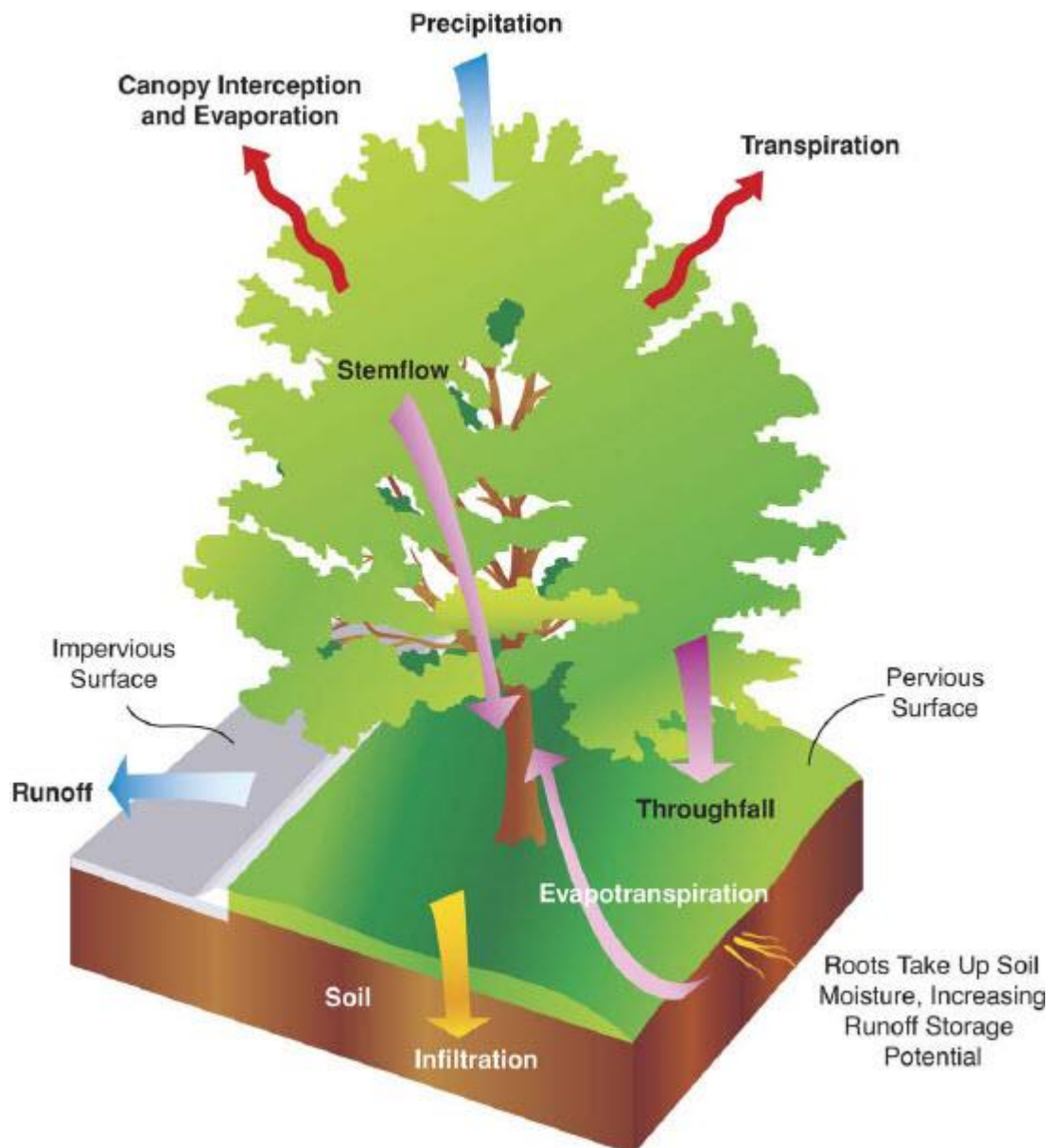


Figure 45: Role of trees in the natural water cycle. Source: (McPherson 2010).

The Eight Hydrologic Functions of Forests and Trees

There are at least eight hydrologic functions provided by forests and trees.

- 1) Canopy Interception:** The leaves of trees and large shrubs act like umbrellas or shallow cups that collect rainwater and other precipitation; they typically capture (reduce) about 10% of total annual precipitation in a healthy forest; this function varies according to whether deciduous or evergreen trees are dominant.
- 2) Stem flow:** The limbs and trunks of trees and shrubs provide year-round capture and delays in peak flows; some studies estimate that stem flow in a dense forest captures as much as 15% of annual precipitation.
- 3) Leaf Litter Absorption:** The duff (dead leaf) layer stores and transmits water and protects the underlying soil from erosion; it is estimated to absorb 2 to 4% of annual precipitation.

4) Soil Infiltration: Native soils with ample organic layers are the 'sponges' of healthy ecosystems; their pore spaces store water and infiltrate it vertically and laterally, interact with root and fungi systems. 80 to 95% of annual precipitation in United States forests is captured via soil infiltration; it's the master hydrologic function of forest ecosystems, governing evapotranspiration; hydraulic lift; groundwater recharge; and large storm conveyance.

5) Evapotranspiration: Trees but also shrubs and forbs release large amounts of water vapor through their leaves during photosynthesis. Total runoff is significantly less for a forested watershed compared to an urbanized one. Evapotranspiration also reduces pollutant loadings and cools the air. Nationwide, in the United States, evapotranspiration has been estimated to capture 57% of average annual precipitation.

6) Hydraulic Lift/ Redistribution: First documented in the mid-1990s, tree roots have been shown to lift groundwater from deeper layers and bring it closer to the surface, where it can be used by other plants as well as the trees themselves.

7) Groundwater Recharge: Recharge refers to replenishment of both groundwater (aquifer) levels and dry weather stream flows. Tree roots in symbiosis with fungi enlarge fissures in bedrock, increasing porosity and groundwater recharge capacities.

8) Conveyance of Large Storms: A well-vegetated catchment conveys runoff from large storms in multiple, distributed channels. Heavy rainstorms, including 100-year storms saturate the soil layer and then cause shallow subsurface flow (interflow); this outcrops as seeps and springheads of temporary rivulets and ephemeral streams.

Source: (Cameron 2011).

7.2.2 Canopy Interception

Tree canopies intercept and store rainfall, thereby modifying stormwater runoff and reducing demands on urban stormwater infrastructure (Xiao et al. 1998; Xiao et al. 2000; Xiao and McPherson 2002; Xiao et al. 2006). Canopy interception reduces both the actual runoff volumes, and delays the onset of peak flows (Davey Resource Group 2008). The extent of interception is influenced by a number of factors including tree architecture and it has been estimated that a typical medium-sized canopy tree can intercept as much as 9000 litres of rainfall year. (Crockford and Richardson 2000). A study of rainfall interception by street and park trees in Santa Monica, California found that interception rates varied by tree species and size, with broadleaf evergreen trees provided the most rainfall interception (Xiao and McPherson 2002). Rainfall interception was found to range from 15.3% for a small jacaranda (*Jacaranda mimosifolia*) to 66.5% for a mature brush box (*Tristania conferta* now known as *Lophostemon confertus*). Over the city as a whole the trees intercepted 1.6% of annual precipitation and the researchers calculated that the annual value of avoided stormwater treatment and flood control costs associated with this reduced runoff was US\$110,890 (US\$3.60 per tree).

7.2.3 Soil Infiltration and storage

Trees and other vegetation can increase the rate or volume of water infiltration into the soil, increasing soil and groundwater recharge. Initially a proportion of rainfall held in the canopy will flow down the stem

and trunk to the ground (Xiao and McPherson 2002). Tree root growth and decomposition in the soil also increases the capacity and rate of rainfall infiltration, and reduces surface flows (Bartens, Day et al. 2008). Trees also draw moisture from the soil through the mechanism of transpiration, increasing soil water storage potential (Stovin, Jorgensen et al. 2008). Trees can remove large volumes of water from the soil to meet their biological needs, acting as virtual ‘solar pumps’. For example a daily summer water usage of 500 litres has been estimated for each tree in an avenue of seventy English elms (*Ulmus procera*) at the Adelaide Waite Arboretum (Lawry 2008).

7.2.4 Flood control

Trees and vegetation also help reduce the risks of downstream flooding by modifying runoff volumes and the timing of peak flows.

7.2.5 Improved water quality

A key WSUD objective is to minimize undesirable impacts on aquatic ecosystems by reducing the volume and timing of runoff, and by improving runoff quality. Vegetation and its associated soil media play an important role in removing nutrients and heavy metals from stormwater runoff (Davis et al. 2001; Henderson et al. 2007; Read et al. 2008). Slowing runoff (for example in vegetated swales) also allows particulate pollutants to settle out before entering waterways or the ocean (Herrera Environmental Consultants 2008). The root systems of trees and other vegetation can also play a role in the bioremediation of stormwater or contaminated soils, through nutrient uptake and pollutant removal (Hough 2004).

7.2.6 Erosion control

Trees and vegetation help reduce soil erosion in two main ways. Tree canopies diminish the impacts of raindrops on bare surfaces (Craul 1992) and root systems reduce erosion by stormwater flows (Lull and Sopper 1969).

7.3 Water Sensitive Urban Design

7.3.1 Negative impacts of urbanization

Urbanization has created significant changes in the natural water cycle including: increased volumes of stormwater runoff from impervious urban surfaces; and a decline in the quality of runoff from pollutants generated by human activities (Thompson and Sorvig 2008). Conventional engineering management of urban stormwater runoff has been driven by the attitude that stormwater has no value as a resource, is environmentally benign, and adds little to urban amenity (Wong 2006). Urban stormwater management practices have emphasized highly efficient drainage systems that collect and remove stormwater and discharge it downstream to avoid stormwater ponding and flood risk, using an engineered system of above ground channels and underground pipes. Such systems driven by public health and flood mitigation concerns, have had significant negative environmental consequences. Impacts on the contributing area or local catchment include the loss of a local water resource. Impacts on the receiving waters downstream include increased runoff and flooding, and the pollution of

waterways, resulting in the decline of aquatic ecosystems. In addition the visual connection between human activities and the water cycle has been lost, with the natural processes being 'out of sight and out of mind'.

Urbanization has in fact seen the 'natural water cycle' replaced with the 'urban water cycle'. Under the natural water cycle a large proportion of rainfall was retained within its local catchment where it infiltrated into porous soils recharging local groundwater and sustaining vegetation growth. The urban water cycle however operates under a different and less sustainable 'water balance' with the three artificial 'streams' of potable water, wastewater and stormwater. Water tends to be exported from urban catchments in the form of stormwater runoff and wastewater, while potable water is imported from external catchments.

Stormwater issues

'Stormwater is a large but almost entirely untapped water source and is considered a highly valuable resource beyond that of simply an undifferentiated commodity. Stormwater runoff is generated across distributed areas and therefore distributed source control measures typically provide the best opportunities to capture and use urban stormwater, and to derive the other beneficial outcomes related to enhanced liveability of a city.'

The most obvious effect of urbanisation on catchment hydrology is the increase in the magnitude of stormwater flow events in urban creeks and the consequent impact on flooding, creek degradation, and public safety. Urban stormwater is predominantly runoff from impervious areas (e.g. roads, roofs, footpaths, car parks, etc.), with runoff from pervious areas (e.g. gardens, lawns, vegetated open spaces, etc.) contributing only during high intensity rainfall events.'

Stormwater management has traditionally focused on stormwater drainage, with the principal (and often only) objective of conveying stormwater runoff safely and economically to the receiving waters. Stormwater drainage infrastructure consists predominantly of pipes and drains. Natural waterways in urbanising catchments have become increasingly compromised in their ability to convey the significantly increased quantity and rate of stormwater runoff generated from urban areas. Bank erosion and increased frequency of flooding are the obvious symptoms of this change. Traditional approaches to resolving these problems typically involved increasing the hydraulic capacity of urban waterways by a combination of channelization and partial, or complete, concrete lining.'

Source: (Wong 2011).

7.3.2 What is Water Sensitive Urban Design?

According to Wong (2011):

'The term Water Sensitive Urban Design (WSUD) is commonly used to reflect a new paradigm in the planning and design of urban environments that is 'sensitive' to the issues of water

sustainability and environmental protection. WSUD, Ecologically Sustainable Development (ESD) and Integrated Water Cycle Management (IWCM) are intrinsically linked. The definitions of WSUD amongst practitioners are often varied, reflecting wide coverage of the applications of the WSUD framework' p.7.

Water Sensitive Urban Design and Integrated Water Cycle Management aim to better replicate the natural water cycle and natural hydrologic processes in urban areas, reducing runoff to aquatic environments, and reducing the use of potable water through demand reduction and the use of alternative 'fit for purpose' water sources. WSUD emerged in the 1990s as a new paradigm for the more sustainable management of the water cycle in the urban landscape (Argue 2004). WSUD includes the more sustainable management of the three urban water streams: potable water; wastewater; and stormwater (Landcom 2004). A key focus is on stormwater management, based on a new attitude, that stormwater is a valuable resource; and an emerging set of 'best management practices', aimed at better replicating the natural water cycle and integrating it into the planning and design of urban areas at a range of scales (Lloyd et al. 2002; Breen et al. 2004).

Stormwater management

'Conventional approaches to stormwater management are based on a single management objective that considers stormwater as a source of potential hazard to public safety. Stormwater management was essentially that of stormwater drainage using two general methods, i.e. (i) conveyance of stormwater to receiving waters in an hydraulically efficient manner; and (ii) detention and retardation of stormwater. Many measures designed for stormwater quantity control have inherent water quality management functions while others can be retrofitted to serve the dual functions of stormwater quantity and quality management. Stormwater quality management measures such as roof gardens, bioretention systems, constructed wetlands and ponds can provide effective stormwater detention to varying degrees and therefore can reduce drainage infrastructure requirements. This is particularly relevant within the context of increasing degrees of impervious areas attributed to urban consolidation. A network of green/blue corridors can effectively convey and/or detain flood waters for flood protection of downstream communities'.

Source: (Wong 2011) p.7.

7.3.3 WSUD Principles

A number of State and local authorities have adopted WSUD strategies or guideline documents (City of Melbourne 2005). These usually comprise a set of 'guiding principles' and a set of 'Best Management Practices' (BMP's) which may address the three 'streams' of urban water cycle management: potable mains water; stormwater and wastewater. The following is an example of key WSUD principles as listed by Melbourne Water (Melbourne Water nd) and are consistent with the *Urban Stormwater: Best Practice Environmental Management Guidelines* (Victorian Stormwater Committee 1999):

- Protect natural systems – protect and enhance natural water systems (creeks, rivers, wetlands) within urban developments
- Protect water quality – improve the quality of water draining from urban developments into creeks, rivers and bay environments
- Integrate stormwater treatment into the landscape – use stormwater treatment systems in the landscape by incorporating multiple uses that will provide multiple benefits, such as water quality treatment, wildlife habitat, public open space, recreational and visual amenity for the community
- Reduce runoff and peak flows – reduce peak flows from urban development by on site temporary storage measures (with potential for reuse) and minimise impervious areas
- Add value while minimising development costs – minimise the drainage infrastructure cost of development
- Reduce potable water demand – use stormwater as a resource through capture and reuse for non-potable purposes (e.g. toilet flushing, garden irrigation, laundry).
- Protect and enhance natural water systems in urban developments. Natural systems become assets which are protected rather than exploited, and which are then able to function effectively.
- Integrate stormwater treatment into the landscape. For example by incorporating multiple use drainage corridors that maximize visual and recreational amenity.
- Protect water quality by improving the quality of water draining from urban environments into receiving environments. Water can be treated by filtration and retention, to remove pollutants closer to their source, reducing pollutant impacts on the downstream environment.
- Reduce runoff and peak flows. Local detention, and minimization of impervious surfaces, can provide flood mitigation using numerous small storage points, rather than one large detention basin. This approach also reduces the demand for downstream drainage infrastructure.
- Add value while minimizing drainage infrastructure development costs. Reduced runoff volumes and peak flows reduce the development costs of drainage infrastructure, while enhancing natural features and value-adding to the development.

A key WSUD concept involves matching available water sources with appropriate uses. The four main water sources are: potable mains water; stormwater (roof runoff and surface runoff); wastewater (light grey water, greywater and blackwater); and groundwater. The philosophy of 'fit-for-purpose' water use would see potable (drinking-quality) mains water replaced with other water sources where appropriate (City of Melbourne 2005). For example re-used stormwater is a better alternative for landscape irrigation than using drinking quality water.

7.3.4 WSUD Practices

7.3.4.1 Biofiltration systems

Vegetated biofiltration systems are important WSUD treatment tools for improving the quality of urban stormwater runoff, and protecting aquatic ecosystems (Wong 2006; FAWB 2009). Small scale 'at source' treatment measures have been developed which can be adapted to small catchments and retrofitted into existing streets (Lloyd, Wong et al. 2002; Wettenhall 2006). Vegetation plays an important role in these biofiltration systems, enhancing the pollutant removal function of the soil media in a number of ways, through a combination of physical, chemical and biological processes (Breen, Denman et al. 2004; Somes and Crosby 2007). Two Australian studies have investigated the biofiltration role of a range of plant species, indigenous to south-eastern Australia (Bratiers et al. 2008; Read, Wevill et al. 2008). Bioretention tree pits are a specialized form of biofiltration systems (Breen, Denman et al. 2004; Denman 2006). One Australian study has investigated the biofiltration performance of a number of common tree species (Breen, Denman et al. 2004). The presence of trees resulted in significant reductions of soluble nitrogen and phosphorus in the treated stormwater.



Figure 46: Batman Drive bioretention tree pits, Docklands Melbourne. By author.

In 2011 Brisbane City Council (BCC) used MUSIC V4.00 model (Model for Urban Stormwater Improvement Conceptualisation) to forecast the benefits of integrating Neighbourhood Shadeways and WSUD retrofit sites across the city (Brisbane City 2013). Neighbourhood Shadeways are Brisbane City Council's program of street and park tree plantings alongside shade-hungry footpaths and bikeways to support greener and more walkable neighbourhoods'. WSUD (Water Sensitive Urban Design) aims to

incorporate water cycle management initiatives into the design of urban landscapes. For 2878 potential street tree planting priority sites of the annual Shadeways schedule, streetscape bioretention was predicted to reduce stormwater flow rates by 5.3% (840ML), suspended solids by 84.1% (2,720 tonnes), phosphorous by 70-72% (4 tonnes) and nitrogen by 43% (11.2 tonnes). These comprise significant potential reductions in stormwater flows and pollutant loads discharging to downstream waterways.

Brisbane City Council has consequently developed WSUD Streetscape Design Guidelines for both developers and Council projects, and promoted partnerships for streetscape retrofit projects between Water Smart Integration and Neighbourhood Shadeways. These partnerships share up front investments in green infrastructure that can deliver both healthier waterways and healthier street trees. In particular, this Brisbane City Council project highlights opportunities to assign dollar values to the stormwater cleansing values of street trees, and incorporating MUSIC modelled stormwater treatment benefits into Australian i-Tree.

7.3.4.2 Stormwater harvesting

Extended drought conditions in most Australian cities since the mid to late 1990's have focused governments on the emerging challenge of securing reliable water supplies for urban areas. In addition to promoting water conservation and water efficiency, stormwater harvesting is now gaining prominence as an alternative water source, supported by increased government funding for stormwater harvesting schemes (Wong 2011). According to Wong urban stormwater harvesting represents a rare opportunity to provide a major new water source for Australian cities, while helping to protect valuable waterways from pollution and degradation. Stormwater harvesting can provide an additional and abundant source of water to support the greening of cities. Such Green Infrastructure provides many benefits in creating more liveable and resilient urban environments, including (Wong 2011):

- 1) Improved human thermal comfort to reduce heat related stress and mortality.
- 2) Decreased total stormwater runoff and improved flow regimes (more natural high-flows and low-flows) for urban waterways.
- 3) Productive vegetation and increased carbon sequestration.
- 4) Improved air quality through deposition.
- 5) Improved amenity of the landscape.

In the recently emerging vision for the 'Water Sensitive City', stormwater flows can be conveyed through a network of green/blue corridors of open spaces and productive landscapes that also detain flood water for flood protection of downstream communities. WSUD elements also help in reducing the need for additional drainage infrastructure to serve increased impervious catchments due to urban densification and consolidation. For effective realisation of these multiple beneficial, it is critical that Green Infrastructure be distributed throughout the urban area, as large scale end-of-pipe systems will have only local impacts.

7.3.4.3 Passive landscape irrigation

In response to issues of drought and landscape irrigation restrictions, a number of authorities have explored techniques for the passive irrigation of street trees by capturing stormwater runoff from kerbs, or from roof runoff (Stein 2009). The primary objective of such systems is to support tree growth and survival, by increasing stormwater infiltration into the root zone of the tree, and also recharging the surrounding soil water reservoir and groundwater. Pollutant removal and flow control may be the secondary benefits of such systems. In Adelaide David Lawry sees trees planted in verges as a new generation of linear 'wetlands' for the city. Assuming a tree can transpire 100 kl of water annually, 10,000 trees could take up at least 1 GL of stormwater, reducing polluted stormwater flows to nearby Gulf St. Vincent by the equivalent of the volume diverted to the Parafield Stormwater Harvesting Facility (Lawry 2008). Such systems can also capture much of the most polluted 'first flush' of road runoff (Porch et al. 2003). Johnson (2009) however, points out that the *'capacity of soil to absorb and store water is a limiting factor on the design of infiltration systems'* p.19. A benefit of trees and other vegetation is their ability to enhance the storage capacity of the soil. They may even increase their rate of water use as the availability of water at a site increases (Eamus et al. 2006). Therefore, according to Johnson (2009):

'Incorporating well vegetated stormwater infiltration infrastructure into streetscape design may therefore be an effective means of managing a considerable portion of all stormwater' p.19.

7.3.4.4 Porous surfaces

Description

The widespread paving of urban surfaces is a relatively recent phenomenon, beginning with the introduction of macadam in the 1880's. Today, impervious paving covers vast areas of the city, particularly roads and sealed car parks. More recently, increased urban densification has seen a further increase in impervious surfaces (Thompson and Sorvig 2008). Impermeable paving has been implicated in a range of environmental problems, reversing the natural water cycle in which rainwater infiltrates into the soil, thereby sustaining vegetation and replenishing soil water and aquifers (Hough 2004). Impervious surfaces reduce infiltration into the soil, reducing groundwater recharge, and increasing stormwater runoff, which can lead to flooding and pollution of downstream waterways, as well as placing greater demands on established stormwater infrastructure.

Thompson and Sorvig (Thompson and Sorvig 2008) make the case for more porous 'soft surfaces' in urban areas, to increase infiltration rates and groundwater recharge, and to reduce pressure on stormwater drainage systems. Seattle landscape architect Richard Haag advocates his 'Theory of Softness' which states that *'no ground surface should be harder than is absolutely necessary for its function'*, as an alternative to the engineer's desire to compact and pave every piece of ground in sight (Thompson and Sorvig 2008) p181. The same principle can be applied to permeability that *'no ground should be more impervious than necessary'* (Thompson and Sorvig 2008). It must be noted that porous (or pervious) surfaces comprise a whole family of different materials and treatments, as described by authors such as Ferguson (2005).

Benefits of porous surfaces

Porous paving can provide economic benefits by reducing the volume and timing of runoff, and therefore the demand for stormwater infrastructure, in terms of the extent of new systems and the continued use of existing systems. These benefits can be increased by including a subsurface reservoir in the design which decreases the need for other retention facilities. It has also been demonstrated that porous paving can play a role in water quality through pollutant removal from stormwater runoff, by assisting in biological decomposition of hydrocarbon contaminants (Anon 2002). By modifying stormwater runoff flows and water quality, porous paving can also help reduce the cost of complying with stormwater regulations. By enhancing infiltration, porous paving can assist in recharging and maintaining natural groundwater and aquifers. Porous paving also creates opportunities to cool asphalt pavements, and thereby reduce the urban heat island effect through the planting of shade trees and increasing reflectivity (measured by albedo) to reduce heat absorption. Asphalt surfaces can be lightened with coloured stones, aggregate or fines. Cooler pavements may also have benefits for tree root systems (Thompson and Sorvig 2000).

One of the main benefits of porous paving however are its multiple uses which can result in more efficient land use planning. For example stormwater management can be combined with other uses, such as car parking, as distinct from single use engineering installations such as detention ponds. In particular, engineered 'eco-paving' systems, if properly designed, can have the same structural performance as conventional pavers (Shakel et al. 2008).

Benefits of porous paving to trees

A number of authors refer to the potential benefits of porous paving to trees. According to Frank (2009):

'The benefit to trees of porous paving, lies in its ability to provide a healthy rooting habitat, contributing to tree longevity' p.2.

In highly urbanized settings, impervious surfaces combined with compacted soils, present trees with a hostile environment with limited groundwater recharge and poor gaseous exchange.

'Conversely, porous paving that allows moisture infiltration and gaseous exchange to the underlying soil, provides an improved rooting environment similar to a natural soil surface. In combination with other 'tree friendly' technologies such as load bearing rooting media or structural soils, providing modified growing environments that includes the application of porous pavement systems will allow more successful urban landscapes to be developed; a landscape in which increased opportunities for tree planting are provided' (Frank 2009) p.2.

And according to Edwards and Gale (2004):

'Porous paving will assist the tree roots so that they need not be dependent on capillary action to draw moisture from the water table.' p.124.

