CIRIA

Large species trees in urban landscapes - a design and management guide

Project Report

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Executive Summary

Text

Foreword

The roles of large species trees within an urban landscape are many and indeed varied. They provide an essential component of Green Infrastructure which permeates our towns and cities, along street, through parks and within gardens. In many cases, and particularly within the urban context, the presence of large species trees stitches together a Green Infrastructure framework, specifically increasing its overall connectedness.

Large species trees are unique in their ability to form a green environment, rich in nature and biodiversity, while still allowing the functionality of the urban environment to continue. They are the mechanism by which the social, environmental and economic benefits of a natural environment can be brought to the millions of people which live in the UK's urban landscapes.

Research prevails from around the globe in support of the benefits attributable to elements of Green Infrastructure. This report focuses on those benefits which can be directly attributed to large species trees, but identifies that research which has also shown benefits arising from views and access to open space and nature. This is an important component of the reporting within this guide, as large species trees represent the single most significant mechanism for creating that green environment that is ambiguously described in research case studies. They also represent one of the most effective means of creating a biodiverse community within urban centres, creating ecological havens that provide communities with that opportunity to experience the natural environment.

This guide summarises and analyses the particular benefits and constraints associated with large species trees in urban landscapes, including those consequential effects of the presence of trees (nature, biodiversity, green space and green views). The social, environmental and economic values are set out with clear reference to the target audience, alongside a practical and authoritative guide for overcoming the challenges associated with implementation in an urban landscape.

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Project steering group

TBC

Other stakeholders

TBC

Glossary

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1 Introduction

Large species trees perform a vital function within urban environments, although their implementation in new and existing urban landscapes is often limited by widespread constraints, both perceived and real. This design and management guide summarises the resource of existing knowledge on the social, environmental and, in consequence, economic benefits of large species trees, and presents solutions for their integration and retention in urban landscapes.

The guide analyses the quantifiable benefits attributable to large species trees against the cost of different implementation techniques, presenting an evidence based argument for their adoption in the urban environment.

Research documenting the benefits of trees and solutions for their implementation in constrained environments is widely available from around the globe. This guide collates the available information and presents benefits and values, alongside priced solutions for implementation, clearly demonstrating the potential benefits arising from large species trees. The document describes the parameters within which an economic value can be attributed. However, the guide also presents these theories in the context of case studies across typical urban character types and situations, providing an accessible implementation to the construction industry.

The guide specifically targets the values and issues associated with large species trees, which are broadly defined for the purpose of this document in Section 1.3.

Ultimately, the guide has been produced to provide the target audience with a mechanism and justification for the widespread implementation of large specie trees, dispelling myths, providing practical delivery guidance and presenting the social, environmental and economic argument for their inclusion.

1.1 Aims and objectives

The primary aim of this guide is to present an authoritative evidence base for the value and technical feasibility of large species trees in urban landscapes. The guide covers the policy background, values and issues associated with both new and existing developments in England, Wales, Scotland and Northern Ireland.

The objectives of the guide are to:

A. Outline the cost benefit ratio of implementing large species trees in relation to a broad cross section of case studies. This covers economic benefits and cost savings set against delivery and ongoing maintenance costs for both newly planted and existing large species trees;

B. Outline the context of large species trees and climate change;

C. Outline the social and environmental value of large species trees, including both qualitative and quantitative information extracted from existing literature, policy and case studies

D. Provide specific advice on species selection, planting techniques and management regimes to maximise social and environmental benefits;

E. Dispel common myths relating to the implementation of large species trees; and

F. Present clearly illustrated solutions for integrating large species trees into the urban landscape in the context of typical constraints, linked to global examples of best practice.

1.2 Target audience

The guide is targeted at a wide range of professionals within the public and private sectors of England, Wales, Scotland and Northern Ireland. However, in line with the primary aim of the document, it is specifically targeted at:

- Providing technical guidance to the construction industry; and
- Providing justification and guidance to developers.

The guide has a secondary purpose in providing design and management support to local authorities, assisting with local policy setting, determining planning applications and managing publically owned stock.

However, the evidence based nature of the guide also provides a concise presentation of both the values of large species trees and the opportunities for their implementation, justified through a cost benefit ratio. This gives the document wider reaching utility amongst advocates of urban greening, helping to support arguments for the inclusion of trees.

1.3 Interpretation of a large species tree

For the purposes of this guide, we have interpreted a large species tree as being one that would grow in excess of 15m high when mature, provided their growth is not restricted by constraints to root development. Some of the trees found within the United Kingdom that fall within this category are summarised below in Table 1 for information. The list is not exclusive, and users should refer to the Right Trees for a Changing Climate website (http://www.right-trees.org.uk/).

Table 1 Indicative list of large species trees commonly found within the UK

Botanical Name	**Common Name**	**Height**	**Spread**
Acer platanoides	*Norway Maple*	*20 to 30m*	*8 to 15m*
Acer pseudoplatanus	*Sycamore*	*25 to 30m*	*20 to 25m*
Aesculus hippocastanum	*Common Horse Chestnut*	*20 to 25m*	*15 to 20m*
Alnus glutinosa	Alder	8 to 30m	8 to 10m
Betula pendula	Silver Birch	8 to 30m	6 to 8m
Castanea sativa	*Sweet Chestnut*	*25 to 30m*	*10 to 15m*
Fagus sylvatica	Beech	25 to 40m	10 to 25m
Fraxinus excelsior	Ash	20 to 40m	10 to 25m
Ginkgo biloba	*Maidenhair Tree*	*15 to 30m*	*5 to 10m*
Juglans nigra	*Black Walnut*	*20 to 30m*	*20 to 30m*
Juglans regia	*Common Walnut*	*15 to 35m*	*8 to 15m*

Pinus sylvestris	Scots Pine	15 to 25m	10 to 15m
Platanus acerifolia	*London Plane*	*25 to 30m*	*15 to 25m*
Populus nigra	Black Poplar	20 to 30m	15 to 20m
Populus tremula	Aspen	15 to 25m	8 to 15m
Quercus petraea	Sessile Oak	20 to 40m	15 to 20m
Quercus robur	Common Oak	30 to 40m	15 to 25m
Salix alba	White Willow	10 to 20m	8 to 15m
Tilia cordata	Small Leaved Lime	20 to 30m	10 to 20m
Tilia platyphyllos	Large Leaved Lime	30 to 40m	15 to 25m
Ulmus glabra	Wych Elm	30 to 40m	15 to 20m
Ulmus procera	English Elm	30 to 40m	15 to 20m

Non-native species are highlighted in italics

As part of this guide, we specifically examine the values and implementation constraints associated with this group of larger trees, with which it is widely recognised that the greatest environmental, social and hence economic benefits are held.

1.4 Legislative and policy context

The value and importance of trees is recognised by various planning guidance from England, Scotland, Wales and Northern Ireland, although no specific policy mechanism exists. Protection of trees is generally determined at a local level through Tree Preservation Orders and Conservation Area status, designed to protect valued trees and woodlands from inappropriate development.

Protection of trees

1990 Planning Act

Section 197 state that there is a statutory duty for a local planning authority:

"to ensure, whenever it is appropriate, that in granting planning permission for any new development adequate provision is made, by the imposition of conditions, for the preservation or planting of trees".

Through the imposition of planning conditions, local authorities are able to ensure the protection of existing trees and also insist on the inclusion of new tree planting within new developments. BS5837:2005 Trees in relation to construction is often cited, as it provides guidance on tree surveying, and hence understanding which have the most value, and tree protection during construction. BS3998 is also often cited to provide best practice guidance when works are to be carried out to trees.

One of the most powerful tools for protection of trees is local authority tree strategies, which are becoming Supplementary Planning Documents within some local authorities (Refer to Section 4.2.3).

Trees also play a key role in meeting policies and objectives for a number of environmental and social targets, particularly in relation to climate change. Where these policies are relevant to large species trees they have been noted throughout the body of the guide.

Finally, there is a wealth of guidance available from a wide range of national bodies, including the Forestry Commission and Natural England, and this has been cited throughout this guide.

1.5 Structure of the guide

The guide has been structured to provide the user with a logical and systematic method for identifying the value and delivery opportunities of large species trees in urban landscapes. The guide is divided into the following key sections:

- **Cost benefit ratio** – *Objective A* - The first objective of the document is to present the cost benefit ratio of large species trees. This section presents the values attributable to trees, arising from their benefits, compared against their implementation costs. This summarises the key findings of the report to economically justify the inclusion and retention of large species trees, and references more detailed information in subsequent sections.
- **The benefits of large species trees** – *Objectives B, C and D* - This section of the guide outlines the social and environmental values associated with large species trees in urban landscapes, cross referenced to the economic values highlighted in Section 2.
- **Implementing large species trees** – *Objectives E and F* - This section provides a detailed summary of the practical solutions to the key constraints associated with the implementation of large species trees.

2 Cost benefit ratio

2.1.1 Introduction

It is becoming increasingly important to ascribe a monetary value (benefitting an individual, community or business) to large species trees, for if they are perceived to have a value then they will be considered seriously in the context of policy making, budget allocation and infrastructure planning. Many local authority tree officers and certain developers now realise that it is advantageous to regard trees in terms of cost benefit ratios and that they can be an instrumental tool in planning for and incorporating large trees within the urban environment.

This section of the guide summarises some of the tree valuation methods available while also highlighting the value of the social and environmental benefits described in Sections 3.2 and 3.3 respectively, linked to case studies from around the globe. Economic benefits are described in relation to who may realise the economic gain and over what indicative timeframe.

Cost savings are also outlined, arising from damages that have been avoided due to the forward planning and correct implementation of trees.

These benefits are described against the costs incurred in the correct implementation of trees (described in Section 4.1), providing a robust justification for the inclusion of large species trees in a range of new developments and existing urban landscapes.

In providing an outline of the economic value of large species trees from a series of case studies, the principles of value transfer can be used to estimate the value of tree planting in a similar urban environment. Further guidance on the methodology behind value transfer is available from DEFRA, in their publication 'Valuing Environmental Impacts: Practical Guidelines for the Use of Value Transfer in Policy and Project Appraisal' (2009).

2.1.2 Tree valuation methods

There are a variety of methods that give a financial value for the urban forest, such as the Helliwell method (Helliwell, 1967), Capital asset value for amenity trees (CAVAT, Neilan, 2008) and i-Tree (formerly STRATUM, Ibrahim, 2009). The Helliwell method of evaluation considers the amenity value of an individual tree which although useful for some evaluations, is not so useful when assessing entire urban forests or for assessing trees in terms of overall benefits that trees can provide. The CAVAT method does incorporate an element designed to record the social value of the tree through the Community Tree Index that relates tree value to population density derived from the Office of National Statistics data.

However, the US American forestry departments have developed systems such as i-Tree and CITYgreen for placing values on lifetime costs of an urban tree, in terms of tangible benefits as described in Section 3 of this guide. The extensive US research has focused on the economic benefits of city trees in relation to energy saving, pollution control, etc, allied to an analysis of relative tree cover, using GIS and data imported from a range of external sources to create software packages.

The studies undertaken by the Centre for Urban Forestry Research PSW, USDA Forest Service have resulted in cost benefit ratios for urban trees for several US cities including Los Angeles, Modesto, Sacramento, and other Californian cities and northern mountain prairie communities. The work has resulted in the estimated annual benefits and costs incurred for small, medium and large trees. These figures then provide the estimated value of net annual economic benefit for each tree size.

The benefits were calculated with models that directly connected benefits with tree size as benefits increase as tree canopy cover and leaf area increase. Prices were assigned to each benefit through direct estimation and implied valuation for each of the following items:

- Energy savings
- Atmospheric carbon dioxide reductions
- Air-quality benefits
- Storm water runoff reductions
- Aesthetic and other benefits

The average annual costs were also calculated for the following items using data from city tree works programs:

- Tree removal,
- Planting/watering /re-staking
- Root-related work,
- Liability
- Storm clean-up
- Integrated pest management

Table 2 below summarises data provided by the US Department of Agriculture and US Forest Service (2004).

Table 2 Net benefits of trees at year 30 (McPherson et al., 2003)

	Small trees (<7.5m)	**Medium trees (7.5-12m)**	**Large trees (>12m)**
Benefits per annum	$23	$33	$55
Costs per annum	$14	$17	$18
Net benefits	**$9**	**$16**	**$37**

This research concluded that large species trees provide bigger cost savings and greater benefits than small and medium trees, and that benefits outweighed whole life costs in all instances.

2.1.3 Case studies

Detailed valuation of the costs and benefits of urban trees and forests is extremely well developed in parts of the US. Two specific case studies have been referenced below which clearly demonstrate the positive economic effects large species trees have upon an urban landscape. While elements of the case studies may not be directly transferable to the UK, for example effects on microclimate, there is enough synergy to make these a useful and authoritative reference.

San Joaquin Valley, California

San Joaquin Valley has seen a rapid urban expansion over the last 50 years and this has been associated with a steady increase in urban temperatures of 0.4^{o}C per decade. The area has hot dry summers, leading to high cooling costs, and urban storm water runoff is a major source of pollution entering watercourses and bodies. Tree planting programmes were recognised to be an essential way of combating rising temperatures, reducing energy consumption and minimising water pollution. An extensive study was undertaken to investigate the economic benefits of tree planting in the region and established estimated annual costs and benefits.

The study (McPherson et al., 1999) indicates that large trees provide bigger cost savings and greater benefits than small and medium trees over a forty year lifespan. The research here demonstrated that it took only five years for net benefits to outweigh net costs, based on implementation and subsequent maintenance costs, against benefits arising from improved air quality, water attenuation, carbon sequestration and water filtration in addition to increased property values.

Table 3 Cost benefit ratio realised immediately on planting

	Large Private Tree	**Large Public Tree**
Benefits		
Air quality	$3	$2
Net energy/CO_2	$2	n/a
Other benefits	$40	$43
Net benefits	**$45**	**$45**
Costs		
Tree and planting costs	$60	$50
Pruning costs	$2	$5
Irrigation/disease control/inspection	$3	$37
Net Costs	**$65**	**$92**
Cost Benefit Ratio	**0.69:1**	**0.48:1**

Table 4 Cost benefit ratio realised within five years of planting

	Large Private Tree	**Large Public Tree**
Benefits		
Air quality	$3	$2
Net energy/CO_2	$2	n/a
Other benefits	$40	$43

Net benefits	**$45**	**$45**
Costs		
Pruning costs	$2	$5
Irrigation/disease control/inspection	$3	$37
Net Costs	**$5**	**$42**
Cost Benefit Ratio	**9:1**	**1.07:1**

Table 5 Cost benefit ratio realised within five to ten years of planting

	Large Private Tree	**Large Public Tree**
Benefits		
Air quality	$10	$10
Net energy/CO_2	$5	$4
Other benefits	$45	$47
Net benefits	**$60**	**$61**
Costs		
Pruning costs	$6	$7
Irrigation/disease control/inspection	$1	$1
Net Costs	**$7**	**$8**
Cost Benefit Ratio	**8.57:1**	**7.62:1**

Table 6 Cost benefit ratio realised within ten to twenty years of planting

	Large Private Tree	**Large Public Tree**
Benefits		
Air quality	$30	$30
Net energy/CO_2	$12	$20
Other benefits	$28	$25
Net benefits	**$70**	**$75**
Costs		
Pruning costs	$9	$8
Irrigation/disease control/inspection	$6	$1
Net Costs	**$15**	**$9**
Cost Benefit Ratio	**4.66:1**	**8.33:1**

Table 7 Cost benefit ratio realised within forty years of planting

	Large Private Tree	**Large Public Tree**
Benefits		
Air quality	$454	$45
Net energy/CO_2	$23	$35
Other benefits	$10	$8
Net benefits	**$78**	**$8**
Costs		
Pruning costs	$10	$9

Irrigation/disease control/inspection	$8	$1
Net Costs	**$18**	**$10**
Cost Benefit Ratio	**4.33:1**	**8.8:1**

Modesto, California

McPherson et al. (1999) also undertook a similar study in Modesto, California, with annualised costs and benefits for a forty year period summarised as follows:

Energy savings – Saves $30 in summertime air conditioning by shading the building and cooling the air, equating to approximately 9% of total annual air conditioning costs.

Air quality benefits – Absorbs 10lbs of air pollutants, including 4lbs of ozone and 3lbs of particulates. The value of the pollutant uptake by the tree is $45 using the local market price of emission reduction credits. The nitrogen oxide uptake by the tree is equivalent to the nitrogen oxide emissions of a typical car driven 3,600 miles.