Edwards and Gale (2004) also conclude that, as the size of a tree pit is related to the water holding capacity of the soil, the porosity of the paving will affect the size of the tree pit required. A recent study by Morgenroth and Buchan (2009) however, raised issues regarding the benefits of porous pavements for urban trees. Oriental plane (*Platanus orientalis*) trees showed improved growth under porous concrete compared with normal concrete. Soil moisture and aeration were similar under both types (wetter and less aerated than the open control), however the soil under the porous concrete was better aerated at depth. They concluded that, while soil moisture dynamics are different between porous and non-porous pavements, the differences are not significant, and if urban trees do benefit it is probably not as a consequence of aeration or soil moisture (Morgenroth and Buchan 2009). May (2009) however, interprets these findings as reinforcing the idea that placing a permeable pavement on 'normal' soil may not enhance tree performance due to poor aeration, and the use of well drained soils may be required to maximize the benefits of permeable paving. It has also been shown that urban trees themselves can act as tools for increasing infiltration and groundwater recharge, if their roots can penetrate compacted soils and increase infiltration rates, with root paths acting as conduits for water. It should be noted that vegetation may also be considered as a constraint on permeable paving installations. Decomposing leaves may be beneficial, as they lead to microbial activity and accelerated hydrocarbon removal, but can also lead to clogging. Current advice is not to plant trees close to porous paving (Shakel, Beecham et al. 2008).

Street trees can be used as water sensitive urban design measures and they have been shown to substantially reduce nitrogen and other pollution loads in stormwater. However, urban planners and local council designers have often been reluctant to include trees as part of their urban street designs in the past due to the susceptibility of pavements to damage by tree roots. Permeable pavements may offer a solution to a number of the common problems associated with incorporating street trees into urban landscapes.

This recent paper by Beecham (2012) reports on a new experimental research project to assess and quantify the long-term performance of permeable pavements in reducing stormwater flows and pollution loads, reducing the incidence of structural damage to pavements by tree roots and in promoting healthier and faster growing trees under typical Australian conditions. Initial experimental results from 18 new street tree-permeable pavement systems have been very promising. Three separate paving configurations were used in the field trials; two pavements were constructed as permeable pavements and the third was constructed as a typical impermeable pavement. The initial results suggest that trees planted with permeable pavement surrounds generally have a higher growth-rate than trees planted within the impermeable control pavements. The author notes however that it is still too early to make any long-term predictions on the effects of the different permeable pavements on the growth rates of the trees, and it is expected that future results from the study should significantly increase knowledge in this area.

7.4 Linking water and liveability

A number of recent initiatives in Australia have expanded the debate on sustainable water management from stormwater treatment to the wider role that water and Green Infrastructure can play in creating more liveable and resilient cities of the future. According to Wong et al. (2011) water is an essential element in placemaking, both from maintaining and enhancing the environmental values of surrounding waterways, and in terms of amenity and cultural connections to place.

7.4.1 The Water Sensitive City

Three principles set the foundation for this vision of a Water Sensitive City, developed at Monash University (Wong and Brown 2009; Wong and . 2009):

- **Cities as Water Supply Catchments:** meaning access to water through a diversity of sources at a diversity of supply scales.
- **Cities Providing Ecosystem Services:** meaning the built environment functions to supplement and support the function of the natural environment.
- **Cities Comprising Water Sensitive Communities:** meaning socio-political capital for sustainability exists and citizens' decision-making and behaviours are water sensitive.

7.4.2 Water and Liveability

The *Living Victoria Living Melbourne Road Map* focuses on the role of water management in urban liveability (Living Victoria Ministerial Advisory Council 2011). Extended drought, and more recent floods, have shown what a major impact water can have on the liveability of cities and towns. Water management can be seen as playing an important role in underpinning the vitality and prosperity of the city through:

- The provision of safe, secure, affordable water supplies.
- Supporting green landscapes that significantly enhance urban amenity and help to combat the impacts of the urban heat island effect.
- Improving the health of urban waterways and providing opportunities for active and passive recreation.
- Protection from flooding.

A resilient, adaptable and flexible water system is therefore seen as a prerequisite for a liveable city. According to Wong et al. (2011):

'The nexus between urban water management and the vitality and prosperity of urban environments is only beginning to be recognised' p.4.

Some of the key linkages between urban water management and urban liveability are shown schematically in Figure 47.

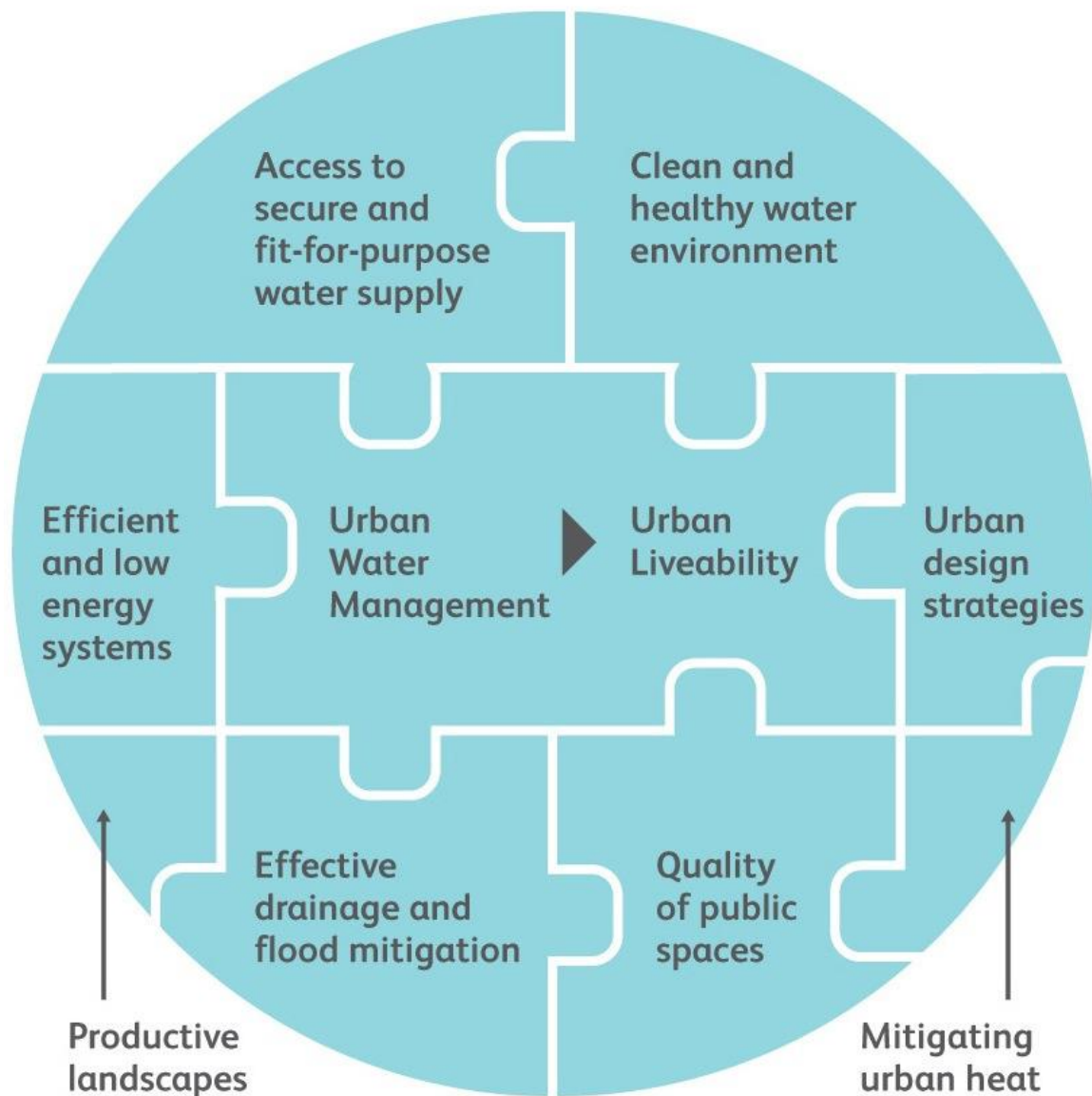


Figure 47: The influence of urban water management strategies on urban liveability. Source: (Living Victoria Ministerial Advisory Council 2011).

It is considered that at least eight measures of urban liveability can be influenced by the way urban water management and services are delivered (2011):

- 1) Access to a secured and fit-for-purpose water supply. The Intergovernmental Panel on Climate Change reports have highlighted that, with the exception of temperature, predictions of future trends in climate conditions in Australia, particularly seasonal rainfalls, remain highly uncertain.

- 2) Clean and healthy water environment. Future water sensitive cities are places where waterways are valued as an integral part of cities, and where ecological integrity is actively protected.
- 3) Effective drainage and flood mitigation. In addition to increased flood vulnerability of coastal cities associated with rising sea levels, future climatic scenarios predict higher climate variability including more severe storms.
- 4) Efficient low energy systems. There is a strong nexus between water and energy.
- 5) Urban design strategies. Future developments will feature solutions for mixed-use developments and increased densities while enhancing the quality of public and private spaces.
- 6) Mitigating urban heat island effects. Predictions of higher heat wave conditions and empirical evidence of the heat island effect will drive more climate-responsive urban designs for urban heat mitigation.
- 7) Quality of public spaces. With a progressive shift in emphasis of the importance of public spaces in response to increased development densities, future public realms will serve to anchor developments with the traditional 'values' of open spaces and landscape features being bolstered with 'ecological functioning' of urban landscapes that capture the essence of sustainable water management, micro-climate influences, facilitation of carbon sinks, and use for food production.
- 8) Productive landscapes. One of the emerging global challenges is that of preserving productive landscapes and improving food productivity.

University of Washington researcher Kathleen Wolf (2014) recently made the case in for trees and green infrastructure to both manage stormwater runoff and also offer a host of health benefits. According to Wolf, "Every small patch of nature in cities and built areas can be 'hyperfunctional' and provide co-benefits. While performing the primary purpose of stormwater management, green infrastructure also can be designed to augment park systems and provide places of respite, recreation, and delight." The article, '*Water and Wellness: Green Infrastructure for Health Co-Benefits*,' shows that "with careful design, green spaces can manage runoff and provide a range of co-benefits. Integrated planning of green infrastructure and parks systems helps to cost-effectively provide multiple benefits and contributes to more livable communities."

7.5 Green roofs and living walls

7.5.1 Green roofs

7.5.1.1 Overview

In a paper *Green Roofs for a Wide Brown Land*, Williams et al. (2010) examine green roofs in Australia, including the challenges to increasing their use, and the major information gaps that need to be researched to progress the industry here. Two main types of green roof can be identified; 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 et al. 2007). Extensive green roofs (EGR) sometimes referred to as 'ecoroofs' have shallow substrate depths less than 20 cm (2-15 cm), require little or no irrigation and are usually planted with low growing drought resistant and fire retardant vegetation (Dunnett and Kingsbury 2004a; Oberndorfer, Lundholm et al. 2007). They are underlaid with drainage and barrier materials to protect the roof from water and root penetration. These green roofs are specifically designed for limited maintenance.

7.5.1.2 Benefits

A number of benefits have been attributed to green roofs including the following cited by Williams et al. (2010):

Benefits to building occupants:

- Increased roof or roof membrane life (Kosareo and Ries 2007; Köhler and Poll 2010).
- Insulating properties that lead to greater energy efficiency through reduced summer cooling and winter heating costs (Sailor 2008). In temperate North America, a cost-benefit analysis of an EGR on a retail store found small, but significant, reductions in energy consumption (Kosareo and Ries 2007). In warmer climates, much greater reductions in energy usage are likely to result. Wong et al. (2007) found that in Singapore over 60% of heat gain by a building could be stopped by an EGR. In subtropical southern China, less than 2% of the heat gained by an EGR during a 24 hour period in summer was retained by the plants and substrate or transferred to the building below. The remainder was lost through evapo-transpiration, re-radiated to the atmosphere, or used in photosynthesis (Feng et al. 2010).
- Reduction of inside and outside noise levels (Van Renterghem and Botteldooren 2008; Yang et al. 2008; Van Renterghem and Botteldooren 2009).
- A general sense of enhanced well-being is also gained by virtue of the aesthetic value of plants (Maas et al. 2006).

Benefits to the local environment:

- Biodiversity and habitat provision (Coffman and Davis 2005; Brenneisen 2006).
- Reduced stormwater runoff (VanWoert et al. 2005; Carter and Jackson 2007). A review of research into the hydrological performance of EGRs has shown that they can retain between 34-69% of precipitation (Gregoire and Clausen 2011). The authors noted that retention capacity is affected by the water holding capacity of the substrate, evapo-transpiration rates, temperature, amount of precipitation, and the number of dry days preceding precipitation. This ability to reduce stormwater volumes is of benefit where expansive areas of impervious

surfaces create problems of localised flooding during heavy rainfall events and disturbance of surrounding natural waterways.

- Improved roof water runoff quality (Berndtsson et al. 2006). Research however indicates that this depends on the characteristics of the green roof, particularly the presence of organic material and fertiliser in the substrate (Gregoire and Clausen 2011).
- It is also noted that, unlike some other WSUD measures, green roofs do not require additional space as they are already part of the building footprint.

Benefits to the wider city:

- Mitigating the urban heat island effect by cooling through evapotranspiration, and subsequent reduction in energy demand and carbon dioxide emissions (Skinner 2006; Alexandri and Jones 2008). Susca et al. (2011) reported an average 2°C temperature difference between areas of New York city that have high and low levels of vegetation. EGRs with their biological activity, high thermal resistance, and low surface albedo (compared with traditional bitumen rooftops) were considered a useful way of combating the UHI effect.
- Carbon sequestration (Getter et al. 2009; Li et al. 2010).

7.5.1.3 Constraints

In the last two decades there has been a substantial expansion of extensive green roofs in the northern hemisphere (Western Europe and North America) mainly through the retrofitting of existing buildings (Oberndorfer, Lundholm et al. 2007) and more recently in Singapore. There are also a few examples in Australia. Despite increasing government, public and industry interest (due to their potential as a climate change mitigation and adaptation tool) there remain a number of potential barriers to the more widespread adoption of green roofs in Australia (Williams, Rayner et al. 2010). These include:

1. Lack of standards.
2. High cost of installations.
3. Few demonstration examples.
4. Lack of relevant and reliable research.
5. Difference of Australian climatic conditions compared with the temperate climate conditions of most of Europe and the USA has made using the Northern hemisphere standards less applicable for Australian conditions.
6. Similarly, relying on northern hemisphere research raises other issues due to different rainfall patterns, substrates and types of vegetation.

Lack of scientific research data is particularly relevant to Australia, which has a very different climate from the temperate regions of the northern hemisphere where green roofs are more common. Relying on European and North American experience and technology may be problematic due to significant differences in climate, available substrates and plants (Williams, Rayner et al. 2010).

7.5.1.4 Water Issues

One of the major drivers for the implementation of green roofs has been to reduce stormwater flows and increase the quality of stormwater runoff from urban areas with extensive impervious catchments, thus reducing impacts on aquatic ecosystems (Walsh et al. 2005). Green roof substrates and plant roots can act as a 'sponge', reducing and slowing roof runoff (Mentens et al. 2006; Carter and Jackson 2007). The hydrological performance of green roofs, however, is dependent on a large number of variables such as roof slope, drainage layer design, substrate depth and composition and plant types (Dunnnett and Kingsbury 2004a; VanWoert, Rowe et al. 2005; Simmons et al. 2008). Hydrological models have been developed that predict the reduction of runoff achieved by green roofs (Mentens, Raes et al. 2006; Carter and Jackson 2007; Hilten et al. 2008). Adapting these models for the Australian context or constructing local models will provide technical information that will help the uptake of green roofs.

It appears that areas with constant or seasonal hot, dry climates have the most to gain from implementing green roofs as a climate change adaptation measure (Alexandri and Jones 2008). However such climatic regions are also subject to water scarcity, which has become a major issue in Australian cities in the last decade (Hensher et al. 2006; Mulley et al. 2007). The use of large volumes of potable water to maintain roof gardens in the Australian climate therefore may not be feasible, however if green roofs are to be used to mitigate urban heat island effects through evapotranspiration in hot weather, some irrigation will be required. *'This creates an inherent contradiction between one of the objectives of establishing green roofs in Australian cities and the realities of doing so'* (Williams, Rayner et al. 2010). WSUD practices which utilize greywater recycling and stormwater harvesting and reuse may be one solution to this problem.

7.5.1.5 Plant selection

Williams et al. (2010) specifically highlight the need to identify plant species that can survive and also be aesthetically pleasing in the Australian climate. Plants selected for green roofs must be able to tolerate increased wind velocities, sun exposure, extreme heat, drought conditions and shallow root depths (Durhman et al. 2004). These factors point to water availability being the most limiting factor on green roofs. According to Williams et al. (2010):

'If green roofs are to be successful in Australia it is therefore necessary to understand the drought tolerances and associated water requirements of a range of Australian and exotic plant species so that a diverse plant palette is available to green roof designers'

Plant selection is becoming a global issue as green roof monocultures of *Sedum* (as found in the Northern Hemisphere) restrict the potential for aesthetic diversity and may limit the biodiversity and ecosystem service value of green roofs (Dunnnett and Kingsbury 2004a). Studies into the selection of plants for extensive green roofs have been conducted, but predominantly in cool temperature regions of the northern hemisphere. *Sedum* species feature recurrently as the primary choice for these regions. Overseas studies, however, are difficult to adapt to Australian conditions, where climate is characterised by low rainfall, high evaporation and high year-to-year rainfall variability (Perkins and Joyce 2012).

Williams et al. (2010) investigated the performance of native and exotic species for extensive green roofs in Melbourne. The researchers assessed the suitability of three species of native forbs, three succulents (two native and one exotic) and three native grasses for Australian green roofs by conducting drought trials using species readily available at nurseries and planted in green roof microcosms. They found that many of the species assessed in this study will not be suitable for green roofs in Australian Mediterranean climates due to the extended periods of drought stress experienced.

A recent study by the CSIRO developed a 'plant selection matrix' tool, identifying plant species suitable for extensive green roofs and exterior living walls in subtropical Australia, and reported on a workshop aimed at conveying findings to industry and identifying consensus priorities for future work (Perkins and Joyce 2012). The researchers concluded that:

'... it is clear that long-term evaluation of a wider range of plant species, substrate formulations and irrigation regimes is required to support increasing confidence in Green Infrastructure for Australia'.

They also concluded that:

'... climate-specific modelling of environmental benefits such as thermal buffering and mitigation of stormwater flows is vitally important to ensure their accurate representation in building sustainability indicators such as the Green Building Council's 'Green Star' rating. This would offer greater incentive for implementation of Green Infrastructure'.

7.5.1.6 South Australian research

According to Beecham et al. (2012) Adelaide is the capital city of the driest state in Australia and it currently faces three major challenges:

- Urbanisation.
- Water scarcity.
- Climate change.

These threats place increased stress on the urban water cycle, and increases metropolitan temperatures through urban heat island effects. Introducing green infrastructure through water sensitive urban design is one of the solutions to reduce harmful impacts of urbanisation while providing additional amenity and water quality benefits for communities and the environment.

Razzaghmanesh (Razzaghmanesh et al. 2012; Razzaghmanesh 2012a) at the University of South Australia, reviewed a range of studies from different climatic regions in Europe, North America, Asia,

Australia and New Zealand to better understand how green roofs can be adapted to meet WSUD objectives in Australia. They concluded that green roofs have been used as an important WSUD infrastructure around the world but the technology is very much in its infancy in Australia. Furthermore, more specific design criteria need to be developed for a range of Australian conditions to develop resilient green roofs. In order to develop resilient green roofs for Adelaide in terms of growing media type and depth, plants, water retention, flood attenuation and outflow water quality, two locations have been selected in Adelaide for further research. One is located on the top of a 22 storey building in the Adelaide CBD and the other one is at the Mawson Lakes Campus of the University of South Australia.

A paper by Beecham et al (2012) describes the results of an ongoing research project investigating the water quantity and thermal benefits of two different types of green roofs (intensive and extensive). The study site consists of a series of small scale green roofs located at the University of South Australia's Mawson Lakes campus (see figure 48). Laboratory and field investigations of rainfall and runoff confirmed that green roofs can retain significant amounts of stormwater and can also mitigate the peak flow and attenuate the time of concentration.

The thermal benefits of green roofs were also investigated for two scenarios (cold and warm days). The results indicated that the thermal variation of the planting media is less than surrounding areas. On cold days the media's temperature is warmer than outside and on warm days it is cooler. The authors concluded that integrating green roofs into the built environment of Adelaide could act as one of the main potential options for achieving the WSUD objectives outlined in the Adelaide 30-year Plan, and that developing resilient green roofs could also be an effective climate change adaptation tool to mitigate urban heat island effects and to reduce urban temperatures.



Figure 48: Green roof bed layouts at University of South Australia's Mawson Lakes campus. Source (Beecham, Razzaghmanesh et al. 2012).

Several green roof and living wall projects have recently been part funded through the South Australian Government's Building Innovation Fund (BIF) which aims to demonstrate innovative ways to reduce the carbon footprint of existing commercial buildings.

In one project four green roof systems were installed in a challenging urban environment on the 22nd level roof of ANZ House Adelaide, and were monitored for environmental benefits including insulation, stormwater quality, water use, cost effectiveness, vegetation and visual amenity (Fifth Creek Studio 2012). Two proprietary green roof systems commercially available in Australia were used to compare profile depths (an intensive profile depth of 300 mm and the extensive profile depth of 150 mm). Part of the plots were also covered with an open mesh or grating above the plants (aimed at creating a sheltered micro-climate and also facilitating pedestrian access). Key findings of the monitoring included:

- The insulation value of a 125-300 mm thick profile was sufficient to reduce summer heat flow in Adelaide's climate. The deeper the profile the larger the insulation value and the longer the time delay for peak temperatures. This is based on a dry substrate condition and when water is introduced into the green roof systems the insulation values reduce as temperatures within the profile layers rise, because water is a good thermal conductor.

- Insulation R-Value was difficult to calculate but temperature reduction factors which could be used for the various green roof profiles in Adelaide are: a 300 mm profile can give a 41% reduction in temperature; a 125 mm profile plus grating can give 20.5% reduction; and a 125 mm profile can give an 8% reduction.
- In stormwater quality the performance of the 125 mm extensive green roof was better than the 300 mm intensive system in terms of pollutant removal, which may be related to the reduced volume of soil that can leach pollutants.
- The building energy impact resulting from the 125 mm profile plus grating in summer reduced heat transfer through the roof by 4.2 W/m² for a NABERS 5 Star rated commercial building.

Table 22: Green roof monitoring summary. Source: (Fifth Creek Studio 2012).

Green roof factors	300 mm profile	125 mm + grating	125 mm profile
Saturated weight	290 kg/m ²	124 kg/m ²	117 kg/m ²
Insulation ratio	5	2.5	1
Surface temperature reduction	41%	20.5%	8.2%
Cost	\$288 m ²	\$683 m ²	\$268 m ²
Rating tool	300 mm profile	125 mm + grating	125 mm profile
Temperature reduction/\$/m ²	7	33.3	32.6
Weight/temperature reduction factor	7	6	14

This project has shown that green roof design needs to be carefully considered in a hot, dry climate. The use of a grating to shade the substrate and vegetation shows great potential, and especially when constructed around plant equipment it provides a light weight trafficable surface in addition to the environmental and energy saving benefits of the green roof system.

7.5.2 Living walls

7.5.2.1 Overview

Living walls comprise plants rooted in a vertical structure attached to a building, as opposed to traditional façade greening, in which plants are rooted in the ground and are trained to grow up a wall or trellis. The vertical structure usually comprises rigid modular panels filled with a special lightweight growing medium or a two-layer blanket of synthetic fabric in which ‘pockets’ are filled with plants and growing medium (Hopkins and Goodwin 2011). Examples of living walls can be found in Europe and North America, but are perhaps most widely adopted in Singapore. The vision of creating a ‘city in a garden’ has led Singapore to focus on research and development of green wall systems that are suited to its tropical climate (Chiang and Tan 2009). More locally Hopkins and Goodwin (2011) have presented five case studies of recently completed living walls in Australia.

7.5.2.2 Benefits

The benefits cited for green walls are similar to those cited for green roofs (Perkins and Joyce 2012). Some recent studies cite the following benefits:

- In Hong Kong, coverage of a concrete wall with modular vegetated panels reduced exterior wall temperatures by up to 16°C in summer (Cheng et al. 2010). In terms of internal wall temperatures, a difference of more than 2°C was maintained even late at night, indicating that green walls can significantly reduce energy use for building cooling.
- At HortPark in Singapore, a number of green wall systems were assessed for their thermal performance (Wong et al. 2010a.). The researchers reported differences in external wall temperatures of up to 10°C between vegetated and bare concrete walls.
- The acoustic benefits of living walls vary according to the type of construction and level of vegetation cover. Wong et al. (2010b) showed that green wall substrates effectively reduce sound at the low to middle frequencies. A relatively smaller reduction is achieved at higher frequencies due to the scattering effect of the foliage. The sound absorption properties increase as the level of vegetation increases.

7.5.2.3 Façade Greening

Façade greening is a term used to describe vegetation used on or adjoining a building surface (Dunnett and Kingsbury 2004a). Traditionally this has involved self-clinging climbing plants grown directly on a building, but more recent methods use plants grown away from the face of the building, often using high tensile steel cables, wire or modular trellis systems (Rayner et al. 2010).

The benefits of façade greening are similar to those provided through green roofs and living walls (Dunnett and Kingsbury 2004a; Oberndorfer, Lundholm et al. 2007; Currie and Bass 2008) (Dunnett and Kingsbury 2004a). The effects on building microclimates can be substantial, and one study reported a 28 % reduction in peak radiation from a west-facing wall covered with Ivy (*Hedera helix*) during summer (Di and Wang 1999). Urban greening strategies such as these are also becoming important potential climate change adaptation and mitigation tools, particularly as studies of the life-cycle cost benefit analysis quantify the economic benefits they can provide (Wong et al. 2003; Carter and Keeler 2008).

Despite the extent of vertical building faces in cities, there are comparatively few studies of façade greening in urban settings. Rayner et al. (2010) conducted a study of the façade greening at Council House 2 (CH2) building in the Melbourne CBD. An evaluation in March 2008 showed a 61% 'failure' (meaning death or poor cover) of all plantings. This 'failure' was caused by a number of factors including irrigation system failure, poor plant selection, poor plant quality, container substrate issues and problems in installation and establishment.

7.5.2.4 South Australian Research

Another project supported by South Australian Government's Building Innovation Fund investigated the viability of establishing living wall systems suitable for application on multi-storey buildings in the Adelaide CBD (Fifth Creek Studio 2012). The project had two main components:

- An initial feasibility study involving a temporary site on the Old Telephone Exchange building in the Adelaide CBD.
- The installation of a prototype hybrid living wall system for Tower 8 in the City Central precinct.

The initial feasibility study had three main aims:

- Identify living wall design criteria appropriate to the extreme conditions of Adelaide's climate.
- Assess the potential for reduction in Greenhouse Gases, CO₂ and the Urban Heat Island effect.
- Address and resolve the hurdles to achieving large scale coverage at height on multi-storey buildings.

Key findings from the post-construction monitoring of the prototype hybrid living wall system included:

The prototype living wall system with its vegetated layer one metre out from the building facade reduced ambient air temperature at 600 mm from the facade and reduced the surface te

- mperature of the facade by some 80C on an extreme summer day compared to the control wall. This reduces the heat flow through the facade into the building by approximately 2.4 W/m². Conversely during the winter, the prototype living wall reduced heat loss from the building by approximately 3.6 W/m².
- The vegetated wall reduced the amount of daylight reaching the building facade. The 100mm cable spacing allows up to 43% of daylight through and the 200 mm cable spacing allows up to 63% of daylight through.
- Solar radiation is reduced 95% by the vegetated wall.
- The living wall can reduce energy and Green House Gas (GHG) emissions when applied to a building. This positive impact would be beneficial to both new and existing buildings.

The data suggests that the living wall also influences the surrounding environment and modifies conditions in the urban canyon.

- The research also showed that the entire prototype living wall removed an average of 11% CO₂ per year and sequesters CO₂ at a rate of 1.375% (or 187.5 g) per m², per year, from the atmosphere.
- The surrounding ambient temperature was reduced in comparison with the control wall. This reduces the urban heat island (UHI) effect and creates a more pleasant environment at footpath level.

7.6 Green Streets

7.6.1 Introduction

'Green streets' is one label for a growing practice in the United States, where streets are designed or reconfigured to accommodate stormwater runoff management and treatment, along with other

sustainable design practices such as: traffic calming; pedestrian and cycle use; and the creation of attractive streetscapes. Green streets have been described by Thompson and Sorvig (Thompson and Sorvig 2000) as 'constructed ecological networks'. Two cities leading the way in green street design are Portland in Oregon and Seattle (Vogel 2006).

7.6.2 Green street examples

Portland, Oregon

The City of Portland has a long history of comprehensive planning, including urban design, multimodal public transport and Green Infrastructure systems. In Portland, a street that uses vegetated components to manage stormwater runoff at its source is referred to as a Green Street. Portland offers several examples of well-designed green streets. The SW 12th Ave Green Street project in 2005 involved retrofitting a series of stormwater planters into an inner urban street. The retrofit project demonstrates how existing or new streets in highly urbanized areas can be designed to achieve both environmental benefits and be aesthetically and functionally integrated into the urban streetscape (ASLA 2006).

Seattle

Seattle has probably developed the most innovative green street solutions. Seattle Public Utilities has adopted a Natural Drainage System (NDS) strategy. This is based on Street Edge Alternative (SEA) neighbourhood streets, incorporating a variety of low impact development techniques to store, infiltrate and filter stormwater (City of Seattle 2008). These techniques were tested in SEAStrEet No 1 where a conventional street was redesigned with a narrowed, curvilinear carriageway. A subsequent project, Pinehurst green grid, (covering twelve city blocks), involved redesigned the streets with an offset template, incorporating drainage swales in the widened side of the street. The next step in Seattle is to adapt NDS to more densely developed areas. A current project, 'Swale on Yale' applies NDS techniques to the redevelopment of high-density commercial area, incorporating four blocks of interconnected swales in a wide planting strip between street and footpath.

City of Seattle Natural Drainage Systems(NDS) and Street Edge Alternative (SEA) Streets

Today, in several neighbourhoods throughout Seattle - with more to come as funding becomes available - SEA-Streets and their variations have become a much-admired community amenity. Their NDS technologies are being used to provide a variety of community and environmental benefits, including:

- Drainage control thanks to narrower roadways which reduce impervious surface, creating more space for vegetated street-side swales which temporarily hold and often absorb rainwater;
- Improved water quality through “biofiltration” - pollutant removal provided by healthy plants and soils in swales where they capture and break down pollutants washing off roadways and parking areas;
- Increased street-side landscaping, beautifying and adding value to neighbourhoods;
- Traffic calming due to narrower pavement, the narrower visual corridor created by street-side vegetation and at some locations by gradually curving roadways that still allow for emergency vehicle access;
- Increased community interaction thanks to residents’ collaborative involvement in landscape maintenance, watershed stewardship and the pedestrian friendliness of new sidewalks and streets;
- Public education through neighbourhood-scale examples of what communities in Seattle and other cities can do to reduce stormwater runoff and improve water quality with “outside the box” Natural Drainage Systems strategies.

Source:(City of Seattle 2008)

New York City

New York City has developed a set of *High Performance Infrastructure Guidelines*, which provides a roadmap for incorporating sustainable practices into the City’s right-of-way infrastructure capital program (New York City Department of Design and Construction 2005). In guidelines such as these, street trees are formally recognized as a form of ‘Green Infrastructure’ delivering tangible benefits.

Chicago

Chicago has approximately 3057 km of public alleys representing 1417 ha of impervious surfaces (City of Chicago nd). The Green Alley Program is a strategy for the sustainable redevelopment of the city’s alleys based on five techniques: improved drainage through proper grading; permeable pavements; high albedo pavements; recycled construction materials; and dark sky compliant light fixtures. Four different approaches are adopted in the design of Green Alleys: Green Alley materials with conventional drainage; full alley infiltration using permeable pavements; centre alley infiltration using permeable pavements; and green pavement materials with a subsoil infiltration system. Green Alleys are part of

Chicago Department of Transport's (CDOT) wider 'Green Infrastructure' program, which includes recycled construction materials, permeable pavements, recycled rubber sidewalks and other efforts. The program began as a pilot in 2006, and at 2008, more than 80 Green Alleys had been installed.

7.7 Summary

- Streams and drainage corridors are an important component of the urban Green Infrastructure network.
- In some areas the term Green Infrastructure is synonymous with more sustainable stormwater management practices.
- Healthy trees, soils and vegetation also play an important role in the natural water cycle. In Australia the term Water Sensitive Urban Design has been adopted as a new paradigm for the more sustainable management of the urban water cycle.
- Vegetation plays a significant role in Water Sensitive Urban Design through the use of vegetated systems to improve stormwater quality and manage stormwater runoff.
- More recently there has been a broadening of the concept of Water Sensitive Urban Design to that of Water Sensitive Cities and the role of water in urban liveability, backed by a major research effort in Australia.
- One Green Infrastructure initiative being promoted in Australia is that of 'green roofs and living walls', popular overseas but with their viability in Australian climatic conditions now being researched locally.
- Recent and ongoing research is investigating the application of green roofs and walls to South Australian climatic conditions.

7.8 References

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8 Urban ecology

Green Infrastructure

Green Infrastructure is the network of green spaces and water systems that delivers multiple environmental, social and economic values and services to urban communities. This network includes parks and reserves, backyards and gardens, waterways and wetlands, streets and transport corridors, pathways and greenways, farms and orchards, squares and plazas, roof gardens and living walls, sports fields and cemeteries. Green Infrastructure secures the health, liveability and sustainability of urban environments. It strengthens the resilience of towns and cities to respond to the major current and future challenges of growth, health, climate change and biodiversity loss, as well as water, energy and food security.

8.1 Introduction

Biodiversity has been shown to be fundamental to healthy ecosystems and their ability to deliver ecosystem services. Biodiversity is therefore fundamental to human health and well-being, and issues of global biodiversity loss are a major area of concern. At the city level biodiversity is impacted on by habitat degradation and fragmentation. Research shows that retaining and enhancing 'nature' in urban areas has a wide range of human benefits. This is maximized in an 'urban ecology' approach in which nature is seen to be an integral part of the city, with people being part of a functioning urban ecosystem. Green Infrastructure can play a significant role in enhancing urban biodiversity including countering habitat fragmentation, and in linking the different ecological assets in green networks.

Figure 49 summarizes the biodiversity roles of Green Infrastructure.

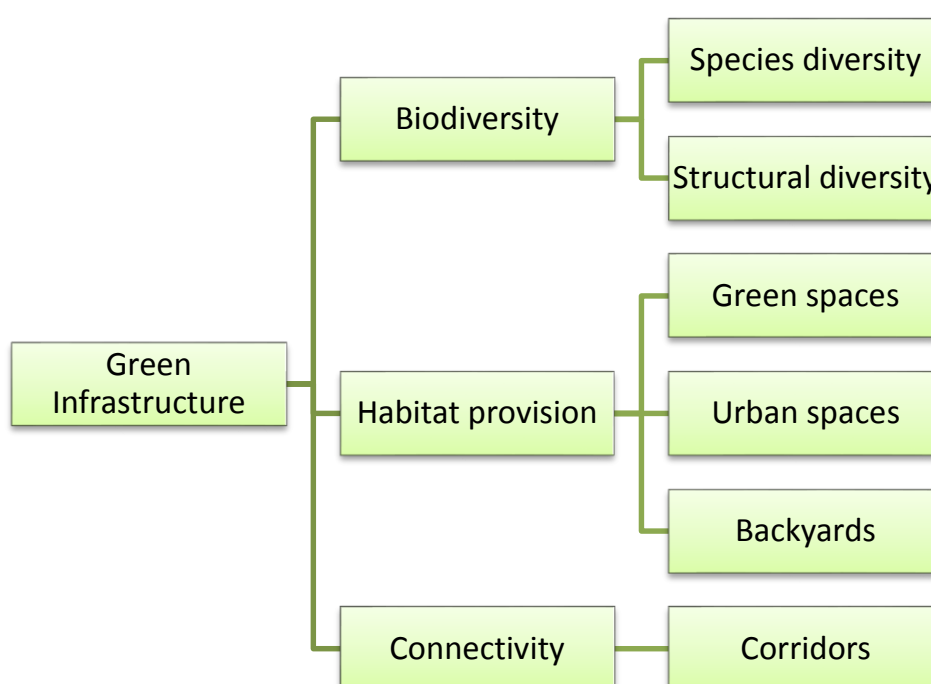


Figure 49: Summary of biodiversity role of Green Infrastructure. By author.

8.2 Urban Ecology

Today most of the world's population lives in cities, and this is expected to reach 70% by 2050 (United Nations 2008). Urbanization has shown to have dramatic impacts on ecosystems (Grimm et al. 2008). Recently the urban environment has gained the attention of an increasing number of ecologists (Fontana et al. 2011). Historically nature and cities have been seen as 'mutually exclusive' (Platt 2004). Cities were often compact and highly urbanized, but had easy access to surrounding rural and natural landscapes (Hough 2004). Just as cities and nature have been viewed as 'mutually exclusive', the natural and social sciences have similarly tended to operate independently of each other, despite an understanding of the interdependence of cities and nature (Alberti 2008). An urban ecology approach sees humans, nature and the city as part of the same 'urban ecosystem' (Hough 2004). This 'urban ecosystem' comprises the physical environment (both natural and man-made) and biotic communities (including humans as well as native and introduced flora, fauna and micro-organisms) (Tarran 2006). The concept of 'urban ecology' sees the city as a habitat for people alongside vegetation, wildlife and built form (Moll and Petit 1994).

The concept of 'biophilic urbanism' has been championed by Tim Beatley and Peter Newman for several decades, as a way to create more liveable cities (Beatley 2009). The concept of biophilic urbanism is inspired by E. O. Wilson's concept of 'biophilia' which suggests an innate affinity between humans and the rest of nature. Beatley proposes that incorporating nature in cities can produce many benefits for urban dwellers. Biophilic cities are seen to be in harmony with ecological systems, foster place-based relationships, and embody the attributes of nature in their design. In Beatley's view, a city exemplifies 'green urbanism' if it (1) strives to live within its ecological limits, (2) is designed to function in ways analogous to nature, (3) strives to achieve a circular rather than a linear metabolism, (4) strives toward local and regional self-sufficiency, (5) facilitates more sustainable lifestyles, and (6) emphasizes a high quality of neighbourhood and community life (Beatley 2000).

'Urban ecology' is a relatively new field involving the systematic study of urban ecosystems using an integrating multi-disciplinary approach, drawing on both the natural and social sciences (Grimm, Faeth et al. 2008). Ecological models derived from natural settings have also been applied to urban areas (Lord et al. 2003). The city has also been conceptualized as an ecosystem created by humans specifically for human habitation (McIntyre et al. 2000). Urban ecology is a growing field which has been investigated in a number of journal articles (Pickett et al. 1997; Niemela 1999; Platt 2004). Recent books have also been published on urban ecology (Alberti 2008; Marzluff et al. 2008) and on the broader topics of 'green cities' and 'sustainable urbanism' (Birch and Wachter 2008; Farr 2008; Beatley and Newman 2009).

Tarran (2006) attributes the development of urban ecology in the late 1990s to a number of factors including:

- Increased urbanization and the need to make urban areas more habitable.

- Recognition by ecologists that disturbed ecosystems are more common than 'pristine' ecosystems and worthy of study in their own right.
- Increasing concern about human impacts on ecosystems, including biodiversity loss and the impacts of urbanization on aquatic ecosystems (Wallbridge 1997).
- Recognition of an emerging sustainability crisis in cities.
- Recognition that the 'ecosystem services' provided by nature could be applied in urban areas (Daily 1997).

Most recently there has been an increased focus on issues of sustainable urban development on the global scale, increased population growth and urbanization, and issues of climate change and water scarcity (Grimm, Faeth et al. 2008).

8.3 Urban biodiversity

8.3.1 Biodiversity

According to Roetman and Daniels (2008) 'biodiversity is a term used to describe all living things and the variation within and between them. It includes plants, animals, fungi, and micro-organisms, and can be considered at various levels of complexity'. These include:

- **Genetic Diversity** - the variation **within** a particular species.
- **Species Diversity** - the variation **between** different species.
- **Ecosystem Diversity** - the variation **within** and **between** different ecosystems of the world, comprising habitats, the species that they contain and the processes and interactions occurring between the biological and physical components.

8.3.2 Global biodiversity

Issues of biodiversity and ecosystem health have been shown to be fundamental to the delivery of ecosystem services from the global to the local scale. Biodiversity plays a fundamental role in the functioning of ecosystems and their ability to deliver long-term ecosystem services. Worldwide biodiversity loss is therefore an area of great concern (Groombridge and Jenkins 2002). Links between biodiversity and human health and well-being have been well documented (Tzoulas et al. 2007) and loss of biodiversity impacts the quality of essential life support systems, the incidence and spread of infectious diseases and the potential for developing new treatments and medicines (Chivian and Bernstein 2004).

8.3.3 Values of urban biodiversity

While loss of global biodiversity is a major concern, what are the specific benefits of retaining and enhancing biodiversity within cities and urban areas?

8.3.3.1 Ecosystem services

Biodiversity provides a wide range of 'ecosystem services' to human populations which underpin human health and well-being and economic prosperity (Millennium Ecosystem Assessment 2005). Within cities biodiversity can help to:

- Regulate urban climate and microclimate,
- Improve air quality.
- Purify water.
- Control stormwater runoff.
- Improve soil fertility.
- Recycle wastes.

8.3.3.2 *Ecosystem resilience*

A recent focus has been on the role of biological diversity in engendering 'resilience' in natural systems, providing an 'insurance policy' allowing natural systems to recover from disturbances such as drought, fire and flood (Roetman and Daniels 2008).

8.3.3.3 *Quality of life*

There is an increasing consensus that biodiversity is important for maintaining quality of life for people in general, and urban inhabitants in particular:

- On a sociological level, urban nature and biodiversity in cities contributes to human sense of place, identity and psychological well-being (Horwitz et al. 2001).
- Sandström et al. (2006) have claimed that perceived quality of life might improve when the 'fraction' of nature in urban areas increases.
- Natural areas in cities provide the opportunity to directly experience nature (Miller 2006). This is considered to be a crucial aspect for restoration in a world with a highly urbanized population (Home et al. 2009a).
- The environmental attitudes of urban residents are largely formed by interactions with their local environment (Mayer and Frantz 2004; Schultz and Tabanico 2007).
- A recent study has shown the popularity of birds amongst the public (Home et al. 2009b). Therefore urban birds and their diversity represent a significant way in which people can experience urban nature. Such experiences are considered to be essential for the well-being of city inhabitants (Fuller et al. 2007).
- Animals, and urban wildlife are an important driver of our 'sense of place' in Australia, for instance the sound of magpies (Daniels 2012).
- Biodiversity adds to a sense of place and builds place identity. People identify with their local flora and fauna (van Roon 2005) and rare species are of particular concern (Mallawaarachchi et al. 2006).
- Personal experience of urban biodiversity by city residents can influence their opinions and can influence political decisions on environmental conservation matters (Turner et al. 2004; Dunn et al. 2006).
- Townsend suggests that the effects of the urban forest and other greenery are influenced by the quality, as well as the quantity, of the forest cover, which may be a reflection of greater biodiversity. (Townsend and Sick 2011).

- An interview survey conducted by Fuller et al. (2007) explored the benefits to psychological well-being from spending time in green spaces, with participants reporting greater well-being benefits in parks with a greater diversity of plant species and habitat types, '*an effect that was not simply attributable to the area of the green space involved*' (Fuller, Irvine et al. 2007).p.1.

8.3.3.4 Intrinsic values

Society also places a value on maintaining biodiversity for future generations for its scientific, educational and aesthetic values and also for its intrinsic value (Cork et al. 2006). Literature on the benefits of urban biodiversity tends to focus on the benefits to the human inhabitants of the city. This is an 'anthropocentric' or human centred approach, however the values of preserving biodiversity can also be viewed from other perspectives. Thompson (2000) reviewed the different human attitudes to nature and environmental ethics and identified the following typologies or positions within environmental ethics shown in Table 23.

Table 23: Attitudes to nature and environmental ethics. Source: Adapted from (Thompson 2000).

Anthropocentric position	Ego-centric	Self-interest.
	Homo-centric	The greatest good for the greatest number. We are responsible for stewardship of nature for human use and enjoyment.
Non-anthropocentric position	Bio-centric	Members of the biotic community have moral standing.
	Eco-centric	Ecosystems and/or the biosphere have moral standing. We have a duty of care to the whole environment.

An eco-centric position sees intrinsic value in preserving nature and ecosystem biodiversity. Aldo Leopold's (1948) *Land Ethic* is an early statement of the eco-centric position, as is McHarg's (1979) philosophy of *Design with Nature*, and James Lovelock's (1979) *Gaia* hypothesis.

Professor Chris Daniels at the University of South Australia considers that the benefits of urban nature can be classified into three categories (Daniels 2012):

- 1) **Benefits of people connecting with nature.** Biophilia (Wilson 1984) our intrinsic connection to nature, and the many benefits of interacting with nature, including creating our sense of place, human health and well-being and social cohesion benefits. The large body of evidence in this area is now seen as 'incontrovertible'.
- 2) **Alleviation of 'Nature Deficit Disorder'** (Louv 2005). There is now a large and growing gap between 'people and nature' in urban areas, with cities becoming larger, especially in Australia. In the current century the environment has become the 'driver' of social change, and there is a

need to connect with nature to be able to engage the community in environmental debate. The issue also applies in engaging with other cultures which may not see nature as we do.

- 3) **Multi-functionality.** The 'multiple use' benefits of open space and other forms of green infrastructure. In the past our open spaces have been dedicated to single use groups, such as sporting clubs or even environmental pressure groups, and tend to be fenced off from public use and used for only short periods of time. For example, people do not feel 'ownership' of the Adelaide Parklands as they are underutilized by the general community, and are subdivided up into a number of special use parcels. Instead the Parklands should be dedicated to delivering wider benefits including biodiversity preservation, water management and climate change adaptation. The concept of multiple use can be applied to other areas utilized by the community including roof tops, streets and public urban spaces.

8.4 The nature of urban biodiversity

8.4.1 Habitat fragmentation

According to the European Commission (European Commission 2012):

'Urbanisation, industrialisation, unsustainable agriculture and the continued expansion of grey infrastructure are increasingly eroding our natural fabric and natural capital'.

Landscapes have become more fragmented and polluted, which in turn has disrupted ecosystems and the patterns and level of biodiversity (Mazza et al. 2011). As shown in Figure 50 a fragmented landscape consists of small 'patches' of intact natural habitat. Large patches will continue to provide habitat for 'interior' wildlife species. Fragmentation into smaller patches, however, decreases the amount of interior habitat and increases the amount of edge. While some 'generalist' species may benefit from this fragmentation, the majority are negatively affected, particularly large animals with large territorial ranges (Weber 2007). Lucius et al.(2011) suggest that negative effects generally start to appear when about 70% of the original habitat has been lost. These impacts may include: changes in species, composition of different species, community structure, population dynamics, behaviour, breeding success, individual fitness and a range of ecological and ecosystem processes. As shown on Figure 51 the size and shape of remnant patches affect the amount of habitat available for interior wildlife species. Large areas are better than small areas, and circle-shaped areas are generally better than square-shaped or rectangle shaped ones (Barnes 1999).

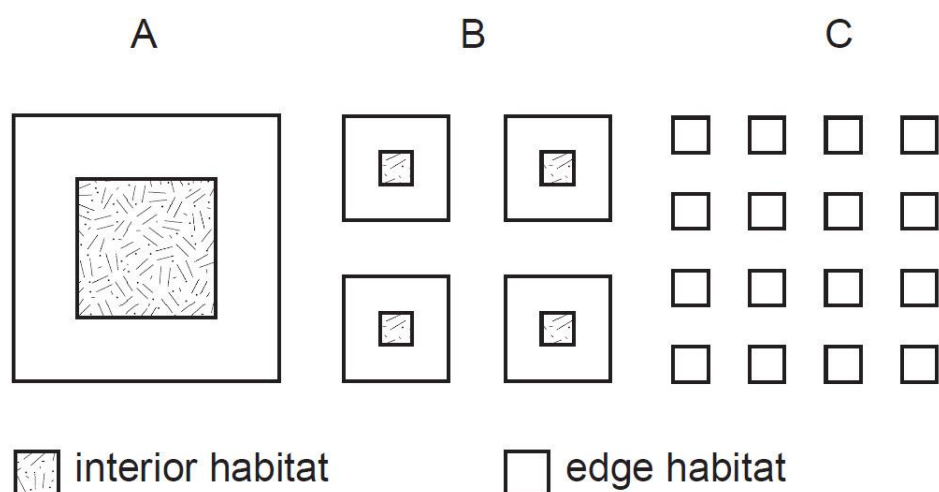


Figure 50: Large patches provide habitat for interior wildlife species. Fragmentation shown in B and C decreases the amount of interior habitat and increases the amount of edge. Source (Barnes 1999) adapted from (Soule 1991).