Storm water runoff reductions – Intercepts 760 gallons of rainfall in its crown, thereby reducing the runoff of polluted storm water and flooding, valued at $6 based on local expenditures for water quality management and flood control.

Atmospheric carbon dioxide reductions – Cleans 330lbs of CO_2 from the atmosphere through direct sequestration in the tree's wood and reduced power plant emissions due to cooling energy savings. The value of this benefit is $5 assuming the California Energy Commission's price of $30/ton. This contribution to reducing atmospheric CO_2 equates to the CO_2 emissions from a typical car driven 500 miles.

Increased property values and other benefits – Adds about 1% to the sales price of the property, or about $25 each year over a forty year period (assuming a median residential property sales price of $100,000).

The total value of these benefits amounts to $111 per tree, per year for a forty year period.

Implementation and maintenance costs were taking to include:

- Planting costs;
- Pruning costs;
- Tree removal costs;
- Pest and disease control;
- Irrigation;
- Infrastructure repairs;
- Litter and storm cleanup;
- Litigation liability; and
- Inspection and administration.

These costs together amounted to $58.50 per tree, per year for a forty year period.

The cost benefit analysis for Modesto's 90,000 street and urban park trees found $1.89 returned annually for every $1 invested in management and maintenance.

2.1.4 The benefit of large species trees to residential developers

Research undertaken, principally in the US but also in the UK, has shown that integrating large species trees within developments has a positive influence in property prices, in addition to the saleability and desirability of residential properties.

Research in New Kensington, Philadelphia (Wachter and Gillen, 2006) demonstrated that properties within close proximity to new tree plantings were increased in price by approximately 10%. This would equate to £23,056 on the average UK house price in the UK (October 2010).

In Quebec City, Canada, an opinion poll of 640 home buyers was undertaken during 1993 – 2001. The results indicated that the impact of large trees on house value is highly related to family composition and stated appreciated of wooded areas, and the effect varies according to the socio-economic status of the neighbourhood. However, large trees in high income areas were found to raise property values by 10-15% (Theriailt et al., 2002). This would equate to £23,056 to £34,584 on the average UK house price in the UK (October 2010).

A recent study (Butry et al., 2010) in Portland, Oregon, established how much street trees increase the value of a home, by quantifying the impact of street trees on Portland's housing market. The study found that on average, street trees add $8,870 to sales price and reduce the time on the market by 1.7 days. In addition, the study found that the benefits of street trees spill over to neighbouring houses.

These studies generally appraised the economic value of mature large species trees within the urban landscape, and therefore highlight the importance of retaining mature tree stock when undertaking a new development. Such retention need not impose excessive costs on developments, if considered appropriately at the strategic masterplanning stage. If a development is planned appropriately, allowing enough space for the existing mature large species trees to be retained, the only significant costs would arise from tree protection in line with the guidance in BS5837:2005 Trees in relation to construction.

However, these percentage increases in value would not directly equate to a new developments where new trees were being established, unless semi-mature stock were being used. In this instance, it is important to recognise the importance of adequate allocation of green space within developments. Once areas within the development have been committed to open green space schemes, the additional cost of planting large species trees is negligible and contributes significantly to the saleability and desirability of residential properties (Warwick District Council).

Research undertaken by CABE (2005) has quantified the value of green space in proximity to people's homes, through a case study in Newton-Le-Willows, Merseyside, where a large park was regenerated with new woodlands, wildflower meadows, footpaths and play facilities. Properties overlooking the park command a 19% premium over properties away from it.

In Emmen, Holland, a view of a park was shown to raise house prices by 8%, and having a park nearby raised prices by 6%. Further to this, attractive landscape types were shown to attract a premium of 5-12% over less attractive green settings.

Therefore, establishment of green spaces within new developments could equate to significant increases in the value of homes, with the planting of large species trees a cost effective method of maximising this premium as far as practicable. Where large species trees are implemented as smaller stock (for example feathered or standard trees) within a relatively unconstrained situation, planting costs may be around £100 per tree (built up from Spon’s External works and landscape price book, 2011).

Developments on shrinkable clay soils

Losses incurred due to differential subsidence of low rise buildings constructed on clay soils, have cost British insurers several hundred million pounds annually. The problem of subsidence is exacerbated by the fact that much of the recent housing in the UK is built on shallow concrete strip foundations (Lawson and O’Callaghan, 1995) and most of London and the south-east lies on shrinkable clay soils. As Section 4.1.1 highlights, trees are only one potential cause of subsidence, along with periods of drought (to become more frequent with climate change) and leaking drains. Therefore, the importance of deeper or engineered foundations is an essential consideration not just in the context of allowing space for large species trees, but also in minimising future damage caused by any number of factors. The National House Building Council (NHBC) provides detailed advice on foundation depths and types on different soil types and in proximity to different tree species.

Land value

A study (Luther and Gruehn, 2001) in Frankfurt and Berlin (Germany) and Malmoe (Sweden) identified a significant correlation between land prices and distance, quality and density of green space. As part of the study, it was identified that a high number of street trees resulted in an increase of 17% in land values.

2.1.5 The benefit of large species trees to commercial businesses

Encouraging inward investment and growth

Between 1988 and 1996 in Chattanooga, Tennessee, new parks, greenways and street trees have injected an estimated $500 million into the city. In addition, the number of businesses and full time jobs in the district more than doubled, and assessed property values went up over $11 million, an increase of 127.5% (Lerner and Poole, 1999).

Workplace productivity

Dr. Rachel Kaplan has identified that desk workers who can see nature from their desks experience 23% less time of sick than those who cannot see any nature. Desk workers who can see nature also report greater job satisfaction (Wolf, 1998). The annual cost of sick leave cost Britain £17.3 billion in 2009 and in 2008, sickness absence cost companies an average of £692 per employee (CIPD, 2009).

In addition, employers report greater employee productivity, satisfaction and retention at properties endowed with trees and other vegetation (Georgia Urban Forest Council, 2004).

Heating and cooling costs

A Chicago study indicates that a utility-sponsored shade-tree program could be cost effective for both existing and new construction in the city.

The following Information is based on a computer simulated study in the Chicago area for typical 1-3 storey brick buildings and 1-2 storey wood-frame buildings.

- One large tree can reduce annual heating and cooling costs by 2 to 4% ($23 to $86);
- Increasing tree cover by 10% (approximately three trees per building) could reduce total heating and cooling energy use by 5-10% ($50 to $90);
- Per-tree - annual heating energy can be reduced by about 1.3% ($10);
- Per-tree - annual cooling energy can be reduced by about 2-7% ($15);
- Per-tree - annual peak cooling demand can be reduced by about 2-6% ;
- Per three trees – annually reduced heating energy use by 16% ($84 or £54)
- Per three trees – annually reduced air-conditioning energy use by 9 kWh suggesting that the benefit from reduced infiltration is slightly greater than the detrimental effect of lower wind speeds on natural ventilation; and
- For old buildings substantial savings can be made saving in heating energy from wind protection is especially large because older buildings are less well insulated and have high rates of infiltration and inefficient heating equipment, saving around $75 per tree (increased tree cover can account for 70-90% of total annual savings). (McPherson et al., 1994).

2.1.6 The benefits of large species trees to the retail industry

The importance of having trees in retail areas has been studied by social scientists at the University of Washington, who investigated the associations between trees and people’s response to shopping settings. The studies found that shoppers respond positively to trees in shopping areas, also that providing trees is an important investment for a retail community. The presence of a quality urban forest positively influences shoppers' perceptions, and probably, their behaviour.

These findings were consistent across the following large, small and mid-size cities surveyed in the United States:

- Large cities with populations greater than 250,000, including Los Angeles; Washington, D.C.; Chicago; Portland, Ore.; Pittsburgh; Austin, Texas; and Seattle;
- A downtown shopping district for a mid-sized city, including Athens, Georgia, which has a population of approximately 100,000 people; and
- Main Street shopping districts in 14 smaller cities and towns, having populations between 10,000 and 20,000.

The studies indicate that shoppers do not purchase goods and services just to meet needs, but are increasingly interested in the experience of shopping. The appearance of the shopping area is an important part of creating a welcoming, interesting shopping environment and the most positive consumer response was associated with streets having a mature, well-managed urban forest where overarching tree canopy helps create a "sense of place."

- Visual quality – Ratings of visual preference were lower for places without trees and much higher for places with trees, particularly when large trees form a canopy over the pavement and street;
- Place perception – Visitors judged districts with trees as more pleasant to be in and better maintained with higher quality products and more helpful retailers;
- Patronage behaviour – Shoppers claim they are willing to travel more often, longer and over greater distance, and once arriving, will spend more time in a retail district having trees; and
- Product pricing – The people surveyed were willing to pay 9-12% more for goods and services in shopping areas with large, well-cared for trees. In addition they will pay more for parking on streets with trees.

For retailers, a good-quality public environment can improve trading by attracting more people into an area. It has been shown, for example, that well-planned improvements to public spaces within town centres can boost commercial trading by up to 40 per cent and generate significant private sector investment. (DoE and The Association of Town Centre Management, 2007).

If these findings were applied to London's Oxford Street, an increase in expenditure of 9-12% could be worth as much as £540million to the streets retailers (Drapers for the New West End Company).

2.1.7 The benefits of large species trees to local authorities and the government

Crime

The benefits trees have on crime rates are set out in Section 3.2.2. The total cost of UK domestic violence to services (criminal justice system, health, social services, housing, civil legal amounts to £3.1 billion, while the loss to the economy is £2.7 billion. Including all costs, the total cost of domestic violence for the state, employers and victims is estimated at around £23 billion (Walby, 004). Trees and greenery around housing can, according to the above research, reduce domestic violence by 11%, therefore potentially reducing the UK total cost for domestic violence by £2.5 billion.

The cost of violent crime in the UK is £16.8 billion. Trees and greenery around housing can reduce violent crime against people by 56%, potentially equating to a reduction in the total UK cost of £9.4 billion (Brand and Price, 2000).

The cost of crime to domestic property in the UK is £4.2 billion. Trees and greenery around housing can reduce crime against property by 48%, potentially equating to a reduction in the total UK cost of £2 billion (Brand and Price, 2000).

Health

A 10-year comparative study of post-operative patients in Pennsylvania found that hospital patients with views of trees recovered significantly faster than those who could not see any natural features. The study showed that patients with window views of the trees spent less time in the hospital than those with views of a brick wall: 7.96 days compared with 8.70 days per patient.

The research also found that the patients with window views of the trees took 61% fewer doses of stronger strength painkillers than those with views of a brick wall and were able to cope on weaker strength painkillers such as aspirin (Ulrich, 1984).

The average cost for a patient to stay in an NHS surgical ward is up to £400 per day; therefore, nearly £300 could be saved per patient by providing trees within view of hospital wards.

Willis et al. (2003) outlined further benefits of:

- £124,998 saved for each death avoided by 1 year due to PM_{10} and SO_2 being absorbed by trees; and
- £602 saved due to an 11 day hospital stay being avoided due to reduced levels of respiratory illness.

Carbon sequestration and offsetting

As documented in Section 3.3.3, trees play an important role in sequestering carbon and also reducing energy usage, which generates carbon. The economics of climate change has been well document in the Stern Review (2006), of which some key points are summarised below.

If we take no action to control emissions, each tonne of CO2 that we emit now is causing damage worth at least $85 - but these costs are not included when investors and consumers make decisions about how to spend their money. Emerging schemes that allow people to trade reductions in CO2 have demonstrated that there are many opportunities to cut emissions for less than $25 a tonne. In other words, reducing emissions will make us better off. According to one measure, the benefits over time of actions to shift the world onto a low-carbon path could be in the order of $2.5 trillion each year.

The shift to a low-carbon economy will also bring huge opportunities. Markets for low-carbon technologies will be worth at least $500bn, and perhaps much more, by 2050 if the world acts on the scale required.

Using the results from formal economic models, the Review estimates that if we don't act, the overall costs and risks of climate change will be equivalent to losing at least 5% of global GDP each year, now and forever.

If a wider range of risks and impacts is taken into account, the estimates of damage could rise to 20% of GDP or more.

In contrast, the costs of action – reducing greenhouse gas emissions to avoid the worst impacts of climate change – can be limited to around 1% of global GDP each year.

- Developed countries in lower latitudes will be more vulnerable - for example, water availability and crop yields in southern Europe are expected to decline by 20% with a 2°C increase in global temperatures. Regions where water is already scarce will face serious difficulties and growing costs;

- A 5 or 10% increase in hurricane wind speed, linked to rising sea temperatures, is predicted approximately to double annual damage costs, in the USA;
- In the UK, annual flood losses alone could increase from 0.1% of GDP today to 0.2 - 0.4% of GDP once the increase in global average temperatures reaches 3 or 4°C; and
- Heat waves like that experienced in 2003 in Europe, when 35,000 people died and agricultural losses reached $15 billion will be commonplace by the middle of the century.

Water attenuation

The study of a river catchment in south-east Northumberland estimated the value of existing woodlands for flood alleviation at around £1,200 per hectare, based on savings to the engineering costs of flood control.

Amenity value

Studies in the Chicago area have shown that people are willing to pay substantially more to visit an amenity space with trees and shrubs than to an area with few trees by the following amounts:

- $1.60 more for a visit to a site that was "mostly wooded, some open grassy areas under trees" than for a site with "mowed grass, very few trees anywhere."
- $0.21 more per visit for "mowed grass, scattered trees, no woods"
- $0.99 more for "mowed grass, scattered trees, some dense woods"

For example, the Ned Brown Forest Preserve located northwest of Chicago receives more than 2,500,000 visits per year. An estimate of $1.00 per visit attributed to this Forest Preserve's vegetation—a mixture of mowed grass, scattered trees, and forests would total up to $2,500,000 per year, suggesting that the trees and forests on the area are valuable assets that merit considerable attention.

While the willingness of users to pay for trees and forests is not surprising, it is somewhat surprising that users were willing to pay the most for the most heavily forested areas. While the ranking of the attributes varied significantly over the five segments, trees and forests always ranked higher than terrain, children's playgrounds, or athletic fields.

The study indicated that trees and forests are important to the users of urban parks and forest preserves. This importance is reflected in users' willingness to pay to have these features in a park and their likelihood of choosing a park with these attributes. The dollar values of trees are substantial and compare favourably with dollar values of other park resources (Dwyer et al.,1991).

Reduced maintenance of paved surfaces

Section 4.1.2 documents approaches that can be adopted to avoid or minimise damage to pavements and roads arising from large species trees. Studies undertaken in US cities indicate that the cost of repairing pavements, kerbs and gutters is $4.15 per tree per year (Randrup et al., 2000). In 1998, California's cities spent $62 million on pavement, kerb and gutter repair, tree removal and replacement, prevention methods and legal/liability costs, covering street trees only (Burger et al., 1998). The initial implementation cost of a large species trees, using techniques documented in Section 4.1.2, such as using a structural soil as a backfill, may cost around five times more than a more standard technique initially, but will prove to be cost effective within only a few years. This is in reference to both reduced maintenance of the tree, which is likely to have healthier, sustained growth and is less likely to need replacing, and reduced maintenance of paved surfaces.

Shade from the canopies of large species trees also help to protect paved surfaces by moderating the temperature, avoiding extreme highs and lows which can reduce the life of a surface significantly, particularly asphalt (Centre for Urban Forest Research and Education, 1999).

Reduced maintenance of utilities

Section 4.1.3 highlights techniques for ensuring tree roots do not damage utilities. The cost savings associated with minimising repairs to utilities can be significant, as shown in a study undertaken in eight US and Canadian cities. The study indicates that the average cost of repairing sewer damage caused by trees is $4.28 per tree, per year, and this can represent between 13-30% of an authorities annual tree budget.

Annual water line repair costs due to tree related damage were reported to average $0.17 per tree in San Jose and $0.10 per tree in Sacramento. Damage was attributed to pressure from expanding roots that dislodged water meters and water lines damaged from concussive force when large trees fell above them.

Sewer repair costs range from $0.11 per tree in Boston to $6.39 per tree in Vancouver. Other cities with costs over $1 per tree are Atlanta ($1.71) and Sacramento ($3.40). The mean annual repair cost is $1.66 per tree for the eight cities. Expenditure associated with repairing tree damaged sewer lines are equivalent to 13% or more of the annual tree budgets in Sacramento, 15% in Atlanta, 20% in Rock Valley and 30% in Vancouver. Vancouver's relatively high costs were due to the large number of clay and concrete lines that are over 100 years old.

Repair costs typically range from $100 for rodding drains or roto-rootering (mechanically cutting roots in pipes) to $1,000 or more for excavation and replacement of broken drains (McPherson and Peper, 1995).

3 The benefits of large species trees

This section of the guide outlines the social and environmental values associated with large species trees in urban landscapes, cross referenced to the economic values highlighted in Section 2. Social and environmental benefits are summarised, quantified where possible and linked to relevant case studies from around the globe.

Specific advice is given throughout this section, where it is relevant in trying to maximise a particular benefit. Advice on species selection should always be read in conjunction with the guidance given in the Right Trees for a Changing Climate website, as a tree which is advantageous for one reason may be problematic for another. Specialist arboricultural advice should generally be sought in order to maximise benefits and minimise impacts.

This section is set against the context of our changing climate, highlighting the risks to trees and the contribution they make in mitigating the effects of climate change.

3.1 Climate change adaptation

The impacts of climatic change in the UK have been extensively researched by the UK Climate Impacts Programme (UKCIP), with the key findings suggesting how our climate might change described as:

- All areas of the UK get warmer, and the warming is greater in summer than winter;
- There is little change in the amount of precipitation (rain, hail, snow etc.) that falls annually, but it is likely that more of it will fall in winter, with drier summers, for much of the UK; and
- Sea levels rise, and are greater in the south of the UK than in the north (UK Climate Impacts Programme, 2010).

The Landscape Institute Position Statement on the challenge of climate change (2008) summarises the potential significant impacts on UK landscapes as including:

- Intensification of the urban heat island effect;
- Water shortages as a result of reduced rainfall;
- Flooding, particularly in our built environments and floodplains, as a result of increased rainfall intensity and increasingly frequent storm events;
- Rising sea levels leading to significant landscape impacts in coastal areas;
- Change in biodiversity as a consequence of new climatic conditions, particularly temperature and humidity levels;
- Decreasing air quality as a result of higher temperatures and possible increases in ultraviolet radiation; and

- The character of our landscapes, as a changing climate impacts upon environmental, cultural, social and economic factors which shape this character.

Large species trees are an important component of urban Green Infrastructure that is susceptible to a changing climate, but also a tool for mitigating the effects of climate change.

3.1.1 The risks of climate change to trees in urban landscapes

It is anticipated that newly planted trees in urban environments are likely to be among the first to be affected by changing climatic conditions, due to the constraints that are often imposed upon their healthy growth and development. The productivity of many species will fall and mortality increase as a result of more frequent and intense dry spells during the summer months. The Forestry Commission (2010) list a number of basic methods for minimising the adverse effects of climate change, including:

- Species and provenance mixtures will provide some insurance against climate change, as not all stock will be affected to the same extent;
- Tree species should be well matched to the site; if conditions are at the dry end of their suitable range, they should not be planted; and
- Climate change predictions covering changing frost patterns, increased heat/drought and waterlogging of roots should be considered in the choice of planting stock.

However, the key to maximising resilience to climate change is by providing trees with optimum conditions for healthy, sustained growth and development. This will enable trees to develop into fully mature heights and spreads. Further guidance on planting large species trees in the context of typical urban constraints is given in Section 4.1.

3.1.2 Reducing the effects of climate change

Large species trees, as one element of Green Infrastructure, are an essential tool for combating climate change. They provide cost effective methods of reducing the effects of rising temperatures, increased rainfall intensities, increased carbon emissions and diminishing air quality. These in turn provide benefits to local communities through improved health and wellbeing, reducing stress levels, encouraging healthy lifestyles and raising property values. The benefits of large species trees on our environment are summarised in more detail in Section 3.3.

3.2 Social benefits

3.2.1 Health and wellbeing

Introduction

Large species trees contribute to the health and wellbeing of local communities in a variety of different ways. Indirectly, trees improve air quality and thereby improve human health, particularly the frequency and severity of breathing disorders. In addition, trees have an effect on ambient noise levels, linked to stress relief. These topics are discussed in more detail in Section 3.3.2 and Section 3.3.4 respectively. Large species trees in urban landscapes also promote health enhancing behaviour such as participation in physical activity. There are also more direct health and wellbeing benefits derived from living and working within a greener environment, such as one created by large species trees in an urban area.

There is a great deal of anecdotal evidence on how trees make communities liveable for people; how trees add beauty and create an environment beneficial to our mental health by affecting our moods and emotions; and how large trees can create feelings of relaxation and wellbeing, providing privacy and a sense of solitude and security. Crucially, scientific, medical and social research and studies have begun to quantify and assess these benefits.

There is increasing interest in the role the natural environment has to play in the human health and wellbeing, particularly amongst a number of public health and environmental organisations. The Environment Agency recognise the social value of certain landscape and habitat types, including trees when undertaking an economic evaluation of the environmental benefits of flood and coastal erosion risk management (FCERM) schemes, using guidance from the FCERM: Economic valuation of environmental effects handbook (Eftec, 2010).

There is now a well documented evidence base examining the links between the environment and physical and psychological health and well-being (Bird, 2007 and Kaczynski and Henderson, 2007). These documents, amongst others specifically highlight benefits to:

- Communities;
- People at work;
- Children;
- The elderly; and
- People recovering in hospitals.

Benefits to local communities

The value of large species trees on local communities relate to the provision of green amenity space and the promotion of greater interaction between local communities, discussed in Section 3.2.2. Macintyre, Ellaway and Cummins (2002) demonstrate how a cohesive neighbourhood has a contribution to human health over and above the sum of any risk factors, an important factor of which is the inclusion of large species trees as a significant component of Green Infrastructure.

Kaplan (2001) explored the correlation between community wellbeing and natural views. In a study based in a low rise residential area, views from windows of a well cared for natural environment which, most importantly, contained trees, was found to be a strong indicator of neighbourhood satisfaction and wellbeing.

A study undertaken in the West Midlands identified that doubling the tree canopy cover throughout the region could prevent 140 premature deaths per year (Trees: Relief for the City).

Benefits to people at work

Specific studies have explored the influence large trees and natural views have on people at work. Desk workers who can see a green environment from their desks experience 23% less time off sick than those who have an entirely urban view. Similarly, these office workers also report greater job satisfaction (Wolf, 1998).

Benefits to children

Large species trees are recognised as having significantly greater ecological value than many other forms of Green Infrastructure and smaller tree stock (Refer to Section 3.3.7). This has a clear link to children with Attention Deficit Disorder, whereby contact to nature has a positive influence on their behaviour (Taylor, Kuo, Sullivan, 2001).

Trees are also an important component of natural playgrounds within urban settings. A report commissioned by the Children's Play council (Lester and Maudsley, 2006) summarises the benefits of playing in nature, which include direct benefits for children's physical, mental and emotional health, and wellbeing.

The effect large species trees have on reducing asthma rates, particularly among children, relate to an improved air quality, and are discussed in Section 3.3.2.

Benefits to the elderly

Bird (2007) notes that contact with nature is an effective method in maintaining activity, concentration and quality of life for elderly people. In the case of retirement homes, provision of green space with trees should attract a premium and be more desirable than those without, where quality of life is lessened.

Large species trees are also associated with life expectancy. Studies have documented that living in areas with tree-lined streets and walkable green spaces has positively influenced the longevity of senior citizens living in urban areas, independent of their age, sex, marital status and socioeconomic status (Takano, Nakamura & Watanabe, 2002).

Benefits to people recovering in hospital

As discussed above, large species trees are proven to have significant benefits on human health, relating to promoting exercise and reducing levels of stress, in addition to environmental benefits referenced in Section 3.3. Specific benefits to people recovering in hospitals have also been documented and quantified. A classic study compared the recovery of two groups of patients who had undergone gallbladder surgery. One group had views of deciduous trees from their hospital bed, while the other had views of a brick wall. Patients with the views of trees recovered more quickly from the surgery, requested less medication for pain and had shorter hospital stays (Ulrich, 1984).

A study in the US (Cooper and Barnes, 1995) asked hospital patients where they went when they were stressed, with 95% stating they went outside and 69% highlighting trees and plants as being particularly helpful.

Summary

Large species trees are an invaluable tool in combating major health and wellbeing issues such as obesity, stress and mental health, particularly in urban areas lacking good access to the natural environment. Trees have been proven to have a positive influence on human health through improving the environment (discussed in Section 3.3), promoting physical exercise and community interaction, and more directly creating a greener environment, reducing stress and improving wellbeing.

Large species trees are an essential component of a green urban landscape which is rich in biodiversity, clearly correlating with the substantial research undertaken into the health and wellbeing benefits of green environments and access to nature.

3.2.2 Social cohesion and crime

Introduction

Large species trees are an important component of an urban landscape which engages the local community, promoting social cohesion and reducing levels of crime. Coley et al. (1997) present a theory that trees and natural vegetation are more likely to draw people out of their homes, increasing natural surveillance, strengthening communities and hence reducing crime, based on a study outside an urban housing complex. Whilst dense vegetation is perceived to be associated with crime, or the fear of crime, widely spaced, high-canopy trees, along with other forms of visually permeable vegetation are recognised as not promoting crime (Kuo and Sullivan, 2001). The same study goes on to propose that this type of vegetation can inhibit crime by:

- Increasing surveillance; and
- Mitigating some of the psychological precursors to violence.

Increasing surveillance

Large species trees help contribute to creating a green character which is attractive to the local communities surrounding it, encouraging greater occupation of the public realm. This is supported by a series of studies undertaken in inner city neighbourhoods (Coley et al. 1997, Kuo et al. 1998, Sullivan et al. 2001), which together demonstrate that treed outdoor spaces are consistently more well used by all age groups, and the more trees, the greater the density of users at any one time.

Kuo (1998) also undertook a comparison study between images of barren common spaces amongst high rise flats against those with trees superimposed, whereby a strong preference was shown for the treed spaces. One in three people indicated that they would use the space more often if trees were planted. Sullivan et al. (2004) also undertook a survey of public spaces around low-rise flats, which indicated there was a 90% increase in individuals in green space compared to barren space and 83% more people socialising.

The presence of well maintained trees and vegetation within the public realm also implies surveillance and active care of the public realm, potentially suggesting that an intruder would be noticed and hence reducing crime rates (Nassauer, 1988).

This proven increase in surveillance of treed spaces correlates with evidence supporting lower crime rates in populated public spaces (Jeffery, 1971 and Jacobs, 1961).

Mitigating psychological precursors to violence

A number of studies have also shown a connection between trees and lower levels of violence (Mooney and Nicell, 1992; Rice and Remy, 1998), which is closely related to the stress reducing properties of large species trees and green environments. Recovery from mental fatigue, a trigger of angry outbursts and potentially violence, has been shown to be helped by greater contact with nature (Canin, 1991).

Specific studies have also been undertaken into the effect of natural environments on children with ADHD and other behavioural problems. Childhood psychiatric illness has long term consequences, and by the age of 28 the costs to society for these individuals are ten times higher than those for people with no childhood problems (Bird, 2007). Faber et al. (2001) compared parents' analysis of ADHD symptoms in children playing in green, urban and indoor environments. For those undertaking activities in grassed and treed environments, 85% had better scores, and the differences between the three categories were significant.

Case Study – Robert Taylor Housing Project, Chicago

Studies assessed the impact of large species trees on residents within the largest public housing development in the world. The studies looked at what residents were doing in their daily lives based upon the amount of contact they had with trees, and determined that trees have the potential to:

- *Residents who live near trees have significantly better relations with and stronger ties to their neighbours;*
- *Those residents who lived with trees nearby, socialised with their neighbours more, felt safer and suffered 52% fewer crimes. They felt emotionally and physically healthier than those in 'treeless' blocks;*
- *There were fewer reports of physical violence in homes that had trees outside the buildings. Of the residents interviewed, 14% living in barren conditions had threatened to use a knife or gun against their children versus 3% for residents living in green conditions;*
- *Trees have the potential to reduce social service budgets, decrease police calls for domestic violence, strengthen urban communities and decrease the incidence of child abuse; and*
- *There were fewer crimes against both people and property occurring in tower blocks surrounded by trees and greenery than in identical blocks surrounded by barren land; 48% fewer property crimes and 56% fewer violent crimes. The greenery was found to make people relax more and reduced aggression, and the green spaces helped bring people together outdoors, increasing surveillance and discouraging criminal activity. (Kuo & Sullivan 2001(a)&(b)).*

The results of the study were so significant that the city government spent $10 million on planting 20,000 trees (Chicago Tribune).

Summary and recommendations

Access to nature, of which large species trees are an important component, particularly in urban environments, have been demonstrated to increase community occupations of public spaces, thereby reducing crime through increased surveillance and their psychological effects.

Improved social cohesion and reduced crime can be linked to reducing policing costs, decreased vandalism and the resulting repair and maintenance, reduced social service budgets and improved community involvement in the local public realm. Further economic analysis of the benefits is provided in Section 2.

Large species trees play an important role in creating a community, and therefore are an essential component of any new development, particularly residential. Similarly, existing mature trees should be retained wherever possible, given the value afforded to them by members of the local community.

Design Guide – Considering safety and security

Careful consideration should be given to the structure and layout of the planting to maximise connectivity throughout the urban realm and avoid negatively perceived spaces created by densely, visually obstructive clusters of trees in inappropriate locations. Further detail on designing for a safe environment, including giving consideration to CCTV coverage, is provided in Section 4.1.7.

3.2.3 Educational benefits

Introduction

In line with the health and wellbeing, and social cohesion benefits described in Sections 3.2.1 and 3.2.2 respectively, green space, views of nature and trees are known to have educational benefits.

Effects on self-discipline

In a small study, Wells (2000) assessed 17 children for inattention and hyperactivity before and after a move from substandard accommodation to new apartments with varying degrees of natural views from the windows. The results showed that the amount of nature accounted for 19% of the improvement of the attention score compared to only 4% that could be attributed to improved housing quality.

In a larger study, Taylor et al. (2001) measured concentration, impulsive behaviour and delay of gratification using validated tasks and questionnaires. In girls, all three aspects of self discipline showed a positive and significant relationship with the greenness of the immediate vicinity and view from the flat, by up to a 20% increase.

Effects on concentration and motor ability

Bird (2007) states that “several studies have found that playing in nature has positive impacts on children’s social play, concentration and motor ability”.

A study in Sweden compared two nurseries, one surrounded by tall buildings and low plants, and the other by a mature orchard and woodland area. In the latter, children played outside in all weathers and the results showed that this group of children had better motor coordination and attentional concentration abilities (Grahn et al., 1997).

Attention Deficit Hyperactivity Disorder (ADHD)

Three studies have specifically explored how green space, nature and trees can help children with ADHD. Together, the studies highlighted that involvement and activity within green outdoor environments benefited the symptoms of ADHD significantly. It was found that all children with ADHD may benefit from more time in contact with nature, greener routes to school and better views of trees and green environments from their windows (Bird, 2007).

3.3 Environmental benefits

3.3.1 Microclimate adaptation

Introduction

Microclimate refers to the variations of the climate in small localised areas and often differs significantly from the general climate of a region. Microclimates in urban areas are typically significantly altered and influenced by a number of elements, including proximity to buildings, vegetation (or lack thereof) and bodies of water than can locally alter wind speed, humidity and temperature. Adaptation of urban microclimates is becoming increasingly important due to the effects of climate change, with the resultant intensification of the urban heat island effect, and rising temperatures and wind speeds.

The UK is becoming more vulnerable to higher temperatures due to global warming. The severe impacts associated with overheating are well known, with the summer of 2003 bringing 3,000 additional heat related deaths. There is a need to adapt and plan for these higher temperatures.

One of the challenges is to reduce the urban heat island effect which is greatest in the most densely populated areas. Urban temperatures are consistently several degrees higher than surrounding rural areas of parks, as vegetated surfaces have been replaced with paving and buildings that absorb and trap heat to create mini-heat islands. Temperatures are higher by 2 to 6^{o}C in these hotspots than elsewhere.

The latest climate predictions show that by 2080, every part of the UK will be hotter with surface temperatures in town centres potentially rising up to 35.5^{o}C. By 2050, August nocturnal temperatures could be 3^{o}C warmer, whilst during peak intensity periods it could be 10^{o}C warmer (Wilby, 2008).

Large species trees are an invaluable tool for manipulating urban microclimates by the regulation of temperature extremes (through shade and shelter) and air humidification, making it cooler and more pleasant, which has the following benefits:

- **Increased human comfort** by protecting humans from temperature extremes by through providing shade that lowers temperatures, provides protection from harmful UV radiation and increases humidity.
- **Reduced energy use** by using trees to reduce local wind speeds and provide shelter for buildings, thereby reducing heat loss and winter fuel bills for heating and by providing shade in summer to reduce cooling costs.