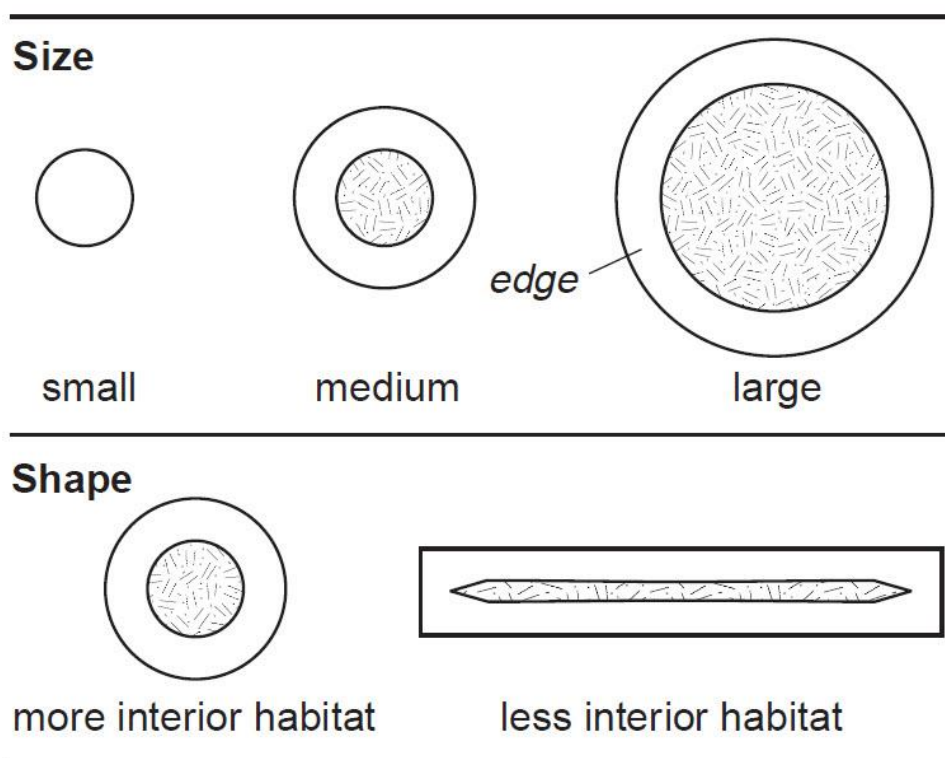


Figure 51: A patch's size and shape affect the amount of habitat available for interior wildlife species. Large areas are better than small areas, and circle-shaped areas are better than square-shaped or rectangle shaped ones. Source (Barnes 1999) adapted from (Forman and Godron 1986).

The size and shape of patches is therefore an important consideration in the planning of urban areas to maximize habitat and biodiversity values, with large patches preferred, and connection of remnant patches with habitat corridors (Barnes 1999a).

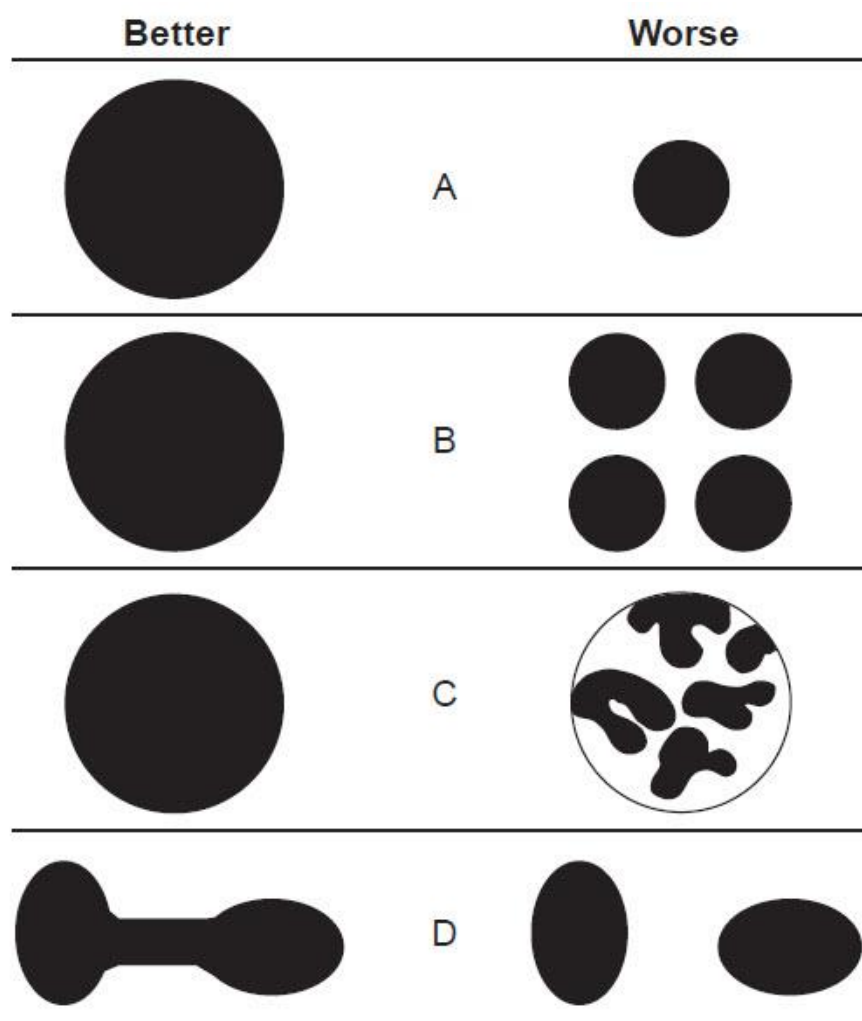


Figure 52: Patch size and shape considerations are important when planning for wildlife. Large circular patches are best for wildlife and are even better when connected by a corridor. Source (Barnes 1999) adapted from (Soule 1991).

8.4.2 Rural-urban gradients

Studies on urban birds have generally revealed a rural-urban gradient and negative impacts of urbanization (i.e. increasing sealed area) on bird species richness and diversity (McDonnell et al. 1993; Clergeau et al. 1998; Palomino and Carrascal 2006).

8.4.3 Urban wildlife

Urban habitats and species are often considered to be less important than their wild or rural counterparts. Biodiversity, however, can be higher in cities than surrounding rural areas and may comprise a rich and diverse ranges of plants and animals, often occurring as unusual or unique communities (Angold et al. 2006). According to Fontana et al. (2011):

'Despite the strong and permanent human impact, urban biodiversity has generally proved to be surprisingly high' p.278.

Many studies show a surprisingly high number of species and individuals present in cities (Marzluff 2001; Palomino and Carrascal 2006; Sattler et al. 2010a; Sattler et al. 2010b). It has even been found that 'moderately urbanized' areas often support higher 'species richness' than rural areas (Blair 1996; Blair and Launer 1997). Such species richness and diversity are generally considered to be good indicators of ecosystem health (Rapport 1999). However these indicators do not necessarily provide a full picture of species composition and community dynamics (Jost 2006). Community analyses are used to explain changes in community composition (Moretti et al. 2006).

8.4.4 Impacts of urban densification

Impacts on tree cover

Policies of 'urban consolidation' which encourage smaller lot sizes and denser forms of urban development are supported by governments in most major metropolitan areas of Australia. In addition to creating smaller lots, the size and coverage of the average suburban houses has increased dramatically since the 1990s, whilst the average size of the private garden has substantially diminished (Hall 2010). Large trees however require space to grow and an Honours research project at the University of Queensland investigated the impact of these trends in Brisbane through the use of existing tree cover and other spatial data (Daniel 2012). The results showed that while urban trees on private property form a large component of Brisbane's suburban environment, this has decreased with modern development, with 30% less canopy cover over parcels developed in the 1990s than over parcels developed before this period. For infill development, low-rise multiple unit dwellings exhibited negligible canopy cover (between 0 and 2.5% over most parcels sampled). While a decrease in tree cover was as expected, the magnitude of this change has significant implications for the quality of the suburban environment. Analysis of current planning policies showed that, even if residents would prefer not to plant large trees, development permitted under current parameters severely limits opportunities for future residents to do so, leading to a slow but permanent loss of tree cover on private property throughout the city's suburbs. This research provides the first quantitative measures of the effects of planning and development policies on Brisbane's tree cover and provides an evidence base for future planning and policy development.

Impacts on urban green space

Rapid urbanization has ignited concern about the potential effects on biodiversity conservation and quality of human life from scientists and policy makers alike (Dye 2008). Foremost among these concerns is maintaining human well-being. Contact with the natural environment is a fundamental component of well-being (Wilson 1984; Miller 2005) yet opportunities for such contact are dramatically

limited in urban areas. Predictions of the consequences of rapid ongoing urbanization for human well-being require information on how green space provision will change as cities grow. One way to achieve this is to study variation in green space provision within and among present-day cities. A research paper by Fuller and Gaston (2009) explores the relationships between urban green space coverage, city area and population size across 386 European cities. The researchers showed that green space coverage increased more rapidly than city area, yet declined only weakly as human population density increases. Thus, green space provision within a city is primarily related to city area rather than the number of inhabitants that it serves, or a simple space-filling effect. Thus compact cities (small size and high density) show very low per capita green space allocation. However, at high levels of urbanization, the existing green space network is robust to further city compaction. The authors conclude that, as cities grow, interactions between people and nature will depend increasingly on landscape quality outside formal green space networks, such as street plantings, or the size, composition and management of backyards and gardens.

Impacts on biodiversity

Urbanization causes severe environmental degradation and continues to increase in scale and intensity around the world, but little is known about how we should design cities to minimize their ecological impact. Two main types of urban development can be identified. With 'urban sprawl', low intensity impact is spread across a wide area, and with a 'compact development' intense impact is concentrated over a small area. It remains unclear however which of these development styles has a lower overall ecological impact. A recent study compared the consequences of compact and sprawling urban growth patterns on bird distributions across the city of Brisbane (Sushinsky et al. 2013). The researchers predicted the impact on bird populations of adding 84,642 houses to the city in either a compact or sprawling design using statistical models of bird distributions.

The results showed that urban growth of any type reduces bird distributions overall, but compact development substantially slows these reductions at the city scale. Urban-sensitive species particularly benefited from compact development at the city scale because large green spaces were left intact, whereas the distributions of non-native species expanded as a result of sprawling development. As well as minimizing ecological disruption, compact urban development maintains human access to public green spaces, however, backyards are smaller, which impacts on opportunities to experience nature close to home. The results suggest that cities built to minimize per capita ecological impact are characterized by high residential density, with large public urban green spaces and small private backyards, and that there are important trade-offs between maintaining city-wide species diversity and people's access to biodiversity in their own backyard.

Melbourne Urban Forest Strategy

Strategy: Improve biodiversity

Target: Melbourne's green spaces will protect and enhance a level of biodiversity which contributes to the delivery of ecosystem services.

Over 40 per cent of nationally listed threatened ecological communities in Australia occur in urban areas. Loss of natural habitat, urbanisation, and air and water pollution have all impacted upon the survival of plant and animal species. A 2009 Victorian Environmental Assessment Council study showcased ten major threats to biodiversity in Melbourne including: fragmented landscapes, connectivity loss due to major roads, urban pollution, human impacts (e.g. rubbish and trampling), predation from cats and dogs, and competition from other introduced species. With the potential expansion of urban growth into brown and green field sites, the potential loss of biodiversity from these threats becomes even greater, highlighting the need to seriously regard biodiversity in our city.

In terms of biodiversity in the urban landscape, we recognise that cities and biodiversity have often been mutually exclusive however research continues to demonstrate that urban areas can provide large opportunities for protecting and enhancing vulnerable species. Public parks and gardens, golf courses, remnant vegetation and private property gardens are capable of providing habitat for certain species.

This is not to underestimate the impact that urbanisation has had on biodiversity. Our imperative is to ensure protection and enhancement of vulnerable species. Whilst certain species (e.g. Eastern Quoll) face severe loss or even extinction due to loss of habitat, others (e.g. Brush Tail Possum) have adapted all too well to urbanisation, to the extent of becoming overpopulated in many inner area parks.

Biodiversity in the City of Melbourne includes a wide range of wildlife species. The urban forest plays a crucial role in providing habitat, food and protection to wildlife as equally as it provides a diversity of plant species throughout the municipality.

In summary, healthy trees supported by adequate soil moisture and structural and biological diversity collectively contribute to healthy ecosystems. Taking all these factors into consideration is essential for setting and achieving our benchmarks and goals.

Source: (City of Melbourne 2011).

8.5 Biodiversity in Australian cities

8.5.1 Introduction

In their book *Adelaide, Nature of a City: The Ecology of a Dynamic City from 1836 to 2036*, Daniels and Tait (2006) provide a comprehensive review of the impacts of urbanization on the biodiversity of metropolitan Adelaide and the current status of the different aspects of urban nature in the city. More recent research into the role of sustainability in Australian cities, including urban biodiversity, is being carried out by the Barbara Hardy Institute at the University of South Australia (Roetman and Daniels 2011).

Taylor et al.(2011) have investigated urban biodiversity from an Australian context. The authors note that ecologists generally ignored the biodiversity of cities until the later decades of the 20th century (Martin et al. 2010) but research into urban biodiversity is now 'on the rise' (Mayer 2010). Urban biodiversity is complex, but with increasing urbanization the design of the built environment and associated green infrastructure becomes the main determinant of biodiversity (Muller et al. 2010).

8.5.2 Typology of urban species

According to Taylor et al.(2011) from an ecological viewpoint Australian cities can be conceptualized as a 'mosaic' of fragmented habitat patches over the 'grey' urban landscape. This mosaic tends to be highly fragmented with many small patches of varying size, shape and biodiversity, separated by 'abrupt' edges (Johnson and Klemens 2005). As shown on Table 24 this 'mosaic' provides an urban habitat for a wide range of 'native' and 'adventive' plant and animals, as well as cultivated plants and domesticated animals (Niemela 1999a; Muller, Werner et al. 2010).

Table 24: Typology of Australian plants and animals: Source (Taylor 1990) in (Taylor, Roetman et al. 2011) p.180.

Native	Introduced	
Species indigenous to the locality. Individuals spontaneous in occurrence.	Cultivated/Domestic Species may be indigenous to the locality, but usually exotic or alien. Individuals established and maintained by human agency.	Adventive Species alien or exotic to the locality. Individuals spontaneous in occurrence.
		Wild Not an escaped cultivar or domesticate.
		Feral An escaped cultivar or domesticate.

According to Taylor (1990) Australia's 'urban vegetation' comprises four main classes:

- **Native vegetation**, having both a canopy layer and an understorey (where present and distinct) dominated by plant species that are indigenous to the locality and spontaneous in occurrence.
- **Relict vegetation**, having a canopy layer dominated by native plant species that are indigenous relicts of the original native vegetation cover and an understorey (where present and distinct) dominated by cultivated or adventive plant species.
- **Cultivated vegetation**, having a canopy layer dominated by indigenous, exotic or alien plant species that have been deliberately introduced to the locality by human agency (cultivated) and an understorey (where present and distinct) dominated by cultivated or adventive plant species.
- **Adventive vegetation**, having a canopy layer dominated by plant species that are exotic or alien to the locality and spontaneous in occurrence (adventive), while the understorey is normally indistinct or dominated by adventive plant species.

The landscape of Australian cities tends to be dominated by 'cultivated vegetation' in landscaped public/private spaces, or adventitious on derelict sites. Extensive areas of 'native vegetation' are rare, and are usually 'relict vegetation', lacking the capacity to regenerate, and vulnerable to invasion by adventitious species (Johnson and Klemens 2005). The 'grey spaces' of cities, and the fragmented patches of relict, cultivated and adventive vegetation are lacking in both native plant species and habitats for a range of native animal species.

Animal species vary in their tolerance to the stresses of an urban environment and can be classified as 'urban avoiders', 'urban adapters' or 'urban exploiters' (Blair 2001; McKinney 2002). Urban avoiders cannot survive in highly urbanized situations due to climatic stress, soil, water and air pollution, and high levels of habitat disturbance due to landscape maintenance, and high levels of human activity (Soule 1991; Whitford et al. 2001; McKinney 2002; Zerbe et al. 2003). Urban adapters tend to be small, mobile or arboreal animals, animals with amenity value for city dwellers (including charismatic bird species) and habitat generalists. Native animals with these characteristics may find better qualities of sustenance and shelter in the city rather than surrounding rural/natural areas. Urban exploiters are similar to urban adapters, but become so reliant on living in proximity to people that they may now occur mainly in cities.

Urban avoiders, adapters and exploiters

Urban avoiders cannot survive in the built environment as they cannot tolerate fragmented habitat, reduced food or shelter resources, environmental pollution, or introduced competition or predation. Large, mammalian predators are usually identified as urban avoiders, in some cases more because people avoid allowing them in, rather than the animal avoiding urban areas.

Urban adapters benefit from developed environments because there are increased food sources or shelter sites. Australian examples (both native and introduced) are brushtail possums, foxes, blackbirds, magpies and bluetongue lizards.

Urban exploiters, like adapters benefit from food sources and shelter sites that are afforded by urban development, but these species are now so reliant on human activities that they are primarily, if not only, found in dense settlements like cities. Australian examples are black rats, redback spiders and spotted turtle-doves.

Source: (Roetman and Daniels 2008).

8.5.3 Concepts of nativeness

Such typologies of 'nativeness' are considered essential to understanding biodiversity in Australia and other southern hemisphere countries (Head 2004; Meurk and Swaffield 2007). In Europe and North America 'nativeness' is considered the norm for landscapes and plant species, while in Australia, New Zealand and South Africa urban landscapes are based on European models and invasiveness is the main characteristic of urban biodiversity (Head 2004; Ignatieva 2010). Since European settlement, over 27,000 exotic plant species have been introduced into Australia, and about 10 per cent of these have become established in native vegetation (Taylor, Roetman et al. 2011). Similarly exotic animal species have invaded Australia impacting on the biodiversity of the whole continent. According to Muller et al. (2010) however urbanization, rather than invasion has now become one of the main threats to global biodiversity. For example Australia's major cities are located in or adjacent to 'biodiversity hotspots' (Australian Government 2009) and biodiversity impacts can extend more than 100 km from urban boundaries (Cincotta et al. 2000).

In Australia, therefore, the primary role of urban biodiversity conservation has been one of 'nativeness' (Ignatieva 2010). There are also scientific arguments for conserving the unique 'intrinsic' values of Australian biodiversity in a global context (Muller and Werner 2010). However Taylor et al. point out that (Taylor, Roetman et al. 2011)

'...because cities are primarily human habitats, urban biodiversity cannot be valued solely in terms of its nativeness. In addition to the intrinsic (natural) value of the native biodiversity in urban areas, all urban biodiversity (native and introduced) has instrumental (or social) value because it provides a wide variety of productive, environmental moderation, ecosystem service and amenity benefits for the people who live in cities' p.183.

8.5.4 Biodiversity of Adelaide

The recent book *Adelaide, Nature of a City: The Ecology of a Dynamic City from 1836 to 2036* (Daniels and Tait 2006) provides a comprehensive overview of the original biodiversity of metropolitan Adelaide, and the impacts of urbanization on the city's wildlife and vegetation. Tait and Daniels (2004) also provide a detailed account of the changes in species assemblages within the Adelaide metropolitan area from 1836 to 2036.

Historically, Adelaide supported a diverse range of natural habitats. Before 1836, the Adelaide Plains supported approximately 1130 species of native and exotic plants, approximately 290 species of birds (including migratory and nomadic species) 40 mammal species, 56 reptile species and 7 species of amphibians. The authors created a database on native and introduced species present in Adelaide between 1836 and 2002 using 200 historical and recent sources of information. The data was then used to produce graphs showing the changes in species richness through time. Some of the overall patterns of change were:

- A 30% increase in the total number of all species, with around 132 native species lost and 648 introduced.
- Plants increased by 524 species (46% increase over the original).
- Native plant species have decreased by approximately 8% (89 species).
- Vertebrates experienced an overall decline of 12 species, or 3%.
- 50% (20 out of 40) of the original native mammal species were lost.
- Amphibians did not lose or gain any species.

The increase in total species numbers was found to be due to introductions (54% in plant species, 22.5% in mammals, 7% in birds, 3.5% in reptile species). With respect to birdlife, 286 species were present in 1836, and 283 species in 2002. 21 native species of birds were lost, while 20 introduced species arrived. The major decline in species richness began in 1959, with the greatest rate of extinction occurring over the past 30 years. The authors suggest several major reasons for the loss of native birds. Contributing factors include the loss of relatively un-fragmented habitat outside the city, changes in urban predators (such as foxes and cats) and changes in the nature of available habitats within the city (such as private and public gardens and street trees). The loss of native understorey plants, as well as increases in particular exotic plants in urban areas has also led to the change in species composition. An increase in resource competition between bird species and individuals, due to dwindling resources has possibly also contributed to population declines and subsequent extinction.

8.6 Responses to habitat fragmentation

It may not always be possible to preserve large areas of natural habitat within cities, however Green Infrastructure elements can act as reserves of species biodiversity within urban areas (Alvey 2006).

Green Infrastructure provides a means of enhancing biodiversity and reducing habitat fragmentation in urban areas (European Commission 2012).

8.6.1 Ecosystems approach

One approach to addressing the changes caused by fragmentation has been to create 'conservation areas'. In the past the focus has been on protecting particular species or habitats, but it is now recognised that there is a need to acknowledge 'nature as a system rather than individual parts' This has involved shifting the focus of conservation from the level of species or habitat level, to the ecosystem level (Vimal et al. 2011).

Science behind conservation at the ecosystem level

The shift to conservation at the ecosystem level is based on the large body of evidence that demonstrates habitat fragmentation is a threat to the survival of species (Boitani et al. 2007). Theoretically, it has its roots in island biogeography theory, which, although developed from work done on islands (MacArthur and Wilson 1967), considers an island to be any area of suitable habitat that is surrounded by unsuitable habitat, for example, lakes surrounded by dry land or fragmented forests. Island biogeography theory states that the number of species found on an 'island' depends on immigration, ex-migration and extinction, where the two former processes depend on connectivity between different 'islands'.

Further theoretical support comes from meta-population theory (Hanski 1999) which suggests that no single population can guarantee long-term survival of a given species, but the combined effect of many connected populations could. As such, the long-term survival of populations depends on the cohesion of habitat networks as it determines whether or not local extinction and re-colonisation rates are in equilibrium. (Opdam et al. 2006). In turn, this maintains the structures, material and energy flows of ecosystems which can provide different ecosystem services.

Source: (European Commission 2012).

The *Convention on Biological Diversity* (1993) has adopted the ecosystem approach where it defines an ecosystem as '*a dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit*' (Convention on Biological Diversity 1993). The ecosystem approach aims to integrate the management of land, water and living resources in a way that promotes conservation and sustainable use. It also recognises that humans, with their cultural diversity, are an integral component of the ecosystem and gain benefits from ecosystems in the form of ecosystem services (European Commission 2012).

8.6.2 Connectivity

Central to the ecosystem concept of conservation are the connections and interactions between species, habitats and resources. Ecosystems are not static, but are open, dynamic systems, and their interactions and connections evolve in space and through time (Fisher et al. 2009). Maintaining and

enhancing connectivity is one way to help offset the losses caused by fragmentation. As shown on Figure 53 Green Infrastructure can enhance connectivity between natural areas, improving the ability of organisms to move through a landscape (landscape permeability) and minimizing further fragmentation (European Commission 2012).

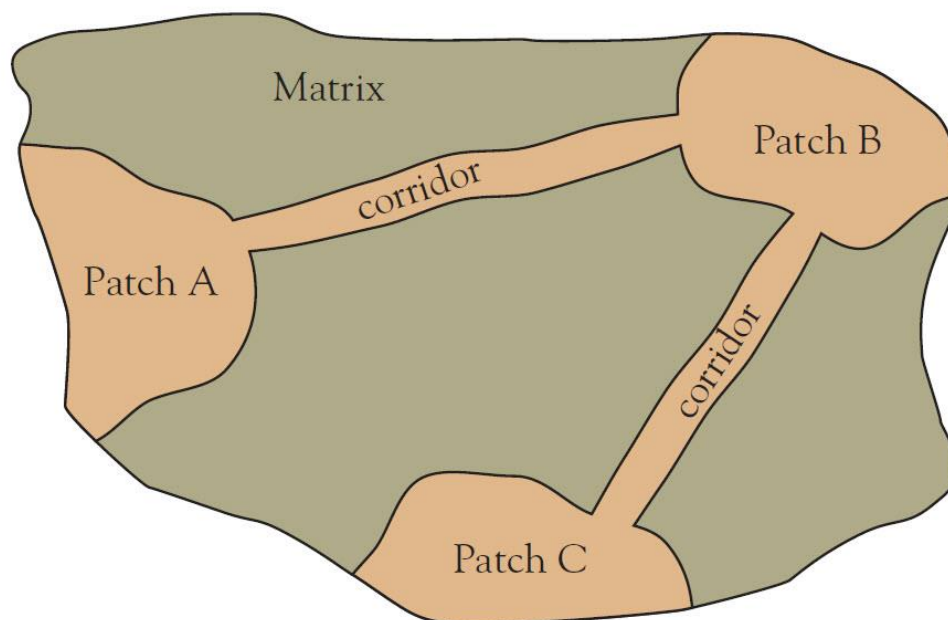


Figure 53: Landscapes consist of the matrix (the dominant feature), patches, and corridors that connect the patches. Source: (Barnes 1999a).

8.7 Urban nature

8.7.1 Biodiversity indicators

It is important to identify thresholds of habitat variables linked to maintaining or enhancing biodiversity (Marzluff and Ewing 2001). According to Fontana et al. (2011):

‘Quantitative information on the effect of management actions on biodiversity is often lacking but is an indispensable basis for decisions by urban planners and managers’ p.278

8.7.2 Birds as indicators

Birds are often chosen as indicators of habitat quality, as their ecology is well known, and they respond well to the availability of habitat structures (Clergeau, Savard et al. 1998; Evans et al. 2009). In cities, birds are widely considered as an optimal model group to study the ecological effect of urbanization (McDonnell and Hahs 2008). There are strong inter-species differences in responses of birds to urbanization (Møller 2009). Increased urban densification is therefore expected to lead to modifications of bird community composition and structure. Physical, abiotic conditions are similar between cities (Grimm, Faeth et al. 2008), so bird communities are often comparable at different latitudes (Clergeau et al. 2006; Evans, Newson et al. 2009).