The value of large species trees as windbreaks

Trees have long been used as windbreaks as they form a physical obstacle and inhibit wind speed and turbulence. This in turn can be used to provide shelter for buildings, thereby reducing air infiltration which in turn reduces heating and cooling costs. The location, density and positioning of wind breaks needs to be considered carefully to avoid any reduction in natural ventilation during summer.

Windbreaks can reduce annual heating costs by 10 – 30% 9Dewalle et al. 1983; Heisler, 1991).

Case Study – Windbreaks study in Chicago

The following information is based on reduced infiltration from wind shielding by three trees around a well insulated Chicago residential building:

- *Heating energy use was reduced by 16% (%84);*
- *Air conditioning energy use was reduced by 9kWh, suggesting that the benefit from reduced infiltration is slightly greater than the detrimental effect of lower wind speeds on natural ventilation;*
- *For old buildings, the potential for savings on heating costs is especially large because they are generally poorly insulated, have high rates of infiltration and have inefficient heating equipment.*

Design Guide – Creating an effective wind break

The following should be considered when looking to use trees as a wind break:

- *Scattered trees throughout an urban area increase surface roughness, thereby reducing wind speeds by as much as 50% (Heisler, 1990).*
- *Trees located slightly upwind of buildings provide additional protection that reduces the amount of cold outside air that infiltrates a building, as lower wind speeds result in reduced infiltration.*
- *While a dense wood acts as an effective barrier to wind, an open row of trees is more advantageous because it not only reduces wind speeds, but also creates a larger protected area with reduced wind speeds behind it. The width of this area can be around 15 to 20 times the height of the trees in the row.*

Temperature reduction through evaporative cooling and shading

Large species trees are hugely important to our survival as they provide shade and protection from UV radiation, and localised cooling and shading in urban areas, especially streets.

Reducing surface temperatures through shading

The shade cast by large urban trees has the following benefits to surface temperatures:

- Trees can offset warmer conditions by shading soils, riverbanks, park grassland, living spaces and streets;
- Trees reduce localised temperatures by direct shading of incoming radiation (Dimoudi and Nikolopoulou, 2003; Brown and Gillespie, 1995);
- A tree canopy intercepts the incoming radiation mainly with its leaves, but also its stems, branches and twigs (Brown and Gillespie, 1995);
- Deciduous trees vary their characteristics, but can intercept up to 90% of the light falling on them (Hough, 2004), typically allowing a quarter of sunshine through in summer, compared with three quarters in winter (Brown and Gillespie, 1995);
- Trees are more effective than buildings in providing shade, as they continue to provide shade at midday when buildings are less effective. This shade reduces

the temperature of surfaces and to some extent air (Hough, 2004; Brown and Gillespie, 1995);

- Large species trees tend to cast more shade than smaller ornamental species. A pilot study on a hot summer's day in Manchester city centre found surface temperatures in a paved public open space reduced by 13^{o}C under a mature canopy, compared to full sunlight (Gill, 2006); and
- Vegetated surfaces provide evaporative cooling and, by increasing green cover by 10%, surface temperatures could be maintained at or below the 1961-1990 baseline temperature, up to but not including the 1980s (Gill et al. 2007).

Design Guide – Trees and car parks

Plant trees in car parks to shade parked cars and reduce surface temperatures, thereby reducing the number of volatile organic compounds evaporating from their petrol tanks.

Reducing ambient temperatures in urban landscapes

Research has demonstrated that temperatures can be reduced, thereby ameliorating the urban heat island effect, by providing more green space and high tree cover in urban situations (Gill et al. 2007). In particular, urban forests play a significant role in reducing temperatures in urban landscapes, providing an important source of relief during heat waves. Maximum mean air temperatures can be up to 5.2^{o}C cooler under a canopy, recorded in broadleaved and mixed forests containing beech (Renaud and Rebetz, 2009).

The shade from trees, particularly large species trees with broad canopies, makes streets and squares cooler. Large broadleaved tree planting is one of the most effective strategies for maintaining a more comfortable human public realm, particularly during heat waves (Watkins et al. 2007). In comparison to other forms of Green Infrastructure, a large species tree can provide the largest volume of leaf area and cooling effect due to evaporative cooling, whilst occupying very little ground level area within the urban environment, as they form 'natural umbrellas' (Trees Design Action Group, 2008).

Reducing energy consumption

Trees influence the microclimate of the surrounding area by cooling and humidifying the surrounding air. This has been shown to significantly reduce the energy required to run air conditioning systems, thereby contributing to a reduction in fossil fuel use. Air conditioning is becoming more widespread in Britain as global temperatures rise (Camden Council Strategy for Managing, Maintaining and Replacing Council-owned Trees 2003-2006, Anon.) Installing air conditioning drives up energy use as well as creating waste heat and becoming an ongoing cost. The shade provided by large species trees is an alternative, cost effective method for reducing internal temperatures, when well planned. The UK building stock is not well adapted to a warmer climate and problems of thermal comfort are already being experienced in London and other cities (Hacker and Holmes, 2007; Huang et al. 1987).

The use of deciduous trees is important as they allow sunlight to permeate through to buildings during the winter (Brown and Gillespie, 1995), thereby allowing the building to benefit from natural heating from the sun in winter and natural cooling from tree shade in summer. In the USA, tree planting programmes have been devised with the express intention of reducing or avoiding peak energy demand for cooling and heating (Akbari et al. 2003).

Shade tree planting can be a cost effective energy conservation measure associated with new home construction, making savings on heating and cooling of around 4% per tree (United States Department of Agriculture, 1994).

Case Study – Energy consumption study in Chicago

A study undertaken in Chicago indicates that a utility sponsored shade tree program could be cost effective for both existing and new construction in the city (United States Department of Agriculture, Anon., 1994). The following information is based on a computer simulated study in the Chicago area for typical 1-3 storey brick buildings and 1-2 storey wood-frame buildings:

- *One large tree can reduce annual heating and cooling costs by 2 to 4% ($23 to $86);*
- *Three large trees located for maximum summer shade and winter wind protection could save a typical homeowner about $50 to $90 a year, or 5 to 10% of a typical heating and cooling bill. This equates to increasing tree sover by approximately 10%;*
- *Per tree, annual heating energy use can be reduced by about 1.3% ($10);*
- *Per tree, annual cooling energy use can be reduced by 2 to7% ($15);*
- *Per tree, annual peak cooling demand can be reduced by about 2 to 6%.*

Design Guide – The variables that affect how effective a tree is at moderating urban heat island effect

***Type and size of tree** – temperature reductions are increased by planting the right trees. Different trees provide varying amounts of shade at different times of the year. Large broadleaved trees with dense canopies should be selected as they provide more shade than smaller ornamental species. In addition, conifers are less effective than deciduous trees as they prevent sunlight from heating up buildings in winter, thereby creating shade at the wrong time of the year, which can increase fuel consumption. Further information on suitable species is included below in Table 8.*

***Location** – the location of a tree can influence how effective they are at moderating urban heat island effect. Streets provide good locations for tree planting as they provide shade for pedestrians while also cooling buildings. Parks and urban forests are also effective as their cooling effect spreads out into surrounding urban areas as well as creating lower temperatures within the green space itself. More detail on plant placement and selection is outlined below:*

- *Proper placement and tree selection is critical because winter shade on south-facing surfaces increases heating costs in the UK climate (Heisler 1986; McPherson and Rowntree, 1993; Sand and Huelman, 1993; Thayer and Maeda, 1985).*
- *Generally the best place to locate trees for maximising microclimatic benefits is opposite west-facing windows and walls. Trees positioned in the west provide the most protection from prevailing winds. In the west, select evergreens if space permits, or low-branching deciduous trees with broad crowns for extensive shading during summer. Planting windbreaks 9-15m upwind of the building can provide savings once they reach the height of the building. Large species trees should be selected which will grow to about twice the height of the building they protect, planted in staggered rows where possible. Windbreak planting should be longer than the building to provide protection if the wind shifts direction.*

- *Typically, the next best place to locate shade trees is opposite east walls, using solar friendly deciduous trees with broad spreading crowns and relatively short foliation periods to provide summer shade without reducing winter solar gain.*
- *Avoid planting trees opposite south walls as this would obstruct winter solar gain which is beneficial in reducing heating costs. If trees are to be located on the southern aspect of a building, then solar friendly ones that are large enough to branch above windows should be selected.*
- *Locate trees within 10m of the building to increase the amount of shade. Where feasible, shading an external air conditioning unit improves efficiency and can save electricity. Trees on the southern aspect should be located fairly close (2.5 to 6m) to the building to optimise energy savings.*

Planting provision *– the health and vigour of a tree can affect its capacity to moderate temperatures. Adequate provision should be allowed for the tree's root system and crown to grow. By not planning and providing for the best planting conditions, there can be an adverse effect on the growth of urban trees.*

Aftercare and maintenance *– the biggest risks to large publically owned trees is the health and safety risk from structural failure, often causing them to be removed due to this perceived or real risk, negating any climatic benefits. The best way to minimise this risk is through regular and appropriate maintenance to ensure continuing healthy growth.*

In addition, the evaporative cooling process of trees is only possible if there is water available to be used for evapotranspiration (Brown and Gillespie, 1995), therefore urban trees are likely to require irrigation in times of drought so that they continue to evapotranspire and reduce cooling costs when most needed.

Table 8 Indicative list of large species trees appropriate for maximising microclimatic benefits (McPherson et al., 1994)

Botanical Name	**Common Name**	**Solar friendly** Y=Yes N=No	**Form** R=Rounded O=Oval P=Pyramidal B=Broad	**Growth rate** M=Moderate R=Rapid	**Longevity** I=Intermediate L=Long
Acer platanoides	Norway Maple	Y	R	M	L
Acer pseudoplatanus	Sycamore	N	O	R	L
Aesculus hippocastanum	Common Horse Chestnut	N	R	M	L
Betula nigra	Black Birch	N	O	R	I
Fraxinus Americana	White Ash	Y	O	R	L
Ginkgo biloba	Maidenhair Tree	Y	O	M	L
Larix decidua	European Larch	Y	P	R	L
Pinus strobus	White Pine	N	P	M	L
Quercus macrocarpa	Bur Oak	N	B	M	L
Quercus robur	Common Oak	N	R	M	L
Ulmus procera	English Elm	N	P	R	L

The benefits to human health

Provision of shade through large species trees not only reduces temperatures but also filters and blocks radiant heat from direct sunlight. This is important in helping to reduce sunburn and skin cancer. Children's skin in particular is more sensitive to UV damage, and the amount of sun exposure during childhood is thought to increase the risk of developing skin cancer in later life.

> **Design Guide – Creating shaded areas**
>
> *Shading from large trees is particularly important in school grounds and places where children play. Providing direct shade using trees in playgrounds reduces the risks associated with exposure to UV radiation (Heisler and Grant, 2000).*

3.3.2 Improving air quality

Introduction

Air quality in urban areas is highly important due to its implications on human health. Urban areas are associated with increased use of transportation, especially road transport which the source of many air pollutants. These pollutants occur in the atmosphere in the form of gases and particles.

Large species trees in urban landscapes can directly and indirectly affect local and regional air quality by altering the urban atmospheric environment in a number of ways:

- Removal of air pollutants;
- Temperature reduction;
- Reducing energy demands of buildings; and
- Effects on volatile organic compounds (VOCs).

Removal of air pollutants

Trees remove gaseous air pollution primarily by uptake via leaf stomata, though some gases are removed by the plant surface. Trees also remove pollution by intercepting airborne particles. A comprehensive study (Nowak et al. 1998) found urban trees in Philadelphia, USA, to have removed over 1,000 tonnes of air pollutants from the atmosphere in 1994. A study in the West Midlands (Hewitt, 2002) concluded that doubling the number of trees in the region would reduce excess human deaths by up to 140 per year due to the removal of particles from the air. Coder (1996) documents that there can be up to a 60% reduction in street level particulates where trees are present.

> **Tree planting and air quality**
>
> *London Mayor's Air Quality Strategy (2010)*
>
> *Policy 10 of the strategy states:*
>
> *"The Mayor will encourage the improvement of air quality in the public realm by planting urban vegetation to trap particulate matter…Plant trees in areas of poor air quality under the 'right place, right*

tree' principle through the Mayor's Street Trees programme and other schemes." It also provides a target of reducing local particulate matter (PM_{10}) concentration by around 20% using vegetation.

A study (Nowak et al. 2000) that integrated temperature, deposition and emission effects of trees revealed that urban trees can have a significant effect on reducing ozone concentrations (due to the temperature reduction effect). Based in part on these findings, the US Environmental Protection Agency has introduced urban tree cover as a potential emerging measure to help meet air quality standards. Taha (1996) undertook a study which identified a series of impacts that are experienced when tree loss occurs, which, when tested in the USA, would account for a 14% increase in ozone concentrations if 20% of wooded areas around Los Angeles were lost.

Design Guide – Maximising capture of pollutants

Research undertaken (Beckett et al. 1998) has concluded that there are marked species differences in the ability of trees to capture pollutant particles, indicating that conifers are often the best choice when solely considering their pollution control characteristics. The study indicated five species deemed to be appropriate for urban air pollution planting schemes in the UK:

- *Whitebeam (Sorbus aria);*
- *Field Maple (Acer campestre);*
- *Hybrid Poplar (Populus deltoides);*
- *Corsican Pine (Pinus nigra var. maritime); and*
- *Leyland Cypress (Leyland cypress).*

Temperature reduction

As discussed in Section 3.3.1, urban areas are often significantly warmer than their rural surrounds, which in the centre of London means temperatures can be up to 9^{o}C warmer than nearby rural locations (London Climate Change Partnership, Anon., 2010). This increased temperature can aggravate the production of air pollutants which are created by photochemical reactions in the air, as these reactions are more likely to intensify at higher temperatures. The cooling effect trees have on a microclimate (refer to Section 3.3.1) reduces the rate of photochemical reactions in the atmosphere and hence reduces the formation of secondary pollutants such as O_3.

Reducing energy demands of buildings

Section 3.3.1 provides a detailed analysis of the effects large species trees can have on urban microclimate, and, in particular, how this reduces energy consumption for heating and cooling costs. This has the indirect effect of reducing pollutant emissions from power plants.

Effects on volatile organic compounds

Trees and other forms of vegetation produce VOCs, which play a role in the formation of one of the most damaging pollutants, ground-level ozone, a major component of what is more commonly regarded as smog. The ozone forms when VOCs react with nitrogen oxides emitted by cars and other industrial activities, therefore it is fair to acknowledge that without these manmade pollutants, VOCs from trees would not present a problem. VOC emissions are also known to be temperature dependent, therefore it is important to consider the overall picture when analysing the effects trees have on air quality. In a vast majority of cases, the temperature reductions caused by trees, reducing VOC emissions, the filtering of air pollutants and reduced energy use will greatly outweigh any emission of VOCs from the tree itself.

Design Guide – Understanding VOC emissions

Rates of VOC emissions from trees vary be species. Where air quality is a particular issue, it may be appropriate to consider low VOC emitting species such as certain types of pine and maple trees, and avoid high VOC emitting species such as eucalyptus, sycamore, willow and some oaks (Geron et al., 1994).

Much more detailed information relating to VOC emissions has been produced by Stewart and Hewitt, 2002.

Benefits to human health

In 1998, the government released figures indicating that every year, 24,000 people in the UK die prematurely from air pollution.

An improved air quality is linked to a positive influence on the incidence of asthma, skin cancer and stress related illness. The Woodland Trust (2010) state that asthma rates among children aged four and five fell be a quarter for every additional 343 trees per square kilometre (Lovasi et al., 2008). This is particularly significant given that the UK has one of the highest rates of childhood asthma in the world, with about 15% of all children affected, with a higher occurrence in urban areas (Townshend et al., 2007).

The removal of carbon gases, principally carbon monoxide, is also proven to have considerable cardiovascular health benefits (Department of the Environment, 1996).

3.3.3 Carbon sequestration

Introduction

Carbon sequestration is the process by which carbon dioxide (CO_2) is transformed into above and below ground biomass and stored as carbon. Large species trees contribute to reducing levels of carbon dioxide and other greenhouse gases in the atmosphere. During photosynthesis, atmospheric CO_2 is absorbed and utilised by the tree. Most of the resultant by-products become fixed as wood, although some are respired back as CO_2 or used to make leaves that are eventually shed by the tree. Consequently, large species trees directly reduce atmospheric CO_2 through sequestration, in addition to indirectly reducing other carbon pathways by reducing energy use, as documented in Section 3.3.1.

Whilst this role of trees is well documented, there remains much debate over the extent and efficiency of large species trees to contribute meaningfully to direct carbon sequestration. McAliney (1993) suggests that:

"A single mature tree can absorb carbon dioxide at a rate of 48 lbs/year and release enough oxygen back into the atmosphere to support two human beings."

However, this figure is variable depending on a number of factors including species, location and size, typically recorded as diameter at breast height (dbh). Nowak et al (in review) estimate the gross sequestration rates for individual trees in Brooklyn, summarised below in Table 9.

Table 9 Carbon sequestration rates of different tree sizes in Brooklyn

Dbh class (inches)	**Carbon sequestration (lbs/year)**
0-3	2
9-12	19
18-21	43
27-30	55
39+	93

In the US, it has been estimated that urban trees throughout the country currently store 700 million tonnes of carbon ($14,300 million in value) and have a carbon sequestration rate of 22.8 million tC/yr, equating to £460 million/year (Nowak and Crane, 2001).

Case Study – California

Initial research suggests that planting lots of trees in California communities can make a difference when it comes to fighting climate change. The California Global Warming Solutions Act of 2006 (AB32) requires a reduction in GHG emissions to 1990 levels by 2020. This amounts to a reduction of 173 million metric tons from the predicted level in 2020. Using aerial photography, 242 million empty tree planting sites in California cities were identified. If 50 million trees were planted, they would sequester about 4.5 million tons of CO2 annually. If they were planted strategically to shade east and west walls of residential buildings, they would reduce air conditioning energy use by 6,408 GWh, equivalent to an average annual CO2 equivalent emission reduction of 1.8 million tons. The estimated total CO2 reduction of 6.3 million tons annually is 3.6% of the state wide goal, about the same as would be obtained from retrofitting homes with energy-efficient electric appliances.

In the UK, the Forestry Commission (2010) have produced a protocol to enable the amount of carbon in living trees and woodlands to be quantified.

In the publication ‘Trees and Sustainable Urban Air Quality’, produced by Lancaster University, the total amount of carbon stored by different tree species throughout the West Midlands has been quantified, as described below in Table 10.

Table 10 Total amount of carbon stored by tree species in the West Midlands

Species	**Stored Carbon (kt)**	**Percentage Total**
English Oak	180	36.7
Austrian Pine	35	7.1
Ash	27	5.5
Common lime	26	5.2
Silver birch	25	5.1
Sessile Oak	22	4.4
Sycamore	16	3.3

Species	Stored Carbon (kt)	Percentage Total
Lombardy Poplar	16	3.2
Horse Chestnut	15	3.0
Common Alder	11	2.3

Design Guide – Maximising carbon sequestration rates and capacity

From the same study by Lancaster University, it is noted that generally, faster growing species have higher carbon sequestration rates, but this is tempered with a shorter life span, reducing the total overall amount of carbon that is likely to be sequestered. Some large species trees have greater growth, and hence sequestration rates, than others, documented below. This guide is designed to augment other selection criteria when choosing tree species.

High	*Medium*	*Low*
Crack Willow	*Apple*	*Common Elm*
Goat Willow	*Ash*	*English Oak*
Larch	*Common Alder*	*Field Maple*
Lawson Cypress	*Common Lime*	*Sessile Oak*
Leyland Cypress	*Elder*	
Poplar	*Grey Alder*	
Silver Birch	*Hawthorn*	
White Willow	*Italian Alder*	
	Mountain Ash	
	Norway Maple	
	Red Oak	
	Scots Pine	
	Sycamore	
	Wild Cherry	

Carbon impact of maintenance activities

All newly planted and existing mature trees require some form of ongoing maintenance, particularly those located in an urban environment where demands for water may be greater and the consequences of structural failure much more pertinent. While the ongoing maintenance has a carbon footprint which should be considered on a project, it has been found to be about 2 to 5% of annual CO_2 reductions achieved through both carbon sequestration and reduced power plant emissions (McPherson and Simpson, 1999).

3.3.4 Ambient noise attenuation

Introduction

Noise can be defined as any unwanted sound and has increasingly become a concern in the outdoor environment of towns and cities due to increased urbanisation and technology. Noise can cause anxiety, tension, illness and prolonged exposure to high levels can cause hearing loss. Noise is now regarded as a form of environmental pollution or even an international health concern.

In 1980, the World Health Organisation (WHO) issued recommendations for the limitations of environmental noise. It recommended that 55dB should be considered a desirable environmental health goal for outdoor noise in residential areas during daytime and 45dB at night.

The ability to reduce noise within buildings has improved significantly by using building materials that control acoustics; however, less progress has been made in the external environment. Noise is a significant outdoor issue, in that it has a great impact on the perception of the character and quality of the urban landscape. The use of vegetation to reduce noise pollution is now being more widely incorporated by the US and continental Europe, as communities become less prepared to continue accepting high levels of noise pollution.

Using trees to attenuate ambient noise

Large species trees and other vegetation can play an important role in attenuating noise through reflecting and absorbing sound energy. One estimate suggests that 7dB of noise reduction is achieved for every 33m of forest (Coder, 1996), whilst other reported field tests show apparent loudness reduced by 50% by wide belts of trees and soft ground (Dwyer et al., 1992).

In the UK, the benefits of using trees for noise attenuation are regarded somewhat subjectively. This is partly due to the fact that noise occurs at low, mid and high frequencies, and planting is most effective at reducing high frequency noises only. A belt of planting 7.5 to 15m wide can reduce higher frequency noises by 10-20dB. Unfortunately, the most irritating frequency is the mid range, which also happens to be the dominant component of traffic noise, for which planting has been found to have little or no benefit in reducing (Kotzen and English, 1999).

Large species trees are more often used in conjunction with other forms of noise attenuation solutions, such as bunds or fencing, where the vegetation contributes to creating the appearance of a green landscape rather than being focused on attenuating background noise. This said, research has demonstrated that a landform combined with tree cover is more effective at attenuating ambient noise than either a landform or a belt of trees by themselves (Cook and Van Haverbeke, 1974).

Psychological reduction of noise

It has been demonstrated that screen plantings of more than 2m in height, which eliminate visual contact with the source of the noise, will psychologically reduce the irritating effects of noise, even though the plants themselves may not reduce the decibel level measurably.

The effect trees have of filtering high frequencies of traffic noise has been shown to make the sound more pleasant to local communities, reducing ‘apparent loudness’ by around 50%.

Trees also provide ‘white noise’; the noise of the leaves and branches in the wind and associated natural sounds that mask other manmade noise (Coder, 1996).

Design Guide – Using trees as noise buffers

Cook and Van Haverbeke (1974) give some generalised recommendations for reducing ambient noise with rows of trees:

- *Plant the noise buffer as close to the source of the noise as possible;*
- *Plant trees and shrubs as close together as the species will allow;*
- *Use trees with dense foliage. A diverse range of species, with a range of foliage shapes and sizes, may also improve noise attenuation;*
- *Use shrubs and a mix of trees to create a belt with foliage from the ground upwards;*
- *Where appropriate, use evergreen varieties that retain their leaves and provide better year round protection (Carpenter et al.);*
- *When possible, use tall trees. Noise levels can be reduced by 1.5dB with each additional three feet of tree height (Hopper, 2007); and*
- *Use soft porous soils, helping to reduce low frequency noise. Surface porosity of soils can be increased by leaving fallen leaves and branches on the ground.*

Reducing moderate traffic noise in communities

- *Plant belts of trees 7-17m wide along roadsides;*
- *Plant the nearest edge of the belt within 7-17m of the centre of the nearest traffic lane;*
- *The length of the tree belt should be twice as long as the distance from the road to the recipient of the noise; and*
- *The buffer should also extent equal distance in both directions parallel to the road.*

Reducing heavy vehicle noise in suburban areas

- *Plant belts of trees 20-35m wide along roadsides;*
- *Plant the nearest edge of the belt within 20-25m of the centre of the nearest traffic lane; and*
- *Attempt to use trees which will grow to a height in excess of 15m.*

Species selection

- *Attenuation of high frequency sounds is linked to leaf size, and it is therefore essential that any noise attenuation planting contain a high proportion of deciduous species;*
- *Year round noise attenuation needs to incorporate evergreen species such as Douglas fir, spruces and pines, provided foliage is present from the ground up. Large pine and spruce plantings 15-30m wide are capable of reducing some of the mid frequency noise that is characteristic of traffic, by as much as 10dB (Carpenter et al., 1975);*

The benefits of reduced ambient noise levels

Reduced noise levels are closely linked to improved health and wellbeing, discussed in more depth in Section 3.2.1. A proven link exists between long term exposure to traffic noise and an increased risk of heart disease (Ising and Michalak, 1998; Babisch et al., 1994).

Noise pollution has also been found to have a substantial negative impact on housing values. Wilhelmsson (2000) identified that a single family house would sell for 30% less if located near a noisy road.

Reducing outdoor noise levels have also been linked to increasing productivity in the workplace through improvements in concentration and a reduction of fatigue, annoyance and mistake making (Ising and Michalak, 1998; Babisch et al., 1994).

3.3.5 Water attenuation

Introduction

Water attenuation is the ability to control the movement of rainwater as it flows towards a watercourse or drainage system. Under natural conditions, rainfall is intercepted, slowed down by vegetation, where it partially evaporates and partially infiltrates the ground and stored, contributing to soil moisture and groundwater retention.

In urban areas, this natural hydrological cycle is disturbed due to the increase in impervious surfaces, which prevent the infiltration of rainwater and cause rapid runoff to surface water sewers and watercourses. In addition, increased land development results in increased runoff volumes, velocities and peak discharge rates, leading to a greater likelihood of surface water flooding. It is also predicted that climate change will result in more intense winter rainfall, which will cause high levels of storm water runoff, resulting in further flooding.

Around two-thirds of the 2007 flooding was as a result of surface water, with approximately 3.8 million homes in England susceptible (Environment Agency, 2009). The Environment Agency expects the regular annual cost of damage to property from flooding to be in excess of £1 billion, although damage to infrastructure and loss of business increases this figure to £2.5 billion, and this is predicted to rise to £4 billion by 2035 (Newratings, 2007; Environment Agency, 2009).

Urban trees and forests are now being regarded as an important and cost effective way of reducing these flood risks and reducing the impact of prolonged or intense rainfall. One study has estimated that for every 5% increase in area of tree cover within a catchment, runoff is reduced by 2% (Coder, 1996).

Intercepting rainfall and reducing surface water flooding

Large species trees, whether as street trees or as part of an urban forest, provide an opportunity to reduce the rate and volume of surface water runoff. Tree canopies intercept rainfall, allowing the water to evaporate or gradually run down to ground level, where permeable ground beneath the tree allows water to infiltrate and be stored. This lessens the likelihood of flash flooding and helps to conserve groundwater reserves. A dry tree canopy has been found to intercept as much as 20% of the total rainfall in any one event. Large trees with a large surface area are particularly effective at holding rainwater on the surface of its leaves, until it evaporates (Mansell, 2003). As much as 25-45% of water intercepted by conifers will be lost to evaporation, and 10-25% for broadleaved species (Nisbet, 2005).

Case Study – Stormwater attenuation, Garland, Texas

In the US, a new piece of software was used to model three tree canopy percentage scenarios for a 3.86 acre residential area in Garland, Texas. The model showed that the existing 8% tree cover was reducing the amount of stormwater network that would otherwise require management by 34 cubic feet per acre. When this was increased for the three scenarios to 25%, 35% and 45%, stormwater was reduced by 4,223, 5,941 and 7,635 cubic feet per acre respectively. This equates to a potential cost saving of $2,640. (American Forests, 2000).

Reducing demand on surface water drainage and flood risk infrastructure

Using trees, particularly large species trees, in urban landscapes as part of surface water management strategy is a self sustaining and cost effective remedy, which should be used to complement existing and new drainage infrastructure.

Using trees to slow and reduce urban runoff, ultimately reduces expenditure in other means of managing it including maintenance of existing infrastructure and provision of new engineering to increase capacity in the system. The financial benefits of this have been well researched in the US, and have been quantified for settlements in California. The research findings have been used to inform the design and management of the urban forest resource. Xiao and McPherson (2002) indicate that the annual value of avoided stormwater treatment and flood control costs associated with reduced runoff was $110,890, or $3.60 per tree.

In the UK, the challenges are slightly different because of our climate, although the problems of surface water flooding are still significant. Many older towns and cities have a combined sewer system, whereby foul drainage and surface water runoff enter into the same system. During heavy rainfall, these systems are rarely able to cope, and this is known to be a significant problem in London. In the case of London, the loss of urban forestry and public and private green space across the city has contributed to the need for a vast engineering scheme to increase capacity in the system – the Tideway Tunnels, anticipated to cost in excess of £4 billion.

The Environment Agency spend around £500 million on flood risk management each year. In addition to this damages from flooding can be much higher, with flooding estimated to have cost the economy approximately £3.2 billion in the 2007 floods, with a further £100 million in the Cockermouth floods of November 2009 (Environment Agency). It is now recognised that major tree planting projects in floodplains can offer significant benefits to urban communities, by slowing surface flows and minimising the risk of flash floods.

Case Study – Milton Keynes floodplain forest

"By re-establishing a natural floodplain along the Ouse Valley, the Parks Trust is enhancing the landscape, increasing biodiversity and creating valuable protection from flooding.

Once fully completed, it is envisaged that the project will create a total flood storage capacity of 460,000 cubic metres.

By creating a landscape that allows the river to expand into its floodplain, the risk of flooding further downstream has been lessened. Studies showed that the effect of this will extend as much as 12km downstream, so towns as far away as Newport Pagnell will benefit." (CABE).

Design Guide – Maximising water attenuation

Large trees with a large surface area should be used, including both evergreen and deciduous varieties. In appropriate locations, coniferous species may be used as they provide the greatest benefit during winter months when rainfall is typically higher.

Establishing trees in floodplains is an essential component of minimising flood risk. Riparian wetland species local to the area should be used wherever possible, giving consideration to other potential benefits that may be gained from the urban forestry, for example biodiversity.

3.3.6 Water filtration

Introduction

As part of the natural hydrological process, rainwater that is not evaporated, gradually infiltrates the ground and is stored, contributing to soil moisture and groundwater retention. However, in urban landscapes, as much as 70% of the surfaces can be impermeable, preventing water from readily infiltrating the ground. Instead, it forms surface water runoff that enters the drainage network, which in turn eventually flows into natural watercourses.

This rapidly moving surface water transports high levels of sediments, attached pollutants and dissolved contaminants commonly encountered in the urban environment. Coder (1996) notes that 47% of these surface pollutants are removed in the first 15 minutes of a period of intense rainfall. These pollutants have had a dramatic effect on the water quality of both our surface and subsurface drinking water supplies. Unfortunately, contaminants in many groundwater and surface water sources exceed national health and safety standards. Common contaminants include:

- Fertilisers, insecticides and herbicides;
- Sediments from construction sites and from eroded watercourse banks;
- Oil, grease, anti-freeze and salts from roads and car parks;
- Suspended solids, heavy metals and chlorides; and
- Biologically derived materials, litter and other pollutants from urban surfaces that the water has passed over.

Water quality
The Water Framework Directive (Directive 2000/60/EC)
The Water Framework Directive establishes a legal framework to protect and restore clean water across Europe, and ensure its long-term, sustainable use. In the UK, much of the implementation work will be undertaken by competent authorities (for example, the Environment Agency in England and Wales). It came into force on 22 December 2000, and was put into UK law (transposed) in 2003. Member States must aim to reach good chemical and ecological status in inland and coastal waters by 2015.

However, trees can have a vital role in improving water quality through interception of harmful land pollutants and be reducing topsoil erosion. Urban trees and forests can act as filters that remove nutrients and sediments while increasing groundwater storage.

The role of trees in trapping pollutants

Trees act as natural pollution filters. Their canopies, trunks, roots and the soil they sit within filter polluted particulate matter out of the surface water and sub-surface flows towards watercourses and drainage networks. They assist in filtering contaminants primarily by reducing and slowing the flows down, achieved through locally improved soil structure which is easy to infiltrate, and the presence of tree debris and other vegetation that impedes flows. Slowing down surface runoff has the effect of encouraging sediment and the sediment bound contaminants to settle, thereby reducing the amount of pollution that is washed into the drainage network.

However, coniferous plantations can contribute to acidification of waters as their needles catch pollutants in the air, which are later washed off into rivers when it rains (Woodland Trust).

Improvements to local groundwater quality

Trees also filter dissolved contaminants as they infiltrate the ground. Root growth and plant residue improves soil structure, enhancing the infiltration of the dissolved contaminants. Once in the soil contaminants can be immobilised, transformed by soil microbes, or taken up by trees.