The following general patterns have been observed regarding the effects of urbanization on avian biodiversity (Fontana, Sattler et al. 2011):

- 1) Species richness and diversity decreases along urbanization gradients from moderately urbanized to densely built-up areas (Clergeau, Savard et al. 1998; Clergeau, Croci et al. 2006).
- 2) Avian abundance, however, tends to increase along the same gradient (Clergeau, Savard et al. 1998; Palomino and Carrascal 2006; Grimm, Faeth et al. 2008), reflecting the dominance of few 'generalist' species leading to biotic homogenization (Clergeau, Croci et al. 2006; La Sorte and McKinney 2007).
- 3) 'Specialist' species with more narrow ecological requirements tend to decrease with increasing urbanization (Clergeau, Savard et al. 1998; Fernández-Juricic 2004; Devictor et al. 2007).

8.7.3 Enhancing urban bird populations

Several studies provide evidence that site factors such as the size of housing lots influence avian species occurrence in urban areas and that site scale decisions by property owners and developers can affect the nesting and feeding habitats for urban birds (McKinney 2002; Grimm, Faeth et al. 2008; Evans, Newson et al. 2009).

The following management actions have been devised by Fontana et al. (Fontana, Sattler et al. 2011) with the aim of enhancing urban bird populations:

- (1) Providing additional food resources (Gaston et al. 2007; Evans, Newson et al. 2009)
- (2) Enhancing reproduction possibilities with nest boxes (Gaston, Fuller et al. 2007).
- (3) Increasing structural vegetation diversity (Böhning-Gaese 1997; Chace and Walsh 2004).
- (4) Planting native in preference to exotic species (Chace and Walsh 2004; Daniels and Kirkpatrick 2006; Burghardt et al. 2009).
- (5) Preserving vegetation patches in urban developments (Croci et al. 2008).
- (6) Increasing connectivity between green elements within and around cities (Marzluff and Ewing 2001; Fernández-Juricic 2004).

A recent study by Fontana et al. (Fontana, Sattler et al. 2011) in three Swiss cities, quantified key urban variables to predict changes in avian biodiversity when the urban habitat is modified. The researchers found that bird species richness and diversity were negatively affected by increasing the proportion of sealed area or buildings, while increasing vegetation, particularly trees had positive effects. Their models predicted a 54% increase in bird species, from 13 species in the absence of trees to 20 species with 46% tree cover.

Increasing the coverage and complexity of greenery was shown to enhance species richness and diversity at a relatively small urban scale, similar to findings obtained at larger scales (Lancaster and Rees, 1979; Clergeau et al., 2001). The results suggest that the amount of trees is the most important

habitat variable for enhancing bird species richness and diversity in cities, as suggested by previous studies (Goldstein et al. 1986; Clergeau, Savard et al. 1998; Palomino and Carrascal 2006; Sandström, Angelstam et al. 2006; Evans, Newson et al. 2009). According to Fontana et al. (2011):

'Increasing the fraction of tree cover in the urban matrix seems to be the most promising and efficient measure to enhance bird species richness and diversity' p. 283.

8.7.4 Native versus exotic species

With regard to the effect of native vs. exotic plants on urban birds, studies in North America (Donnelly and Marzluff 2004) and Australia (Daniels and Kirkpatrick 2006) have found a higher correlation of native bird species with native plants than with exotic plants. Also in Australia, White et al. (White et al. 2005) found lower bird species richness and modified community composition in areas dominated by exotic vegetation, compared with areas dominated by native vegetation. In their study Fontana et al. (2011) noted that more than 60 bird species can breed in Swiss cities, which is (approximately one third of all regularly breeding species in Switzerland. However endangered and priority bird species are 'specialists' and are under-represented among urban birds Therefore providing optimal habitats in urban areas cannot substitute for bird protection measures outside the city (Miller 2006).

8.7.5 Biodiversity and urban trees

Street trees can also have ecological benefits in terms of enhancing biodiversity and creating urban wildlife habitats and corridors. However street tree plantings often comprise monocultures, lacking species diversity, limiting biodiversity and exposing street tree populations to the threat of species specific diseases (Richards 1993; Alvey 2006; Frank et al. 2006). Street tree plantings also do not usually include the creation of an understorey habitat. Street tree plantings may also exhibit a preference for exotic cultivated species, rather than native or indigenous species (Moore 2003; Hough 2004). However it has been demonstrated that even exotic trees play some role in attracting wildlife (Tait et al. 2005; Young and Johnson 2006). Street trees are utilized by a variety of bird species, including native birds, especially those well adapted to the urban habitat (Tzilkowski et al. 1986; Fernandez-Juricic 2000). Layering of vegetation, with trees, shrubs and understorey plantings, enhances biodiversity and also contributes to the total biomass and ecological services provided.

8.7.6 Biodiversity and Water Sensitive Urban Design

Kazemi et al. (2009) investigated the biodiversity of six bioretention basins in Melbourne, compared with other urban green-spaces. Greater species diversity was found in the bioretention basins compared with garden and lawn type green-spaces. It was concluded that the incorporation of vegetated WSUD systems in urban streets and green-spaces has the promise of enhancing urban biodiversity.

8.8 Biodiversity guidelines













'Rapid industrialisation, urbanisation, population growth and resource consumption in Australia have modified the environment and these factors will continue to drive change. Importantly, changes that reduce the ability of ecosystems to function will increase the difficulty and cost of

obtaining resources and removing wastes, and reduce the aesthetic and recreational benefits we derive from nature. We now have the knowledge and capability to influence future environmental change in a positive way. In order to reduce the negative impacts of climate change, water shortages and the loss of biodiversity, cities must be developed to incorporate, and therefore take advantage of, natural processes' (Roetman and Daniels 2008).

Roetman and Daniels (2008) provide guidelines for including biodiversity as a component in new urban developments in Australia:

- Suitable building sites should be planned that mould the streets and infrastructure to the landscape (Tyne 2000).
- Wherever possible, water courses should be left intact (Tyne 2000) and vegetation left along waterways, or replanted (van Roon 2005).
- Avoid fragmenting existing vegetation and habitat.
- Design biodiversity corridors within developments that link with surrounding environments.
- Where roads bisect the habitat of wildlife, traffic calming designs may be useful.
- To mitigate the impact of development on aquatic biodiversity, limit impervious surfaces (van Roon 2005)
- Maintenance costs, resources, and effort can be reduced by using indigenous species (Tyne 2000).
- Vegetation should be water sensitive, non-invasive, a sensible mixture of natives and exotics; consider all biodiversity (not just trees and grass)
- Urban consolidation reduces the impact of cities on the surrounding landscape, but can reduce biodiversity and the natural environments within cities. For this reason, consideration must be given to increasing urban biodiversity in innovative ways, including rooftop gardens (Tyne 2000; Daniels and Tait 2006).

As shown in Figure 54 Roetman and Daniels (2008) also illustrate the principles of habitat size, shape, and structure to improve biodiversity in urban areas.

Biodiversity value		Comments
Inferior	Superior	
 Small patch of habitat	 Large patch of habitat	More species can persist in a large patch of habitat with more food and shelter resources and less disturbance. The larger a patch of habitat, the more diverse and resilient it is.
 Increased edges	 Decreased edges	Patches of habitat with a high proportion of edges offer less shelter for the species that inhabit them and allow greater disturbance through trampling and weed invasion.
 Fragmented habitat	 Intact habitat	Intact habitats function better than fragmented habitats. Boundaries prevent plants and animals from dispersing through urban environments to find food and shelter resources.
 Disconnected patches	 Connected patches	The interconnection of many small biodiverse areas can emulate the benefits of larger, more intact habitats. Corridors allow biota to disperse through urban environments.
 Simple structure	 Complex structure	A complex assemblage of vegetation is better for wildlife, adapts better to change, and is more highly appreciated by people than a simple assemblage.
 Immature habitat	 Mature habitat	A mature assemblage of vegetation provides habitat for wildlife in logs and tree hollows. It takes many years of succession to establish a complex and healthy ecosystem.

- Figure 54: Principles of habitat size, shape, and structure for urban biodiversity planning. Source: (Roetman and Daniels 2008) based on Diamond 1975 and Soulé 1991.

8.9 Conclusions

- Urban development has impacted, and will continue to impact significantly on global biodiversity, which underlies healthy ecosystems and their ability to deliver ecosystem services which are essential to human health and well-being.
- Within urban areas natural habitats are replaced with urban ones, resulting in habitat fragmentation and biodiversity loss.
- Research shows that biodiversity, under certain measures, can be quite high in urban areas, however this may be a form of 'urban nature' comprising species better adapted to life in cities.
- Nature and the city were once considered mutually exclusive, however researchers in the natural sciences are now investigating 'urban nature', and the concept of nature has been expanded to include the 'urban ecosystem' of which humans are part.
- Urban densification has been found to have a major impact on biodiversity, tree canopy cover and open space provision.
- Urban nature and high levels of biodiversity in cities have been shown to have a number of human health and well-being benefits.
- Green Infrastructure initiatives which promote biodiversity and ecosystem health include the retention of remnant vegetation, the provision of large habitat 'patches' and the linking of those patches with habitat corridors.

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9 Food Production

Green Infrastructure

Green Infrastructure is the network of green spaces and water systems that delivers multiple environmental, social and economic values and services to urban communities. This network includes parks and reserves, backyards and gardens, waterways and wetlands, streets and transport corridors, pathways and greenways, farms and orchards, squares and plazas, roof gardens and living walls, sports fields and cemeteries. Green Infrastructure secures the health, liveability and sustainability of urban environments. It strengthens the resilience of towns and cities to respond to the major current and future challenges of growth, health, climate change and biodiversity loss, as well as water, energy and food security.

9.1 Introduction

Agriculture and productive agricultural land is a form of Green Infrastructure that can deliver a wide range of human health and well-being benefits that go well beyond providing a secure and healthy food supply. Urban agriculture includes the retention of valuable productive land on the urban fringe to provide more sustainable food sources for urban areas. Within cities urban agriculture provides social as well as healthy food production benefits, and includes community gardens, kitchen gardens and 'edible landscapes'. Community gardens are one specific type of urban agriculture that provide a unique range of social cohesion and community building benefits. In a broader context, urban agriculture is part of 'complementary' or 'alternative' food networks that promote more sustainable practices in food production and distribution. These are proposed as alternatives to current global food production and distribution systems driven by supermarket chains and large scale primary producers. Figure 55 summarizes the food production roles of Green Infrastructure.

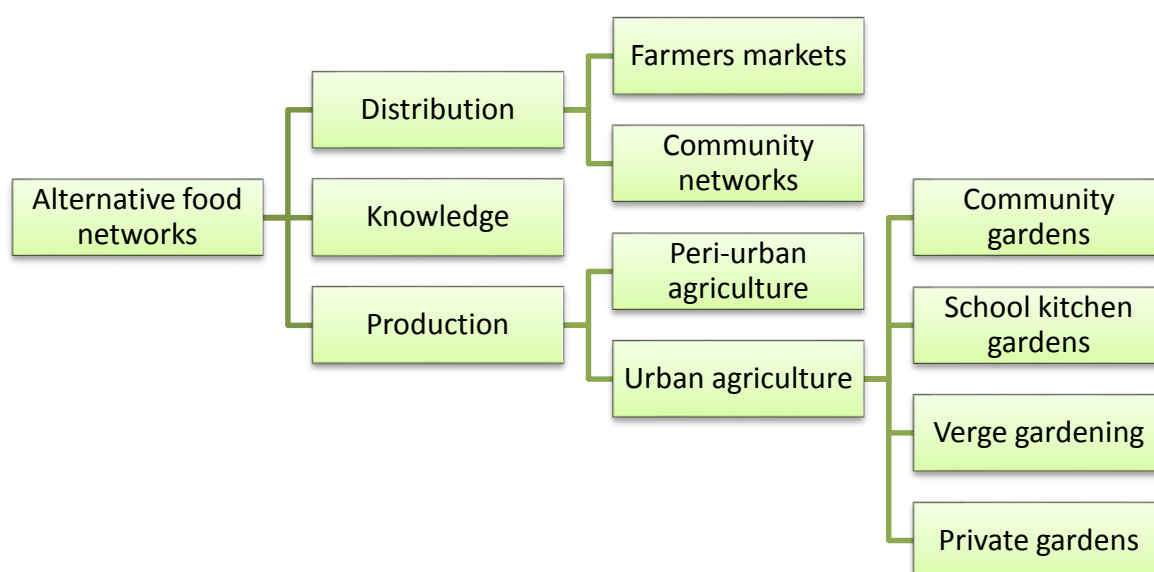
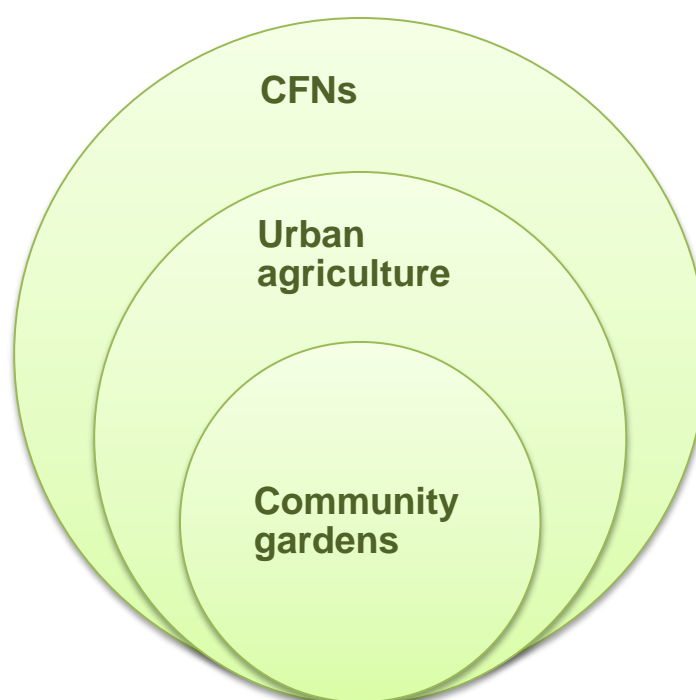


Figure 55: Summary of the food production role of Green Infrastructure. By author.

9.2 Overview

Figure 56 illustrates the positioning of community gardens within the broader context of urban agriculture and alternative food networks.



- **Figure 56: Community gardens, urban agriculture and alternative food networks.** By author.
- **Alternative or Complementary Food Networks (CFNs)** aim to achieve more sustainable models of food production and distribution, as alternatives to the current global system driven by large supermarkets and primary producers.

- **Urban agriculture** is one component of CFNs, and is defined as food production within cities, and can also include agriculture on the urban-fringe (peri-urban agriculture).
- **Community gardens** are one particular form of urban agriculture which have been shown to provide significant social cohesion and community building benefits that go beyond simple food production.

9.3 Alternative food networks

9.3.1 Overview

Urban agriculture and community gardens are one component of alternative or complementary food networks (CFN) (Firth and Pearson 2010). In recent years CFNs have emerged as alternatives the mainstream systems of food supply. Our current food system is based on an extremely effective model developed by large retailers which involves global sourcing of a wide range of food products (Pearson and Hodgkin 2010). According to David and Hodgkin (2010):

'The current food system in many developed countries is dominated by large-scale agricultural production and global sourcing through supermarkets and the food service sector. Collectively the wide range of activities undertaken in urban agriculture provide an important supplementary source of food, which adds to national food security. These complementary food systems also provide additional environmental and health benefits. Within this productive urban agricultural landscape, community gardens provide unique social contributions. The importance and magnitude of these justify continued policy support from government to overcome the market domination by large organisations as well as negative attitudes towards gardening from some members of society'. p.104.

In recent years people have been encouraged to engage as consumers with alternative food networks as a way of contributing to local and global sustainability (Halweil 2002; Pretty 2002; Halweil 2004; McKibben 2007). Alternative or complementary food networks have emerged from dissatisfaction with the modern industrial agricultural system. In essence the concept of alternative, or complementary food networks involves developing ways to grow and distribute food on a smaller, more localized scale (Pearson and Hodgkin 2010). As defined by Evers (2010) alternative food networks can include:

- Shorter distances between sites of food production and sites of food purchase/consumption.
- More 'environmentally friendly' production practices, including small-scale, organic/holistic farming (Pearson and Henryks 2008).
- An emphasis on fair trade, and sale venues that support local agriculture, such as farmers' markets.
- A commitment to socially, economically, and environmentally sustainable food production and consumption (Jarosz 2008)

CFNs are typically driven by 'people and communities' rather than corporate interests. According to Firth and Pearson (2010) the main themes found in literature on CFNs are:

- **Alternativeness.** CFNs are seen as alternatives to globalised conventional food networks, which are considered to be insensitive to place, people and local level concerns (Feagan 2007).
- **Community.** CFNs have their roots in community and consumer concerns about the ways in which food is grown and traded, and in the environmental impact of globalised food networks.
- **Access.** An important aspect of complementary food networks is that of 'localism' and the aim of 're-localising' food systems and shortening of food supply chains (Winter 2003; Pearson and Bailey 2009).

Sydney Food Fairness Alliance

The Sydney Food Fairness Alliance (SFFA) is a network of consumers, rural producers, health professionals, community workers and advocates who want to see food security for all within a socially, economically and environmentally sustainable food system.

In 2012 the SFFA aims to :

- support farmers in the NSW Year of the Farmer as they face increasing pressure from urban development, expansion of mining and the drive to lower prices
- Draw attention to food insecurity among low-income groups & lobby for increases in benefits; showcase projects that address food insecurity.

The SFFA calls for the formation of an independent Food Policy Council with state-wide responsibility to develop and ensure the security of the state's food supply.

The Council would adopt an integrated approach inclusive of:

- protection in perpetuity of prime agricultural land and the agricultural water supply
- compliance of agricultural production and distribution with the principles of ecologically sustainable development
- access to affordable and adequate fresh food irrespective of income
- investigation of innovative measures such as tax reforms and subsidies to promote access to healthy foods and reduce the burden of chronic disease
- a cautionary approach to approving new food production and processing technologies to ensure food safety
- adequate funding for agricultural research and development that complies with principles of ecologically sustainable development and especially the growing organic industry
- ensuring fair economic returns to farmers
- support for the development of community-based and regional food systems which support regional economies and improve food access
- ensuring people have access to information so as to make informed food choices

Source: <http://sydneyfoodfairness.org.au/>

9.3.2 Scope of CFNs

CFNs include a range of 'local food initiatives' or projects including both commercial and community-based ventures (Winter 2003). They encompass a wide range of practices including alternative food production, information and distribution systems. Pearson and Hodgkin (2010) provide the following examples:

- Providing **additional information** to allow consumers to make more informed choices, including food labelling that incorporate food miles and/or a carbon footprints. Maps can be developed showing where food is currently being grown and the location of vacant land in

urban areas with opportunities for food production, such as the VEIL project in Melbourne (Edwards and Mercer 2010). The concept of 'terroir' is also being promoted, which is a term for specialty foods which are valued by consumers because of their association with a particular region (Feagan 2007).

- **Farmers markets** which can bring consumers in contact with local producers and encourage local and seasonal consumption (Mason and Knowd 2010).
- Another community-based model **connects** small local producers and purchasers through websites and collection centres around a city, for example Food Connect.
- Increasing accessibility to local foods for example **food-sharing schemes** which may take place at community gardens, food swaps at fairs or simply by giving excess backyard produce to neighbours (Edwards and Mercer 2010).
- **Innovations** to increase the area used for food production for growing food. This can range from rooftop gardens (Skinner 2006; Wakefield et al. 2007) to vertical farming in climate-controlled skyscrapers custom-built for food production (Sullivan 2009).
- **Urban planning** innovations such as 'eco-cities'. In these alternative models cities can produce their own food and energy, reuse their own water, and treat and reuse wastes. 'Co-housing' is a similar concept in which groups of houses provide a shared space that includes gardens and composting areas. Examples include Pinakarri in Western Australia and Christie Walk in Adelaide (Crabtree 2005).
- **Gardening activities.** Private gardens have been reported to make a noticeable contribution to food production, at around five per cent. However they are not well represented in the literature on urban agriculture (Pearson and Hodgkin 2010).
- **Community gardens.** These are a special type of garden, and have been shown to provide the greatest social benefits of all alternative food systems, as well as providing valuable environmental, economic and health benefits (Pearson and Hodgkin 2010).
- **Kitchen gardens.** The suburban kitchen garden has a long tradition. Before the concept of ornamental gardens, plants were grown out of necessity. In Australia during colonial times and times of hardship (such as the World War Years and the Great Depression) vegetable gardens were an essential part of many Australian households. Community based kitchen gardens (which link food production, food preparation, cooking and eating) are now becoming an increasingly popular way for schools to promote environmental learning and to connect students with healthy food and lifestyles (Block and Johnson 2009).
- Activities such as '**gleaning**' (collecting fruit from street trees) and '**guerrilla gardening**' (where public spaces are cultivated without official approval) can add to the sum of urban agricultural production in a city.

9.3.3 Benefits of CFNs

Firth and Pearson (2010) list the following benefits of CFNs:

- Reducing unnecessary food transportation.
- Utilizing more sustainable food production systems.
- Increasing local employment.
- Retaining more money in the local economy.
- Providing better incomes for farmers.
- Creating greater trust and connection between consumers and producers (Pretty 2001).

Some researchers however have questioned the benefits of CFNs, including claims by their supporters of being more 'sustainable' (Winter 2003; Born and Purcell 2006). 'Localism' has also been criticized as a defensive reaction to protect local parochial traditions and practices (Holloway and Keasfey 2000). Another major criticism of CFNs is that the food they produce is often expensive and accessible only to 'elite' urban consumers and not the majority of the population (Goodman 2004).

9.4 Peri-urban agriculture

9.4.1 Overview

Agriculture on the edge of urban areas, (known as peri-urban agriculture) is not a new concept but was the traditional source of food for cities before cheap transportation enabled more distant production (Pearson and Hodgkin 2010). Peri-urban agriculture is of value both as a source of agricultural production and by creating buffers between cities and surrounding areas (Merson et al. 2010). The importance of preserving urban agriculture, including market gardens and farming, on the urban fringe is increasingly being recognised (Paster 2004; Mason and Knowd 2010). Issues of climate change and sustainable development, especially the impacts of oil based transportation, highlight the benefits of retaining productive agricultural land in close proximity to cities (Knight and Riggs 2010; Pearson et al. 2010). According to Kent et al.(2011):

'Urban agricultural lands play an important part in the production and supply of healthy food to urban areas in Australia and should be protected' p.96.

9.4.2 Planning issues

There is widespread concern in many cities that suburban development is encroaching on, and alienating, viable agricultural lands in close proximity to urban centres (Sinclair 2009).

Retaining agriculture on the urban fringe, however, often conflicts with other planning priorities, and productive land is often rezoned for residential use to accommodate population growth demands, at the expense of food production (Mason and Knowd 2010; Merson, Attwater et al. 2010). According to Merson et al. (2010):

'...it is clear that land-use planning, particularly with reference to lot sizes, subdivision and zoning objectives, is of paramount importance in maintaining agricultural land on the urban fringe' p. 80.

Despite its value, however, there appear to be few policies which protect and support urban and peri-urban agriculture (Mason and Knowd 2010). Some argue that urban and urban fringe farmers may actually need incentives to remain in place (Knowd 2006; Sullivan 2009). In some areas communities have successfully used tourism to support the peri-urban agriculture (For example the Hawkesbury Harvest Farm Gate Trail on the edge of the Sydney urban area) (Pearson and Hodgkin 2010).

9.5 Urban Agriculture

9.5.1 Overview

The term urban agriculture encompasses a wide range of agricultural food production practices occurring within urban areas (Brown and Jameton 2000; Drescher et al. 2006). The concept of urban agriculture is not new, but is now being revived by many communities. Urban agriculture was once common in Australian cities, however it began to decline in the 1980s (Gaynor 2006). Gaynor notes that urban agriculture is still common in many Asian cities. At least to the 1990s Singapore was self-sufficient in meat and 25 per cent self-sufficient in vegetables, and Hong Kong produced two-thirds of the poultry and almost half the vegetables it consumed (O'Meara 1999). Although the situation is clearly different in Australia, it does show the potential for urban food production in even the most dense cities.

9.5.2 Planning issues

Evers (2010) observes that today urban agriculture requires local and state government support in order to survive. In fact one of the reasons for the disappearance of urban and peri-urban agriculture (such as market gardens) from the Australian urban areas has been changes in land-use planning policies (Gaynor 2006). It has been demonstrated, however, that planners can 're-integrate' urban agriculture into land use planning. A recent survey of two northern American cities (Portland and Vancouver) reviewed efforts to better integrate urban agriculture into the planning process by first identifying land with a high potential for agricultural production. Preliminary indications were that this was being done successfully, however it was noted that both of these cities had pre-existing commitments to urban sustainability (Mendes et al. 2008).

9.6 Community gardening

9.6.1 Definitions

According to Evers (2010) a dense urban fabric does not mean that a city cannot provide at least some of its own food. However dense cities often have little private green space, so publicly owned open spaces may often be the most suitable venues for urban food production. Community gardening however, is simply one form of urban agriculture, the common feature of urban agriculture being the production of productive vegetation within an urban setting. Glover (2003) defines a community garden as being:

'organised initiative(s) whereby sections of land are used to produce food or flowers in an urban environment for the personal or collective benefit of their members who, by virtue of their participation, share certain resources such as space, tools and water' p. 264.