Groundwater flowing through the root zone is filtered by tiny roots absorbing chemicals picked up in surface water. These are then stored in wood or processed by the tree and released as water and oxygen into the atmosphere. Tree roots remove nutrients like nitrogen, phosphorus, and potassium that are by products of urban living which reduce water quality and are harmful to aquatic ecology.

Improvements to the surface water quality of watercourses

Increased runoff also causes the erosion of stream embankments, resulting in the degradation of aquatic habitats and the accelerated deposition of sediments into rivers and reservoirs. When rain moves quickly off the land rather than being allowed to soak into the ground, it cannot recharge soil moisture or maintain groundwater base flows. However, water is made cleaner by the presence of trees, especially trees near watersheds or other drainage areas, as trees can protect stream water quality by intercepting and filtering pollutants and stabilising stream banks.

Along with improving water quality, trees help to stabilize soils by gripping soil particles with their roots. Tree roots bind the soil and prevent erosion thus promoting stream channel and bank stability. The presence of trees along watersheds that contain soils which are susceptible to erosion can significantly reduce the amount of pollutants in the water. Woodland also has the potential to soak up water in heavy downpours, swelling groundwater supplies, reducing the amount of water in our rivers during peak flows and helping to combat soil erosion.

Trees can also trap windblown dust before it enters watercourses, improving the surface water quality.

Design Guide – Maximising benefits to water quality

Opportunities for improving water quality in urban landscapes should be explored at a catchment wide level, allowing a comprehensive identification of the locations with the greatest opportunities to improve water quality.

A site based assessment is necessary to determine the best location of the tree planting, and which species are most appropriate. Native species will often be best adapted to the site, although it the hydrology adjacent to the stream has been altered significantly, then drought tolerant species may need to be considered.

Woodland buffers can protect stream and river water quality by intercepting and filtering pollutants, and stabilising the banks. Perpendicular planting can serve as water breaks, slowing flows down and allowing *more to be captured and filtered naturally.*

3.3.7 Ecological value

The direct ecological value of large species trees

Trees are major assets for urban ecological health, valued for their utility and the array of ecosystem services they provide for humans and wildlife alike. Large species trees are considered keystone structures because their effect on ecosystem functioning is believed to be disproportionate relative to the small area occupied by any individual tree (Fischera et al., 2010).

In relation to biodiversity, large species trees in urban areas, whether on streets, in woodland or in parks, gardens, schools or hospitals, provide a wealth of benefits relating to biodiversity. They are unique in their ability to support a variety of wildlife in many of the most hostile environments within in an urban setting. Recent studies have demonstrated the overwhelming value of trees in supporting bat and bird species in cleared or hostile landscapes, which are commensurate with many urban settings. This included doubling of bird and tripling of bat richness with the presence of 3 to 5 trees/ha (Fischera et al., 2010)

Trees benefit wildlife by providing structural diversity and volume of living space. This generally equates to more insects, and the effect cascades up the food chain. For example, many garden bird species are able to utilise large trees for nesting, within the canopy or within holes and cavities, and foraging opportunities, including insects, seed and fruit. Other features of trees such as bark supports specialist insects from foraging to shelter and breeding but also provides space for lower plants such as mosses and lichens. Older wood and cavities, that don't adversely impact on the health of a tree, provide significant micro-habitats for insects including beetles, sawflies, parasitoid wasps, craneflies and long-legged flies. Many structural features within trees are also actively utilised by key species such as bats.

The importance of large species trees on surrounding habitats is very important, providing damp and shaded conditions for many species, including within leaf litter. The presence of such species will in turn attract other predatory invertebrates along with amphibians and mammals. Additionally, in disturbed landscapes, scattered trees are often biological legacies that provide ecological continuity through time (Manning et al., 2006).

Ecological permeability in the urban environment

Urban areas generally adversely affect biodiversity through conversion of land to urban uses unwelcome to the natural environment. Many cities are rapidly expanding outward, reducing and fragmenting habitats (Gaston & Evans, 2010). Large species trees, and other forms of Green Infrastructure, create continuous belts that provide wildlife with shelter, food and movement corridors. The ecological value of large species trees include the provision of increased plant species richness, improved microclimate, increased soil nutrients, increased structural complexity and habitats for animals. At the broader scale, the ecological value of large species trees include increased landscape-scale tree cover; increased connectivity for animals; increased genetic connectivity for tree populations, dispersal of genetic material and creation of focal points for future large-scale

Green Infrastructure initiatives. In combination, these ecological functions support the argument that large species trees are keystone structures; that is, their contribution to ecosystem functioning is disproportionately large given the small area occupied and low biomass of any given tree and the low density of large species trees collectively (Manning et al., 2006). Because large trees fulfil unique functional roles in a wide range of ecosystems, their loss may result in undesirable ecological regime shifts.

Large species trees can support species in terms of foraging and breeding. Consequently, they form the backbone of any ecologically permeable landscape. However the ecological effectiveness of large species trees within in an urban green network, allowing for suburban to urban gradients, is often associated with accompanying vegetation and habitats.

Large species trees in gardens provide the benefit of biodiversity conservation networks in urban ecosystems (Hillary et al., 2002). Studies within urban gardens have repeatedly demonstrated the presence of large species trees could be the best way of enhancing abundance in the widest possible range of taxa (Smith et al., 2006 and Smith et al., 2005). The current trend in the UK for new developments is to have small private gardens, often discouraging eventual owners from planting trees. Consequently context and awareness of existing green infrastructure elements combined with a local tree strategies will maximise opportunities to create more wildlife friendly landscapes.

The relative values of native and non-native tree species

A fundamental debate lies in the use of native or exotic species when considering the large species trees in relation to wildlife. Within an urban context a tree's value for wildlife does not therefore necessarily equate to the number of species directly associated with it. Large species trees also provide a range of resources for species other than those simply eating their foliage. Selection of large species trees in urban areas will often be based on appropriateness, survival or urban resilience, climate change adaptation and other environmental benefits, other than for wildlife. Consequently there may often be a preference for use of non-native species; however it is the ability to reconcile conflicting goals, and by understanding that the wildlife value of large species trees within an urban setting will be best achieved by maximising variation, structure and species.

Birds and mammals tend to be less affected by the specific varieties of plants in a habitat and more by the actual structure of the habitat. For example, birds will usually be more concerned with the height of a tree and the availability of refuge areas (Luniak, 1992).

The relative ecological values at different stages of maturity

The value of individual large species trees for wildlife may depend upon the age of the tree. Different species may be associated with an individual tree at different stages of its lifecycle. For example, insects associated with flowers and fruits, will only be able to benefit from a particular tree once it has grown sufficiently and is mature enough to flower. Older trees also have a much greater variety of microhabitats available for colonisation.

As trees age, they get bigger increasing the surface area for other plants to colonise. The increase in the girth and development of branches and twigs allows for the production of a much greater number of leaves, providing a substrate for other life to colonise, including algae, mosses, ferns and lichens.

Depending on the species, periodically, the tree will also flower and set seed, providing seasonal abundance for many different animals. The enormous number of leaves produced is fodder for a staggering number of individual invertebrates from aphids and leaf miners, to caterpillars. When the leaves fall, they will often decompose providing another microhabitat for fauna.

Standing deadwood or trees which retain deadwood is one on the most important invertebrate habitats in the UK, supporting several key species. Often these trees are ancient and classed as veteran trees, many of which are incorporated within UK Biodiversity Action Plans (BAP), such as Wood-pasture and Parkland.

Design Guide – Maximising ecological value

It is important to consider the hierarchical structure and organisation of habitats and landscape features within an urban context. Whilst many species respond to the network of habitats connected through a city, many also rely on the finer scale, such as the provision of a single large tree. In order to maximise the biodiversity value of large species trees, it is important to promote a variety of different tree species, improving local structural diversity and variation. Different tree species have different growth habits, sizes, branching shapes and physical properties. The bark and wood of different types of trees will have varying physical properties and construction. This has significant effects on the type and variety of microhabitats provided by the tree for species such as lichens and algae. Research has shown that both bird density and the number of bird species are positively correlated with the number of tree species present (Peck, 1989). Additionally, providing mature vegetation and trees in urban areas could be the best way of enhancing abundance in the widest possible range of taxa (Smith et al., 2006).

On the broader scale, exploring the proximity, size and configuration of neighbouring habitats, large species trees are equally critical. Various studies of species have shown a strong positive correlation between species richness and area; i.e. the larger the area the greater the number and diversity of species. The numbers of floral and faunal species often increase with larger urban green spaces. Therefore, maintaining larger green spaces with high structural diversity may be effective in maintaining plant and bird diversity in urban systems (Khera et al., 2009). However, as noted above, other elements of a habitat, such as vegetation density, may be more important than area. For example, small areas of grouped large trees may be more favourable than larger areas of scattered large trees. In terms of an overall ecological perspective, some studies have suggested that a realistic target of 10% of tree cover throughout urban areas is necessary to create an ecologically sustainable city (Hashimoto et al., 2005).

Summary and recommendations

The ability to value the general ecological functions or ecosystem services and their ability to support wildlife value cannot be viewed in isolation without omitting critical components. Direct costing methods for establishing the value of wildlife such as BAP habitat/species creation are inappropriate and would not capture the true value of large species trees. Large species trees are recognised as contributing to a number of ecosystem services in urban areas (Bolund & Hunhammar, 1999). These various services arise from the natural ecological functioning of large trees. Consequently the ecosystem framework is a useful approach for highlighting potential benefits and functions in the valuing of large trees.

4 Implementing large species trees

This section provides a detailed summary of the practical solutions to the key constraints associated with the implementation of large species trees in urban landscapes, alongside a clarification of what the constraints are. A further section gives practical advice on strategic level planning and policy setting.

The Trees and Design Action Group (2008) highlight the fact that there is a huge gap between the aspirations of climate change strategies and policies, and an understanding of the practical considerations needed to encourage greater planting of large species trees.

4.1 Solutions to typical implementation constraints

Constraints to the implementation of large species trees in urban landscapes comprise both real and perceived issues. The sections below highlight what particular set of conditions would be required for the issue to become relevant.

4.1.1 Subsidence

Clarifying the risks

Subsidence is a serious risk on shrinkable clay soils, on which parts of large conurbations, such as London, are built upon, while other urban centres do not experience the same problems. Vegetation caused subsidence only occurs on shrinkable clay soils where there are active clay minerals within the tree root desiccation zone (Trees in Towns II, 2008). During dry periods, the tree will draw more water from the surrounding clay soils, causing it to shrink and leading to the potential for subsidence.

Subsidence, caused by ground heave due to variations in the water content or volume of the soil, doesn't typically occur in any other soil type than clays.

Trees in Towns II (2008) highlight the fact that the perceived risk of subsidence gives rise to a significant number of insurance claims, seen as one of the key risks to large species trees in urban environments.

Subsidence can however be caused by a number of other issues other than trees, and it is important that thorough assessments are made of claims using an engineering evaluation on a case by case basis rather than generic scenarios. Many local authorities in London now use the London Tree Officers Association 'A risk limitation strategy for tree root claims 3rd Edition 2007'. A common cause of subsidence in buildings with shallow foundations is simply seasonal variations and dry spells, varying the water content of the soil and hence the volume of the clay. Research undertaken by the University of the West of England (2009) also notes that the removal of large species trees may actually exacerbate the issue of subsidence, with the potential to cause ground heave in clay to a depth of around 6m, affecting even buildings with deep foundations. These findings are supported by Robert et al., 2006), which goes onto suggest that removing a tree in stages may help, but that rehydration of the soil is predetermined by the size of the soil water deficit and the expansive nature of the soil. The University of the West of

England also highlight leaking drains as a known cause of subsidence in shrinkable clay soils.

With new and existing developments, it is essential to properly understand the causes and risks, and design accordingly. Poorly planned tree planting and development layouts can give rise to a legacy of problems, while properly implemented schemes allow the benefits of trees to be maximised without generating an ongoing maintenance and legal liability.

Of particular importance is the retention of existing mature tree stock and cyclical replacement of those coming towards the end of their natural life. The Times (2008) state that between 2002 and 2007, London councils chopped down almost 40,000 street trees, including ones over 100 years old, out of a total stock of approximately 500,000. The Mayor's London Tree and Woodland Framework (2005) challenged this figure and estimated that less than 1% of the total tree population has actually caused damage to properties.

Minimising the risk of subsidence

Species selection

Where it is known that subsidence is a risk due to the presence of shrinkable clay soils, technical advice on species selection should be sought from arboriculturalists, landscape architects and geotechnical engineers. Species selection will be based on tree root depth, habit and water uptake, alongside other criteria discussed elsewhere within this report (for example carbon sequestration rates, ecological value etc.).

A key criterion is the rate of water uptake through transpiration. Some trees have high water demands, including poplar, willow and oak, while others have lower water demand, including beech and birch. Table 11 below gives more detail on the relative water uptake of some large species trees (National House Building Council).

Table 11 Water demands of different large species trees found in the UK (Roberts et al., 2006)

Botanical name	Common name	Mature height (m)
Trees with low water demand		
Betula pendula	Silver Birch	15
Fagus sylvatica	Beech	20
Trees with moderate water demand		
Acer platanoides	Norway Maple	18
Acer pseudoplatanus	Sycamore	22
Aesculus hippocastanum	Horse Chestnut	20
Ailanthus altissima	Tree of Heaven	20
Alnus glutinosa	Alder	18
Carpinus betula	Hornbeam	17
Cedrus libani	Cedar of Lebanon	20
Fraxinus excelsior	Common Ash	23
Juglans regia	Walnut	18

Botanical name	**Common name**	**Mature height (m)**
Picea abies	Norway Spruce	18
Pinus sylvestris	Scots Pine	20
Platanus x hispanica	London Plane	26
Prunus avium	Wild Cherry	17
Pseudotsuga menziessii	Douglas Fir	20
Robinia pseudoacacia	False Acacia	18
Tilia platyphyllos	Large Leaved Lime	22
Trees with high water demand		
Cypressus x leylandii	Leyland Cypress	20
Cypressus macrocarpa	Monterey Cypress	20
Chamaecyparis lawsoniana	Lawson Cypress	18
Eucalyptus spp.	Eucalyptus	18
Populus nigra	Black Poplar	28
Populus nigra italic	Lombardy Poplar	25
Quercus cerris	Turkey Oak	24
Quercus ilex	Holm Oak	24
Quercus robur	Common Oak	20
Quercus rubra	Red Oak	24
Salix alba	White Willow	24
Salix fragilis	Crack Willow	24
Salix sepulcralis	Weeping Willow	16
Ulmus glabra	Wych Elm	18
Ulmus procera	English Elm	24

The above list is widely used and based on experience of tree-related damage cases, although the water demand information is collected from trees in forestry conditions which differs to conditions associated with urban environments. Lawson and O’Callaghan (1995) highlight that water demand is only one aspect and other factors that influence the water content of a clay soil should also be considered, including:

- The different rooting habits of various species, which may affect the water uptake ability and zone of influence. For example, London Plane trees in Central London have been found to have adapted to the soil conditions and developed a thick, long tap root, supplemented with a fibrous root network very close to the surface;
- The ability of the tree to effectively intercept precipitation, based on its leaf surface area (refer to Section 3.3.1 for more guidance on maximising interception rates); and
- The extent of hard, impermeable surfaces, reducing the water content of the soil and causing trees to spread roots further looking for water.

Development and tree planting layout

It is important to consider large species trees at the outset of laying out a new development to ensure that the maximum value of trees are attained, alongside minimising implementation costs and saving money from avoiding subsequent damage from poorly planned layouts.

On highly shrinkable clay soils, research undertaken by the National House-Builders Registration Council (2003 cited in Roberts et al., 2006) provides figures for the extents of influence on groundwater different species have. With reference to Table 11 above, the following can be identified:

- A 20m high low water demand tree planted 10m away from a building will influence groundwater to a depth of approximately 1.8m;
- A 20m high deciduous moderate water demand tree, planted 15m from a building will influence groundwater to a depth of approximately 2.4m;
- A 20m high coniferous moderate water demand tree, planted only 7m from a building will still only influence groundwater to a depth of approximately 2.4m;
- A 20m deciduous high water demand tree, planted 25m from a building will influence groundwater to a depth of almost 3.5m; and
- A 20m high coniferous high water demand tree, planted only 11m from a building will still only influence groundwater to a depth of around 3.5m.

These figures allow developers to factor space for trees into the initial masterplans. Where tight is relatively constrained, species choice should be carefully considered, along with planting techniques outlined below and greater investment should be placed in providing deeper foundations, also as described below. Where larger areas are available within a development, creating pieces of public realm, more freedom of choice is attainable, allowing other social and environmental considerations to lead on tree selection and layout as set out in Section 3.