Community gardens have been defined by Somerset et al. (2005) as spaces that:

'provide an agricultural environment within city limits, where vegetables and fruit are produced, and in some cases livestock is cultivated. They are either owned and farmed by members of the community or subdivided into allotments cultivated by individuals' p. 26.

The *Australian City Farms and Community Gardens Network* provides a useful starting point for exploring the concept of community gardening. They define community gardens as *'places where people come together to grow fresh food, to learn, relax and make new friends.'* <http://communitygarden.org.au/>. Astbury and Rogers (2004) however consider that this broad description does not account for the many ways in which community gardens are manifest in urban areas. Projects vary considerably in size, from large-scale urban farms that occupy significant areas of land, to small-scale community allotments on restricted areas of vacant or unused public or private land. While community gardens are but one component of the wider urban agriculture system (and deliver the same economic, health and environmental benefits as urban agriculture) it is now recognized that they can make a unique contribution to social development and community building. Pearson and Hodgkin (2010) observe that this social contribution emerges from their unique structure, a structure which is also the major source of the challenges that they face.



Figure 57: Randwick community organic garden. Source: Randwick City Council.

9.6.2 History of community gardening

In the past community gardens were seen as an important way of overcoming food shortages during times of depression and war. Community gardening however declined during the post-war boom period when economic prosperity reduced the need for alternative food sources (Astbury and Rogers 2004). In the past 15 years however there has been renewed interest in community gardens, supported by government (especially local governments) which recognise their potential as cost-effective tools for community building (Grayson 2007). This has seen a shift of focus from community gardens as being primarily food sources to community gardens delivering long term social benefits.

Grayson (one of the inaugural founders of the Australian City Farms & Community Gardens Network) provides a detailed overview of the origins and history of community gardens in Australia, albeit from a Sydney based perspective (Grayson 2010). The 1977 Nunawading Community Garden in Melbourne was the first documented community garden in Australia (despite reports of a possible earlier community garden in South Australia). Sydney's first known community garden was Glovers Community Garden in Rozelle, built on what was then health department land followed in 1991 by Sydney's Waterloo Community Garden (on Uniting Church land) and Angel Street Permaculture Garden (on Education Department land). In Brisbane, Northey Street City Farm began around 1994 and became one of Australia's leading sustainability education centres, like CERES in Melbourne which dates from around 1984.

Darren Phillips created the *Australian City Farms & Community Gardens Network* in 1994 after coming across a large number of community gardens and other community-based initiatives in his PhD research, which were largely unknown to each other. The network is now an informal, national entity advocating and educating about community gardening and associated community food systems. Grayson observes that the late 1990s saw a steady growth in the number of community garden start-ups and this rate increased at the turn of the century. It was during this period that local and state government became involved in community gardens. State government began in the 1990s with the creation of *Cultivating Community* in Melbourne (which manages the community gardening and community food program for the Victorian Department of Human services Office of Housing). In Sydney Housing NSW adopted a policy for community gardens for their tenants on housing estate land. The first social housing community gardens, on the Waterloo Estate in inner urban Sydney, were assisted by South Sydney City Council through its 1995 food security policy which offered support for community gardens and other food initiatives.

Community garden start-ups increased at a more rapid rate from around 2003, due to a number of factors including growing support for community gardening from local government. Community gardens have become 'desirable' things to have in a local government context, although many councils do remain uncertain about their presence. The other stimulus for the growth in community gardens has been their appearance on television gardening programs and other media, which exposed the concept to a broader audience.

In Australia the number of community gardens increased from one in 1977 to over 40 in 1996, according to the pioneering survey undertaken by Dr Darren Phillips (Phillips 1996) entitled *1996 Australian City Farms, Community Gardens and Enterprise Centres Inventory*. Currently there are thought to be around 40 community gardens in South Australia alone, and details of 30 community gardens are listed in the 2012 *Guide to Community Gardens in South Australia* (Staniforth 2012a).

South Australian Community Garden Directory

1. Aberfoyle Park -Aberfoyle Community Garden
2. Adelaide - Box Factory Community Garden, Secateurs Project One
3. Adelaide - St Andrew's Hospital Garden, Secateurs Project Two
4. Adelaide – WalyoYerta Community Garden
5. Aldinga Beach – Aldinga Community Garden
6. Banksia Park Community Garden
7. Bedford Park – Flinders University Community Garden
8. Blanchetown Community Garden
9. Brompton – Green Street Community Gardens
10. Camden Park -Camden Community Garden
11. Campbelltown -Lochiel Park Community Garden
12. Christie Downs -Elizabeth House Over 50'sCommunity Centre
13. Clayton Bay – The Clayton Bay Community Association Garden
14. Davoren Park -Peachey Place Community Garden
15. Dernancourt Community Garden
16. Elizabeth – Anglicare SA Community Garden
17. Fullarton – FernAvenue Community Garden/Alternative 3
18. Gilles Plains – Wandana Community Garden
19. Glandore – Glandore Community Garden
20. Goodwood – The Goody Patch Community Garden
21. Goolwa – Cittaslow Goolwa Community Garden
22. Hackham South School Community Garden.
23. Hackham West – Urban Connection
24. Hackham West Community Garden
25. Henley Community Garden
26. Hillcrest – KurruruPingyarendi Community Garden
27. Kapunda Community Garden
28. Magill - Chapel Street Community Garden
29. Milang – Milang Community Garden
30. Mitchell Park –Marion LIFE Community Garden
31. Morphett Vale – Wakefield House Community Garden
32. Mount Barker – Duck Flat Community Garden
33. Mount Gambier – The Old Mount Gambier Gaol Community Garden
34. Murray Bridge – Murray bridge Community Garden
35. Naracoorte - Naracoorte Community Garden
36. Noarlunga Downs Primary School and Community Garden
37. Parafield Gardens – Morella Community Garden
38. Peterborough – Peterborough Community Garden
39. Port Lincoln – Port Lincoln Community Garden
40. Port Pirie – Port Pirie Community Garden
41. Prospect – Prospect Community Garden
42. Seaford – Seaford Ecumenical Community Garden
43. Seaford - Seaford Meadows Scout Community Garden

44. St Mary's – Picket Fence Community Garden
45. Semaphore – St Bede's Community Garden
46. Stepney – Linde Community Garden
47. Verdun – Adelaide Hills Community Garden
48. Victor Harbor – Victor Harbor Community Garden
49. Wallaroo – Wallaroo Community Garden
50. Williamstown – Williamstown Community Garden
51. Woodville – Ridley Grove Community Garden
52. Wynn Vale – Wynn Vale Community Garden
53. Whyalla Norrie – EcoLETS Garden Group

Source: (Staniforth 2012a).

9.6.3 Scope of community gardening

According to Grayson (2010) five models of community garden have evolved in Sydney over the past ten years, mainly related to the types of organizations that initiate these projects:

- **Self-managed gardens** in which the gardeners make the decisions and have responsibility for the direction the garden takes and for its day-to-day operation.
 - This model forms the largest group of community gardens.
- **Council-volunteer community gardens** in which the gardeners are council volunteers.
 - A council staff member has to be on site when gardening is taking place, so this suits only those with time available then. There are few gardens of this variety but Willoughby Council operates a successful community gardening team of the type.
- **Council-managed community gardens** which operate much like UK allotment gardens, with council licensing access to an allotment for a fixed period.
 - Council remains responsible for major decisions and, although there would be potential to democratise the process to the gardeners, the extent that this happens is likely to differ between gardens.
 - For councils, this model requires a dedicated staff position.
 - There are only a couple gardens of this type in Sydney (Hurstville and Waverley community gardens).
- **Agency community gardens** such as those started by a community centre or health centre.
 - These are reportedly in larger supply in Adelaide.
- **Social housing community gardens** participation in which is limited to state government social housing residents.
 - Cultivating Community manage such gardens in Melbourne, while Housing NSW has a policy to support gardens on its land and the Royal Botanic Gardens Trust has set up the Community Greening program to assist social housing gardens.

The City of Sydney (2009) recognizes a number of community garden models, with the most common in Australia being:

- **Community gardens** with a mixture of allotments for each member and some shared areas.

- **Communal gardens** where the entire garden is managed collectively. Some examples of communal gardens are food forests (which include structured layers of plants such as edible groundcovers, shrubs and trees).
- **Verge gardens** where garden beds are established on the nature strip. These are considered a type of community garden when they are managed collectively by a group of local residents and decisions are made jointly.
- **School kitchen gardens** are defined as community gardens when local residents outside of the school community can join the garden and manage the garden in partnership with the school. In this model, the garden may include individual plots for residents' communal garden beds that the school can manage and use for lessons on cooking, nutrition and the environment and provide produce for the school canteen. School kitchen gardens are not always set up as community gardens due to perceived problems with access and security for people outside of the school community.
- **Community gardens on public housing land** usually contain a mixture of plots and common areas and are specifically open to residents living in public housing. They are supported by the Botanic Gardens Trust and Housing NSW Community Greening program.

Grayson (2010) also looks at new directions which have recently emerged for community gardening, (from a Sydney perspective) and suggests that 'new directions' in other states may possibly be a little different. These new directions include:

1. The emergence of local government policy.
2. A structured approach.
3. Dedicated council staff.
4. Adoption of an educational role.
5. Multiple-use facilities.
6. Development of sustainability education hubs.
7. The 'speciation' of community gardening (i.e. the emergence of a range of different community garden models).

9.6.4 School Kitchen Gardens

School kitchen gardens provide opportunities to connect with nature and learn about healthy eating (Ozer 2007; Carlsson and Williams 2008). The Kitchen Garden Foundation, an Australian organisation founded by Stephanie Alexander, describes kitchen gardens as school gardens that are created to provide 'edible, aromatic and beautiful resources for a kitchen' (Stephanie Alexander Kitchen Garden Foundation 2012). The foundation claims that *'the creation and care of a kitchen garden teaches children about the natural world, about its beauty and how to care for it, how best to use the resources we have, and an appreciation for how easy it is to bring joy and wellbeing into one's life through growing, harvesting, preparing and sharing fresh, seasonal produce.'*



Figure 58: Kilkenny Primary School kitchen garden. Source: Stephanie Alexander Kitchen Garden Foundation.

Henryks (2010) has reviewed the literature on school kitchen gardens and found support for the positive impacts of kitchen school gardens on children in a number of ways including:

- Educational outcomes such as the effect of green environments on children's learning ability (Wells 2000; Bagot 2005; Maller et al. 2009).
- Nutritional knowledge (Graham and Zidenberg-Cherr 2005).
- Positively promoting physical activity for students (Bell and Dymont 2008).
- Children's psychosocial development, behavioural engagement and cooperation with peers (Pranis 2004).

Henryks also observes that school kitchen gardens involve not only children but also teachers, parents and other volunteer community members and there is little evidence on the benefits to these stakeholders. The author investigated this gap in the literature through an exploration of the various ways the Stephanie Alexander Kitchen Garden may have affected the lives of adult volunteers associated with the Majura Primary School in the ACT. A key finding was that volunteers experienced benefits they were not expecting and this had some effect on their lives.

9.6.5 Verge gardening

According to Grayson (2012):

'Street verge gardening is the practice of growing ornamental, native or edible plants on the footpath. The rise in popularity of edible gardens has brought the planting of fruits, herbs and vegetables, sometimes mixed with flowers and native plants, to our street verges'.



Figure 59: Chippendale NSW verge garden. Source: (Grayson 2012).

Verge gardening is another form of urban agriculture, which is now attracting attention and support in professional design circles. Verge gardening is also considered by some to be a form of community gardening, especially if there is collective management of the verge. Edible verge gardening is not new in Australian cities but can be traced to the period of immigration in the 1950s especially immigrants from Mediterranean countries. Some councils have also contributed to edible streetscapes (often unintentionally) by planting fruit and nut trees in urban streets and parks.

Urban agriculture and food security supporters are now advocating for councils to consider planting edible fruit and nut trees as part of street and park replanting schemes. These can provide the same 'ecosystem services' as other urban trees, but with the added benefit of an edible yield. One example is the citrus planted between eucalypts on the street verge adjacent to Glandore Community Centre in Adelaide. The citrus trees provide an edible understorey to the taller eucalypts, providing a pleasant and productive streetscape and a varied urban canopy. Others examples include the Myrtle Street plantings in inner Sydney and the community nut trees established in Totnes in the UK (Grayson 2012).

Some street verge gardens however may be spontaneous installations constructed without the approval or knowledge of council. Councils however have a number of valid concerns including questions of public safety and liability related to their responsibilities for managing council owned streets and street plantings. Potential issues include:

- Responsibilities for maintenance (as staff have may have no training in the maintenance of fruit and nut trees or skills such as pruning, pest management and harvesting).
- Slip hazards from fallen fruit and nuts.

- The possibility of homeowners abandoning their verge plantings. Where the verge garden is a community garden maintained by a team of local people the question is less relevant as such verge maintenance is a collective effort.
- Conflict with other street uses and activities, such as pedestrian access and access to parked cars.
- Conflicts with service infrastructure, both above and below ground.

One suggested solution with respect to fallen fruit is to 'glean' the fruit and nuts before they fall. Gleaners are already at work in cities harvesting apparently unwanted fruit, for exchange at food swaps. There is also potential for community organisations to take on the voluntary jobs of maintaining trees and harvesting produce. However if plantings are on public land it would appear that anyone can harvest from edible verge trees.

Some councils have taken a positive approach to verge gardening producing guideline documents (City of Sydney 2011). Where a number of households on a street is involved, the City of Sydney covers verge gardening within its Community Garden Policy (City of Sydney 2009). Justification for verge gardening may be drawn from a number of sources including:

- Food security.
- Neighbourhood beautification/visual amenity.
- Urban re-greening.
- Increasing biodiversity.
- Carbon sequestration in soils.
- Reduction of urban heat island effects.
- Developing social capital and civic engagement.

In Australia local councils are the traditional managers of the urban verge and have tended to limit resident initiatives in verge planting and management. A number of councils, however, have recently adopted 'Sustainable Streets', 'Adopt-a-Tree' or 'Adopt-a-Verge' initiatives which allow local residents increased 'ownership' and responsibility for verge improvements and maintenance. Such initiatives, however, require careful management policies and practices, to prevent unsustainable outcomes for council. Some Australian councils with edible verge gardening policies include:

- City of Sydney.
- Randwick City Council.
- Marrickville Council.
- Kogarah Council.

The Australian City Farms & Community Gardens Network has highlighted the need for design guidelines for edible verge gardens. The verge is often the 'public face' of the city and its treatment can determine the perceived amenity, desirability and attractiveness of a suburb. Past experience has shown that one of the most effective ways of obtaining community support is through well executed

demonstration projects, especially when undertaken on a shared partnership basis. The other key to a successful project is a collaborative approach involving all of the relevant disciplines within and external to council. In 2012 The Network produced a useful guideline document *Farmers of the Urban Footpath – Ideas for urban food gardeners and local government* (Grayson 2012).

9.7 Community Gardening Resources

There are now a large number of resources available in Australia to assist in the establishment and management of community gardens.

9.7.1 Community gardening websites

A number of state and national organizations maintain websites which are valuable resources for information sharing on community gardens and other forms of urban agriculture, including community gardening websites and guideline documents.

Australian City Farms and Community Gardens Network <http://communitygarden.org.au/>

The Australian City Farms and Community Gardens Network (ACGN) is an informal, community-based organisation linking people interested in community gardening from around Australia. It aims to promote the benefits of community gardening and facilitate the development and maintenance of gardens through information dissemination and advice. The Network was established in 1994 by Darren Phillips as a result of his PhD research into community gardens in Australia, which identified a lack of communication among various gardens, which were acting independently of each other rather than sharing information and providing support. The role of the ACGN has evolved over time to encompass a range of activities.

Australian City Farms and Community Gardens Network

An informal, community-based organisation linking people interested in community gardening from around Australia. Within the limits of our capacity, the network:

- advocates on behalf of community gardeners
- provides information on our website
- provides presentations and advice to local government, other institutions and communities interested in establishing community gardens.
- documents the development of community gardening in Australia
- provides a list of contacts through which the public may contact community gardens.

The Australian City Farms and Community Gardens Network connects community gardeners around Australia.

Source: <http://communitygarden.org.au/>

SA Community Gardens <http://communitygarden.org.au/2010/06/21/south-australia/>

The Australian City Farms and Community Gardens Network has links to networks in each Australian state including South Australia. The SA Community Gardens site provides access to the SA Community and School Gardens Network directory of SA Community Gardens produced by Jo Staniforth and the Adelaide Botanic Gardens Community and Kitchen Gardens Project (Staniforth 2012a).

Kitchen Garden Foundation Stephanie Alexander <http://www.kitchengardenfoundation.org.au/>

The stated aim of the Stephanie Alexander Kitchen Garden Foundation is to introduce pleasurable food education into as many Australian primary schools as possible. The fundamental philosophy that underpins the program is that by setting good examples and engaging children's curiosity, as well as their energy and their taste buds, they can be provided with positive and memorable food experiences that will form the basis of healthy lifelong eating habits. The movement began in 2001 when cook and food writer Stephanie Alexander OAM partnered with an inner-Melbourne school community to establish the Kitchen Garden Program at Collingwood College. According to the Foundation this pioneering approach to food education is now flourishing in many schools, through the support of national and state government funding. Schools joining the Stephanie Alexander Kitchen Garden Program commit to building the necessary infrastructure and delivering the program within the Stephanie Alexander Kitchen Garden Foundation philosophy. Kitchen Garden Schools deliver regular kitchen and garden classes, enabling skills-based learning that extends across the entire school curriculum. South Australian schools participating in the program include:

- Bridgewater Primary School
- Christie Downs Schools
- Clarendon Primary School
- Coober Pedy Area School
- Coomandook Area School
- Elizabeth Downs Primary School
- Elizabeth Park Schools
- Hampstead Primary School
- Happy Valley School
- Hawker Area School
- Indulkana Anangu School
- Kilkenny Primary School
- Littlehampton Primary School
- Loxton Primary School
- Macclesfield Primary School
- McDonald Park School
- McLaren Vale Primary School
- Napperby Primary School
- O'Sullivan Beach School
- Pimpala Primary School
- Quorn Area School
- Stirling North Primary School
- Sunrise Christian School – Whyalla Norrie
- The Heights School
- Ungarra Primary School
- Wirrabara Primary School
- Woodend Primary School
- Wudinna Area School

Community Centres SA <http://www.communitycentressa.asn.au/sector-development/community-gardens/>

In 2003-2004 Community Centres SA was funded by the Department of Health to co-ordinate a 'Community Gardening in SA' project. Community Centres SA sees community gardens as 'places where people come together to grow food and community'. One of the outcomes of this project has

been the '*Community Gardening in SA Resource Kit*' researched and written by Claire Nettle. In 2009, the Resource Kit was revised and updated, and reprinted as '*Growing Community: Starting and Nurturing Community Gardens*' (Nettle 2009).

Kitchen Gardens SA <http://www.kitchengardenssa.com.au/>

The Kitchen Garden Initiative is a strategic priority for the Botanic Gardens of Adelaide which promotes the development of kitchen gardens in homes, schools and communities in South Australia. As a collaborative partnership it encourages people to 'create their own connections between food, plants and culture'. The Kitchen Garden Initiative aims to develop a social, cultural and environmental understanding of where food comes from, from a horticultural, cultural and global perspective. Kitchen Gardens SA maintains a website which is supported by the Department of Environment, Water and Natural Resources, SA Health and Santos. The site includes a list of research publications including research into the benefits of children's involvement in community gardens. Some South Australian schools with kitchen gardens include the following, although many other schools are known to have kitchen gardens:

- Black Forest Primary School.
- Elizabeth Campus Childcare and Learning Centre.
- Elizabeth Downs Primary School.
- Elizabeth Vale Primary School.
- Goodwood Primary School.
- Immanuel Lutheran School Gawler.
- John Hartley School and Children's Centre.
- Mark Oliphant College.
- Woodend Primary School.
- Kilkenny Primary School.

9.7.2 Community gardening guidelines

A number of organizations produce guideline documents for groups wishing to establish community garden projects. An important example is *Growing Community: Starting and Nurturing Community Gardens* (Nettle 2009). Nettle was commissioned to write *Growing Community: Starting and Nurturing Community Gardens* for Community Centres SA and SA Health in 2009. The book and companion website were created to facilitate the establishment of new community gardens and to support existing gardens. Some other useful guideline documents include:

- *City of Sydney Draft Footpath Gardening Policy* 2011 (City of Sydney 2011).
- *Farmers of the Urban Footpath – Ideas for urban food gardeners and local government*. Australian City Farms and Community Gardens Network (Grayson 2012).
- *Getting started in community gardening*, City of Sydney (Thomas 2008).
- *Community Gardens Policy Directions for Marrickville Council* (Grayson 2007).
- *Randwick City Council. Community garden guidelines* (Grayson 2010a).

9.7.3 Links to community gardening projects

Online links to a number of leading community garden projects are also available. Some examples include:

CERES Melbourne <http://www.ceres.org.au/>

CERES is an award winning environmental park in East Brunswick, Melbourne. The CERES Community Food System is a working collection of farms, seed and food swaps, and ethical retail businesses that train, employ and connect diverse groups of people through locally grown organic food. CERES mission is to demonstrate how an urban city farm can anchor a community and contribute to the local economy, providing an ethical market place, and employment opportunities.

Northey Street Farm Brisbane <http://www.northeastcityfarm.org.au/>

Northey Street City Farm is a non-profit community organisation on Brisbane's Breakfast Creek in Windsor. The farm has been developed for people to enjoy and participate in the principles of permaculture. It is also intended to be a demonstration site where people of all ages can learn through practical, hands on experience.

Melbourne Community Gardens - Cultivating Community

<http://www.cultivatingcommunity.org.au/>

Cultivating Community is a non-profit organisation based in Melbourne which focuses on 'people, communities, gardening, farming, the environment and food'. Its mission is to 'work with diverse communities to create fair, secure and resilient food systems'. Cultivating Community was established in 1998 and is best known for its work supporting community gardens for tenants of inner-city public housing estates. Its activities span urban agriculture, food hubs, school gardens, permaculture, Community Supported Agriculture, organic farming, food waste management and environmental education.

9.8 Benefits of urban agriculture

9.8.1 Introduction

Urban or community based agriculture, and the use of local produce, have gained popularity in recent years, as evidenced by the increase in farmers markets and community gardens. The diverse social, economic and environmental benefits of urban agriculture have been examined across a number of research fields (Pearson and Hodgkin 2010; Pearson, Pearson et al. 2010). As well as supplying fresh quality produce (with health related benefits) local food production can be seen as an integral component of community building. Key health and well-being benefits include access to healthy food options and the opportunity to undertake physical activity (Mason and Knowd 2010). Farmers markets and community gardens also provide opportunities for social interaction and contact with nature, with related human health and well-being benefits (Teig et al. 2009; Maller et al. 2010; Pearson, Pearson et al. 2010). At a broader scale, urban agriculture can help address issues of climate change and food security (Macias 2008). The following section provides an overview of the benefits of Green Infrastructure in the form of urban agriculture, summarized on Figure 60.

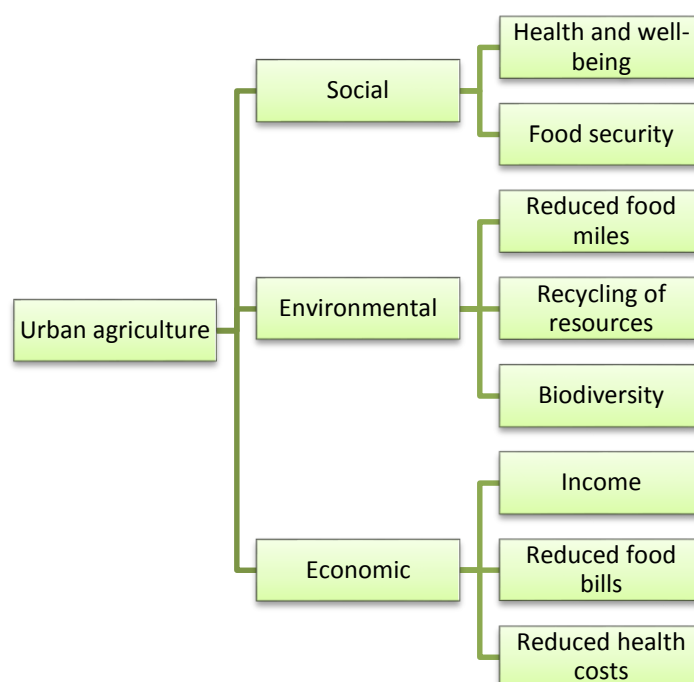


Figure 60: Benefits of urban agriculture. By author.

9.8.2 Environmental benefits

Reduced food miles

Today there are often great distances between where food is grown and where it is finally consumed. Long distance food transportation generates a range of environmental costs including increased air pollution and greenhouse gas emissions. The distance that food travels from initial production to processing, packaging and finally to consumer has been termed 'food miles' (Pearson and Hodgkin 2010). Concern about the environmental impacts of such food systems has led to emergence of a movement aimed at reducing these 'food miles' known as 'localism' (Edwards and Mercer 2010). Urban agriculture is one way to potentially reduce 'food miles'.



Figure 61: How far has your food travelled? Source; (SFFA 2006).