These distances are an indicative guide only. There are a wide variety of factors that influence the extent of area over which tree roots will develop in search of water. A significant influence is the type of surface between the buildings and the tree – impermeable surfaces cause the soil to dry out to a greater extent, which in turn causes tree roots to spread further in search of water.

Foundation design and specification

It is essential for developments on shrinkable clay soils to adopt appropriate foundation design, as subsidence can be caused by numerous elements, not only poorly considered trees. Buildings can be affected by four broad categories associated with interactions between vegetation and underlying clay soils:

- **Normal seasonal movements** - associated with evaporation and transpiration from a grass covered area;
- **Enhanced seasonal movements –** associated with increased transpiration following introduction of trees;
- **Long term subsidence –** as a persistent water deficit develops; and
- **Long term heave –** as a persistent water deficit dissipates.

Therefore, new developments on shrinkable soils should look to implement foundation depths in line with the findings cited in Robert et al. (2006) above – therefore in excess of 3 to 3.5 m. This will greatly minimise the risk of subsidence occurring from any number of factors while also maximising the amount of space available to establish large species trees and enjoy the multiple social, environmental and economic benefits. In some cases it may also be appropriate to consider piling foundations for certain developments or site conditions.

Maintenance requirements

A recognised technique for minimising subsidence at building where it has already begun to be experienced is through controlling the water use of the tree. At its most extreme, this would involve felling the tree or removing the crown, but crown reduction and/or thinning are more often used. These techniques are damaging to the tree, stunting or entirely preventing its continuing healthy growth and development, while also potentially causing further damage to the building by increasing the water content of the soil, allowing it to expand.

4.1.2 Structural damage

Clarifying the risks

Aside from the issues associated with soil heave in shrinkable soils, trees can also cause direct damage to surfaces, walls and low-rise structures arising from the growth of tree roots.

Damage is generally less severe in soft and loose soils that can easily deform as roots grow, rather than dense or hard soils (Day, 1991). MacLeod and Cram (1996) undertook detailed research into the forces exerted by tree roots, and concluded that direct damage is usually more limited to light structures such as pavements, roads and low unsupported walls. It is only as a tree gets larger that there may be a risk of direct damage to more substantial walls and low rise structures such as garages.

Roberts et al (2006) also note that it is almost always the case that the majority of direct damage that tree roots cause occurs close to the base of the tree where the expansion of the trunk and adjacent roots is greatest.

The cost of pavement repairs has been well documented in the US, with an average annual cost of $27,000 per city in California reported (Hamilton et al., 1975) and $14.3 million spent on 200,000m^2 of pavement repairs in San Jose (Sealana and Associates, 1994). In California, the average repair cost was $480 per tree, with one tree out of every 99 requiring pavement repair (Mcpherson, 2000).

In addition, significant indirect costs arise from insurance claims from people who have tripped and fallen due to uneven pavements and exposed roots. This is prevalent throughout the UK and the USA in particular. In California, for every $1 spent on repairing pavements, over $2 are spent on litigation (McPherson and Peper, 2001).

Minimising the risk of structural damage

Roots tend to grow downwards and away from the light. However, roots will also grow towards optimum conditions of water, nutrients and oxygen levels, leading to many tree species developing shallow-growing roots tracking close to the surface (Nicoll and Coutts, 1997). These optimal conditions are often experienced just under hard surfaces such as roads and pavements, due to higher soil oxygen and water content (Roberts et al., 2006).

Construction of hard surfaces

Paved areas such as roads, footpaths and car parks must be constructed with a firm and stable base, able to resist the force of roots as they spread away from the tree. This is often achieved by excavating to a depth of approximately 0.5m, compacting the base material and backfilling with an inert material. Soil compaction acts to restrict root elongation, as the mechanical impedance to root extension is greatly increased (Patch and Dobson, 1996).

Using flexible and permeable pavements or surfaces around tree pits aids infiltration of water to roots below the surface, thereby minimising the development of roots right up to the hard surface, which causes damage. Porous resin bound paving can be laid right up to the trunk of the tree, whilst still allowing rainwater to infiltrate through to the roots.

Species selection

Different trees have different rooting habits, although these are all additionally influenced by soil type and conditions. Wong et al. (1988) surveyed over 2000 trees in Manchester (more than 10% of the cities trees) and ranked them according to damage caused to pavements and kerbs, summarised below in Table 12.

Table 12 Summary of trees causing pavement and kerb damage in Manchester

Tree species	**No damage**	**Minor damage**	**Moderate damage**	**Severe damage**
Pavement Damage				
Ash	51%	26%	14%	9%
Lime	58%	25%	11%	6%
Horse Chestnut	63%	23%	2%	3%
Oak	77%	17%	5%	1%
London Plane	77%	17%	4%	2%
Birch	78%	16%	6%	0%
Whitebeam / Rowan	83%	12%	4%	1%
Cherry	84%	10%	3%	2%
Total	**69%**	**19%**	**8%**	**4%**
Kerb Damage				
Ash	68%	23%	7%	1%
Lime	76%	15%	5%	3%
Horse Chestnut	90%	7%	3%	0%
London Plane	94%	5%	1%	0%
Birch	96%	4%	0%	0%
Whitebeam / Rowan	96%	3%	1%	1%
Cherry	97%	2%	1%	1%

Oak	99%	1%	0%	0%
Total	**87%**	**9%**	**3%**	**1%**

Planting techniques

Matching the growth characteristics of trees to conditions at the planting site, together with using appropriate planting, maintenance and management techniques can greatly reduce damage to pavements as trees mature. The key to successful implementation of trees is providing maximum soil volumes for root growth, encouraging deep rooting and lateral root growth, thereby discouraging surface roots which cause pavement upheaval and damage to occur.

Appropriate planting techniques should include the following:

- Provide a tree pit with as large as possible soil volumes to give tree roots adequate space to grow laterally and prevent drying out of soil;
- Use linear tree planting trenches along streets to provide maximum soil volumes to give tree roots adequate space to grow laterally and prevent drying out of soil;
- Use tree break out zones to encourage growth of deeper roots;
- Improve soil preparation at depth to encourage growth of deeper roots. Reduce compaction to the base and sides of the pits or trenches to ensure waterlogging does not damage tree roots;
- Use good quality imported topsoil (neutral pH) to provide best growing conditions. Loamy soils are best for storing water and minerals without reducing aeration for roots;
- Use structural soils such as Amsterdam Tree Sand to provide a porous growing medium that has the capacity to adequately support hard surfaces above. Structural soils have been found to promote deeper root growth and healthier tree growth;
- Install perforated flexible drainage pipes at the base of the tree pit linked to surface water drainage to reduce waterlogging;
- Add organic matter to improve water retention capacity;
- Install irrigation to prevent water shortages to trees and soil from drying out and causing subsequent shrinkage;
- Lay mulch to prevent drying out of soils and subsequent shrinkage;
- Add water retentive gel to prevent drying out of soils and subsequent shrinkage;
- Use mycorrhizal fungi additives to enhance the growth and drought tolerance of trees, improve nutrient uptake and offer protection from heavy metals and soil contamination; and
- In some instances it may be appropriate to install cantilevered support to pavements in order to create larger tree pits.

An additional mechanism for diverting root growth away from surfaces and structure and hence avoiding damage, is through the use of root barriers. Polythene sheeting and herbicide-impregnated geotextile sheeting barriers perform particularly well (Moffet et al., 1998), although in most cases, constructing a tree pit in the manner described above will be enough to prevent damage to structures. Where root barriers are considered necessary, they should be positioned so as not to unnecessarily restrict the development of roots. Indeed, it may be appropriate and more cost effective to use root barriers to protect individual structures and utility runs, providing trees with the freedom to healthy develop, maximising the social, environmental and consequential economic benefits.

Maintenance requirements

Planted correctly, in line with the guidance described above, the maintenance legacy of trees should be greatly reduced, although a regular regime of inspections and pruning is necessary to continue promoting healthy growth and development.

Where tree roots do become a problem, a common but ineffective solution is root pruning. In some instances, only a few small roots may be affected, and pruning is unlikely to give rise to any noticeable effect to the visible portion of the tree. However, more extensive root pruning leads to the need to also reduce the size of the tree canopy (Phillips, 1999). Root pruning also often results to damage to the trees themselves, particularly through increased vulnerability to disease entering through the wounds (Nicoll and Coutts, 1997). In addition, pruned roots will often rapidly re-grow, causing the problem to return with greater severity. Hamilton (1984) reports that "root pruning of mature ash trees in the San Francisco area required repeat pruning every 4-5 years at a cost of $400-500 per tree".

4.1.3 Utilities and underground structures

Clarifying the risks

Utilities and underground structures pose particular constraints to retaining maturing trees and establishing new trees in existing urban environments. In the case of new developments, careful consideration of the layout of trees, and service runs and other underground elements should be sufficient in mitigating any risks associated with damage to utilities.

The National Joint Utilities Group (1995) summarises the different ways in which tree roots may damage utilities:

- **Direct damage** – caused by roots coming into contact with services and exerting a force, which is typically very small. The greatest risk to damage arises from the main structural roots within 3m of the base of the trunk.
- **Root incursion** – roots will not penetrate intact services, but may exploit existing defences, particularly in the drainage network. Enlargement of the defect is only likely to occur within 3m of the trunk.
- **Indirect damage** – services can be damaged within shrinkable soils in the same way that building subsidence is caused (refer to Section 4.1.1).
- **Wind movement of the tree** – The risk of damage or uplifting of utilities close to a tree may be increased by movement of the lower and trunk and structural roots in the wind, although this is a rare occurrence.

BS5837:2005 gives advice on the minimum distance between young trees and structures. Information relevant to utilities has been summarised below in Table 13:

Table 13 Minimum distance between trees and underground utilities to avoid direct damage from future tree growth

Type of structure	**Diameter of stem at 1.5m above ground level at maturity**		
	<30cm	**30-60cm**	**>60cm**
Drains and services less than 1m deep	0.5m	1.5m	3.0m
Drains and services over 1m deep	-	1.0m	2.0m

Most utility providers provide specific guidance that will need to be considered when looking to plant trees in close proximity to services.

Minimising the constraints utilities pose to urban trees

Protecting and preserving existing trees

Existing mature trees are an incredibly valuable resource within our urban landscapes. A majority of the social, environmental and economic benefits of trees increase with age as they develop into full maturity. The Capital Asset Value for Amenity Trees (CAVAT), first published by the London Tree Officers Association in 2007, provides values for trees based on size, social value and life expectancy amongst other variables. The use of CAVAT as a tool for valuing trees has now been accepted by the insurance, loss adjusting, local authority and private arboricultural sectors through implementation of the Joint Mitigation Protocol (Trees and Design Action Group, 2008).

Using the CAVAT system, a London plane in Mayfair has been valued at £750,000, contributing to an estimated £6.4 billion value of London's total tree stock. Besides London planes, the most valuable trees have been found to be oaks, horse chestnuts and beeches (The Times, 2008).

These valuations justify the importance of avoiding tree removal as a remedy for a problem wherever possible, particularly as there are also continuing annualised economic benefits.

Within existing urban areas, trees are often in close proximity to utilities and other underground structures, which may give rise to significant problems when these services need to be maintained. The National Joint Utilities Group (1995) provides guidance on how to avoid damage to trees when working within the precautionary area (defined as four times the circumference of the trunk, which often equates to slightly larger than the crown of the tree). These techniques include:

- **Trenchless** – using a small tunnelling machine to bore a hole, starting and finishing outside of the precautionary area, below 600mm so as to avoid a majority of the root system.
- **Broken trench** – a combination of hand dug trenches and trenchless techniques, maintaining the open sections as short as possible.
- **Continuous trench** – hand dug trench, minimising damage to all roots and working around roots with a diameter in excess of 25mm. If severance is unavoidable, roots must be cut back using a sharp tool, leaving the smallest wound.

A more specific definition of how to calculate the precautionary area, or root protection zone, is contained within BS 5837:2005 Trees in relation to construction – Recommendations.

Where large trees are to be retained on or close to construction sites, it is important that they are protected in line with BS5837:2005, including appropriate fencing or cellular confinement systems for haul roads to protect the extent of root development from compaction. Opportunities for translocation of existing trees in proposed development sites should also be explored, where they are clearly in conflict with any masterplan layout.

New trees in existing urban areas

Within many existing urban developments, underground constraints in the form of buried services, basements, underground railways etc. are perceived to severely limit opportunities for greater levels of urban greening through establishment of large species trees. In many instances this appraisal is justified, particularly where the historic development of utilities leaves multiple corridors covering large areas just beneath the surface of roads and pavements. However, given the social and environmental benefits that are known to arise from the presence of large species trees (set out in Section 3) and the economic benefits arising from these (summarised in Section 2), there are a number of techniques available for implementing more urban trees.

Firstly, use of the planting techniques described above are also applicable to protecting underground utilities and structures from root growth. Techniques such as using structural soil and linking tree pits together in linear trenches allow greater control on where roots will develop towards, deterring them from less suitable ground around utilities.

Secondly, opportunities to place existing services into shared ducts, and replacing rigid pipes with more flexible plastic ones should be explored, creating space for the establishment of large species trees. Careful consideration should be given to the choice of plastics for services; while polypropylene may be much more cost effective, it is much less strong than polyethylene and is likely to require more repair and maintenance.

New developments

Within new developments, it is essential that large species trees are considered alongside other infrastructural elements of the masterplan at the early strategic planning stages, ensuring enough space is maintained for easy implementation of trees. In order to maximise the value of open space that is incorporated into a new development, it is advantageous to make as much space as possible for the large tree species, maximising the economic, social and environmental benefits highlighted in Sections 2 and 3. To achieve this, service routes should be carefully planned to maximise space available for trees, even if this means a slight lengthening of the routes. Also, new utilities should be placed in combined service ducts, reducing sterilisation of the ground in terms of tree planting and leading to cost savings for future maintenance.

When selecting species, consideration should generally be given towards what social and environmental benefits are being targeted as part of the development, although poplars and willows are known to have particularly invasive root systems, making them less suitable near underground services, particularly drainage networks.

4.1.4 Obstruction of access and over shading

Clarifying the issues

Over shading and obstruction of access is a common problem for large trees in urban landscapes, with local authorities often placed under pressure by local communities and businesses to remove, replace or drastically thin offending trees.

There is also significant pressure on urban trees due to highways, rail and local authority health and safety requirements, including provision of clear sightlines, clearance for lighting and signage, and ensuring pavement widths are fully accessible.

Preserving access

In many urban landscapes, pavement widths are too narrow to allow for street tree planting in addition to maintaining good access, particularly for wheelchairs, prams, the elderly and partially sighted people.

In some instances it may be appropriate to use a structural soil within the tree pit, combined with a porous surface to maintain as much smooth surface as possible. More detail on these systems are referenced in Section 4.1.2. However, in many cases, the most appropriate layout to consider is kerb side build outs, or nib planting. Trees in this instance can be used as a traffic calming measure, narrowing the street and providing demarcation for on-street parking bays. Structural soils and appropriate surfacing are again important considerations for trees within the highway, given that they may be occasionally trafficked over.

Lastly, the principles of minimising and avoiding damage to pavements, described in Section 4.1.2, are essential in preserving a paved surface which is generally accessible and not seen as a nuisance by the local community.

In new developments, alternative locations for urban trees should also be explored, including communal open spaces and boundaries, in shared parking areas and gardens.

Preserving clear sightlines

Clear sightlines are an important health and safety consideration on highways and railways. Sightlines in relation to public visibility and CCTV viewing corridors is discussed in Section 4.1.7. Places, Streets and Movement, A companion guide to Design Bulletin 32 Residential roads and footpaths (1998) provides guidance on how far planting should be set back from different junction types to ensure good visibility, particularly when turning onto a major road where vehicles may be travelling at speed. It is also important that trees do not obscure lighting or signage on highways, ensuring a safe driving environment is retained.

Minimising adverse reactions caused by over shading

Over shading caused by large species trees needs to be considered very sensitively. The microclimatic benefits of tree shade are documented in detail in Section 3.3.1, covering how heating and cooling costs can be reduced in buildings. In addition, Section 3.3.1 documents how this shade can also benefit the hard surfaced streets, by moderating temperatures and reducing damage cause by temperature extremes. However, trees blocking light from entering a home or business is one of the most common complaints local authorities receive in regard of trees (Trees and Design Action Group, 2008).