Composting and waste reduction

Many cities face significant environmental issues dealing with waste, including a move to the recycling of some materials (Pearson and Hodgkin 2010). Agricultural production in and around cities can support practices such as composting, which enables the re-use of high nutrient organic waste from food processing and consumption (Mougeot 2005). This also provides a valuable resource for the intensive production methods often adopted in urban agriculture. Composting and recycling can also help to increase soil quality in urban areas.

Water reuse

Water scarcity has become a major issue in many Australian cities. Urban agriculture can utilize waste water from urban development as well as re-using stormwater runoff in the food production process (Barker-Reid et al. 2010). Sustainable production however requires that appropriate crops be grown which are suited to an area's local water regime (Edwards and Mercer 2010).

Biodiversity

Compared with large scale agriculture, urban agriculture is made up of a large number of small producers, resulting in increased biodiversity (Feagan 2007). This biodiversity includes both spatial diversity (with a 'patchwork' of productive areas across the urban landscape) and biological diversity (with a variety of ecosystems associated with the different crops grown). Small-scale urban food producers also tend to avoid adopting high input monocultures, and production methods may often be more 'environmentally friendly' and can sometimes incorporate organic gardening practices.

Climate

Urban areas are subject to increased temperatures and urban agriculture is one way of increasing the sum of green areas within a city, which can assist in mitigating urban heat island effects (Skinner 2006).

9.8.3 Social Benefits

There are a number of practical ‘social’ reasons for growing food close to urban populations. These include health benefits, community education, fostering a sense of independence, and maintaining food security (Pearson and Hodgkin 2010).

Health benefits

Urban agriculture has a number of human health benefits including (Pearson and Hodgkin 2010):

- Long distance transportation and refrigeration have been shown to decrease the nutrient content of many fresh fruits and vegetables, and locally sourced food can promote a fresher and more seasonal diet (Feagan 2007; Pearson 2007).
- The diet-related human health risks of under-nutrition (malnutrition) or over-nutrition (obesity) may be reduced if people produce some of their own food, and at the same time reduce consumption of highly processed foods (Dixon et al. 2007).

Food knowledge and environmental awareness

- Localized production has the potential to increase food awareness and knowledge. Open days and tours of urban farms are one way for consumers to learn where their food comes from and how it is produced (Knowd 2006).
- Goltsman et al. (2009) highlight the link between environmental stewardship in children and health. They propose that children should be encouraged through learning and play to better engage with their environment. They advocate using neighbourhood parks and open spaces for children’s vegetable gardens or outdoor learning areas, rather than filling these spaces with ‘manicured park lawns and manufactured play equipment’ (Goltsman et al. 2009, p. 90). Their guidelines complement those outlined by Wake (2007) and Rayner and Laidlaw (2007) in an Australian context.

Urban greening

- Land dedicated to urban agriculture can act as a buffers to urban expansion and infill, and can provide increased visual and physical access to green space for city residents (Merson, Attwater et al. 2010).

Sense of independence

- In countries such as Australia a ‘sense of independence’ is considered to be important to individuals (as epitomized by the dream of owning a free-standing house and private backyard). Producing one’s own food can be seen as supporting this sense of independence which can be socially empowering (Gaynor 2006).

- Producing one's food can be an empowering experience, and this can occur through urban agriculture, including community gardens (DuPuis and Goodman 2005). Using in-depth, key informant interviews to study the impacts of a community farm in Ontario, Canada, Sumner et al. (2010) highlighted the important role of the community farm in connecting gardeners to both the community and the local food production process.

Food security

Food security is a global issue, and city dwellers are usually more vulnerable to food shortages than those in rural areas. It has been estimated that around one billion people, mostly in developing countries, are 'food-insecure' and at risk of under-nutrition (Pearson and Hodgkin 2010). Food security, however, can also be an issue in developed countries.

- It may be a particular issue for particular social groups include indigenous and aged people, migrants and the unemployed.
- At times of significant stress (such as drought, depression or war) it can also impact on large sections of the population (Dixon, Omwega et al. 2007).
- Developed countries which rely on imported foods may also be vulnerable to food shortages triggered by global economic or political instability, or other production shortages (Millstone and Lang 2008).
- The production of food in cities in the form of urban agriculture may therefore contribute, in some small way, to national food security.

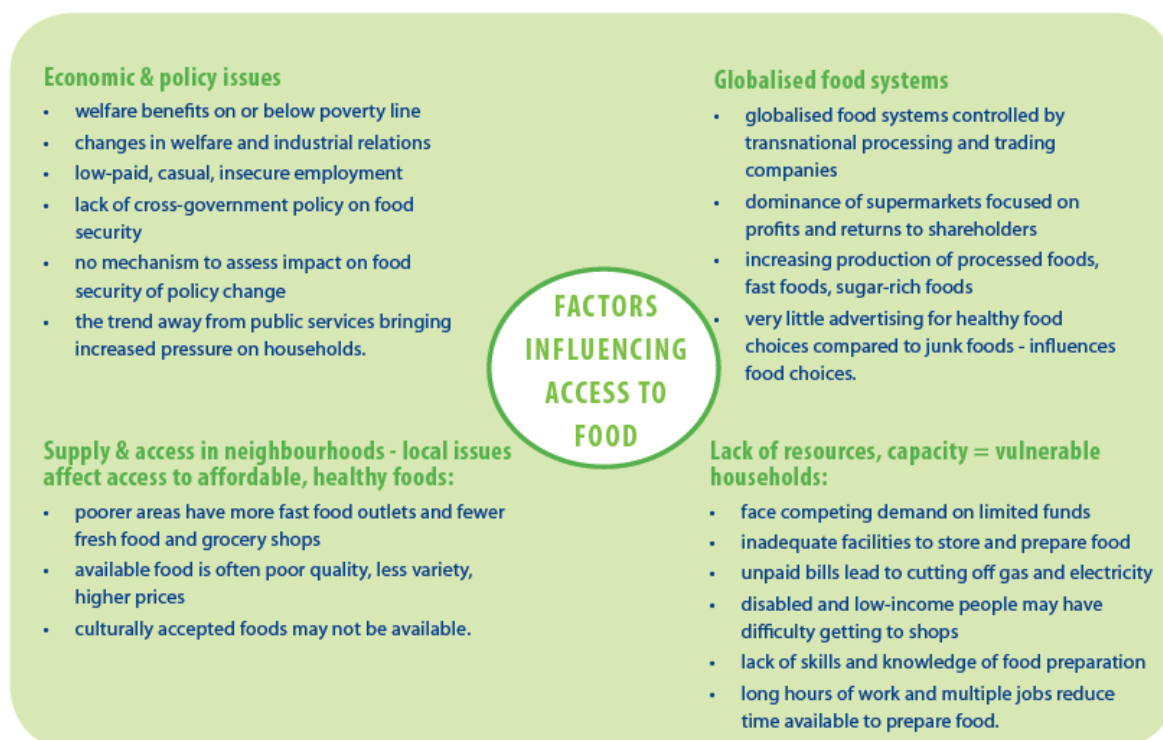


Figure 62: Factors influencing access to food. Source (SFFA 2007).

9.8.4 Economic benefits

A number of economic benefits may also accrue from urban food production (Pearson and Hodgkin 2010). These include:

- Personal income can be generated from working on farms or selling one's own produce. (Houston 2005).
- Producing food for personal use can also lead to a significant reduction in food bills. Pearson and Hodgkin (2010) however note that while increases in food prices may have contributed to the recent widespread participation in urban agriculture, over the long-term the relative price of food has fallen significantly, suggesting that the direct economic advantage of urban agriculture may diminish.
- Intensive small scale agriculture may be more 'efficient' than large scale agriculture in terms of productive output per hectare. In Australia peri-urban farms have been estimated to provide up to 25 per cent of the nation's total gross agricultural production, from only three per cent of its agricultural land (Houston 2005).

9.9 Benefits of gardening activities

Researchers have investigated the benefits of gardening as an activity, both individually and in a community garden context. According to Staniforth (2012b) :

'Research shows that engagement in edible and community gardens is highly beneficial. People, especially children, gain multiple benefits in social, physical and mental health, gain understanding and appreciation for the environment and are more likely to be engaged with the community'.

The following is a summary of some of the benefits cited in the document *Research that supports our work: Building support for your edible gardening program* produced by the Kitchen Garden Initiative at the Botanic Gardens of Adelaide (Staniforth 2012b):

Gardeners are more likely to eat fresh food, engage in healthy activity and have improved mental health.

- Gardeners eat significantly more vegetables than non-gardeners (Blair et al. 1991).
- After gardening, children have shown more positive attitudes toward fruit and vegetable snacks (Lineberger and Zajicek 2000).
- Children who grow their own food are more likely to eat fruits and vegetables (Morris et al. 2001; Pothukuchi 2004; Libman 2007; Dymont and Bell 2008a).
- Adolescents who participated in garden-based nutrition programs increased their servings of fruits and vegetables more than students in two other groups (McAleese and Ranklin 2007).

- Participants in six community garden programs increased their physical activity and their fruit and vegetable consumption (Twiss et al. 2003).
- Participation in a community garden leads to increased fruit and vegetable consumption (Alaimo et al. 2008).

Gardeners have better levels of social engagement.

- Parental involvement improves student achievement and this increases at schools with garden programs (Alexander et al. 1995; Dymont and Bell 2008a).
- After gardening, kids possess an appreciation for working with neighbourhood adults, and have an increased interest in improvement of neighbourhood appearance (Pothukuchi 2004).
- Children engaged in gardening programs are more accepting of others who are different from themselves (Eames-Sheavly 1994; Dymont and Bell 2008a).
- A United States telephone survey of 2,004 respondents showed that people engaged in gardening (picking vegetables, taking care of plants, or living next to a garden in childhood) were more likely to continue gardening as they aged and to form lasting positive relationships with gardens and trees (Lohr and Pearson-Mims 2005).
- Community gardens build community social cohesion and social capital (Glover 2004).
- Gardens improve social networks and community capacity through provision of social gathering space (Armstrong 2000).

Gardeners have enhanced life skills and learning skills.

- School gardening has been shown to increase self-esteem, help students develop a sense of ownership and responsibility, foster relationships with family members, and increase parental involvement (Alexander, North et al. 1995).
- In a project that involved integrating nutrition and gardening among children in grades one through four, students enhanced their understanding of good nutrition and the origin of fresh food and increased the quality and meaningfulness of learning (Canaris 1995).
- Children with learning disabilities, who participated in gardening activities, had enhanced nonverbal communication skills, developed awareness of the advantages of order, learned how to participate in a cooperative effort, and formed relationships with adults.
- Students who are actively engaged in garden projects tend to enjoy learning and show improved attitudes towards education (Canaris 1995; Dirks and Orvis 2005).

- Third to fifth grade students who participated in a one-year gardening program showed a significant increase in self-understanding, interpersonal relationship skills, and ability to work in groups compared to non-participating students (Robinson and Zajicek 2005).
- Students engaged in designing and maintaining gardens show an increase in self-efficacy (Poston et al. 2005; Lekies et al. 2006).

Children with special needs gain great benefit from involvement in gardening programs.

- Juvenile offenders who enjoy gardening show improved self-esteem, inter-personal relationships, and attitudes towards school (Flagler 1995; Waliczek and Bradley 2001; Cammack et al. 2002).

Gardeners have greater understanding of nutrition, science, and environmental processes and place greater value on the environment.

- Third, fourth and fifth grade students who participated in school gardening activities scored significantly higher on science achievement than those who did not experience any garden based activity (Klemmer et al. 2005).
- Students engaged in garden programs show stronger positive attitudes towards the environment (Skelly and Zajicek 1998; Mayer-Smith et al. 2007; Skelly and Bradley 2007) and higher sense of environmental stewardship. They also place higher value on natural areas in adulthood (Lohr and Pearson-Mims 2005).
- Elementary school and junior high school students gained more positive attitudes about environmental issues after participating in a school garden program (Waliczek and Bradley 2001).
- Children involved in gardening programs have higher levels of nutritional knowledge (Morris and Zidenberg-Cherr 2002).

9.10 Benefits of community gardens

9.10.1 Introduction

It is now recognized that community gardens are a special form of urban agriculture, which deliver the same benefits listed previously, but also make unique contributions to social development and community building. The benefits of community gardening have been well documented in recent years (Nettle 2010). Increasing recognition of this range of benefits has also led to community gardening being adopted and promoted by a number of organisations including community centres, social service providers, public health agencies, local governments and schools (Nettle 2010). A large body of research indicates that the benefits of community gardens extend well beyond increased physical activity and access to healthy food (Hynes and Howe 2004; Thompson et al. 2007; Wakefield et al. 2007; Macias 2008; Teig, Amulya et al. 2009). Figure 63 illustrates some of the benefits of community gardening.

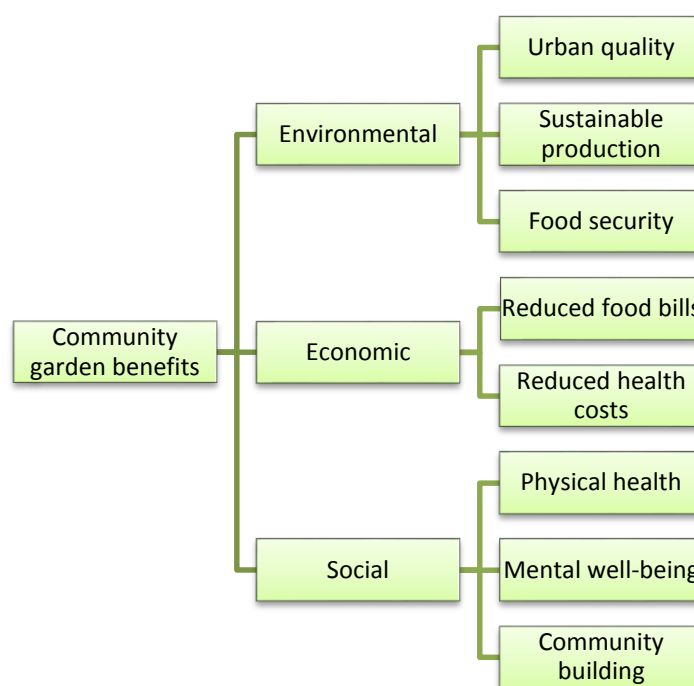


Figure 63: Benefits of community gardens. By author.

9.10.2 Overview of the literature

According to Firth and Pearson (2010) literature dealing with community gardens is mainly drawn from the discipline of social science, with contributions from sociology, human geography and anthropology. Community gardens are generally seen to provide benefits in terms of food production as well as human and social development. Cameron et al.(2010) review a wide range of academic material on community gardens, much of it highlighting the benefits of community gardening. For example:

- Academic health literature has identified individual and collective health benefits (both physical and mental) from access to fresh food, improved nutrition, physical exercise and working alongside others (Armstrong 2000; Teig, Amulya et al. 2009; McCormack et al. 2010).
- Community development literature highlights the role of community gardens in building community networks and social support, particularly in marginalised areas such as public housing estates (Saldivar-Tanaka and Krasny 2004; Glover et al. 2005; Glover et al. 2005a; Kingsley and Townsend 2006; D'Abundo and Carden 2008).
- Environmental education literature includes research on community gardens as educational resources that can promote learning about sustainability, healthy living and even democracy (Ferris. J. et al. 2001; Glover, Parry et al. 2005a; Levkoe 2006).
- Social movement literature includes research on community gardens as sites of grassroots political organising, particularly when gardens are under threat from development pressures. For example in New York City in the 1990s, and more recently around South Central Farm in South Los Angeles (Schmelzkopf 1995; Smith and Kurtz 2003; Irazábal and Punja 2009).

From a 'sustainability' perspective, Stocker and Barnett (1998) see community gardens as having the potential to promote physical, ecological, socio-cultural and economic sustainability in three key ways (p.180):

- 1) The local growth of foods (often organic) can provide people with fresh, safe foods that are fundamental to physical and ecological sustainability.
- 2) The making of community places provides opportunities for social and cultural interactions that form the basis for the evolution of socio-cultural sustainability.
- 3) Community gardens can function as research, development, demonstration and dissemination sites for community science, horticultural techniques and innovative technologies, contributing towards economic sustainability.

9.10.3 Previous literature reviews

A number of research publications include literature reviews of the benefits of community gardens. Several of these are outlined below.

Community Gardening: An Annotated Bibliography.

Nettle has produced an annotated bibliography on community gardening for the Australian City Farms and Community Gardens Network. The first edition was published in 2008 and a revised and expanded version, *Community Gardening: An Annotated Bibliography* was published in August 2010 including the latest research and analysis (Nettle 2010).

Evaluation of the Stephanie Alexander Kitchen Garden Foundation.

An evaluation of the Stephanie Alexander Kitchen Garden Program was undertaken by a joint research team from the Faculty of Health, Medicine, Nursing & Behavioural Sciences, Deakin University and the McCaughey Centre: VicHealth Centre for the Promotion of Mental Health and Community Wellbeing, University of Melbourne (Block and Johnson 2009). The evaluation included a review of literature on the benefits of kitchen gardens.

Healthy Built Environments: A review of the literature.

A literature review by Kent et al. (2011) examined research evidence demonstrating links between the built environment and human health. The focus of the review was on the key built environment interventions or domains that support human health, which comprise:

1. Getting People Active.
2. Connecting and Strengthening Communities.
3. Providing Healthy Food Options.

The study reviewed evidence supporting the proposition that '*Community gardens are forums for incidental and organised interaction. They are spaces for people to establish and maintain contact with community and contact with nature*'.

The researchers investigated the benefits of 'participation and empowerment' in producing one's own food, in a community garden context, and concluded that *'Participation in shaping the built environment supports interaction and psychological health by encouraging a sense of empowerment'*.

The researchers also reviewed the benefits of healthy food options via farmers' markets and community gardens and concluded that *'The link between exposure to community gardens and farmers' markets, with increased consumption of fresh fruit and vegetables, is obvious although difficult to quantify. Markets and gardens also facilitate community interaction and physical activity. They are an extremely valuable element of a healthy built environment'*.

Finally they reviewed the benefits of larger scale food production and concluded that *'Urban agricultural lands play an important part in the production and supply of healthy food to urban areas in Australia and should be protected'*.

A recent paper by Guitart et al.(2012) at Griffith University in Queensland reviewed the extent of English academic literature on community gardens, including: who has undertaken the research, where it has been published, the geographical location of the gardens studied, and the various methods used to undertake the research. The researchers reviewed 87 papers and found the academic literature on community gardens to be dominated by studies investigating gardens in low-income areas with diverse cultural backgrounds. Research based in cities in the USA also dominated the literature. Scholars from a wide diversity of disciplines were found to have examined community gardens but research was mostly concentrated in the social sciences. The authors also found that the natural sciences were notably under-represented, and suggested that they have much to offer to the field, including assessing gardening practices to better understand the agro-biodiversity conservation potential of community gardens.

9.10.4 Community Garden Project Reviews

A number of recent research projects have involved systematic reviews of existing community gardening projects, including assessments of the benefits reported by participants. These include:

Astbury and Rogers (2004). *Evaluation of the Stronger Families and Communities Strategy: Gilles Plains Community Garden. A case study.*

The Australian Government's Stronger Families and Communities Strategy has funded a number of projects to help build family and community capacity to deal with the challenges they face. Capacity, at a community level, refers to the potential for action arising out of the interplay between human capital (levels of skills, knowledge and health status) social and institutional capital (leadership, motivation, networks) and economic capital (local services, infrastructure and resources). The Gilles Plains Community Garden project received funding under the Strategy, and provides insights into how this capacity can be developed, and then used. These insights are relevant to a broad range of capacity building projects, not just to community gardens. In this project, some of the capacity was very tangible

(the physical infrastructure of the garden) but some was less tangible but equally important (the human capital of skills and knowledge; and the developing social capital of networks and trust).

A case study of Gilles Plains Community Garden project was conducted by Astbury and Rogers (2004). The researchers describe how the project was developed and implemented, its short term outcomes, and the potential for further outcomes through further use of the capacity developed in the program. The study analysed the factors seen to have been important in its success (including significant time and attention to planning and consultation, appropriate physical location, the development of effective partnerships, and building on previous developments). The case study also analysed the contribution of the Strategy to the observed outcome. It was concluded that with projects such as these, involving multiple activities and funders, support from the Strategy (through funding and assistance during project development and implementation) was a necessary component, and effective in combination with other efforts. The garden was seen as providing a useful metaphor for other capacity-building projects. Successful gardens and projects were seen to require thorough preparation and durable infrastructure. Once the initial construction has been completed, opportunities are created for a range of new activities and involvements.

Urbis Keys Young (2004). *Community Greening Program Evaluation Final Report, The Botanic Gardens Trust and the NSW Department of Housing.*

Urbis Keys Young was commissioned in September 2003 to conduct an evaluation for the Community Greening community garden program undertaken in partnership by the Botanic Gardens Trust and the NSW Department of Housing. The project was evaluated in terms of the five program objectives set out by the NSW Premier's Department. The main findings were as follows:

Reduced crime and antisocial behaviour

The program's main benefits regarding crime and anti-social behaviour involve reductions to vandalism and other opportunistic crime and increased feelings of safety and confidence moving about the estate for participants. A further, potential benefit is an increased likelihood to report crime.

Improved health and community resilience

The benefits of the program in terms of improved health and community resilience are apparent especially in terms of combating social isolation, increasing interaction between different cultures and between public housing and other residents, giving people a sense of place and of purpose, pride in their achievements and increasing ownership and use of shared spaces. Benefits to the physical health of participants through exercise and better nutrition are also reported to have occurred.

Improved educational and employment opportunities

There is one identified case of a participant taking up horticulture as a profession as a result of involvement in the program. A great number of participants consulted, however, were not of working age and some suffered barriers to education and employment outside the scope of the program (eg English language fluency). It is therefore unlikely that the program has had direct outcomes in terms of enhancing the employment status of most participants.

Improved local coordination and infrastructure

The program has generated cross- sectoral and cross-agency commitment at a local level. In addition there has been considerable partnership development between the business sector and the public sector, both at a local and a higher, program level.

Improved agency coordination and information sharing

The two principal partners in the Community Greening Program, the Botanic Gardens Trust and the NSW Department of Housing, appear to have developed a very successful partnership in which their skills have been effectively harnessed in support of the program.

Thompson, Corkery et al. (2007). *The Role of Community Gardens in Sustaining Healthy Communities.*

In this project the researchers studied a community garden operating in a public housing estate in Sydney's inner west, and drew conclusions on the role of community gardens in building healthy and sustainable communities. The authors described community gardens as 'places of refuge and social support, where knowledge is shared'. The study involved a literature review, data collection on the gardens, in-depth interviews with key stakeholders and five focus groups involving a total of 28 participants (50 per cent of all gardeners). The focus groups explored five key themes: activity and therapeutic benefit, ownership and belonging, social function, managing the garden, cultural diversity and safety. The study conclusions included:

- **Contribution to health and wellbeing.** The gardens were found to provide a setting for physical health benefits, through physical activity, access to fresh food and medicinal herbs, as well as psychological benefits through relaxation, meditation, the maintenance of a daily routine, and spiritual connection.
- **Contribution to community and social life.** The gardens were seen to facilitate social interaction and develop social capital within the community. The community gardens were identified as a place to develop friendships, care for others and break down barriers. Some gardeners also believed that the presence of the gardens improved neighbourhood safety and security.
- **Contribution to cross-cultural relations.** The gardens provided a link to many participants' traditional cultural practices. Specialised produce was grown for cooking ethnic dishes and the sharing of produce translated into the sharing of culture and knowledge.

Kinsley Townsend et al. (2009). *Cultivating Health and Wellbeing: Members' Perceptions of the Health Benefits of a Port Melbourne Community Garden.*

Kingsley et al. (2009) studied a community garden in Port Melbourne, to investigate the ways in which community gardens can contribute to enhanced health, wellbeing and contact with nature for city dwellers. Ten members from an urban community garden were interviewed to explore perceptions of the health and well-being benefits. The study concluded that:

- Many members saw the garden as a supportive place to discuss life issues. Spirituality was featured in the way members described their gardening experiences.
- Gardening was seen to promote enhanced connection with and enjoyment of the community, enabling people to achieve goals they did not think themselves capable of.

- Working in the gardens improved physical fitness and overall health through consuming produce.
- The community garden had individual health and wellbeing benefits, not least through providing an escape from daily stress, and a social outlet in an urban environment.

The authors described community gardens as 'places of refuge and social support, where knowledge is shared'. These conclusions are generally supported by other studies indicating that the benefits of community gardens extend well beyond physical activity and access to healthy food (Hynes and Howe 2004; Thompson, Corkery et al. 2007; Wakefield, Yeudall et al. 2007; Macias 2008; Teig, Amulya et al. 2009).

Block and Johnson (2009). *Evaluation of the Stephanie Alexander Kitchen Garden Program.*

An evaluation of the Stephanie Alexander Kitchen Garden Program was undertaken by a joint research team from the Faculty of Health, Medicine, Nursing & Behavioural Sciences, Deakin University and the McCaughey Centre: VicHealth Centre for the Promotion of Mental Health and Community Wellbeing, University of Melbourne, between 2007 and 2009 (Block and Johnson 2009). The 2½-year study tracked the progress of children participating in food education activities at Kitchen Garden Schools (at Donald, Foster, Sunshine North, Surfside, Westgarth and Yarrunga) and comparison schools (at Castlemaine, Heatherhill, Melrose, Pinewood, Spensley Street and Tongala). The findings were seen to be extremely positive and demonstrated that the Kitchen Garden Program was encouraging positive health behaviour change in participating children. The evaluation also highlighted the transfer of benefits to the home and the broader community. In particular the evaluation found:

- Strong evidence of increased child willingness to try new foods.
- Garden and kitchen classes were greatly enjoyed by children, and children at Program schools were significantly more likely to report that they liked cooking 'a lot'.
- Significant increases in child knowledge, confidence and skills in cooking and gardening.
- The Program was considered particularly effective at engaging 'non-academic learners' and children with challenging behaviours.
- The Program helped to create links between schools and the community. This was noted as one of its most important outcomes.
- Although the transfer of benefits to the home environment was not one of the goals of the Program, it strongly emerged as a flow-on benefit.
- Increased integration with the rest of the curriculum helped to overcome competing priorities for class time.
- Program schools on average generated \$1.93 of additional resources for every \$1 of government funding invested in the Program.

Bartolomei et al. (2003). *A Bountiful Harvest: Community gardens and neighbourhood renewal in Waterloo.*

Bartolomei et al. (2003) examined the social and 'health-promoting' roles of a community garden scheme in a Sydney high-rise public housing estate. The findings confirmed the role of community gardens in strengthening social interaction. The scheme was seen to be associated with increased opportunities for local residents to socialise and develop important cross-cultural ties in a very diverse environment. The authors noted that '*...there were many stories of how participating in the Gardens has helped to diminish cultural boundaries and negative racial stereotypes*' p.5.

Holland (2004). *Diversity and connections in community gardens: a contribution to local sustainability.*

In a comprehensive study of the community garden movement in the UK, Holland (2004) concluded that while some gardens played a strategic role in food production, all gardens were '*based in a sense of community, with participation and involvement being particularly strong features*'.

Wakefield et al. (2007). *Growing Urban Health: Community Gardening in South-East Toronto.*

Wakefield et al. (2007) researched the health impacts of community gardens in Toronto, Canada. The authors concluded that community gardens encourage physical and psychological health. Psychological health was attributed to contact with nature, as well as a general sense of community from the opportunity of gardening together. The research also highlighted challenges faced in establishing urban community gardens, including a general lack of understanding of their benefits, both by decision-makers and the community. This research complemented findings from earlier studies regarding the health benefits of community and private gardens (Irvine et al. 1999; Armstrong 2000; Brown and Jameton 2000; Hancock 2000; Doyle and Krasny 2003; Twiss, Dickinson et al. 2003; Waliczek et al. 2005).

9.11 Environmental benefits of community gardens

9.11.1 Introduction

Community gardens are noted as contributing positively to improving local environmental sustainability objectives within the urban landscape (Holland 2004; Andersson 2006).

9.11.2 Improving urban quality

Research shows that a significant proportion of land in many cities lies vacant and unused due to a number of factors, including population shifts due to de-industrialisation, patterns of irregular or small sized land parcels, and changing perceptions of desirable housing types (Schukoske 2000; Astbury and Rogers 2004). According to Grayson and Campbell (2000) community gardens can help improve the urban environments if they can '*bring derelict land into productive use, re-green streetscapes and increase wildlife habitat*' p.2. Research shows that community gardens can contribute to urban environmental quality by:

- Mitigating the effects of increased urban density and urban decay (Hall 1996).
- Reclaiming public space and blighted sites (Bartolomei, Corkery et al. 2003).
- Contributing to urban greening (Patel 1991; Bartolomei, Corkery et al. 2003).
- Enhancing urban green spaces (Hess and Winner 2007).
- Providing habitat for urban wildlife (Matteson et al. 2008).

Hall (1996) argues that community gardens should become a planning priority, and should be recognised as valuable social facilities as well as sites of food production, and should be zoned appropriately to protect their tenure. Hall portrays community gardens as an 'incremental step to more sustainable communities' which ease the stress of alienating urban environments, and preserve green and community spaces in the middle of increases in urban density.

9.11.3 Education and awareness

Community gardens can enhance environmental awareness through:

- Promoting awareness of organic gardening, permaculture and environmental sustainability principles (Astbury and Rogers 2004; Crabtree 2005).
- Providing settings for environmental education (Howe and Wheeler 1999; Bartolomei, Corkery et al. 2003; Corkery 2004).
- Developing innovative urban agricultural practices and acting as 'incubators' for organic enterprises (Fulton 2005).

9.11.4 Ecologically Sustainable Food Production

Community gardens are also part of broader moves to ensure a secure and ecologically sensitive food supply (Nettle 2009). Aspects of sustainable food production include the following.

9.11.4.1 Local food movements

According to Turner (2010) the localisation of food production (in particular urban agricultural practices such as community gardening) can contribute to the creation of more sustainable cities, and has been the focus of a growing body of research. Community gardens can provide:

'...the potential to redress the 'urban disconnect' from the food system. This disconnection is well documented and largely seen to be a response to the international restructuring of agribusiness, which has increasingly positioned food as a commodity and Western urban dwellers as passive consumers of food increasingly alienated from its production....this disconnection also contributes to the persistence of a nature–culture divide in urban areas. Indeed, a lack of engagement with food production and, more broadly, of regular engagement with nature in familiar, intimate urban spaces may be an important factor in maintaining this divide'.p.81.

According to Turner the separation of our everyday lives from nature contributes to the growing disconnect between urban consumers and the produce they buy and consume. Research indicates that this 'disconnect' is impacting adversely on local economies, personal and community health, the environment and social cohesion (Pothukuchi and Kaufman 1999; Kingsley and Townsend 2006).

Urban or civic agriculture and, in particular, local food movements, have been championed as ways of bridging this disconnect. In recent years people have been encouraged to engage as consumers with alternative food networks as a way of contributing to local and global sustainability (Halweil 2002; Pretty 2002; Halweil 2004; McKibben 2007). Localization of food production can help to reduce 'food miles' (Moskow 1999; Pothukuchi and Kaufman 1999; Drescher, Holmer et al. 2006). Reducing food miles can reduce the energy used to transport produce long distances from growers, to processors, to retailers, to consumers. (Nettle 2009).

9.11.4.2 Sustainable production practices

Community gardens can also support and promote a range of more sustainable food production and land management practices. Nettle (2009) outlines a number of these benefits:

- Organic practices adopted by many community gardens can lower the economic and environmental costs of food production by minimising or eliminating chemical use, and returning nutrients to the soil.
- Genetic diversity of food may be protected by community gardeners who may grow seeds of local plant varieties which are better adapted to the local conditions and the cultures of the communities who grow them.
- Community gardens can promote waste minimisation and nutrient cycling, demonstrating composting techniques that can be used in people's home gardens, and providing community composting facilities.
- Community gardens can demonstrate strategies for waste recycling and re-use. Community gardeners have found ways to redeploy waste resources without sacrificing safety or aesthetics.

9.11.5 Food security

Nettle (2010) has reviewed the potential contributions of community gardens to a more equitable and sustainable food system, and the ways in which food security has become a focus of some community gardening projects. Rychetnik et al. (2003) note that some community garden schemes are seen as part of strategies to increase food production (Rychetnik, Webb et al. 2003). Australian national food supply is currently sufficient, and issues of food insecurity are associated more with unequal access to that food. It has been found that when households are consulted about preferred strategies for increasing food security, access to land to grow their own food is given a high priority (Deane 2009). It has also been observed that the value of community gardens to food security can go beyond access to land for food production, but can also contribute to the building of skills and expertise to improve food knowledge and community food networks.

Recently Australian governments have funded a number of community garden projects which address food security issues (Tyrrell et al. 2003; Fergie 2005; Rowe 2007; Amy 2008; Davis 2010). At the local government level, community gardens have been an important part of programs to address food security (Moffett 2010). A number of councils have developed community garden policies and these are increasingly being linked to food policy, as well as environment and community development themes (Nettle 2010). Community gardens have also become an accepted strategy for addressing food access in remote indigenous communities (Browne et al. 2009). Community garden advocates have suggested that urban agriculture will become increasingly important as agri-food systems are impacted by climate change, water shortages, and oil supplies, and individuals look for alternatives to the industrialised food system (Nordahl 2009). Nettle (2010) observes that:

'In the light of climate change, dwindling water resources, peaking oil supplies, crises in agri-food systems, and persistent social inequity there has been heightened attention on food security. In

this context, community gardens have increasingly been described and promoted as food security initiatives’.

9.12 Economic benefits of community gardens

Community gardens can provide economic benefits to both participants and their local communities.

Researchers have found that community gardens can:

- Contribute to household food budgets (Patel 1991).
- Contribute to household economies (Blair, Giesecke et al. 1991; Patel 1991).
- Incubate small enterprises (Fulton 2005).
- Provide a low-cost form of urban space management (Francis 1987).
- Lead to reduced crime and vandalism (Maxwell 2002; Hatherly 2003; Urbis Keys Young 2004).
- Reduce community health care costs through improved physical and mental health (Patel 1991; Irvine, Johnson et al. 1999; Armstrong 2000; Twiss, Dickinson et al. 2003; Wakefield, Yeudall et al. 2007).

9.13 Human health and well-being benefits of community gardens

9.13.1 Introduction

In addition to food production, community gardening can have a range of social and human health and well-being benefits. According to Kent et al. (2011):

‘The link between exposure to community gardens and farmers’ markets, with increased consumption of fresh fruit and vegetables, is obvious although difficult to quantify. Markets and gardens also facilitate community interaction and physical activity. They are an extremely valuable element of a healthy built environment’. p.96.

9.13.2 Physical health benefits

Community gardening is an active pursuit that can provide a range of physical health benefits (Astbury and Rogers 2004). Researchers have found a number of health benefits from community gardening including:

- Improving the ‘quality of life’ of participants (Blair, Giesecke et al. 1991).
- Increasing participants’ physical activity (Twiss, Dickinson et al. 2003).
- Exercise associated with gardening has been found to provide significant benefits to individual health including reduced cholesterol and blood pressure (Armstrong 2000). In Australia, gardening is one of the most popular leisure pursuits and is a recommended form of physical activity.

9.13.3 Nutritional benefits

Participation in community gardening has been shown to enhance fruit and vegetable consumption through:

- Increasing access to fresh (sometimes organic) produce (Lea 2005; Alaimo, Packnett et al. 2008).
- Increasing fruit and vegetable consumption (Blair, Giesecke et al. 1991; Twiss, Dickinson et al. 2003; Alaimo, Packnett et al. 2008).
- Helping people become more familiar with fresh produce, and adding to the enjoyment of fresh fruit and vegetables (Somerset and Markwell 2009).
- By growing some of their own fresh fruit and vegetables individuals and families can increase their consumption of nutritious food and decrease their consumption of sweet foods and drinks (Blair, Giesecke et al. 1991).

Several qualitative research studies have examined the relationship between community gardens specifically, and increased access to and consumption of fresh fruit and vegetables (Hynes and Howe 2004; Thompson, Corkery et al. 2007; Wakefield, Yeudall et al. 2007).

Wakefield et al. (2007) reported greater access to fresh fruit and vegetables as the most often cited benefit of community gardens in South-East Toronto (including increased intake, decreased cost, and increased variety and freshness).

According to Hynes and Howe (2004):

'A study of 144 community gardeners in Philadelphia and 67 non-gardening controls evaluated the nutrition and economic benefits of community gardens. ... gardeners ate vegetables significantly more than comparable non-gardeners and consumed significantly fewer sweet foods and drinks and milk products' p. 7.

In Australia Thompson et al. (2007) examined the role of community gardens in building healthy and sustainable communities in a large high rise public housing estate in inner Sydney. Their research found that the food from community gardens was perceived to have medicinal as well as nutritional value, and that it was possible grow fresh produce not generally available in Australia.

McCormack et al. (2010) reviewed 16 studies of farmers' market programs and community gardens in terms of nutrition-related outcomes. The researchers also considered the ability of these programs to affect attitudes and beliefs about buying, preparing, and eating healthy food. The study found that such attitudes generally became more positive after exposure to a farmers' market or community gardening experience, but it is not known if this is sufficient to affect long term dietary habits.

Another study by Larsen and Gilliland found that a farmers' market increased local competition with nearby food stores, decreasing the price of fresh fruit and vegetables over a three year period (Larsen and Gilliland 2009).

One study in Canada however found support for organic produce came primarily from highly educated professionals and that 'class-based' differences in market participation highlight the need for local food projects to engage across a range of social groups and geographical locations (Macias 2008).

9.13.4 Psychological benefits

- Astbury and Rogers (2004) note an extensive history of the use of community gardens in improving psychological well-being, through horticulture therapy, which has been used in prison and mental health settings as a form of rehabilitation.
- Several of studies have explored the psychological benefits of gardening and found that it has the potential to relieve anxiety, stress, depression and promote relaxation through nature-based activity (Kaplan 1973; McBey 1985; Brown and Jameton 2000).

9.13.5 Educational benefits (Astbury and Rogers 2004)

- An important psychological benefit of community gardens is the ability to encourage learning and growth among individuals, as well as to facilitate community education. It has been suggested that learning to grow plants stimulates the mind and adds to an individual's knowledge and skill base (Astbury and Rogers 2004).
- Community gardening can assist in community education on issues such as waste management, composting, recycling, water reduction and organic gardening. A number of community gardens have been used as learning venues by local schools, TAFE colleges and universities (Astbury and Rogers 2004).
- School kitchen gardens provide opportunities to connect with nature and learn about healthy eating (Planet Ark 2012).

9.13.6 Cultural benefits

Nettle (2009) notes a number of 'cultural' benefits of community gardens including:

- Community gardens can be places where people of diverse cultural backgrounds can practise and share traditional and contemporary expressions of their culture, which provides a unique opportunity for learning and exchange.
- Community gardens often include community arts projects, from murals to sculptural installations, photo essays to poetry performance, and some community gardens create community culture through festivals and celebrations, including fairs, produce sales, farmers' markets or music performances

9.14 Social benefits of community gardens

9.14.1 Introduction

It is often observed in the literature that community gardens can promote social inclusion and community-building (Glover 2003; Saldivar-Tanaka and Krasny 2004; Lautenschlager and Smith 2007; Kingsley, Townsend et al. 2009; Tan and Neo 2009). A study by Armstrong (2000) of community gardens in upstate New York found that the attributes of community gardens (such as social support, an emphasis on informal networks, and community organising through empowerment) provide a valuable tool for public health promotion in socially and economically disadvantaged communities. According to Nettle (2009):

‘Community gardens engage and involve people in their own communities. They give people the chance to physically shape the character and culture of their neighbourhoods, and to take responsibility for their common land. Community gardens are meeting places, bringing together diverse aspects of local communities. They allow neighbours to meet on neutral soil, and provide common ground for people of varying cultural backgrounds, experiences, ages, and interests’.

An overview of the research shows that community gardens can:

- Reduce social isolation (Urbis Keys Young 2004).
- Contribute to community development outcomes (Armstrong 2000; Hancock 2000; Bartolomei, Corkery et al. 2003; Twiss, Dickinson et al. 2003; Saldivar-Tanaka and Krasny 2004).
- Build social capital (Armstrong 2000; Kingsley and Townsend 2006).
- Create opportunities for communities to develop and tell success stories (Glover 2003a).
- Foster relationships across ‘difference’ (Shinew et al. 2004).
- Provide community meeting spaces (Saldivar-Tanaka and Krasny 2004).
- Foster leadership development (Saldivar-Tanaka and Krasny 2004).
- Foster ‘civic values’ and public spiritedness (Glover, Shinew et al. 2005).
- Address poverty and social deprivation (Hanna and Oh 2000; Glover 2003).

Alternative food distribution venues such as farmers markets can also provide a range of social benefits. Not only are consumers able to get to know the producers of their food, but sociologists have found that shoppers in farmers’ markets have ten times as many conversations as shoppers in supermarkets (Halweil 2002).

9.14.2 Building social capital

The concept of developing ‘social capital’ has been recognized as a particular outcome of community gardening. Firth and Pearson (2010) have analysed the ‘community’ aspects of community gardens in the United Kingdom. According to the authors:

‘Social capital is a term used to refer to social structures, institutions and shared values making up communities. It widely used as a means of explaining ways in which communities or

individuals might (or might not) connect in a variety of community, civic, cultural, or economic structures. The degree of interaction and trust in one's fellow citizens is implicit in the idea of social capital, as is membership of a network, and a shared set of values. Hence social capital is a way of conceptualising community'.

Woolcock (2001) recognises several different types of social capital:

- **Bonding social capital.** Defined as strong ties between individuals in similar socio-demographic situations, such as one's immediate family, close friends or neighbours.
- **Bridging social capital.** A term used to describe more distant ties to like persons such as workmates. Bridging social capital tends to be outward-looking and brings people together across diverse socio-demographic situations.
- **Linking social capital.** This refers to connectivity between unlike people in dissimilar situations, for example connections with people in power, such as those in politically or economically influential positions.

Research by Firth and Pearson (2010) explored the nature of community in and around community gardens. The authors concluded that community gardens do generate social capital, although this varied between different gardens. The authors identified five ways in which community gardens can generate social capital:

- 1) Bringing people together with a common purpose.
- 2) Creating a physical meeting place.
- 3) Sharing in food related activities.
- 4) Building bridges to other neighbourhoods.
- 5) Providing links to institutions and funders.

The researchers also found that the most successful community gardens (in terms of community building) are likely to be those:

- Initiated and managed by participants whose motivations and values are similar.
- That are 'place based' and focussed on 'territorial communities'.
- Engaged through bridging and linking social capital with other community organisations and ethnic groups. This bridging and linking support is seen as vital to their longevity and ability to generate social capital.

Some community gardens however may be 'externally driven' and have little interaction with their local community. The authors regard these as 'issue based' or 'community of interest' and the social benefits can remain largely within the group and not extend to the wider community.

A local example of building social capital is that of the Gilles Plains community garden. A review of the community garden by Astbury and Rogers (2004) showed that it contributed to the social, economic, environmental, psychological and health outcomes for participants, as shown on Table 25.

Table 25: Outcomes for participants at the Gilles Plains Community Garden. Source: (Astbury and Rogers 2004) p.26.

Types of outcomes for participants in community gardens	Examples from the Gilles Plains Community Garden
Social	<p>Sense of working together to accomplish something.</p> <p>Sense of belonging.</p> <p>Shared recreation with family.</p>
Economic	<p>Development of skills and knowledge related to gardening and plants.</p>
Environmental	<p>Improved attractiveness of physical environment.</p> <p>Increased awareness of water conservation, waste management, organic gardening, composting.</p>
Psychological	<p>Sense of well-being and satisfaction.</p> <p>Calming atmosphere.</p> <p>Improved mental health.</p>

Importantly, as shown on Table 26, the researchers found that the community garden had built capacity for further projects and development.

Table 26 Capacity building at the Gilles Plains Community Garden. Source: (Astbury and Rogers 2004) p.27.

Types of capital	Examples from the Gilles Plains Community Garden
Human capital	<p>Secondary and TAFE students' knowledge of history and culture of the area, biology and science of plant growth, food production and preparation.</p> <p>Horticulture skills development of volunteers.</p>
Economic (including environmental) capital	<p>Physical infrastructure of the garden which allows further developments.</p>
Social capital	<p>Co-operation between individuals.</p> <p>Encouraging participation in organisations.</p>
Institutional capital	<p>Development of working group membership, processes and principles.</p> <p>Co-operation between organisations.</p>

9.15 Barriers to community gardens

Despite their benefits, there are a number of barriers to establishing and maintaining successful community gardening projects (Saldivar-Tanaka and Krasny 2004; Grayson 2007). Pearson and Hodgkin (2010) summarize the many challenges facing community gardens and other forms of urban agriculture including:

- Availability of land.
- Support from local government to allow land to be used for food production.
- Attitudes of neighbours and general public to the land use.
- Domination of the food market by large farms and supermarkets.

Societal attitudes have also been found to be significant barriers to urban agriculture. For example:

- Gardens may be seen as 'unconventional'.
- Produce may be stolen or vandalised,
- Neighbours may complain about unsightly areas and unusual smells (Hujber 2008).
- Younger people in cities tend to be socialised for variety and novelty, which may not be compatible with adjusting to consuming local and seasonal production (Dixon, Omwega et al. 2007).
- There may be resistance to 'things outside of the norm' leading to a separation between those involved in urban agriculture and the rest of society (Feagan 2007).

In addition, some government policies are not always supportive of urban agriculture. For example:

- A number of authors argue that adopting appropriate zoning to maintain land for food production and protect it from urban encroachment (in both new green-field sites and urban infill) is essential to maintain a capacity for urban food production (Pearson 2010; Pearson et al. 2010).
- Some government policies (such as water restrictions, animal laws and rental agreements) can be unsupportive of urban agriculture (Pothukuchi and Kaufman 1999).

Community gardens therefore face unique challenges. According to Hujber (2008) who reviewed community gardens in Melbourne, the limited amount of land available with suitable tenure is seen as the most important restriction on expansion. In addition, access to funds for garden establishment, ongoing insurance and restrictions on the use of water were also seen as challenges

9.16 Summary

- Food production in and around cities is considered to be one component of Green Infrastructure.
- Research supports a range of benefits from retaining valuable agricultural land in close proximity to cities.
- Agricultural production can also be integrated into urban areas in various forms including community gardens, productive verges and edible landscapes, and school kitchen gardens.

- Research shows that these initiatives provide a wide range of benefits going well beyond healthy food options, including improving the physical and mental health and well-being of older people, children and the general population, and providing a venue for social interaction.
- Community gardens in particular have become a focus for community building in recent years.
- Researchers have reviewed the scope of recent literature on community garden benefits and have identified areas for further research, including greater involvement by researchers in the natural sciences.

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10 Conclusions

Green Infrastructure

Green Infrastructure is the network of green spaces and water systems that delivers multiple environmental, social and economic values and services to urban communities. This network includes parks and reserves, backyards and gardens, waterways and wetlands, streets and transport corridors, pathways and greenways, farms and orchards, squares and plazas, roof gardens and living walls, sports fields and cemeteries. Green Infrastructure secures the health, liveability and sustainability of urban environments. It strengthens the resilience of towns and cities to respond to the major current and future challenges of growth, health, climate change and biodiversity loss, as well as water, energy and food security.

10.1 Conclusions

The Green Infrastructure Evidence Base study comprised a review of credible, peer reviewed literature and other professional sources covering a broad range of Green Infrastructure benefits. While the literature may not always be comparable between different fields of research, it does make a compelling case for integrating Green Infrastructure into the planning and design of our cities. While a great deal of the literature is US or European based, there is also a recent and growing body of local research which makes the case for Green Infrastructure as a means of addressing many aspects of human health and well-being, as well as addressing key environmental concerns such as climate change adaptation, urban heat island effects and more sustainable management of our water resources.

10.2 Future research

The literature review has identified a number of areas in which additional local research could be undertaken. These include but are not restricted to:

- Quantifying the ecosystem services provided by Adelaide's urban forest.
- Investigating WSUD stormwater harvesting practices to sustain vegetation.
- Continuing research into the Adelaide urban heat island effect and mitigation strategies.
- Continuing research into the adaptation of green roofs and living walls to South Australian climatic conditions.
- The economic benefits of Green Infrastructure in terms of reducing public health costs.
- A comprehensive economic evaluation of the benefits provided by Green Infrastructure in South Australia.
- Local research into the benefits of Green Infrastructure for children.
- Qualitative research into the perceived benefits of Green Infrastructure by urban residents.
- More longitudinal studies into the benefits of access to nature and urban green spaces.

10.3 Key policy linkages

A key consideration will be linkages to wider strategic policies and to other components of the Green Infrastructure Working paper and Green Infrastructure Project Plan. Green Infrastructure initiatives will be strengthened by linkages to key strategies such as the state government's 30 Year Plan, as well as State and National water, community health, biodiversity and climate change strategies, which also provide potential funding sources. Some of the key policy documents that will have an influence on the provision of Green Infrastructure include :

- The State 30 Year Plan.
- South Australia's Strategic Plan.
- Metropolitan Open Space Strategy (MOSS).
- Greater Adelaide Open Space System (GAOSS).
- Regional Biodiversity Plans.
- The Hills Face Zone.
- Development Plans.
- Adelaide and Mt Lofty Ranges Regional Natural Resources Management Plan.
- Strategic Infrastructure Plan for South Australia.
- Precinct and Structure Plans.

10.4 Green Infrastructure Design Principles

To design, build and maintain Green Infrastructure necessitates, in many cases, a new way of thinking about urban environments. To achieve the many potential benefits of Green Infrastructure it must be embraced as an integral element of the urban landscape. Government, industry and community sectors require a thorough understanding of the benefits as well as a robust capacity for design, development and maintenance. Planning and investment in Green Infrastructure need to be guided by principles that reflect and ensure a full acceptance of the concept.

We suggest that successful Green Infrastructure is underpinned by the following five principles:

- **Integration:** Green infrastructure is fundamental to urban planning and design frameworks for both new growth areas and redevelopments.
- **Nature-based:** Green Infrastructure utilises natural processes to provide essential services and functions that improve the quality of urban water, air, soil, climate and wildlife habitat.
- **Collaboration:** The design, development and maintenance of Green Infrastructure require open and on-going collaboration between government, industry and communities.
- **Evidence:** Green Infrastructure policy, planning and design are grounded in science and the lessons of experience, and are informed by emerging practices and technologies.
- **Capacity:** Green Infrastructure requires commitment to building motivation, knowledge, skills and access to resources.