In the case of excessive shade from existing trees, this problem may be resolved by sensitively undertaking selective pruning using a qualified arboriculturalist to ensure the health of the tree does not suffer.

When considering new planting schemes in close proximity to people's homes or places of work, there should generally be a presumption against evergreen species, which continue to block light through the short days of winter. In addition, trees with a fastigiate habit, open branched structure or with less dense foliage should be considered. Indicative large species trees within each of these categories are summarised below in Table 14.

Table 14 Trees for areas with limited space or in close proximity to buildings (Barrell Tree Care)

Botanical name	**Common name**	**Mature height**
Deciduous trees with a fastigiate habit		
Acer platanoides 'Columnare'	Norway Maple	15-20m
Acer saccharinum 'pyramidale'	Sugar Maple	20m
Corylus colurna	Hazel	15-20m
Fagus sylvatica 'Dawyck'	Beech	20-25m
Liriodendron tulipifera	Tulip Tree	15-30m
Platanus hispanica 'pyramidalis'	Plane	15-20m
Populus nigra 'italica'	Lombardy Poplar	30m
Tilia cordata 'Greenspire'	Small Leaved Lime	20m
Trees with an open branch structure		
Gleditsia triacanthos sunburst	Honey Locust	15-20m
Robinia pseudoacacia	False Acacia	25m
Trees with less dense foliage		
Gleditsia triacanthos sunburst	Honey Locust	15-20m
Robinia pseudoacacia	False Acacia	25m
Tilia cordata 'Greenspire'	Small Leaved Lime	20m

4.1.5 Leaf litter and maintenance

Clarifying the issues

One of the barriers to greater adoption of street trees by local authorities is the aversion to accepting the ongoing maintenance liability arising from seasonal leaf litter. The key issues which have been associated with trees in urban areas include health and safety issues from slippery roads, railway lines and pavements, which can give rise to litigation and delays to trains, and blocked drainage networks, including sustainable drainage systems.

A further barrier is the perceived risk that urban trees will cause damage to surrounding surfaces and structures, such as pavements, which will need ongoing repair and maintenance. While this is certainly true, and there are a multitude of examples across the UK of footpath damage, this can be easily overcome by correct implementation of street trees using the guidance contained within Section 4.1.2.

Local authorities spend thousands of pounds each year in managing the conflicts between trees, pavements and other elements of the urban infrastructure. Many authorities have a huge backlog of repair costs for damaged pavements and are spending a fraction of the amount needed to repair all kerbs and pavements. Widespread adoption of the implementation techniques described in this guide has the potential to save the UK economy millions of pounds.

Case Study – Maintenance liability, California

In 1998, California's cities spent $62 million per year ($2.36 per capita) on pavement, kerb and gutter repair, tree removal and replacement, prevention methods and legal costs (Burger et al., 1998). These figures are for street trees only, and do not include repair costs for damaged sewer lines, building foundations, car parks or various other hardscape elements (McPherson et al., 2000).

Pavement damage is the second most common reason that street and park trees are removed, causing the losses of thousands of healthy trees each year and the subsequent loss of social, environmental and economic benefits. It would be more beneficial for local authorities to spend money in minimising these conflicts through appropriate planting and implementation techniques, rather than spend it on ongoing mitigation and short-term prevention.

Case Study – Prevention and mitigation costs, California

McPherson et al. (2000) document the average preventative and mitigation costs of damage caused by trees as follows (per tree):

- *$79 for root and crown pruning;*
- *$44 for grinding to remove stumps and restore pavement heave;*
- *$31 for ramping to locally raise pavements around roots;*
- *$40 for root barriers;*
- *$537 for tree removal and replacement; and*
- *$154 for replacing pavement surfaces.*

There was also found to be an average of $6245 awarded to individuals claiming over trip and fall cases (Randrup et al., 2000).

These case studies highlight the importance of proper planning and implementation of urban trees, and the cost savings these can quickly generate.

Leaf litter

While leaf litter is generally viewed as a significant maintenance liability arising from trees, there is a recent trend towards making this a commercial exercise, using arisings and leaf litter for some of the following:

- Using bark chips and timber as a potential source of bio fuel;
- Creating leaf logs out of fallen leaves;
- Selling leaf litter as mulch, or using it to create compost to sell;
- Creating bark ship and wood ship mulch from branches and twigs;
- Using deciduous leaf matter, green plant material, grass clippings and wood chip to create organic soil improvers; and
- Using red dendra worms in this composting process to create organic liquid fertilisers.

Case Study – Leaf litter in Croydon, London

The London Borough of Croydon faces the same issues and problems that every other local authority faces with regards to managing its urban tree budgets. The borough has a tree maintenance budget of £177,000, although no woodland management budget and has one of the largest stocks of highway trees in London with a recorded number of 32,000 trees, plus a further estimated 3,000 unrecorded trees growing in hedgerows and greens.

The solution to balancing the maintenance costs has been to manage trees through certification under the Forestry Stewardship Council (FSC) certification. This allows Croydon to sell the wood on a commercial basis and a market for timber, charcoal and woodchip for fuel to develop. This has the effect of reducing the amount of waste wood going into landfill on the basis of green waste utilisation and raise further income to cover tree maintenance work.

Croydon has set up a Tree Station which is capable of generating up to 10,000 tonnes per year of high quality woodchip from waste material and arboricultural arisings from the borough's trees. The woodchip is sold for bio-fuel with an initial market for 1,000 tonnes a year at the BedZED combined heat and power plant. Through achieving accreditation, charcoal is now sold to B&Q by a business (commercial partner) which has been set up as a direct result of a market need.

Croydon has also developed its own compost. Green waste from woodland and arboricultural works and street tree leaf fall is used to produce the compost. The material is mixed with green garden waste that is collected at Household Waste Recycling Centres and arisings from landscape contractor operations. The resultant composted product is used for a number of products including soil improver, mulch, turf dressing and horticultural compost which is bagged and sold. The product is sold to a variety of end users including farmers, landscapers and garden centres. (Britt and Johnston, 2008)

Case Study – Recycling green waste, California

Nearly all California cities are recycling a portion of their green waste. In 1992 the state's tree programs recycled 66% of their wood waste as mulch or compost (Bernhardt and Swiecki, 1993). The amount of waste wood disposed of as firewood is relatively low and few programs burn their waste wood. In most cases, the net costs of waste wood disposal are about 1% of total tree care costs as cities and contractors strive to break-even (hauling and recycling costs are nearly offset by revenues from purchases of mulch, milled lumber, and wood products) (personal communication, Pat Mahoney, President, West Coast Arborists, Inc., October 29, 1999). Hauling waste wood is the primary cost in Southern California, where virtually all waste wood is now recycled. Portable mills are increasingly used to produce lumber that is sold or worked to create park benches, picnic tables, and other wood products.

Renewable energy

2006 Energy Review

In addition to government policy and legislative requirements, the UK is committed to generating 10% of its electricity from renewable sources by 2010. There is a further target of achieving 20% by 2020. Waste wood from arboricultural and forestry operations qualify as biomass under the Electricity Regulations 2003 (Guarantees of Origin of Electricity Produced from Renewable Energy Sources).

In Scotland, the Scottish Executive has a target of generating 17-18% of electricity from renewable sources by 2010, rising to 40% by 2020.

The problems associated with blocked gutters and drains can be avoided or minimised by fitting mesh guards. Species with particularly large leaves which have been associated with blocked drains include London Planes, Maple species and Sycamore.

Honey dew drip and fruit fall

Trees known to be particularly prone to honeydew drip and fruit fall need to be carefully located within urban landscapes. These species should be positioned away from roads, car parks and seating areas to prevent the requirement for an onerous maintenance regime. Honeydew is a particular issue when it drips onto cars, paving or glazed surfaces, while fruit fall can lead to hazardous slippery pedestrian surfaces. Table 15 below gives a summary of trees known to be prone to honeydew drip or fruit fall.

Table 15 Large species trees prone to honeydew drip and fruit fall

Botanical Name	**Common Name**
Trees that suffer from honeydew drip	
Acer spp.	Maple
Acer pseudoplatanus	Sycamore
Betula pubescens	Birch
Tilia europaea	Lime
Fruit bearing and large seed trees	
Platanus x hispanica	Plane
Prunus avium	Wild Cherry
Quercus spp.	Oak
Nut bearing trees	
Aesculus hippocastanum	Horse Chestnut
Castanea sativa	Sweet Chestnut
Juglans regia	Walnut
Cone bearing trees	
Cedrus libani	Cedar of Lebanon
Picea abies	Norway Spruce

Pinus sylvestris	Scots Pine
Pseudotsuga menziessii	Douglas Fir

Pavement maintenance

As outlined in Section 4.1.2, correct implementation of urban trees can avoid the damages currently experienced by poorly planned street trees, potentially saving local authorities a considerable amount.

Trees also help to reduce pavement maintenance costs by shading hard surfaces, moderating the temperature and reducing extremes of temperature that cause pavements to expand and contract, damaging them.

Case Study – Reduced radiation damage to roads, California

Asphalt roads contain stone aggregate in an oil binder and without tree shade, the oil heats up and volatizes, leaving the aggregate unprotected. Vehicles then loosen the aggregate and much like sandpaper, the loose aggregate grinds down the surface.

Roads should be resurfaced using a surface dressing of slurry seal (a mixture of bitumen emulsion, well-graded fine aggregate, mineral filler or other additives, and water) every 7-10 years over a 30-40 year period, after which reconstruction is required A surface dressing costs approximately 0.17p or £31,510/linear mile ($0.27/sq.ft or $50,000/linear mile).

Because the oil does not dry out as quickly on streets shaded by large trees as it does on a street with no shade trees, this street maintenance can be deferred. The surface dressing can be deferred from every 10 years to every 20-25 years for older streets with extensive tree canopy cover, therefore resulting in a potential saving of half the resurfacing costs. (McPherson et al., 2000).

4.1.6 Structural failure of trees

Clarifying the issues

Trees are living things and hence are susceptible to damage, disease and decay for a number of reasons. However, they are remarkably resilient and the structural failure of the whole or part of a tree is rare, albeit high profile when it occurs.

Minimising the risk of damage from structural failure

The key to minimising the risk of a tree failing and causing damage, is regular inspections undertaken by a competent arboriculturalists. This is particularly important in the towns and cities due to the greater risk exposed to human health than in more rural locations and also the fact that the urban landscape can often cause damage to trees which may lead to structural failure. Regular inspections can then be supported by appropriate levels of maintenance, avoiding the need to remove the entire tree and retaining the social, environmental and economic benefits associated with it.

Certain species are more susceptible to disease and structural failure than others, summarised below in Table 16, and it may be considered inappropriate to use these on highway or car parking schemes.

Table 16 Trees susceptible to disease and structural failure

Trees susceptible to disease/weak pathogens	
Species	**Disease**
Elm	Dutch Elm Disease
Horse Chestnut	Horse Chestnut leaf minor
Oak	Oak Wilt
Trees with structurally weak branches	
Botanical name	**Common name**
Acer saccharinum	Silver Maple
Eucalyptus spp.	Eucalyptus
Fraxinus angustifolia ‘Raywoodii’	Redwood Ash
Pyrus calleryana ‘Chanticleer’	Pear
Robinia pseudoacacia	Locust Tree
Salix fragilis	Crack Willow

4.1.7 CCTV and security

Clarifying the issues

Britt and Johnston (2008) highlight the conflict that exists between urban trees and CCTV coverage, referencing the fact that 55% of local authorities have cited requests for tree maintenance on the grounds of community safety, helping to reduce perceived security risks or anti-social behaviour.

However, as set out in Section 3.2.2, it has been proven that living and working in a treed environment has a significant impact on criminal activity, reducing domestic violence, violent crime against people and property crime.

Minimising security risks

Evidence summarised in Section 3.2.2 highlighted that well maintained trees and green spaces also help to reduce levels of crime in a neighbourhood. Similarly, maintenance is the essential mechanism for retaining adequate visibility for CCTV cameras. Therefore, regular maintenance and upkeep of trees is considered to be the main factor associated with trees that can contribute to minimising any security risk. Large species trees are particularly effective to this end, as they generally provide clear views at eye levels, with the body of the crown above head height.

In new developments, large species tree planting should be carefully planned to avoid creating dense patches of vegetation behind which criminals can hide, particularly along quiet footpaths, children’s playgrounds or near secluded car parks. Secured by Design, a flagship initiative set up by the UK police, can provide advice on how to design to minimise criminal activity.

The London Borough of Islington have recognised the importance of trees, and incorporated them into policy guidance about CCTV.

CCTV and trees

A policy for trees in Islington

Paragrph 17.2:

Any agency tasked with installing CCTV cameras within Islington must work with the council before any camera is installed. This must be agreed regardless of the presence of trees or not. If consent is not gained the removal or the substantial pruning of trees to improve sightlines will not be considered. And priority must always be given to trees with a high value.

4.2 Strategic approach

4.2.1 Planning policy

Local authorities perform a central role in the aims and objectives of this report. Through the Local Development Framework, local authorities are able to set strategic objectives for the widespread implementation of large species trees. This is further supported by the planning system within the UK, which requires an applicant to develop a proposal and submit and application for consideration and decision by the planning authority. This enables the local authority to be engaged during the pre-application process, helping to ensure that development proposals are acceptable and in-line with local policy. Further to this, when a planning application is determined, conditions can be applied to ensure that the development adheres to local policy. Local authorities are also able to seek improvements to development proposals where they would be in the general public benefit through Section 106 agreements (England and Wales), Section 75 agreements (Scotland) and Article 40 agreements (Northern Ireland).

4.2.2 Ownership and management

In addition to setting policy and determining planning applications, local authorities are also responsible for the management of a large amount of urban tree cover along streets and in public spaces. Based on research undertaken for the 'Trees in Towns II' document (Chris Britt & Mark Johnston, 2008), approximately 12% of all trees and shrubs were on streets and highways, 20% in public parks and open spaces and the remainder on private property or less accessible public land (e.g. schools, churchyards, allotments, etc.). These figures are based on a study of 590 sites across 147 towns and cities in England, and varied regionally. Within these percentages, 31% of all trees were large broadleaved tree species, including sycamore (Acer pseudoplatanus), silver birch (Betula pendula) and common ash (Fraxinus excelsior), although relatively few were over 10m high.

In some instances, this management responsibility is viewed as a liability with departmental conflicts, time constraints and budget limitations and, at the time of the survey, only seven local authorities out of 389 had undertaken any form of cost benefit analysis of either the whole or part of the urban forest in their district (Britt & Johnston, 2008). However, central to both the widespread implementation of urban trees and the appropriate level of cost effective management of tree stocks, is the development of local authority tree strategies.

4.2.3 Tree strategies

The existing situation

Currently many local authorities do not have comprehensive tree strategies or tree management systems in place, and some of those which do exist do not adequately provide an overarching framework within which to implement tree planting through policy mechanisms. The responsibility for trees is often divided between different departments, potentially leading to conflicting approaches to tree management and maintenance criteria and also contributing to a general trend towards planting smaller ornamental trees as opposed to large species, minimising environmental, social and economic benefits. In general, the focus within local authorities is on employing staff to maintain trees on an ad-hoc basis rather than develop and implement strategies. In many situations, this has manifested itself through a lack of accurate tree survey information. The lack of data, records and surveys means that it is impossible to formulate proper, effective tree strategies, management systems and realistic budgets. Currently, many local authorities base their budgets on what has been spent in previous years rather than on planned works, due to the lack of an overriding, cost effective strategic approach.

The importance of tree strategies

Developing a tree strategy is the best way to improve local authority tree programmes to ensure the long term survival of large species trees in urban settings. The current migration of local planning systems from Unitary Development Plans to Local Development Frameworks (in England), presents a prime opportunity for tree strategies to be developed as Supplementary Planning Documents, integrated into the portfolio of Local Development Documents.

Comprehensive tree strategies help to ensure that developers are required to provide appropriate levels of large species tree planting within new developments, especially where high development densities are being realised. They also provide a proactive framework for effective cyclical maintenance based around systematic and frequent inspections rather than an ‘on-demand’ response. Regular, planned maintenance is important to ensure the continuing value and public perception of large species trees and cost effectiveness of management. Management techniques for maximising environmental, social and economic value are summarised in Section 3, along with techniques for minimising the risk of issues arising associated with tree planting in Section 4.1.

In addition to regulating tree maintenance across the local authority and delivering cost efficiencies, tree strategies can assist in securing external funding to finance tree programmes. A lack of general funding and resources is cited by local authorities as a threat to the practicality of further urban tree planting initiatives, and an increase in funding is viewed as the best opportunity to improve the urban tree programme.